OPTIMIZING THE USE OF GREEN ENERGIES, AN APPLICATION TO CROP IRRIGATION

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Abstract*: This paper assesses the optimal farmland that can be irrigated by a predetermined renewable energy system. The optimal irrigated surface from an agriculture area, cultivated by potatoes and tomatoes and powered by a PV system is studied. Two scenarios are discussed: the constraints applied to the first scenario is the limited surface of the agricultural area. While in the second scenario, the surface cultivated with tomatoes must be at least ¼ the surface cultivated with potatoes. Linear programming based on the Simplex algorithm is used to solve the optimization problem. The obtained results show that for the specified cultivating area, and for 10 panels at hand, an optimal surface of about 5.6 ha and 4.7 ha for the first scenario and the second scenario, respectively can be satisfied.*

1. INTRODUCTION

Energy is key in human lives. When converted into different forms, energy sources can power all important utilities, like water or electricity. Renewable energy systems (RESs) are systems that use energy coming from natural resources and are naturally replenished [1]. They are major components to reduce harmful greenhouse effect and to deal with depleting energy sources [2].

RESs are used in two modes: grid-connected or stand-alone. They can be used uniquely or in mixtures. Optimization techniques such as cost minimization [3, 4], production maximization [5] and storage optimization [6] are applied to RESs to deploy them in the best possible way.

The combination of renewable energy power generation and agriculture activities is a natural response to supply sustainable green electric power to agriculture. Crop irrigation is one of the main agriculture applications, it can promote the conservation of farmland and halt the degradation of grassland.

The application of optimization techniques to crop irrigation using RESs is widely covered in the literature. Campana et al. [7] investigated the geospatial distribution of grassland to implement photovoltaic water pumping systems. They used a spatially explicit optimization model of RESs based on cost minimization to assess the optimal location to implement the photovoltaic water pumping (PVWP) system. A drip irrigation system powered by renewable energy and diesel genset is proposed by [8], in which the levelized cost of energy based on the net present cost is optimized using Genetic Algorithms (GA). Authors in [9] used GA to find the optimal size of PVWP systems for irrigation. Their objective was to maximize the annual profit. Tsang and Jim [10] noted that green roof irrigation lacks reliable and cost-effective water conservation measures and employed neural network and fuzzy logic trained by real-time weather variables to develop an optimal irrigation strategy. Authors of [11] integrated a technique for order performance by similarity to ideal solution (TOPSIS) method with analytic hierarchy process (AHP) method to optimally size a PVWP with respect to the economic respect.

All the above publications studied the optimization duty from one side; it concerns the optimization of the energetic system to achieve some goals and/or benefits such as maximizing the energy generated by the systems and minimizing the cost of the energy obtained. But what if people do not have capitals to finance the required size of the system? This study was conducted as a result of an investigation involving several farmers in the region of El Hadaiek, concerning the replacement of diesel generators used for irrigation with renewable energy systems. One of the major concerns is their limited capital to power the irrigation system using the local abundant renewable energy sources.

This paper investigates the use of a fixed size photovoltaic system to optimally irrigate a farmland. The paper presents an application on crop irrigation where the hypothesis is that a farmer has predefined and limited energy system components. The objective is to maximize the surface that can be irrigated with an already sized system. The rest of the paper is organized as follows: the methodology followed in this work is presented in section 2, section 3 gives the case studied, results and discussions are given in section 4 and section 5 concludes the paper.

2. METHODOLOGY

The conceptual framework applied to identify the optimal surface that could be irrigated by the PVWP system is depicted in *fig. 1*. The methodology is divided into three main steps:

Step 1: Meteorological data (irradiations, wind speed, humidity, ambient temperature, effective rainfall) are collected using the FAO CLIMWAT software [12].

Step 2: These data are then used in one hand, with the technical characteristics of the PV panels to calculate the energy produced by the PV system according to eq. (3). In the other hand, these are used with the crops properties and the soil characteristics to estimate the irrigating water required (IWR) for each crop with the FAO CROPWAT software.

Step 3: deals with the resolution of the optimization problem using the simplex algorithm.

