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Mobilising Renewable Energy Investments

Senegal: Renewable Energy in Agricultural Value Chains

Model Business Case: Solar Photovoltaic Water Pumping for Large-Scale Irrigation Scheme with High Water Demand

INTRODUCTION

This Model Business Case studies the viability of solar photovoltaic (PV) powered water pumping investments for irrigation, compared to diesel and grid-connected options in Senegal. The modelling covers water pumping systems powered by diesel, grid electricity and PV for large-scale[1] plot sizes of: 50 and 250 hectares (ha).

The 50 ha plot is modelled as a group irrigation scheme with a shared solar array and pump. It considers 60 farmers each cultivating plots of less than one hectare corresponding to the typical plot size in the country where about 90% of farmers cultivate plots below 5 ha[2]. The 250 ha plot considers a large-scale agribusiness, which is a growing sector in Senegal in line with the government's priority of promoting a modern and diversified agricultural sector including the desire to increase exports and trade revenues. For both plot sizes, relatively high water demand crops such as paddy rice, banana and sugarcane are modelled.

Globally, the solar irrigation market has a significant potential for growth. One recent study predicted a global increase of installed units from around 120,000 in 2014 to 1.5 million by 2022[3]. For Senegal, the accompanying GET.invest Developer Guide estimated a market opportunity of over EUR 55[4] million considering a significant expansion of the area under irrigation.

1) A second Model Business Case investigates the feasibility of solar pumps for small-scale irrigation systems: 0.1, 1 and 5 ha; accessible at www.get-invest.eu
2) Centre for Environmental Economics and Policy in Africa (CEEPA) research
3) HYSTRA (2017) Reaching scale in energy access: Lessons from Practitioners, at: www.hystra.com/a2e/ – accessed January 2019
4) Please refer to the accompanying Developer Guide for details; accessible at www.get-invest.eu

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The area of land in Senegal with relatively good potential for irrigation is estimated at 497,500 ha and is concentrated around the Senegal River in the north, the Niayes area in the west and the Groundnut Basin in the centre. Until recently, the total area under irrigation is estimated at 95,400 ha, including 26,000 ha for horticulture and about 69,400 ha for cereals being predominantly rice.

Medium sized irrigation systems covering areas ranging from a few ha to tens of ha often utilise diesel-powered systems and can be private farms, enterprises or organised via groups or associations (medium-size group irrigation schemes). Such systems are common along the Senegal River and valley and the banana area in the Gambia River Valley, with pumping frequently carried out from surface water bodies.

Larger scale irrigation schemes in Senegal, a few hundred to a couple of thousand ha, are typically developed and financed by the government with recipients paying a fee for the water use. Over time, selected schemes are handed over for management by the farmer and village groups. In these cases water is typically pumped using large electric or diesel pumps of over a 50-kilowatt (kW) capacity with mostly gravity used to transport water through irrigation canals. These include for example larger horticultural farms (150–350 ha), private rice producers (one of 7,000 ha) and the sugar industry.

Even where medium and larger-scale farms and irrigation schemes may have grid access, diesel can still account for approximately one third of pumping energy requirements due to frequent power black outs.

Within this context, Senegal's abundant solar energy resource combined with the falling price of PV panels and emerging financing schemes may provide attractive conditions for solar-powered irrigation for some larger farms, group irrigation schemes and agribusinesses.

TARGET AUDIENCE

- **Medium and large-scale farmers, farming associations and agribusinesses,** who are considering solar pumping to lower operational costs among other potential benefits
- **Project developers and financiers**, who may be interested in an estimated solar-powered irrigation market of over EUR 55 million and need to understand a potential future client base

TECHNOLOGY OVERVIEW

Annex A provides more details.

ASSUMPTIONS AND MAIN PARAMETERS

Three pumping alternatives are modelled supplying two plot sizes (50 ha and 250 ha) with an irrigation need of between 73–84 m^3/ha/day[5]. This water need corresponds to higher demand crops such as paddy rice, banana, and sugarcane.

