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# The Development of an Application Conceived for the Design, Feasibility Study and Data Analysis of Photovoltaic Pumping Systems

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## ABSTRACT

Because of the rise in diesel and butane prices widely used for pumping, added to their negative impact on both Morocco's environment and trade balance, the use of renewable energies should sound obvious, practical and cost effective. This study offers the transformation of a traditional butane pumping system (*BPS*) and diesel pumping system (*DPS*), located on a farm nearby the city of Agadir, into an optimized solar pumping system (*SPS*). The suggested method is based on a techno-economic study according to the "Business-As-usual" scenario. As a first step, we have dimensioned our pumping system and chosen the elements that constitute it. As a second step, we carried out an economic analysis, based on the calculation of all costs, which makes it possible to ensure the viability of the components of our SPS over its life cycle and brought it to a discounted value. The processing of the different data is made possible thanks to the computer application "*PVDesign*" which we have developed. This application has allowed us to carry out a comparative study of several techniques of pumping systems. The result of the study is that the *SPS* beats the other systems at various levels, namely economic, environmental and technical.

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## 1. INTRODUCTION

According to the National Agency for the Development of Renewable Energies and Energy Efficiency (*ADEREE*) [1], the agricultural sector represents 13% of the Moroccan energy bill. Nevertheless, Morocco has a considerable solar field, estimated at more than 3,000 h / year of sunshine; that is, an irradiation of more than 5 KW.h / $m^2$per day.

The national solar pumping program aims to reduce the government subsidy of the butane gas and diesel fund by benefiting from green and free energy. This requires measures to eliminate all regulatory economic and technical barriers.

Several research studies on the design, feasibility and cost-effectiveness of solar pumping systems have aroused the interest of researchers. In fact, one of these studieshas economically investigates *SPS* systems taking into account the effects of the key components of the initial cost, life cycle cost and incomes. The obtained results show that the cost of photovoltaic modules is the most sensitive parameter in this analysis [2]. Another has study used the genetic algorithm (*GA*), as well as the Pareto optimality concept, for the techno-economic optimization of an SPS storage system [3]. A farther study has examined the application of the permanent magnet synchronous motor (*PMSM*) in renewable energies, particularly in solar pumping.

Its objective wasto model the complete system, including the photovoltaic inverter, PMSM and the centrifugal pump in the Matlab / Simulink environment [4]. An additional study has examined all the necessary stages and key components to design and build an *SPS* by making a comparison with the diesel system [5] and [6] develops a sizing and simulation tool dedicated to autonomous solar systems and *PV* pumping systems.

All these works focus either on the technical dimensioning of the pumping station components or on a purely economic analysis of the system. During the interviews we had with farmers, technicians and engineers, all expressed the necessity for a complete computerized tool integrating a database of equipment available in their areas and joining the technical and economic studies.

In this context, the present research aims at promoting a wider use of solar energy as an alternative to diesel and butane in irrigation and drinking water sectors. We propose the development of a ***PVDESIGN*** application for sizing, feasibility study and detailed economic analysis of the profitability of a photovoltaic pumping system compared to a Butane Pumping System (*BPS*) and Diesel Pumping System (*DPS*). This application allows us to carry out the whole process of designing an *SPS*, from the preliminary assessment of the producibility to the practical realization of the project. This tool makes it possible to analyze the foreseen solutions with precision and to evaluate the expected results before any financial commitment.

This work begins with a description of the project and then presents the theoretical elements that have been used for the dimensioning of our system. The next section focuses on the explanation of the method used for the economic study. The last section 4th paragraph exposes the architecture of the application and presents the results of our work.

## 2. PROJECT DESCRIPTION

Our work is based on the study of an existing butane and diesel pumping station for irrigation in a village known as Zaouia located in the rural commune of Isn, province of Taroudant. This station is composed of a diesel engine (or butane) and centrifugal pumps which flow in a very large basin. Other surface pumps allow the water to be redistributed to the crops through a drip system (Figure 1). Our objective is to transform this traditional solution into an *SPS* (Figure 2) and, therefore, demonstrate its economic and technical competitiveness compared to traditional solutions beforehand.

Figure 1. Existing projects, *DPS* (left) and *BPS* (right)

Figure 2. Installed solar panels

The parameters taken into account are the farmer's water requirements ($Q$ = 400 $m^3$ / day), Total dynamic head (*TDH*), estimated at 100 m and the meteorological parameters of the site.

