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ECONOMIC VALIDATION OF LARGE POWER PV IRRIGATION SYSTEMS

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ABSTRACT: This paper presents an economic evaluation of large-power PV irrigation systems (from 40 to 360 kWp) installed in Mediterranean countries, evaluating the economic feasibility of substituting or reducing their current energy sources (diesel or electrical grid) with a Photovoltaic (PV) generator and also an economic assessment based on PVIS simulated for ECOWAS region is also presented.
In the first case, five PV irrigation systems, operating in Portugal, Spain, Italy and Morocco were considered and two energetic scenarios were created in order to do the economic analysis (Optimistic and Pessimistic Scenario). The normalized Net Present Value (NPV) values are in the 2.3-3.8 €/W_p range, Internal Rate of Return (IRR) values are in the 10-16% range and Payback Period (PBP) values are in the 7-11 years range. Finally, the Levelized Cost of Energy (LCOE) values for PV irrigation systems the values are in the 0.05-0.20 €/kWh range, which represents a percentage reduction of 34-67% % if compared to the actualized cost of the previous energy source.
Regarding the second case, seven countries from the ECOWAS region were considered and two irrigation operating modes were compared (pumping to a water tank or at constant pressure). NPV values are in the 0.28-35.2x10^5 € range, (IRR) values are in the 8-47% range and (PBP) values are in the 2.1-10 years range. LCOE for PV irrigation systems are in the 0.04-0.15 €/kWh range, which represent percentage savings of 30-84% if compared to diesel-powered and grid-powered systems.
Keywords: Design, Monitoring, Stand-alone PV Systems, Water-Pumping

1 INTRODUCTION

Irrigation for agricultural applications is a very high water and electricity-consuming activity, as most of the water demanded must be pumped from underground reservoirs. Traditionally, water pumps are powered by the local electric grid, if accessible, or by diesel generators in isolated regions or in regions where the grid service is unreliable [1]. Solar photovoltaic (PV) generators to feed irrigation systems represent an attractive alternative for reducing the cost of this electricity consumption. A H2020 project named MASLOWATEN [2] recommended solutions which included the installation of 5 real scale photovoltaic water irrigation systems (PVIS) as a way to answer the irrigators' needs [3], [4], [5], [6] in Spain, Portugal, Italy and Morocco, ranging from 40 to 360 kWp. The economic effectiveness of these large power systems has been evaluated and it is here presented. However these results are site-dependent, so it would be interesting to evaluate the economic feasibility of large power irrigation systems in other regions. One of particular interest is the ECOWAS (Economic Community of West African States) region [7], where institutions like the ECREEE (ECOWAS Centre for Renewable Energy and Energy Efficiency) or the World Bank are promoting renewable alternatives for agricultural applications. Countries from this region are generally characterized by highly decentralized farms, with very limited or unreliable grid-access points. This has favored an abundance of diesel generators for back-up services, with the consequent elevated fuel and transportation costs.

First, an economic validation of the real large scale demonstrators in the Mediterranean Countries is presented. Based on this, it is estimated the economic feasibility for the ECOWAS region.

In Section 2 is presented the methodology used to preform both studies. Section 3 shows the results and finally, in section 4 are summarized some conclusions.

2 METHODOLOGY

2.1 Economic study

The viability of the economic investment required for substituting diesel generators or grid-connection points by a PV generator was evaluated through three indicators (NPV, IRR and PBP). Thirdly, the LCOE of the PV-powered systems was estimated and compared with the LCOE of the previous energy source.

For estimating the values of NPV, IRR and PBP for the investment, the annual cash flows were calculated for the whole lifetime of the system (25 years), considering both the annual profits obtained and the Amortization (AM) of the Initial Investment Cost (IIC). In the particular case assessed in this work, the annual profits are given by the economic savings derived from substituting the national grid or diesel generators by a PV generator.

An investment should be considered as profitable if the NPV is positive, IRR is higher than the local discount rate and PBP is significantly lower than the lifetime of the system.

2.2 Mediterranean Region

During the MASLOWATEN project, 5 PVIS were installed in Portugal, Spain, Italy and Morocco and they have been fully operating for the past two years. It must be emphasized that these systems are intended to be wide-ranging of configurations (stand-alone or hybrid - one with the grid, another with diesel - pumping to a water pool or at constant pressure).

