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Mobilising Renewable Energy Investments

Senegal: Renewable Energy in Agricultural Value Chains

Model Business Case: Solar Photovoltaic Water Pumping for Small-Scale Irrigation Scheme with Low 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 small-scale[1] plot sizes of 0.1, 1 and 5 hectares (ha). This plot size range represents about 90% of Senegalese farmers cultivating plots below 5 ha[2] and considering horticulture of relatively low water demand crops such as peanuts, onions and carrots. It is assumed that these schemes could be implemented at the individual farmer or group level (5 ha), with the latter applying a shared solar array and pump.

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.

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,

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1) A second Model Business Case investigates the feasibility of solar pumps for large-scale irrigation systems: 50 ha and 250 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 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. The role of irrigation is fundamental to agricultural production in the country with the FAO/IFC (2016)[5] stating that irrigated small scale (0.2 ha) plots utilising surface water provide for 90% of the vegetables sold at local markets.

Currently, for small-holder farmers in Senegal irrigating up to a 2–3 ha surface area, diesel-powered lower capacity pumps (<5 kilowatts (kW)) are widely used. Electric-powered pumps, on the other hand, are generally of a higher capacity (50–90 kW) and are mostly operating on existing and emerging medium and large-scale agri-businesses. The daily operating expenditure (OPEX) including fuel for a diesel pump on the small-scale plots ranges between EUR 1.55/ha to EUR 2.63/ha. This is over 3 times higher than the price of grid electricity, though grid access remains limited with around 40% of rural households connected.[6] Diesel also accounts for approximately one third of pumping energy requirements of grid-connected farms due to frequent power blackouts. Diesel systems are often paired with a hose[7], pumping a large amount of water over a short period of time, therefore resulting in significant runoff including of fertiliser and diminishing crop yield and quality.

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 farmers.

TARGET AUDIENCE

- **Farmers and their associations**, 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 the three plot sizes (0.1 ha, 1 ha and 5 ha) with an irrigation need of between 63–70 m³/ha/day[8]. This water need corresponds to lower demand crops such as peanuts, watermelon, carrots, crucifers (broccoli, cauliflower, cabbage), onions and lettuce. Two growing seasons per year, totalling 274 irrigation days between March and November were assumed[9], with the specific irrigation needs adjusted per season based on temperature and rainfall.[10]

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 30m is considered in order to allow for system losses and ensure the necessary water pressure to run all available irrigation technologies (hose, sprinkler & drip[11]) and support systems containing water storage tanks.

In order to ensure security of supply, the capacity of the accompanying solar PV array is dimensioned with relevance 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 capacity PV system — while it increases the cost — will allow the pump to start earlier 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

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[5] FAO/IFC (2016) Senegal Irrigation Market Brief , at: http://www.fao.org/3/a-i5365e.pdf – accessed January 2019

[6] The World Bank (No Date) Access to Electricity, % of Rural Population, at: https://bit.ly/2QEo0Hk – accessed January 2019

[7] More information on the irrigation methods can be found in **Annex A**

[8] FAO (1986) Irrigation Water Management: Irrigation Water Needs, at: https://bit.ly/2TFqvea – accessed January 2019

[9] While many farmers in Senegal use only one growing season, it is expected that those with access to (improved) water pumping will use two growing seasons. The impact of the number of irrigation days is analysed in the "Sensitivity Analysis" section of this document

[10] The climate data for Dakar is applied in this case as an average representation for the country

[11] More information on the listed irrigation methods can be found in **Annex A**

in Senegal, specific local conditions 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)	**0.1**	**1**	**5**
No. irrigation days	274	274	274
Irrigation demand (m³/ha/day)	70	70	70
Irrigation demand (m³/day)	7	70	350
Pump sizes (kW)	0.07	0.74	3.7
Dynamic head (m)	30	30	30
PV capacity (kWp)	0.9	0.87	4.3

INVESTMENT AND OPERATING COSTS

The capital expenditure (CAPEX) in all cases covers the direct cost of the pump. For the solar pump, the cost of the solar array is included. The 0.1 ha plot case is specifically based on a combined pump and PV panel unit. For electric pumps, the costs associated with grid connection are not considered, though the charge for connection to a low voltage line at the 0.1 ha plot is considered. Import duty is not considered as the equipment is readily available in Senegal. 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.[12]

For the operating expenditure (OPEX), solar pumps are subject to a naturally low operating and maintenance (O&M) costs of around 2% of CAPEX. Diesel pumps incur higher operating costs at around 10% of CAPEX, in addition to fuel consumption costs which specific to this model case range from EUR 1.20/litre (l) to EUR 1.29/l depending on the system size.[13] For electric pumps, electricity from the grid is considered an operational cost. The tariff for "Professional Use" (usage professional) applied by Senelec[14] and determined by the national regulator (CRSE — Commission de régulation du sect EUR électrique) is utilised for these calculations with no fixed charge being applicable for all three plot sizes. The 5 ha plot falls under the medium consumer category (UD-MP — usage professionel moyenne puissance), with the small consumer rate (UD-PP — usage professionel petite puissance) being applicable to the other two plot sizes. 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 has been assumed. No equipment replacement costs are foreseen during the 10 years across the three 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.