## 3. THEORETICAL ELEMENTS

The implementation of an *SPS* must meet certain economic and technical criteria; therefore, our application must meet the following requirements:

a. Optimum station size that would ensure a reliable and economical operation of the system and allow a good choice of solar equipment (photovoltaic modules, inverters, motor pumps and accessories).
b. A feasibility study and economic profitability of the project, since the analysis of costs and the credibility of an energy system is prerequisite before any decision to invest in equipment.

### 3.1. System Design

The dimensioning of a *SPS* [7-10] begins with the computation of the daily average hydraulic energy required from relation 1 [11], and the power in peak watts, that the photovoltaic field must have by using equation 2 [12].

$$E_h = C_h.Q.T_{DH} \tag{1}$$

with:

$E_h$: Hydraulic Power [*KWh/day*]
Q : Water Volume [$m^3/day$]
$T_{DH}$ : Total dynamic head [*m*]
$C_h$ : Constant [$Kg.s.h/m^2$]

Or

*g*: Earth's Gravity = 9.81 $m/s^2$
*ρ*: Water Density =1000 $Kg/m^3$
$C_h$= *g*.*ρ*/3600 = 2.725

$$P_C = \frac{G}{F_m[1-\gamma(T-T_r)]G_d(\beta)}\frac{E_h}{\eta_{MP}\eta_{ond}} \tag{2}$$

with:

$G$: Illuminance in the Standard Condition of Measurement:$G = 1000W/m^2$, *T*:= 25°*C* and air mass = 1.5.
$F_m$: The coupling factor, defined as the ratio between the electrical energy generated under operating conditions and the electrical energy that would be generated if the system was operating at the maximum power point, which is equal 1 if a perfect maximum power point tracking system is used.
$\gamma$: The temperature coefficient of the cells (0.004 / ° C≤γ ≤0.005 / ° C for mono and polycrystalline silicon modules, and 0.001 / ° *C*≤γ ≤0.002 / ° *C* for amorphous silicon modules.
*T*: The average daily temperature of the cells.
$\eta_{MP}$: The performance of the motor pump unit ($\approx$ 0.40).
$\eta_{ond}$: Inverter efficiency ($\approx$ 0.95).
$G_d(\beta)$ The average daily irradiation incident on the modules plan at the inclination β in Kwh / $m^2$ /day.

The following tasks will then be performed:

1. The lowest irradiation in *KW.h / $m^2$* / day of the site under study.
2. The choice of the pump according to *Q* and *TDH*.
3. The choice of the inverter compatible with voltage, current and power.
4. The choice of the appropriate panel.
5. Determining the total number of panels, as well as the number of modules in series and in parallel.

### 3.2. Economic Analysis

The economic analysis consists of calculating all costs that will ensure the viability of the components of our pumping system over a period of time, reduced to a discounted value. This makes it possible to compare costs on a common basis with other options and then make the most economical choice. This cost analysis should include the cost of the initial capital funding and the present value of operating, maintenance and replacement costs over the expected life span of the pumping system. This analysis is called Life Cycle Cost (*LCC*). Equation 3 gives the expression of the overall cost [13].

$$LLC = C_0 + C_{exploi} + C_{c-maint} + C_{c-repl} \tag{3}$$

with: $\boldsymbol{LLC}$: Total cost of the system, $\boldsymbol{C_0}$: Cost of equipment, acquisition and installation, $\boldsymbol{C_{c-maint}}$: Maintenance cost, $\boldsymbol{C_{exploi}}$: Operating cost and $\boldsymbol{C_{c-repl}}$: Replacement cost.

$\boldsymbol{C_{c-maint}}$ and $\boldsymbol{C_{c-repl}}$ are recurring and require updating throughout the life cycle of the system. In fact, replacement cost is the sum of all equipment replacement costs expected during the life of the system, and replacement costs normally only occur for years determined by the life of each component. Similarly, the cumulative cost of maintenance is the sum of all expected repair costs over the life of the system.
Life cycle cost analysis consists of determining the current value of all planned spending over the life cycle of the system. The discounted costs are obtained by applying to the costs appearing in future years the factor "q" of discounting expressed by the following expression [14]:

$$LLC_{n-Updated} = q.LLC_n \text{With} \qquad q = \frac{1}{(1+d)^n} \tag{4}$$

with: $q$: the discount factor, $LLC_{\mathrm{n}}$: cost to be updated for year "n", $d$: the expected annual actual discount rate and $n$: the year of the appearance of the cost to update.
The updated price cubic meter ($m^3$) of water for the year 'n' considered is given by equation 5 below [15]:

$$The\ updated\ price\ cubic\ meter\ of\ water = \frac{LCC_{n-updated}}{Q*n*365} \tag{5}$$

## 4. GENERAL ARCHITECTURE OF $PV_{DESIGN}$

The global architecture of the application developed with the *C#*language is visible in Figure 3. Our study is limited to the analysis of the *SPSs*. This software can be broken down into four main parts.