For the 50 ha plot with 60 farmers, two growing seasons per year, totalling 274 irrigation days between March and November are assumed. For the 250 ha plot run by an agribusiness, three growing seasons per year, totalling 364 irrigation days, are assumed. In both cases specific irrigation needs are adjusted per season based on temperature and rainfall.[6]

Publicly available information about the most common pumps in the Senegalese market was taken into account including the specifications and costs. Suitable pumps are selected from supplier catalogues to satisfy the needs of the estimated flow rate and head for each of the profiles. A head of 15m is considered in order to allow for system losses and ensure the necessary water pressure to run available irrigation technologies (centre-pivot, sprinkler, drip, flood and hose[7]) and support systems containing water storage tanks.

In order to ensure security of supply, the capacity of the accompanying solar PV array is dimensioned in comparison to the pump. A pump requires a certain power to produce a desired amount of pressure and flow. Therefore the PV array size has to be optimised for the required amount of power. A higher

5) FAO (1986) Irrigation Water Management: Irrigation Water Needs, at: https://bit.ly/2TFqvea – accessed January 2019
6) The climate data for Dakar is applied in this case as an average representation for the country
7) More information on the listed irrigation methods can be found in **Annex A**

capacity PV system — while it increases the cost — will allow the pump to start faster and operate for longer periods during low insolation conditions.

In general, water demand as well as the required dynamic head is highly dependent on the local conditions and crops planted. Even though all assumptions made reflect a typical situation in Senegal, specific circumstances can vary significantly and therefore influence the calculated results and financial viability. **Table 1** summarises the main system parameters used.

TABLE 1. Main layout parameters

INPUT PARAMETERS	VALUES	
Plot Size (ha)	**50**	**250**
No. irrigation days	274	364
Irrigation demand (m^3/ha/day)		Maximum — 84 Minimum — 78
Irrigation demand (m^3/day)	Maximum — 4,191 Minimum — 4,009	Maximum — 20,955 Minimum — 19,500
Pump sizes (kW)	47	244
Dynamic head (m)	15	15
PV capacity (kWp)	59	304

Investment and operating costs

The capital expenditure (CAPEX) in all cases covers the direct cost of the pump. Import duty is not considered as the equipment is readily available in Senegal. Additionally, for the solar pump, the cost of the solar array is included. For electric pumps, the cost associated with grid connection is considered at a rate of over EUR 34,000[8] in both cases. It is assumed that all three options have similar costs for installation, logistics, transportation and civil engineering works, hence these are excluded for comparison purposes.[9]

For the operating expenditure (OPEX), solar irrigation systems are subject to a naturally low operating and maintenance (O&M) costs of around 2% for the pump and 2.5% for the solar array of the CAPEX. Diesel pumps incur higher O&M costs at around 10% of CAPEX in addition to fuel consumption costs which are assumed at EUR 0.92/litre. For electric pumps, electricity from the grid is considered an operational cost. The medium voltage customer tariff (moyenne tension) applied by Senelec[10] and determined by the national regulator (CRSE — The Commission de régulation du secteur électrique) is utilised for these calculations with a fixed monthly charge being applicable for both plots. Other tariffs could apply in cases where electricity is provided by third party actors other than Senelec.

In general, replacement of pumping installations depends on the reliability of the system and the operating environment (e.g. water quality, diesel quality, direct exposure to sunlight, excessive temperature) as well as the level of maintenance performed. Based on sector knowledge and discussions with pump suppliers, an estimated project lifetime of 10 years is assumed. No equipment replacement costs are foreseen during the 10 years across the two scenarios.

Table 2 summarises the pumping system CAPEX and OPEX. As expected, solar pumps require higher upfront investment while incurring the lowest operating costs. **Figure 1** compares the total solar PV pump CAPEX with the cost per kW, showing the impact of economies of scale.