Photographs of the systems can be found in the next figures.

Figure 1: Villena, Spain

Figure 2: Alaejos, Spain

Figure 3: Uri, Italy

Figure 4: Tamallalt, Morocco

Figure 5: Alter do Chão, Portugal

They are all different from each other, regarding configurations, sizes and applications:

- A 360 kWp stand-alone PV pumping system to a water pool (WP) at variable water flow (in Villena, Spain);
- A 160 kWp stand-alone PV irrigation system with one pump elevating water from a borehole to an intermediate tank at variable water flow and other pump irrigating at constant pressure (CP) through pivots (in Alaejos, Spain);
- A 40 kWp stand-alone PV irrigation system with 2 pumps pumping from a borehole at variable water flow to a water tank and one pump irrigating at CP through sprinkles (in Uri, Italy);
- A 120 kWp PV-grid drip irrigation systems, with 2 pumps and hybridization in the electric part of the system (in Tamallalt, Morocco);
- A 140 kWp PV-diesel drip irrigation systems, with 3 pumps and hybridization in the hydraulic part of the system (in Alter do Chão, Portugal).

In order to do the economic validation, 2 different scenarios (optimistic and pessimistic scenarios) were considered, depending on the irrigation needs and water availability which greatly influence the use of the PVIS.

2.3 Simulation for the ECOWAS region

In the case of the ECOWAS region, since there is no real system installed we had to do some assumptions and to design a possible PVIS. Using the simulation tool SISIFO, we had simulated a 380 kWp PV System mounted on a North-South horizontal axis tracker (due to its better match between incident irradiance and irrigation needs). It was also considered thatt it could operate by pumping to a water tank or at constant pressure. For these two kind of systems, the viability of the economic investment was done considering the substitution of the diesel generators or grid-connection points by the PV generator. Simulations were carried out for the 7 locations presented in Table 1. Based on it, SISIFO is able to import the monthly mean values of horizontal daily irradiation, as well as the maximum and minimum ambient temperatures for each place from the PVGIS database [13].

Country	Latitude [°]	Longitude [°]
Benin	12.050	3.032
Burkina Faso	14.881	-0.1
Cape Verde	14.924	-23.533
Guinea	11.222	-10.723
Liberia	8.413	-9.748
Nigeria	12.018	-8.613
Sierra Leone	9.649	-12.225

Table1: Location input used for the simulation of the PV irrigation systems.

3 Results

Figure 6 shows the NPV values for the 5 PVIS (for the two scenarios). It is easy to understand that Villena's system is the one that offers the best profitability because of many reasons: its size, for being stand alone but also because the PVIS operates the whole year.

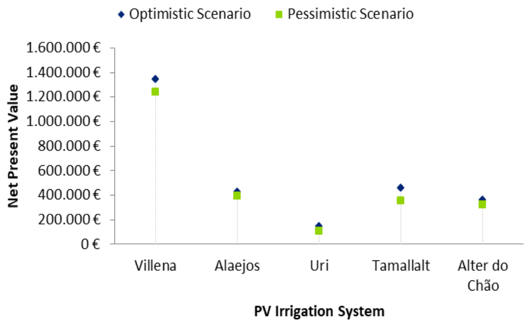

Figure 6: Net Present Value (€) for the 5 PVIS considering two different scenarios (optimistic and pessimistic).

Figure 7 shows the NPV normalized by the PV peak power for the 5 PVIS, regarding the two scenarios. As it can be observed, in this case the profitability is very similar for the 5 PVIS, ranging from 2280 €/kWp (pessimistic scenario of Alter do Chão) to 3770 €/kWp (optimistic scenario of the Tamallalt).

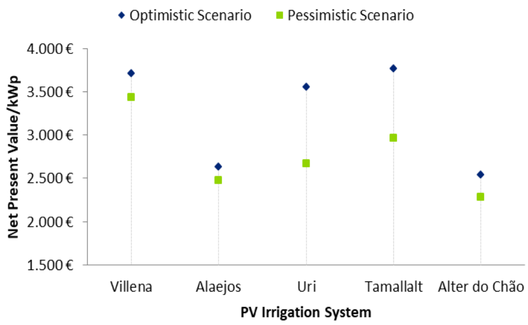

Figure 7: Net Present Value (€) normalized for the size of the PV system for the 5 PVIS considering two different scenarios (optimistic and pessimistic).