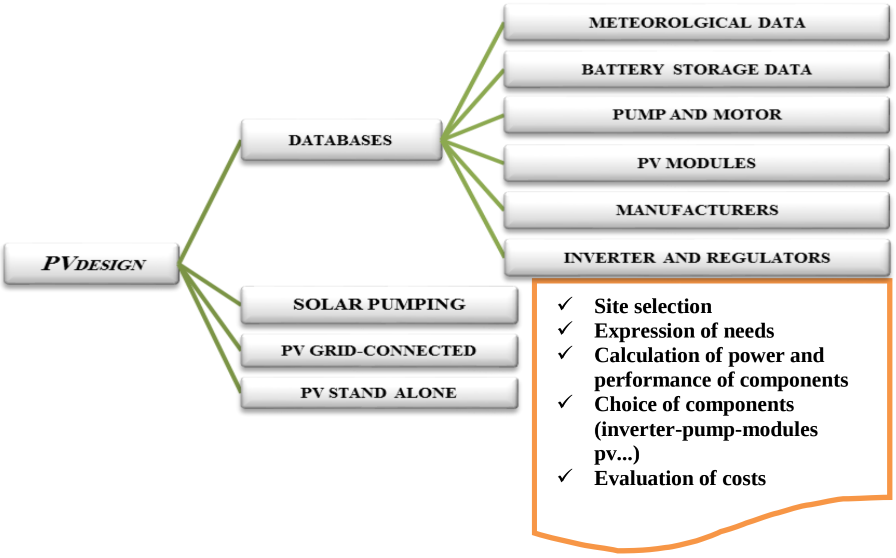


Figure 3. Architecture of the developed application (***PV**<sub></sub>*$\boldsymbol{PV_{DESIGN}}$)

1. Databases: The application offers a wide range of choices in these different databases for manufacturers, inverters, regulators, pumps, photovoltaic modules and batteries. Meteorological data can be imported from (*PVGIS*: Photovoltaic Geographical Information System) [16], *METEONORM* [17] or *NASA-SSEdata* [18]) or manually entered. These data are displayed as tables or charts.

2. Sizing of *SPSs*: This part of the software requires the introduction of certain quantities, particularly the flow of water to be pumped per day $Q$ ($m^3$ / d) and *TDH* (m). These parameters make it possible to determine the power and electrical energy of the motor-pump unit. The daily running time of the solar pump and the overall irradiation in the local site would make it possibleto determine the peak power of the photovoltaic network. This allows us to choose the type of *PV* panel and the type of solar pump that would give us the optimum configuration.

3. Dimensioning of the photovoltaic systems connected to the global network [19], [20]. This system is not dealt with in this paper. It consists essentially of photovoltaic panels and an inverter capable of ensuring an optimal connection to the public grid and improving the quality of the electrical power generated

and injected. This system is intended to meet the energy needs of the producer and inject the surplus into the public grid. In return, when photovoltaic production is insufficient, the grid fills the energy deficit [21]

4. Dimensioning of autonomous (or isolated) photovoltaic systems [22]. This part is also beyond the scope of our study. This system is not connected to the distribution power network. It consists of solar panels, a charge regulator, batteries and an inverter.

## 5. RESULTS AND DISCUSSIONS

The aim of this project is twofold. On the one hand, it seeks to satisfy the water requirements of our farm ($Q$ = 400 $m^3$ /day) for the estimated total dynamic head (*TDH*) of 100 m and taking into account the meteorological data of the study site. On the other hand, it aims at carrying out a comparative economic study of our *SPS* with the traditional systems *BPS* and *DPS*. The $\boldsymbol{PV_{DESIGN}}$ application has been developed to achieve the following results:

### 5.1. Design

Figure 4 shows the $\boldsymbol{PV_{DESIGN}}$ home screen, whereas Figure 5 shows the screen for selecting the site, as well as the introduction of the parameters of our pumping system. The desired performances are visible to the left of the image, Including the daily flow rate (400 $m^3$ /day) and the total head (*TDH* = 100 m). From the databases, the software exposes to the right of this image the average daily and monthly irradiations of the chosen site.

Figure 6, shows the results proposed by our software with our choices of imposed material. Indeed, choosing the manufacturer LORENTZ, $\mathrm{PV_{DESIGN}}$ offers us a range of solutions for the controller and the motor pump. In this case PSk2-40 C-SJ42-19 -D was chosen. In the same way, the solar panels chosen are of the type LC 250-P6 of LORENTZ. $\mathrm{PV_{DESIGN}}$ offers 152 panels, 19 in series and 8 in parallel.