8) The grid connection cost is derived by multiplying the average distance of farm plots to the grid in Senegal (4.52 km) by an average cost per km (EUR 7,669) for a 33 kV supply line
9) Although there are differences in cost, this approach was taken for simplification. This Model Business Case serves to directly compare the costs of alternative pumping options (solar, diesel and grid-connected) for irrigation in Senegal
10) Senelec is the national electricity company of Senegal (Société nationale d'électricité du Sénégal). Please see the accompanying Developer Guide; accessible at www.get-invest.eu for the Senelec tariffs

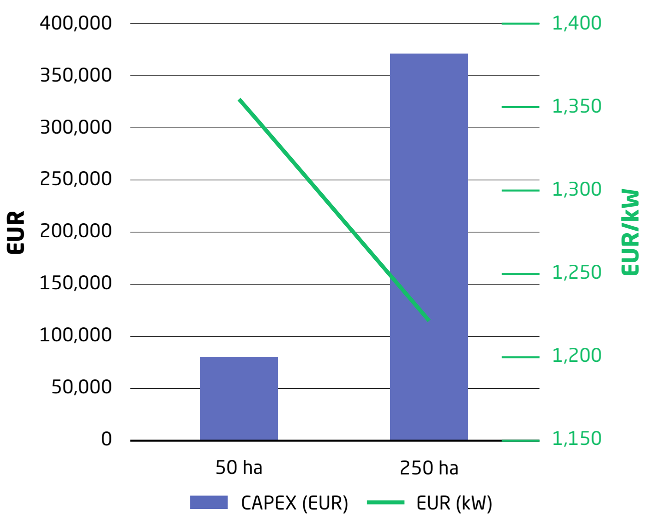
TABLE 2. CAPEX and OPEX overview

INPUT PARAMETERS		VALUES	
Plot Size (ha)		**50**	**250**
CAPEX (EUR)	Diesel	30,000 (500 per farmer)	150,000
	PV	79,289 (1,321 per farmer)	371,776
	Grid	59,692 (995 per farmer)	159,692
OPEX incl. fuel (EUR/year)	Diesel	20,034	126,754
	PV	1,732	8,044
	Grid	10,285	59,653

TABLE 3. Financial assumptions

INPUT PARAMETERS		VALUES	
Plot Size (ha)		**50**	**250**
Debt/equity ratio	%	50/50	70/30
Weighted average cost of capital (WACC), pre-tax, real	%	15	14
Interest rate, real[12]	%	12.5	12.5
Expected rate of return on equity, real	%	17.5	17.5
Loan grace period	years	2	2
Loan repayment period	years	5	7

FIGURE 1. Solar PV pump cost (pump and PV array)



Financing scenarios[11]

In this Model Business Case, no grant or concessional funding is assumed. Please refer to the accompanying Case Studies where a concessional financing scenario was studied. **Table 3** summarizes the financial assumptions used in this Case:

FINANCIAL ANALYSIS

Levelised cost of electricity (LCOE)[13] and net present value (NPV)[14] of cost savings

Figure 2 summarises the results of LCOE calculations using the pre-tax real weighted average cost of capital as the discount rate. **Table 4** summarises the NPV of saved costs of using solar PV pumps against pumps powered by diesel and grid electricity. For the LCOE, it is evident that investing in a PV pump is a better option in both the 50 ha and 250 ha irrigation scenarios compared to both the diesel and grid connected pumps. For NPV, all cases result in a positive outcome at the assumed discount rate except for the grid-connected pump scenario on the 250 ha plot where the NPV for cost savings using a solar PV pump is negative. This is due to the higher upfront cost of the solar pump that leads to higher debt servicing and given the retail electricity tariffs at the time of writing. In reality, whether solar PV pumping is more attractive would depend on the individual conditions of each farm and further consideration should be given to the sensitivities presented later in this document.

11) Please refer to the accompanying Developer Guide; accessible at www.get-invest.eu for more details on potential financing options

12) Based on average commercial bank nominal rates

13) LCOE is used here as an indicator to compare the cost of electricity of different options. LCEO is the ratio of lifetime costs to lifetime electricity generation, both discounted back to a common year using an appropriate discount rate

14) NPV is the difference between the present value of the project future cash flows and initial investment. The present value is the current worth of a future sum of money or stream of cash flows given an assumed discount rate representing the investment risk

It is important to note that if power service quality and outages are factored in, means of backup generation should be considered which might tilt the cost advantage further in favour of solar PV pumping (see the sensitivity analysis section for more information).