In terms of IRR (Figure 8), the values vary from 10% to 16%. Villena's system is the one which offers the best profitability in both scenarios. On the other side, the worst results are obtained for the Uri's system, which presents an IRR of 10% for the pessimistic scenario. It is important to emphasize that an investment is profitable if this tax is higher than the discount rate, in this case the WACC considered for each place.

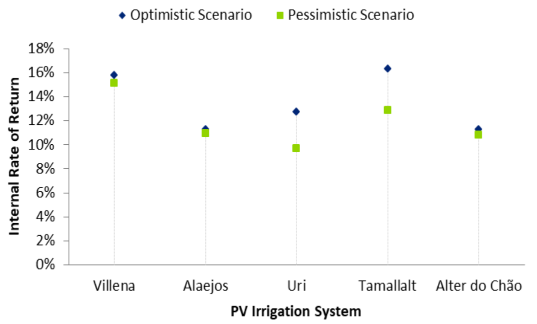

Figure 8: Internal Rate of Return (%) for the 5 PV Irrigation Installations considering two different scenarios (optimistic and pessimistic).

Regarding PBP values (Figure 9), they are less than 11 years for all the cases under study and for both scenarios. For the optimistic scenario, this value goes from 7 to 9 years.

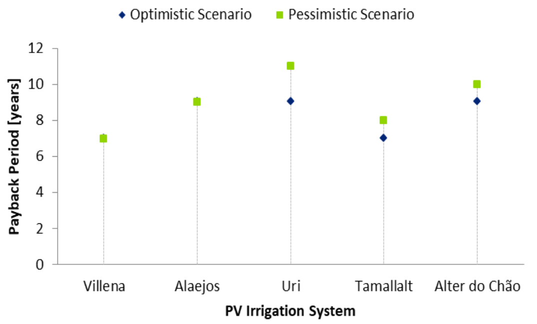

Figure 9: Payback Period (years) for the 5 PVIS considering two different scenarios (optimistic and pessimistic)

Figure 10 shows the values of LCOE obtained for the 5 PVIS, together with actualized electricity or diesel prices for the 5 PVIS under study. It is important to highlight that generating electricity for irrigation applications would be cheaper by far with a PV generator than with the electric grid or with diesel generators: percentage savings are all higher than 30%, and for the case of Villena, they are higher than 60%, for the two scenarios.

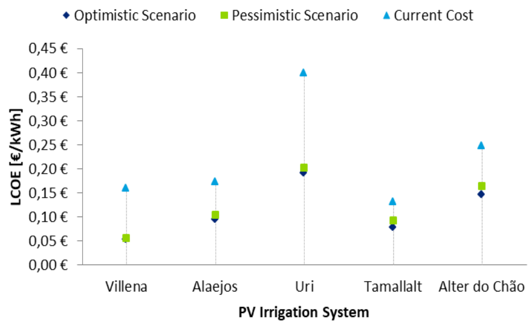

Figure 10: Levelized Cost of Energy (€/kWh) for the 5 PVIS considering two different scenarios (optimistic and pessimistic) compared to the current cost.

Regarding the economic analysis for the ECOWAS countries, if comparing the 7 countries in terms of NPV (Figure 11), Guinea offers the best profitability for the substitution of diesel-powered systems because of its elevated diesel price and its low real discount rate and corporate tax rate (both equal to zero); Burkina Faso presents the highest profitability for the substitution of grid-powered systems due to its low real interest rate, although it has an intermediate electricity price.

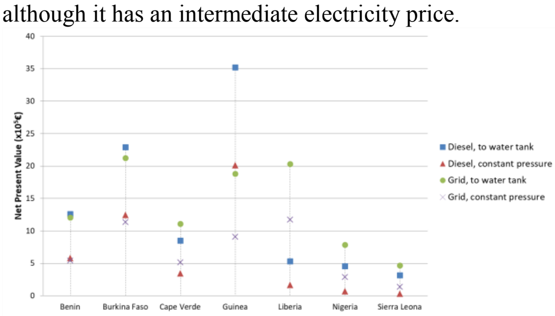

Figure 11: NPC (x10^5€) for the 7 countries and the 4 cases under study: substitution of diesel generators or the grid with PV irrigation systems, for both operating modes (to a water tank or at constant pressure).