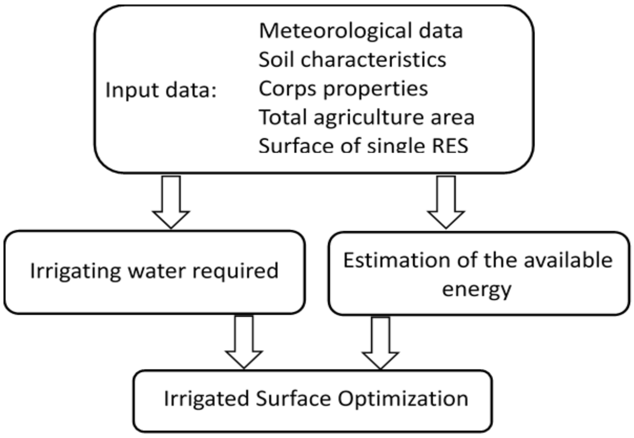

Fig. 1: conceptual framework to assess the optimal farmland irrigated by PVWP system

The calculation of the IWR is assessed using the meteorological data such as wind speed, ambient temperature, the solar irradiations at the crop surface, the effective rainfall and the crop properties as the evapotranspiration, the crop coefficient and the soil type. The IWR is estimated using the CROPWAT software.

The calculation of the equivalent hydraulic and electric energies required to pump the necessary volume of water is detailed is section 2.1. The energy generated by the PV system is calculated using the solar irradiations, the ambient temperature and the PV panel characteristics such as the active surface and the efficiency. The estimation of the energy produced by the PV generator is detailed in Section 2.2.1.

The calculation of the optimal farmland to be irrigated is assessed using the following data: the energy produced by the PV system, the electrical energy required to pump the daily volume of irrigating water required, and the surface of the parcel to be irrigated. The formulation of the optimization problem is detailed in section 2.2.2.

2.1. Load Profile

In this application, the system must power a motor-pump to pump the IWR. The electric Energy required ($E_{elec.}$) is given as:

$$E_{elec.} = \frac{E_h}{\eta} \quad (1)$$

where: η: the efficiency of the motor-pump; E_h(Wh/day): is the required hydraulic energy which is related to the daily water needs and the hydraulic head and it can be calculated by:

$$E_h = \frac{g*\rho*V*h}{3600} \quad (2)$$

g: gravity, ρ: water density (1000 kg/m^3), V: daily required water volume (m^3), h: total head (m).

2.2. System Modelling

2.2.1. PV model

The daily electrical energy produced by the PV system is given according to [13] by the following formula:

$$E_{PV} = F_m.\left[1 - \gamma.\left(T_c - T_{c,ref}\right)\right].\eta_g.A.G(\beta) \quad (3)$$

where: E_{PV}: is the daily electrical energy produced by the PV system $(in \frac{KWh}{m^2}/day)$, F_m: is the coupling factor, γ: is the cell temperature coefficient, T_c: is the daily average cell temperature during the sunshine hours.

$$T_C = T_a + (NOCT - 20) * \frac{G}{800} \quad (4)$$

$T_{c,ref}$: cell temperature at reference conditions, η_g: generator efficiency at reference temperature, A: the active surface of the generator $(in\, m^2)$, $G(\beta)$: is the daily average irradiation incident on the module inclined by β.

2.2.2. Problem formulation:

The problem of the optimal exploitation of the energy generated by a fixed size standalone RES to maximize the surface irrigated by this system can be discussed as follows.

Consider that a RES can generate an amount $E_{PV}(t)$ of energy. This system is used to satisfy a costumers demand D. This demand can be estimated as the amount of energy necessary to pump the volume of water (V_i) required to irrigate different parcels cultivated by some crops. These parcels have a surface $S_i(t)$ and may have different total heads.

The optimization problem can be formulated as:

$$\begin{cases} Max\ S(t) = \sum_{i=1}^{n} S_i\,(t) \\ ST: \\ \sum_{i=1}^{n} E_i(t).\frac{S_i(t)}{S_u} \leq E_{PV}(t) \\ S_i(t) \geq 0 \end{cases} \tag{5}$$

$E_i(t)$: is the electrical energy required to pump the irrigating water for parcel (i), expressed in Wh/ha.

$$E_i(t) = \frac{1}{\eta}.\frac{g.\rho.V_i(t).h_i}{3600} \tag{6}$$

$V_i(t)$: is the IWR for crop (i) (in m^3/ha), S_u: is the unit surface assumed to be 1 ha.