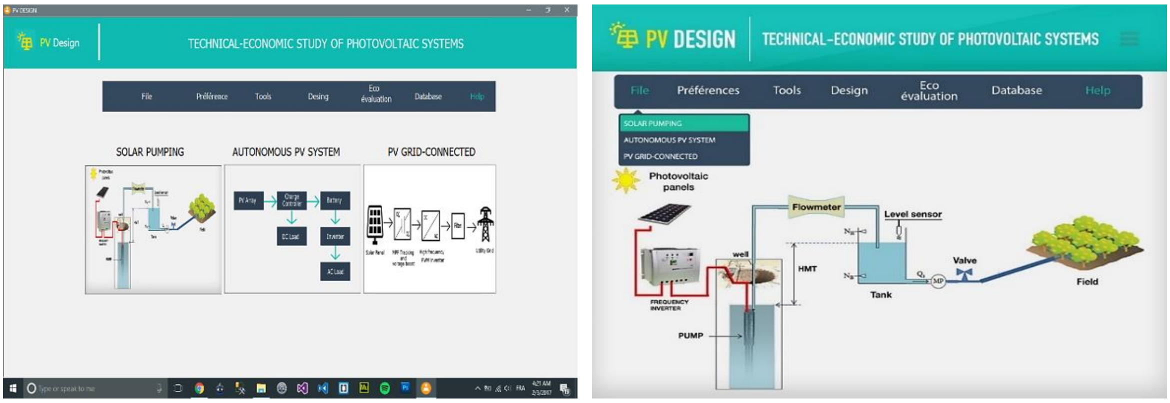
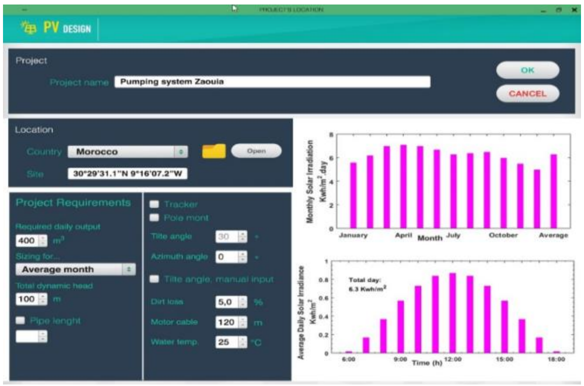


Figure 4. $\boldsymbol{PV_{DESIGN}}$ Home Screen



Project
Project name: Pumping system Zaouia

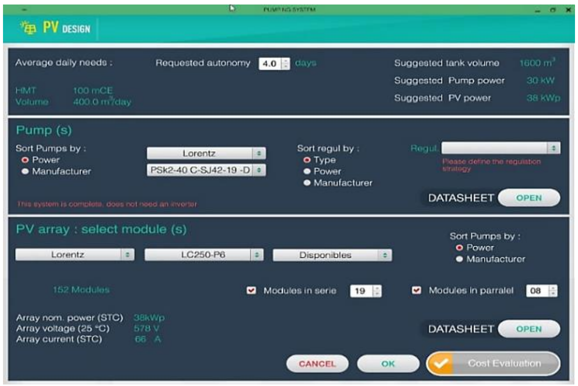
Location
Country: Morocco
Site: 30°29'31.1"N 9°16'07.2"W

Project Requirements
Required daily output: 400 $m^3$
Sizing for...: Average month
Total dynamic head: 100 m
☐ Pipe lenght

☐ Tracker
☐ Pole mont
Tilte angle: 30 °
Azimuth angle: 0 °
☐ Tilte angle, manual input
Dirt loss: 5,0 %
Motor cable: 120 m
Water temp.: 25 °C

Total day: 6.3 Kwh/m²

Figure 5. Site selection and performance of the pumping system in $\boldsymbol{PV_{DESIGN}}$



Average daily needs :
HMT 100 mCE
Volume 400.0 $m^3$/day
Requested autonomy 4.0 days
Suggested tank volume 1600 $m^3$
Suggested Pump power 30 kW
Suggested PV power 38 kWp

Pump (s)
Sort Pumps by :
○ Power
● Manufacturer
Lorentz
PSk2-40 C-SJ42-19 -D
Sort regul by :
○ Type
● Power
● Manufacturer
Regul.
Please define the regulation strategy
This system is complete, does not need an inverter

PV array : select module (s)
Lorentz
LC250-P6
Disponibles
Sort Pumps by :
○ Power
● Manufacturer
152 Modules
☑ Modules in serie 19
☑ Modules in parralel 08
Array nom. power (STC) 38kWp
Array voltage (25 °C) 578 V
Array current (STC) 66 A

Figure 6. Dimensioning of the pumping system by $\boldsymbol{PV_{DESIGN}}$

### 5.2. Economic Analysis

Equation 3 is used to calculate the cost of the *LLC* life cycle, while equation 4 is used to calculate the discounted costs for each year of the lifetime considered in our study. Equation 5 gives the updated price cubic meter ($m^3$) of water for each year.