TABLE 2. CAPEX and OPEX overview

INPUT PARAMETERS		VALUES		
Plot size (ha)		**0.1**	**1**	**5**
CAPEX (EUR)	Diesel	300	800	1,500
	PV	600	3,814	9,504
	Grid	442	1,000	1,500
OPEX incl. fuel (EUR/year)	Diesel	78	544	2,386
	PV	12	82	216
	Grid	23	169	794

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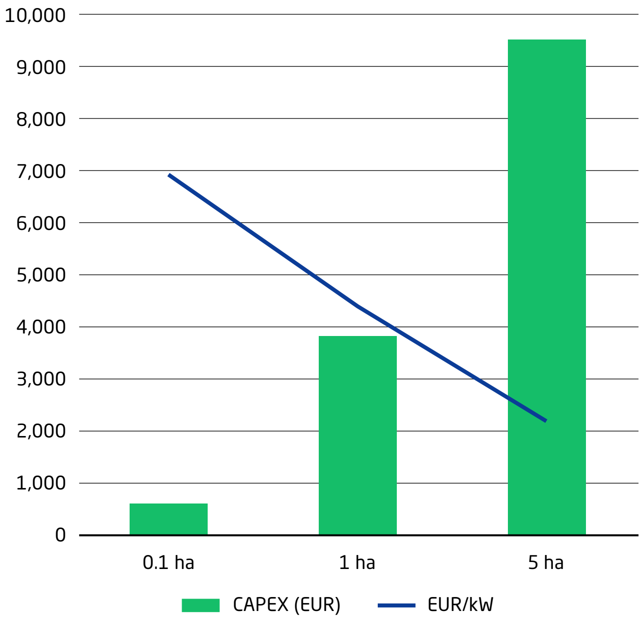
[12] Although there are differences in cost, this approach was taken for simplification. This Model Business Case serves to directly compare the costs of alternative pumping options (solar, diesel and grid-connected) for irrigation in Senegal

[13] Diesel fuel prices have been adjusted from the national average (EUR 0.92/l) to account for higher pricing and costs in rural and remote areas

[14] 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

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



Financing[15] scenarios

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** summarises the financial assumptions used in this Case:

TABLE 3. Financial assumptions

INPUT PARAMETERS		VALUES		
Plot Size (ha)		**0.1**	**1**	**5**
Debt/equity ratio	%	80/20	50/50	50/50
Weighted average cost of capital (WACC), pre-tax, real	%	16	15	15
Interest rate, real[16]	%	15.7	12.5	12.5
Loan grace period	months	6	12	12
Loan repayment period	years	1.5	3	3

FINANCIAL ANALYSIS

Levelised cost of electricity (LCOE)[17] and net present value (NPV)[18] of cost savings

Figure 3 summarises the results of LCOE calculations using the pre-tax real weighted average cost of capital as the discount rate. **Table 3** summarises the NPV of saved costs of using solar PV pumps against those powered by diesel and grid electricity, using the pre-tax real weighted average cost of capital as the discount rate. It is evident that investing in a solar PV pump is a better option for the 0.1 ha and 5 ha irrigation scenarios compared to diesel pump. For the 1 ha plot size, the diesel pump is more attractive than the solar option despite the close LCOE values. In reality, whether diesel or 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 in this document.

On the other hand, compared to a grid-connected electric pump, the cost advantage of solar pumps is less definitive. However, if power service quality is considered and outages are factored in, means of backup generation should be considered which might tilt the cost advantage to the solar PV pump (see the sensitivity analysis section for more information).