Substitute (6) in (5):

$$\begin{cases} Max\ S(t) = \sum_{i=1}^{n} S_i\,(t) \\ ST: \\ \sum_{i=1}^{n} \left(\frac{1}{\eta}.\frac{g.\rho.V_i(t).h_i}{3600}\right).\frac{S_i(t)}{S_u} \leq E_{PV}(t) \\ S_i(t) \geq 0 \end{cases} \tag{7}$$

2.2.3. Simplex method:

The simplex method [14, 15] is used to solve the optimization problem of this study. It is a basic and efficient computational algorithm for solving linear programming problems, introduced in 1947/48 [14]. The flowchart of the simplex algorithm is presented in *figure 2*.

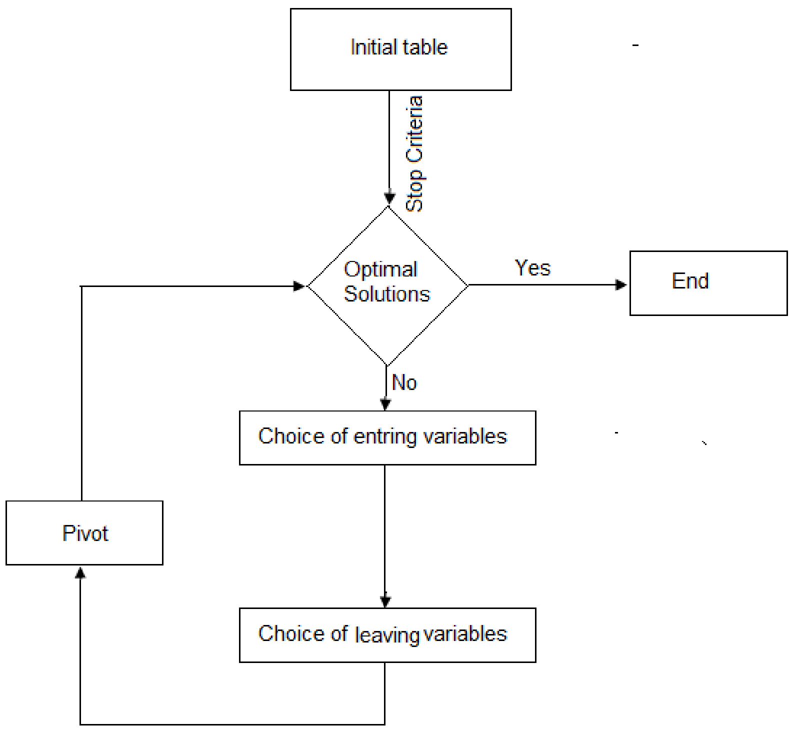

Fig. 2: Flowchart of the Simplex algorithm

3. CASE STUDY

Consider that 2 crops have to be irrigated. The IWR for crop 1 is $V_1(t)$, and for crop 2 is $V_2(t)$. This required water varies within the age of the crop, the meteorological data and, the soil properties. $S_1(t)$ and $S_2(t)$ are the surfaces of the cultivated crops: 1 and 2 respectively.

If these two crops are selected to be potatoes and tomatoes, the IWR for these two crops when cultivated in the region of Skikda, Algeria (Latitude: 36.8762, Longitude: 6.90921) is evaluated using the software CROPWAT. The meteorological data used is obtained from the FAO CLIMWAT. Table 1 illustrates the annual variations of meteorological data in a typical year in the specified area. The IWR for different age stages is represented in figure 3. The cultivation period is supposed to begin on May, 6th.

Table 1: Meteorological properties of the selected site [12].

Month	*Min Temp °C*	*Max Temp °C*	*Humidity %*	*Wind km/day*	*Sun hours*	*Rad MJ/m²/day*	*ETo mm/day*
January	*7.1*	*13.8*	*76*	*156*	*3.4*	*7.3*	*1.20*
February	*7.1*	*14.3*	*69*	*156*	*4.8*	*10.4*	*1.67*
March	*8.8*	*17.1*	*76*	*190*	*6.3*	*14.9*	*2.29*
April	*10.0*	*18.8*	*75*	*138*	*6.8*	*18.1*	*2.85*
May	*13.2*	*21.6*	*77*	*138*	*8.7*	*22.4*	*3.67*
June	*16.6*	*25.0*	*69*	*138*	*9.6*	*24.3*	*4.52*
July	*19.3*	*28.2*	*74*	*138*	*11.3*	*26.2*	*5.08*
August	*20.5*	*28.8*	*75*	*147*	*10.2*	*23.3*	*4.72*
September	*18.8*	*26.6*	*76*	*147*	*8.7*	*18.7*	*3.69*
October	*15.0*	*22.7*	*79*	*138*	*6.0*	*12.5*	*2.30*
November	*11.6*	*18.2*	*74*	*147*	*4.2*	*8.3*	*1.60*