FIGURE 2. LCOE (EUR/kWh) per pump alternative at two plot sizes

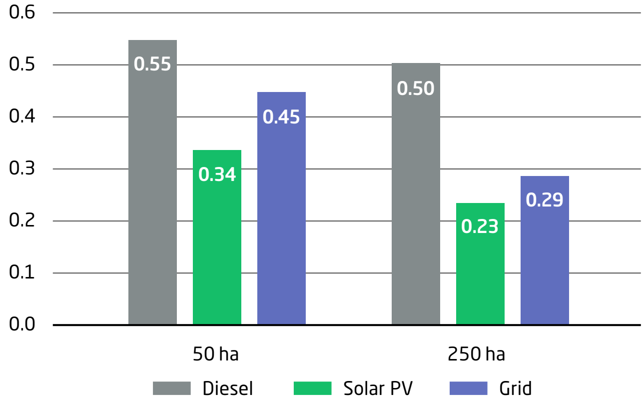


TABLE 4. NPV of saved costs of using solar PV vs. diesel and grid electricity pumps

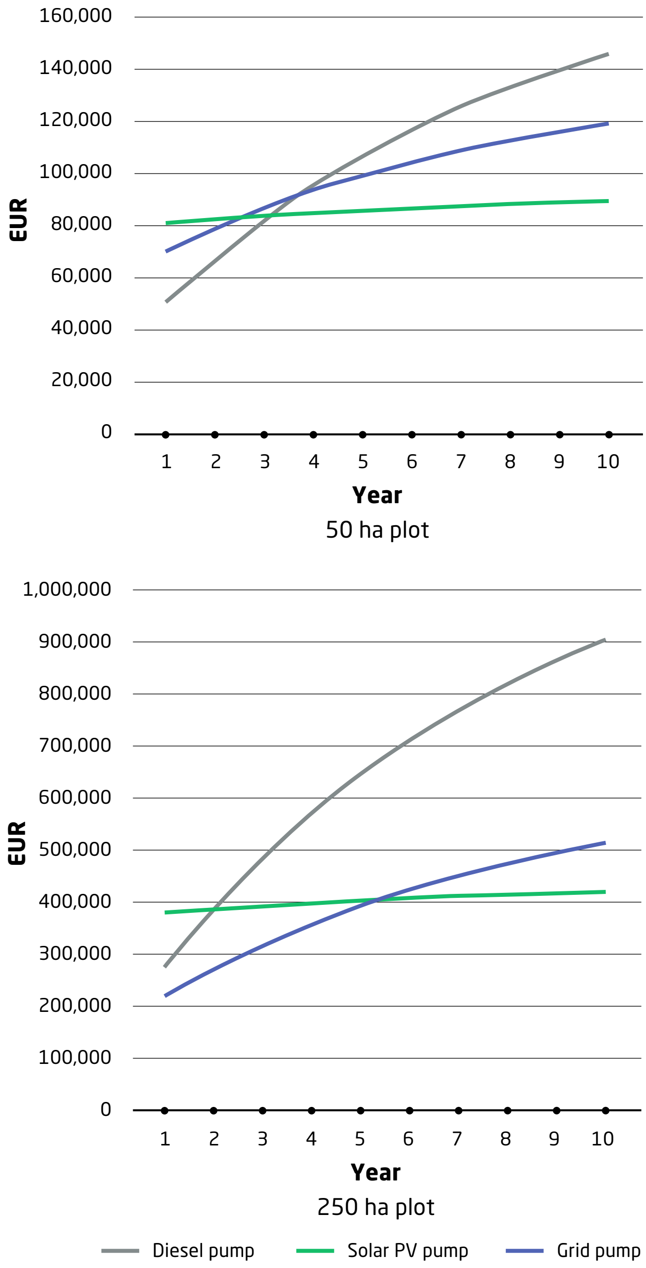
		50 ha PLOT	250 ha PLOT
NPV of saved costs of using solar PV pump against: (EUR)	Diesel pump	18,485	225,018
	Grid-powered pump	11,628	– 3,668

Break-even analysis
The break-even analysis of the cumulative total discounted expenses (CAPEX and OPEX) is presented to illustrate the relative economic feasibility of each scenario.

Figure 3 summarises the results. It is evident that PV pumps become more attractive than diesel pumps within four years for the 50 ha plot and two years for the 250 ha plot scenarios respectively. In general, it can be observed that solar irrigation pumps are attractive due to the high fuel cost associated with the diesel option.