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

[16] Based on average commercial bank nominal rates

[17] 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

[18] 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

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

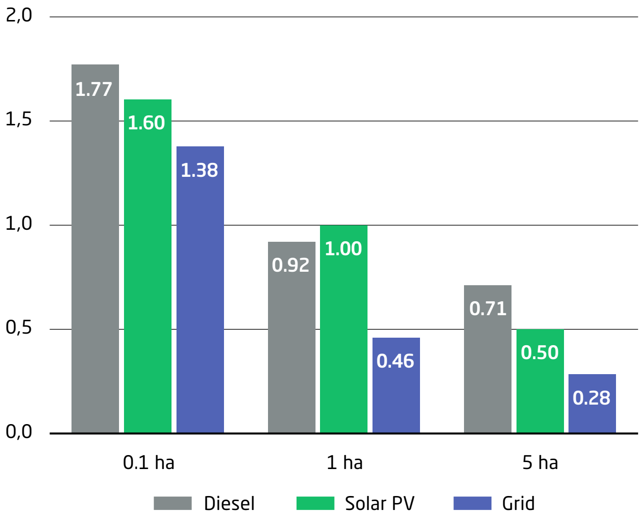


TABLE 3. NPV of saved costs of using solar PV vs. diesel and grid electricity pumps

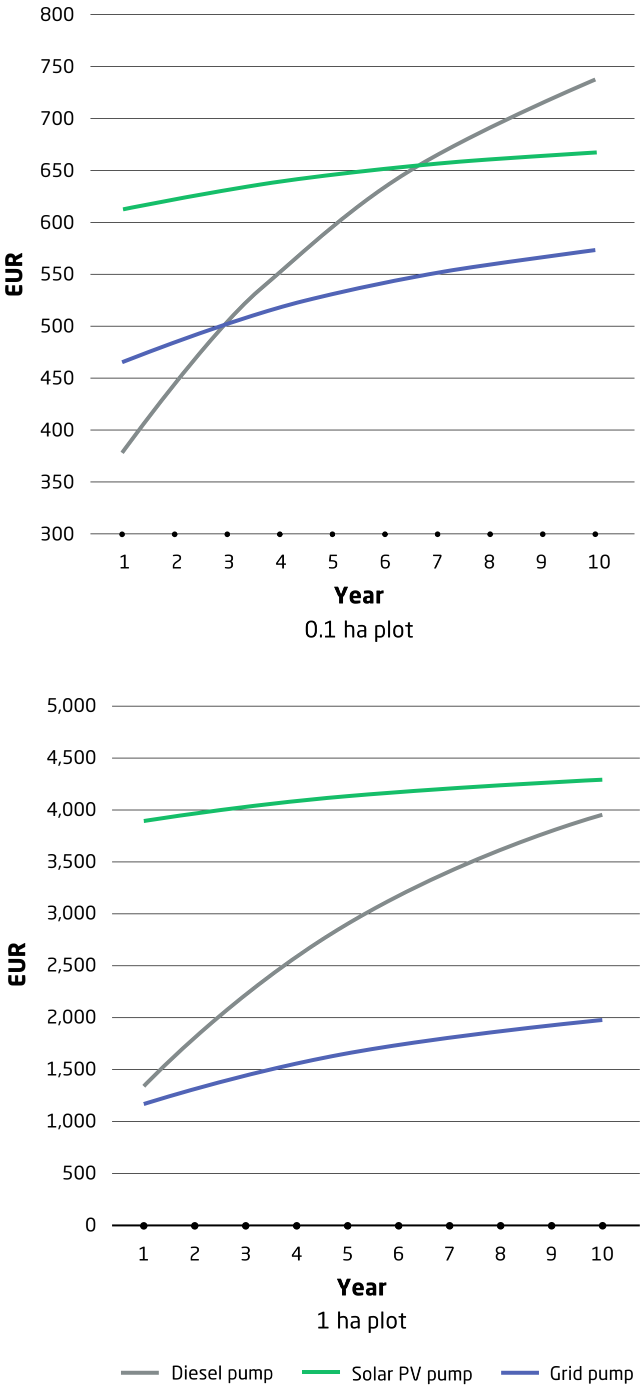
		0.1 ha PLOT	1 ha PLOT	5 ha PLOT
NPV of saved costs of using Solar PV pump against: (EUR)	Diesel pump	70	−346	4529
	Grid-powered pump	−94	−2313	−4665