Tab. 1 shows that the cultivation period is characterized by:

- High ambient temperature values, the highest min and max values appear in the month of August with a maximum mean daily average of 24.6°C.
- The highest radiation reaches 26.2 MJ/m²/day (7277,8 Wh/m^2/day), in July.
- An important sunshine duration with a maximum of 11.3h in July.

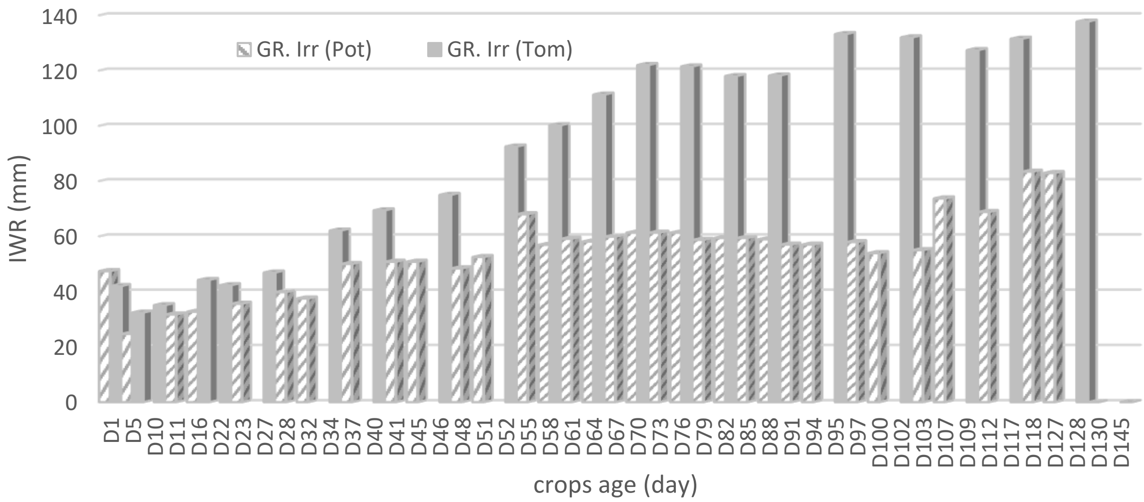

Fig. 3: Irrigating water required of the two crops during the crop life cycle

Fig. 3 presents the irrigating water required by the two crops during the different stages of life cycle.

During the 145 days that represent the cycle life period the following observations can be made:

- ✓ Tomatoes need more water than potatoes during the life cycle except in the first day.
- ✓ 45 rounds of irrigation must be scheduled where 9 times the two crops are irrigated on the same day.
- ✓ IWR increases with the age of the two crops.

To power the irrigating system, a stand-alone Photovoltaic system constituted by 10 (Sunmodule Plus SW 250 poly) panels are used. The Technical characteristics of the used panels are presented in Table 2.

Table 2: Technical characteristics of PV panels.

Item	*Value*
P_{max}	*250 Wc*
U_{OC}	*38.0 V*
U_{mpp}	*30.5 V*
I_{Sc}	*8.88 A*
I_{mpp}	*8.27 A*
Dimensions	*1675/1001/31 (mm)*
weight	*21.2 kg*
Cell numbers	*60*
Cell technology	*Polycrystalline silicon*
Cell dimensions	*156/156 (mm)*

4. RESULTS AND DISCUSSIONS

Two scenarios are discussed within this case study, where the maximum bound is fixed to 10 ha for the entire surface (i.e. $S_1 + S_2$) in the first one. However, another constraint is imposed to the model presented in (7).