Compared to the grid connected alternative, PV pumps become more attractive within three years for installations on the 50 ha and six years on the 250 ha plot scenario respectively. For the grid electricity option, the connection cost is a significant portion of the initial investment and is briefly explored further under the sensitivity analysis section.

FIGURE 3. Break-even of different pump alternatives across the two scenarios



SENSITIVITY ANALYSIS

A sensitivity analysis was performed on two variables to test the impact on the economic performance of the water pump investment. The variables are:

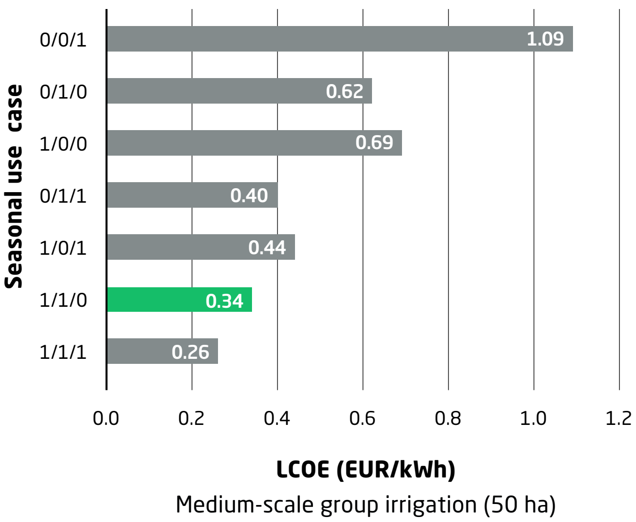
— The number of growing seasons
— The price of solar PV module

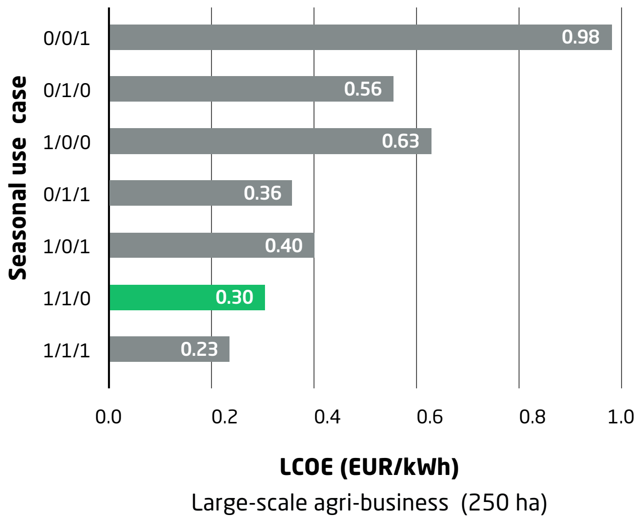
Variable 1 — Effect of the number of growing seasons on the LCOE of the PV pump

The number of growing seasons (1 to 3)[15] can significantly impact the economic performance of solar irrigation pumps. Electricity use and diesel fuel consumption increase with more growing seasons, thus increasing the potential savings associated with solar PV pumps, and vice versa.

Figure 4 displays the solar irrigation pump LCOE for different growing seasons scenarios with the previously reported LCOE figures marked in red. It is clear that the solar option becomes less economically attractive with shorter growing periods.

FIGURE 4. LCOE of PV pumps with varying number of growing seasons (Season 2 / Season 1 / Season 3)





Variable 2 — Effect of PV module price on LCOE of solar pumps compared to diesel and grid-connected pumps

The costs associated with utilising a solar pump are directly correlated with the upfront expenditure required to procure the solar array. Despite global trends of declining solar PV costs, the price of the panels secured by an individual investment could be a critical variable. Therefore, the effect of the PV module price on the solar pump LCOE has been tested through a sensitivity analysis, with the results displayed against the fixed diesel and grid-connected pump LCOE in **Figure 5**.