Table 1 lists the values of the parameters observed in our calculations While Table 2 gives the investment values for each component of our stations with their estimated lifetimes.

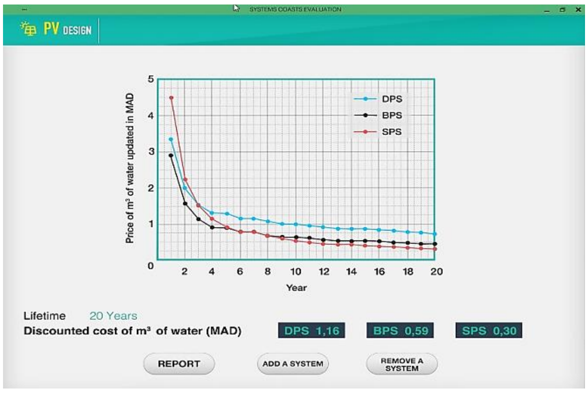
Table 1. Parameters considered in economic study

| Diesel Price (*MAD/liter*) | Butane Price (*MAD/container*) | Consumption in (*liter/hour*) or in (*container /hour*) | | Energy (*Kwh/day*) Flow Rate($m^3$)/day) |
|---|---|---|---|---|
| 9 | 40 | Diesel | 10 | 210 |
| | | Butane | 1 | 400 |

Table 2. Initial investments and lifetimes of *BPS*, *DPS* and *SPS* equipment.

| *DPS/BPS* | | | *SPS* | | |
|---|---|---|---|---|---|
| Equipement | Investment (*MAD*) | Lifetime (*Year*) | Equipment | Investment (*MAD*) | Lifetime (*Year*) |
| Generator | 120,000,00/50,000,00 | 5 | PV panels | 281200,00 | 20 |
| Motorpump | 60000,00 | 7 | Inverter | 60000,00 | 7 |
| Drilling | 80000,00 | 20 | Motorpump | 60000,00 | 7 |
| Tank | 70000,00 | 20 | Drilling | 80000,00 | 20 |
| Accessories | 8000,00 | 20 | Tank | 100000,00 | 20 |
| G. Investment | 218000,00 | | Accessories | 30000,00 | 20 |
| maintenance | 2% | 4360 | G. Investment | 611200,00 | |
| | | | maintenance | 0,25% | 1528,00 |

Figure 7 shows a screenshot of the ***PV**$_{DESIGN}$* application, indicating the results obtained by comparing our studied systems namely *BPS*, *DPS* and *SPS*. These results show that the photovoltaic system has a high price at the beginning compared to other systems. However, it recovers very quickly in less than 2 years compared to the *DPS* system, and after 5 years, the price of the $m^3$ of the *SPS* system becomes much lower than that of the *BPS* system. This economic study shows that the photovoltaic system is the best solution for our pumping system. Let alone, the classic advantages of solar compared to the other two techniques, namely: respect of the environment, better reliability, repair, limited maintenance and lack of fuel.



Lifetime 20 Years

Discounted cost of m³ of water (MAD) DPS 1,16 BPS 0,59 SPS 0,30

Figure 7. Costs comparison of $m^3$ of water pumped by *BPS*, *DPS* and *SPS* depending on the number of years of operation.

## 6. CONCLUSION

The development of a computer application for solar pumping is considered part of optimization by adopting the best techno-economic solutions. This tool allows us to analyze the expected solutions with precision and to evaluate the results, prior to any material commitment. The developed software makes it possible to predict the performance of the system and to evaluate all the possible costs, for different probable cases, by varying the parameters that have a significant impact on the operation of the project. The developed software also offers comparative economic studies of several pumping system techniques, therefore providing reliable economic indicators. These should be the basis on which various choices have to be made. Following the findings, we can say that solar pumping is more economical in comparison with butane pumping, even though it is subsidized by the Moroccan state, and that diesel is largely exceeded today by *SPS* and *BPS*.

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