4.1. Scenario 1

In this scenario the number of panels available is fixed at 10, the maximum surface to be irrigated is fixed at 10 ha. The problem formulated in (7) becomes:

$$\begin{cases} Max\ S(t) = S_1(t) + S_2(t) \\ ST: \\ \left(\frac{1}{\eta}.\frac{g.\rho.V_1(t).h_1}{3600}\right).S_1(t) + \left(\frac{1}{\eta}.\frac{g.\rho.V_2(t).h_2}{3600}\right).S_2(t) \leq E_{PV}(t) \\ S_1(t) + S_2(t) \leq 10 \\ S_i(t) \geq 0 \end{cases} \tag{8}$$

Fig. 4 illustrates the optimization results. The optimal surface depends on the quantity of water required by the crop. The surface irrigated on the fifth day (D5) represents the most optimal surface can be irrigated by the system, this surface is equal to 5.6 ha cultivated by potatoes. The PV system generates 9493 Watts and the pumping system pumps a volume of about 138.3 m^3 of water.

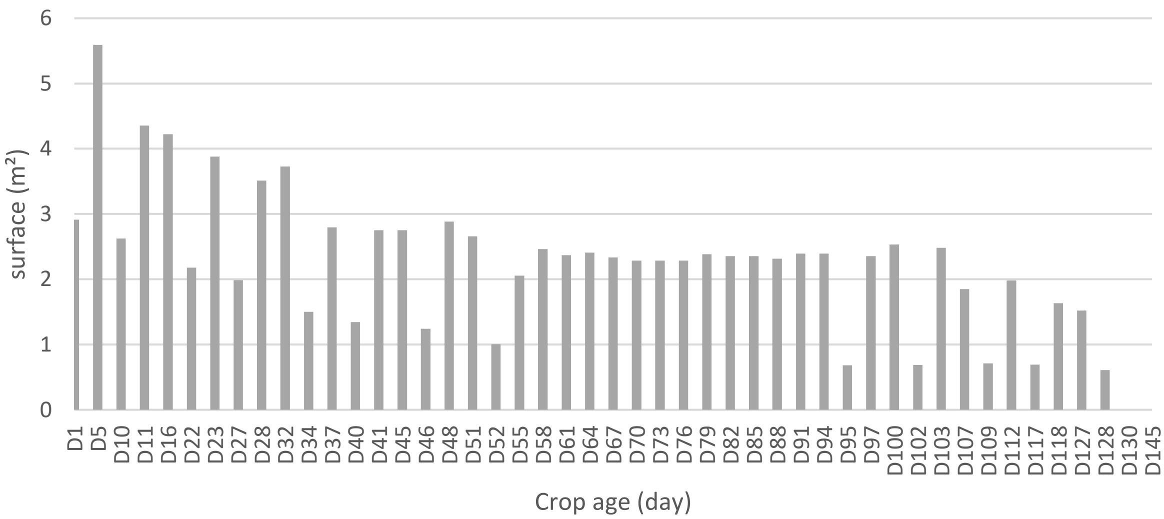

Fig. 4: Optimal surfaces irrigated by the implemented PV system

The repartition of the optimal surfaces that can be irrigated by the system on the two parcels is illustrated in *Fig. 4*. According to this figure, and according to the constraint imposed, the optimal surface covers most of the lifecycle days surfaces cultivated by potatoes (S_1). This is due to that the irrigating water required by potatoes is less than that required by tomatoes. Twelve cases of optimal surfaces cultivated by tomatoes (S_2) appears in the histogram of the *figure 5* corresponds to the days where irrigation of potatoes is not scheduled.