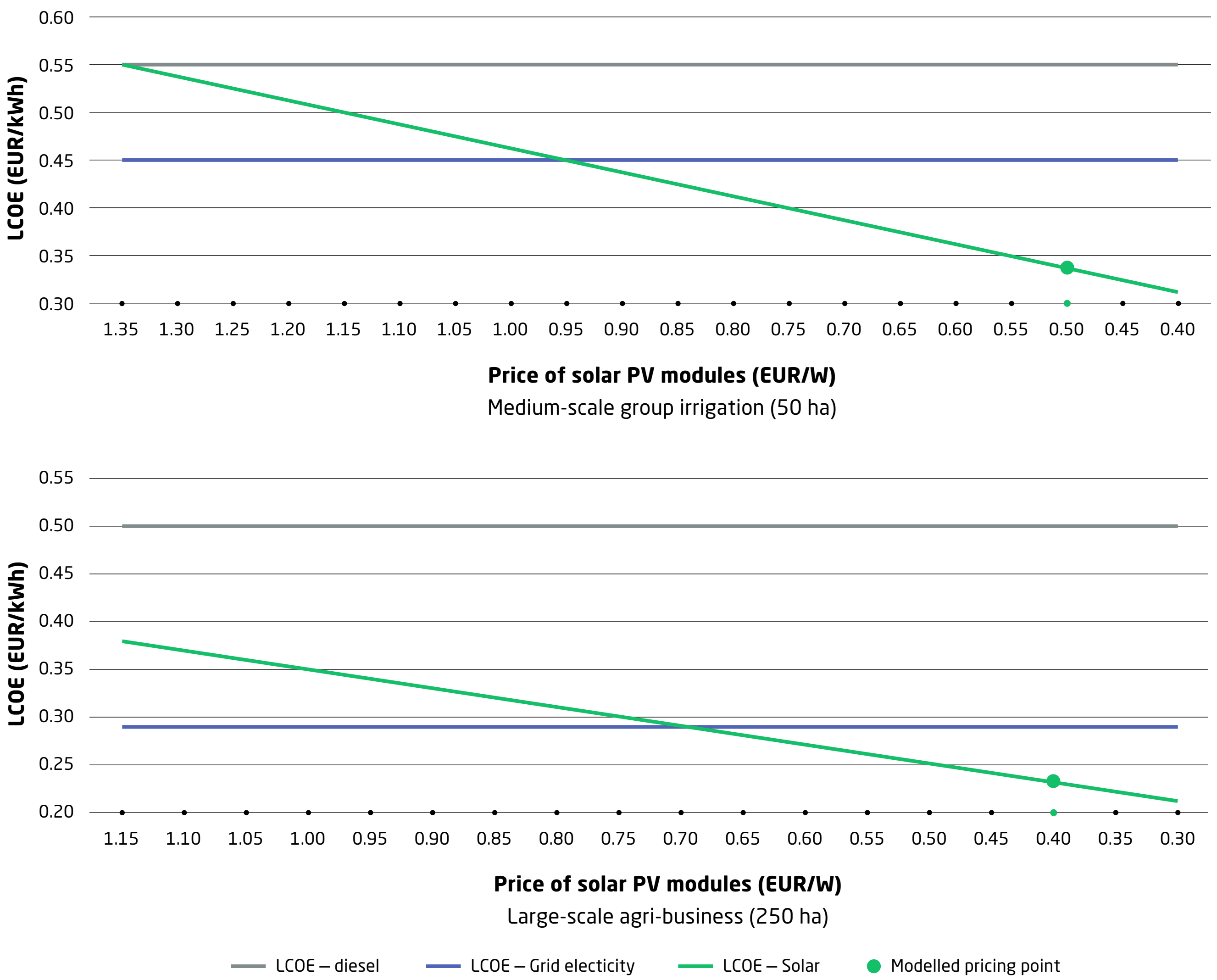
It can be seen that for both plots, the price of PV modules need to increase by at least about 100% (50 ha) and 50% (250 ha) for the grid-connected pumping option to become competitive on LCOE basis at the modelled assumptions.

A note on grid connection costs and backup diesel generation

The LCOE difference between the solar PV and grid pump narrows if costs for a new grid connection are not considered. Without grid connection costs, the electric pump LCOE would decrease to EUR 0.30/kWh (down from EUR 0.45/kWh) on the 50 ha plot against EUR 0.34/kWh for solar. This significant reduction is owing to the high cost of the connection. Therefore, in a case where a new grid connection is not required or there is an existing connection, the solar option becomes less attractive at the given electricity retail tariffs and other assumptions. Similarly, for the 250 ha plot, the LCOE for the grid-connected pump decreases from EUR 0.29/kWh to EUR 0.26/kWh against an LCOE of EUR 0.23 kWh for the solar PV.