In terms of IRR (Figure 12), Guinea also offers the best profitability for the substitution of diesel-powered systems because fuel is very expensive in this country, which implies big savings for a PV powered system, and the income tax rate is zero; Liberia offers the highest IRR for the substitution of a grid-powered system due to the elevated electricity prices, despite it having the highest income tax rate.

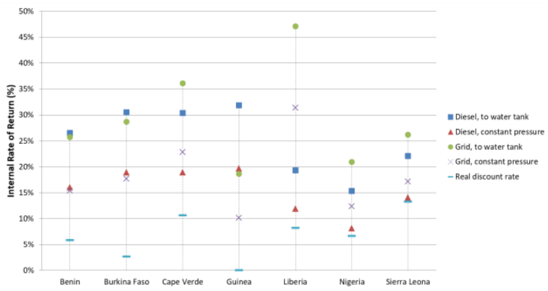

Figure 12: IRR (%) and local discount rate (%) for the 7 countries and the 4 cases under study: substitution of diesel generators or the grid with PV irrigation systems, for both operating modes (to a water tank or at constant pressure)

As regards PBP values (Figure 13), they are less than 10 years for all the cases under study, and lower than 6 years (which represents less than a quarter of the lifetime of the system) except for some systems pumping at constant pressure.

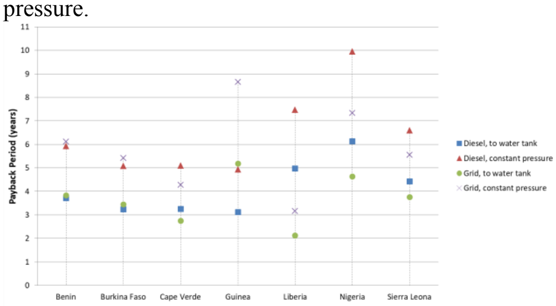

Figure 13: PBP (years) for the 7 countries and the 4 cases under study: substitution of diesel generators or the grid with PV irrigation systems, for both operating modes (to a water tank or at constant pressure)

As regards LCOE values (Figure 14), they are smaller than electricity prices and the LOCE for diesel powered systems.

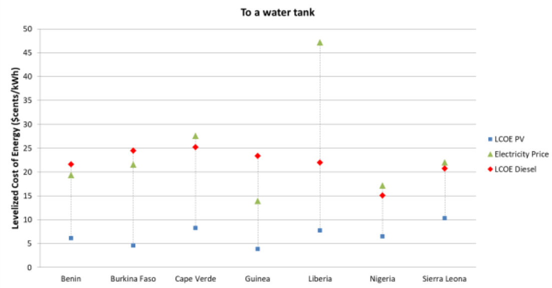

Figure 14: LCOE (€cents/kWh) for PV-powered and for diesel-powered systems and electricity prices for the 7 countries under study, for systems pumping to a water tank.

4 CONCLUSIONS

Regarding the real scale demonstrators, it can be concluded:

- NPV values are all positive and in the range 2279-3771.6 €/kWp.
- IRR values are all higher than the discount rate and in the 10-16% range.
- PBP are far below the lifetime of the system (25 years) and in the 7-11 years range.
- LCOE values are the lowest for PV irrigation systems and in the 0.05-0.20 €/kWh range, representing very high percentage savings in the range 34-67% if compared to the cost of the previous energy source.

In what concerns, the ECOWAS region, the following may be concluded:

- NPV values are all positive and in the range 0.28-35.17x10^5 €.
- IRR values are all higher than the local real discount rate (*i*) and in the 8-47% range.
- PBP are far below the lifetime of the system (25 years) and in the 2.1-10 years range.
- LCOE values are the lowest for PV irrigation systems and in the 0.04-0.15 €/kWh range, representing very high percentage savings in the range 30-84% if compared to diesel-powered and grid-powered systems.

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