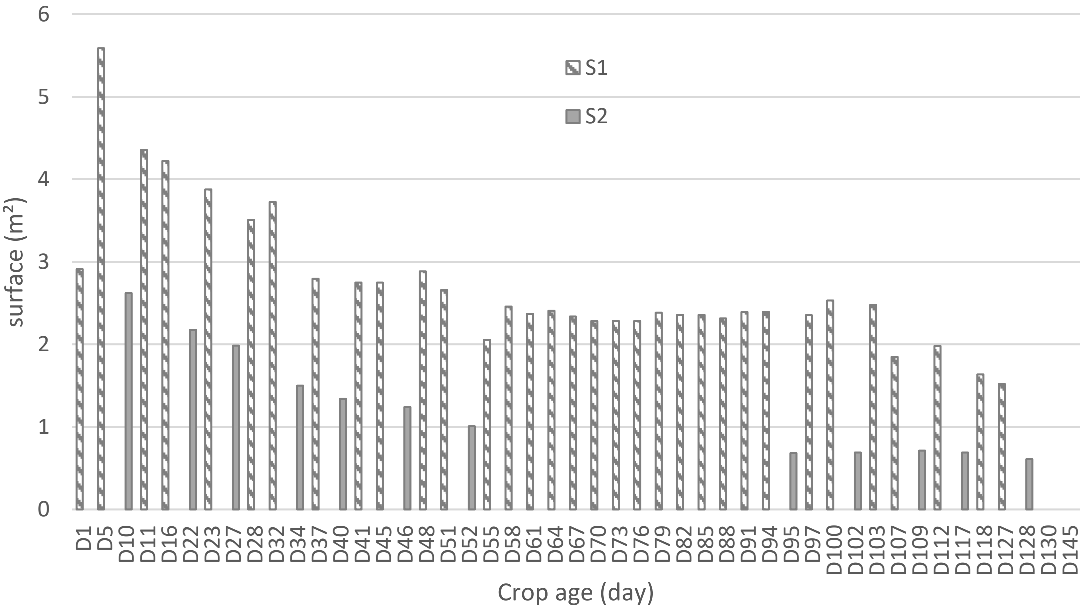

Fig. 5: Repartition of the optimal surface irrigated on the two parcels

4.2. Scenario 2

In this scenario the number of panels available is fixed at 10, the maximum surface to be irrigated is fixed at 10 ha and when the two parcels must be irrigated in the same day, the surface irrigated from the parcel cultivated by tomatoes (S_2) must be at least ¼ the surface irrigated from the parcel cultivated by potatoes (S_1). The optimization problem presented by (6) becomes:

$$\begin{cases} Max\ S(t) = S_1(t) + S_2(t) \\ ST: \\ \left(\frac{1}{\eta}.\frac{g.\rho.V_1(t).h_1}{3600}\right).S_1(t) + \left(\frac{1}{\eta}.\frac{g.\rho.V_2(t).h_2}{3600}\right).S_2(t) \le E_{PV}(t) \\ S_1(t) + S_2(t) \le 10 \\ S_2(t) \ge \frac{1}{4}.S_1(t) \\ S_i(t) \ge 0 \end{cases} \tag{9}$$

Fig. 6 represents the optimization results for all the scheduled irrigation days. In this case, the most optimal surface is always on the fifth day (D5) and compared with that of the first scenario drops to about 4.68 ha, where 3.74 ha is from (S_1) and about 0.93 ha from (S_2)

as detailed in Figure 5. In this case the total volume of water pumped is 122.51 m^3 and the system generates about 9405 watts.