15) The scenarios are based on a tripartite growing year, whereby: Season 1 (Dry and Hot – Contre-saison chaude), runs from March to June, Season 2 (Wet – Hivernage) runs from July to November and Season 3 (Dry and Cold – Contre-saison froide) runs from December to February

FIGURE 5. Sensitivity of LCOE of solar PV pumps based on the price of PV modules (EUR/W) compared to the static LCOE of diesel and grid-connected pumps



In many cases, plot owners should consider the impact of backup diesel generator due to grid downtime. In a case where the cost of new grid connection is not considered but 30% grid downtime is assumed, grid pump LCOE increases to EUR 0.36/kWh and EUR 0.33/kWh for the 50 ha and 250 ha plots, respectively, thus tilting the balance to favour the solar PV pumping option.

KEY TAKEAWAYS

— A decision to invest in a solar powered irrigation system is unique to each case and careful consideration should be given to critical factors such as water demands and dynamic head requirements with regards to local conditions and the crops planted. Further attention should be given to the impact of the irrigation on future yields including the potential for additional harvests and the method of financing for the upfront investment.

— The upfront costs for solar irrigation pumps remains a significant investment decision, even for large scale emerging agribusinesses. For the two plot sizes modelled in this case, the approximate CAPEX requirements including the pumps and solar array are around EUR 79,000 (50 ha) and EUR 372,000 (250 ha).

— Investment in solar PV pumping technology can be attractive for both plot sizes modelled in this case when compared with diesel pumping. When evaluated against grid-powered electric pumps, in the 250 ha case the NPV for solar based cost-savings is slightly negative.

— Break-even analysis of the cumulative total discounted expenses (CAPEX and OPEX) shows that PV pumps become attractive within four (50 ha) and two (250 ha) years against the diesel pump. The PV pumps also break even with grid-connected pumps within three (50 ha) and six (250 ha) years.

— The sensitivity analysis demonstrates the role of critical parameters:

a) The number of growing seasons (1 to 3) can significantly impact the economic feasibility of the solar irrigation pumps. The PV pumps become more attractive with an increase in growing seasons and therefore the utilisation rate. This is linked to the water needs for which factors such as the crop and geographical location (rainfall and temperature) are important. This is an especially important consideration for the large scale agribusinesses for which it is assumed will be operational for 364 days a year;

b) The price of PV panels for a given project is critical in determining its financial attractiveness. For the electric pump LCOE to become competitive with that of a solar pump, the price of modules would need to increase by about 100% (50 ha) and 50% (250 ha). In both cases, but the latter one in particular, these effects should be closely analysed before a potential investment;

c) For the grid electricity option, the connection cost is a significant portion of the initial investment, being over 50% of CAPEX in the 50 ha case. It is important to also consider the cost for a backup diesel generator for the electric pump. In a case where the cost of a grid connection is not considered but 30% grid downtime is assumed, solar PV is the most attractive option in both plot scenarios.

ANNEX A

Technology overview

Solar-powered irrigation is based on PV technology that converts solar energy into electrical energy to run a Direct Current (DC) or Alternating Current (AC) motor based pump. The technology is similar to any other conventional water pumping system except that the power source is solar energy.

A typical solar water-pumping unit (**Figure 6**) includes three main components: the PV panels, the solar pump and the controller. In addition, selected systems include storage facilities being physical water storage methods (e.g. overhead tanks) and/or energy storage i.e. batteries. However, due to their relatively high cost, batteries are rarely used for storage compared to their alternatives i.e., overhead tanks, small irrigation dams or canalisation systems (used for channelling water for example in rice paddies).

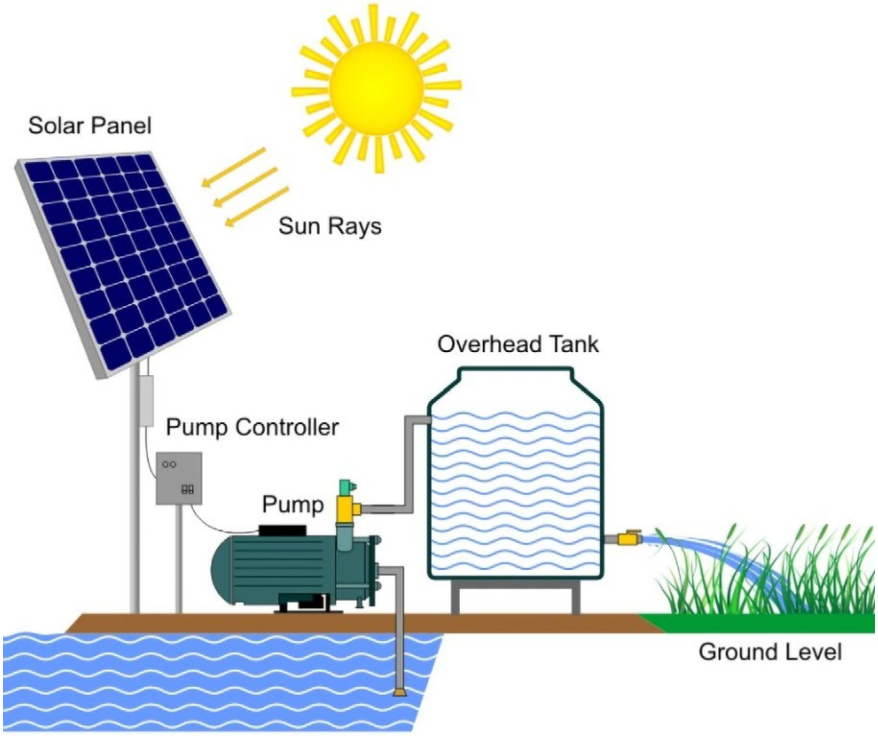
Additional system components include the mounting structure, wiring, piping and float switch. Often a lockable security structure is used to house critical equipment, including for example the pump and control panel, to protect against the risk of vandalism and theft.

Solar water pumps are classified into three types according to their applications: submersible, surface and floating. A submersible pump draws water from deep wells, a surface pump from shallow wells, springs, ponds, rivers or tanks, and a floating pump from reservoirs being adjustable to the water height.

For utilising the pumped water for medium and large-scale farms in Senegal, different irrigation methods may be applied: centre-pivot, sprinkler, drip, flood and hose).

The reason for irrigating is to provide water to crops in the field with the aim of increasing yields. In this regard, hose irrigation is inefficient in that only a limited amount of the water spread onto the field is available to the growing crops. In comparison, sprinkler irrigation has a higher efficiency, while of the three-drip irrigation is considered the most efficient. In water consumption terms if the irrigation methods are directly compared against the same outcome, with drip irrigation set at 100%, sprinkling would require 133% and use of a hose 250%.

FIGURE 6. Schematic diagram of a PV surface pump[16]



16) Unknown creator, "Solar Water Pumping System". Not licensed. Link: https://greenlifesolution.in/solar-photovoltaics/solar-water-pumping-system/ – accessed April 2019

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Each Market Insight package includes **a)** a 'how to' Developer Guide, **b)** Model Business Cases and **c)** Case Studies. The Developer Guide enables the reader to navigate the market and its actors, to understand the current regulatory framework and lays down the step-by-step process of starting a new project/business. The Model Business Case analyses project economics and presents hypothetical, yet realistic, investment scenarios. It hence indicates the criteria for a viable project/business to enable the reader to identify the most cost-effective project/business opportunities. The Case Study analyses the viability of operational or high-potential projects/businesses to highlight lessons learnt and industry trends.

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GET.invest is a European programme which supports investment in decentralised renewable energy projects. The programme targets private sector business and project developers, financiers and regulators to build sustainable energy markets.

Services include project and business development support, information and matchmaking, and assistance in implementing regulatory processes. They are delivered globally and across different market segments.

GET.invest is supported by the European Union, Germany, Sweden, the Netherlands, and Austria, and works closely with initiatives and industry associations in the energy sector.

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CONTACT

GET.invest
E info@get-invest.eu
I www.get-invest.eu

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