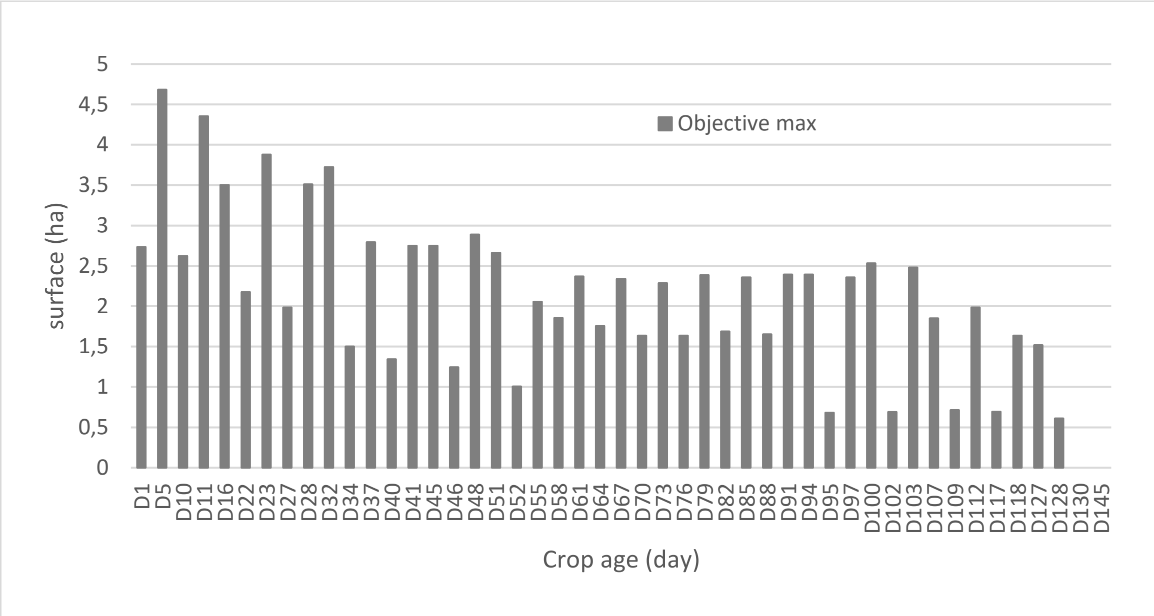

Fig. 6: Optimal surface irrigated by the PV system for the 2nd scenario

The optimal surface irrigated by the system from (S_1) is at the day (D11) with 4.33 ha irrigated by 137.3 m^3 and consumes 9394.3 watts. While the optimal surface irrigated from (S_2) is at the day (D10) with a surface of 2.62 ha, irrigated by a volume of water equal to 91.96 m^3. The pumping system is powered by 9397.4 watts generated by the PV system.

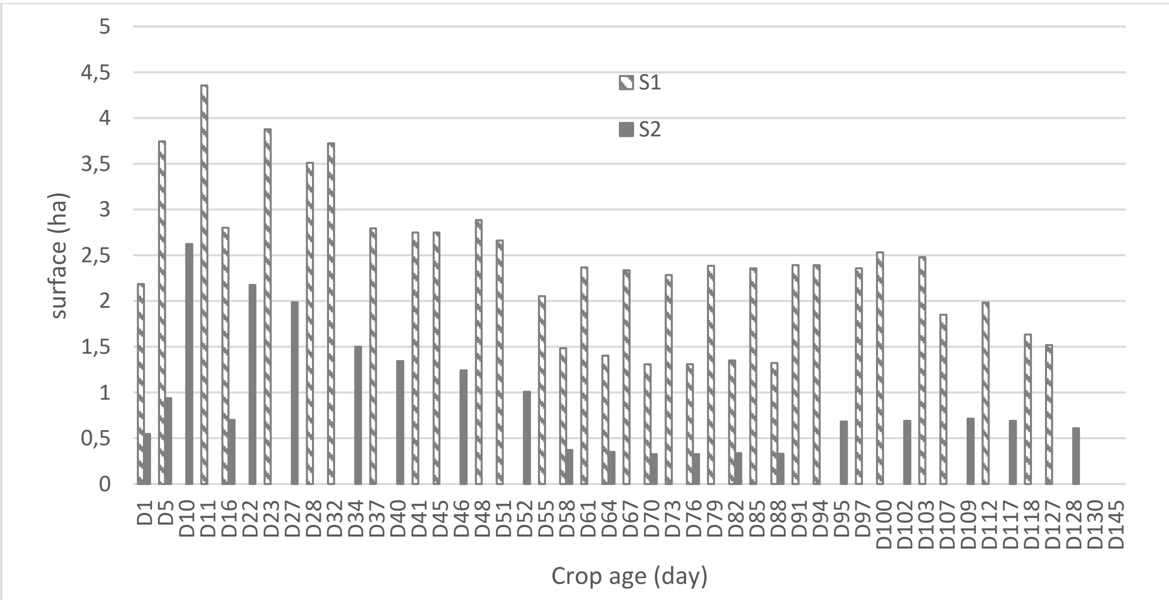

Fig. 7: Repartition of the optimal surface irrigated on the two parcels for the second scenario

Fig. 7 illustrates the repartition of the optimal surfaces that can be irrigated by the system on the two parcels for the second scenario. The optimal surface irrigated from S1 within this scenario is achieved at the day (D11) with about 4.35 ha. where the irrigation of S1 is not scheduled. Whereas, the optimal surface irrigated from S2 is achieved at the day D10 with about 2.62 ha.

CONCLUSION

The PVWP systems are an alternative solution to the diesel based irrigating systems. It is a clean and renewable-based solution to the sustainable development of the agriculture in Algeria. The optimal sizing of the PVWP systems is an important task to satisfy the costumer's demand. However, the optimal use of the energy produced by the renewable energy systems is required to reduce the costs.

This paper presented a methodical solution to optimize the use of a fixed and predetermined size PV system in the irrigation of crops. The proposed methodology may be applied for different locations, and for several crops.

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