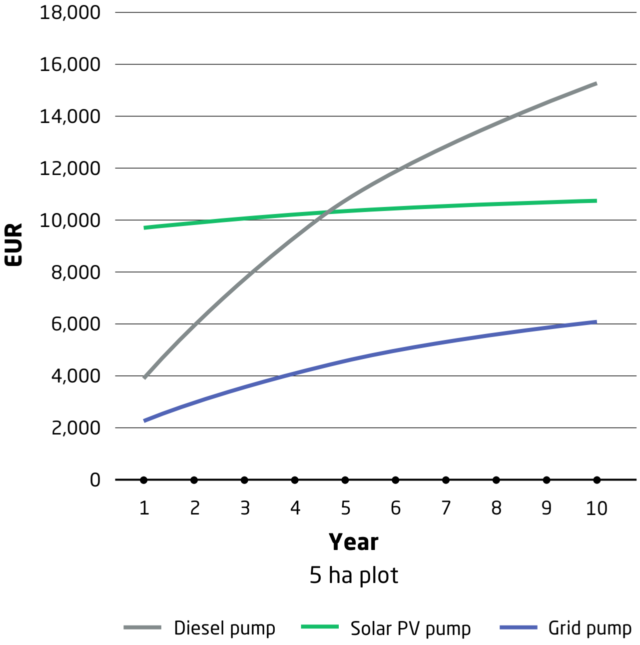
Break-even analysis

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 seven and five years respectively for installations on 0.1 and 5 ha plot scenarios. For the 1 ha plot size scenario, break-even of the solar pump is not reached across the ten-year timeframe as modelled.

In general it can be observed, that solar irrigation pumps are attractive due to the high fuel cost associated with the diesel option. This is not the case for the 1 ha scenario which can be explained by a relatively significant increase in initial investment costs for the pump at this plot size. This is due the size of the pump required to ensure supply of the water volume according to the pumps available on the market. The net savings of the solar PV system against the diesel option are further presented as charts in **Annex B**.

FIGURE 3. Break-even of different pump alternatives across the three plot sizes





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:

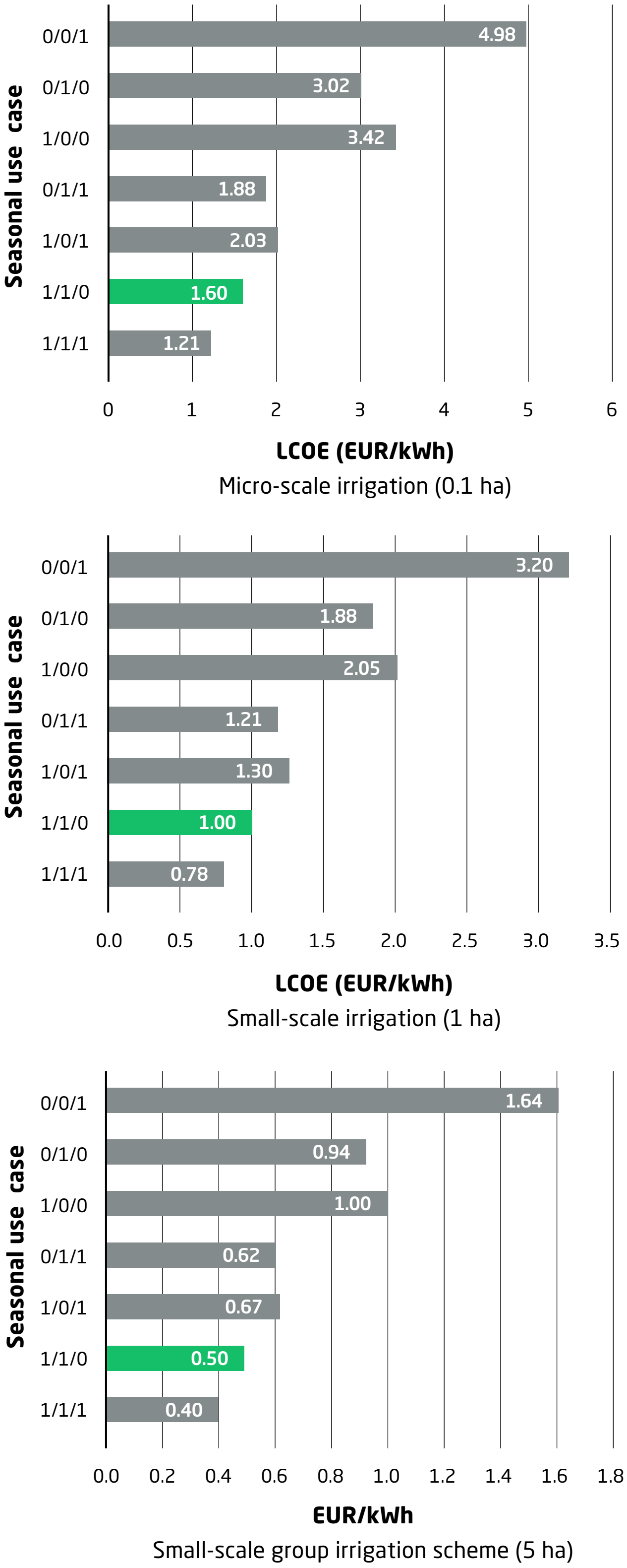
- The number of growing seasons
- The price of solar PV module

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

The number of growing seasons (1 to 3)[19] 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 green. 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)



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19) 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

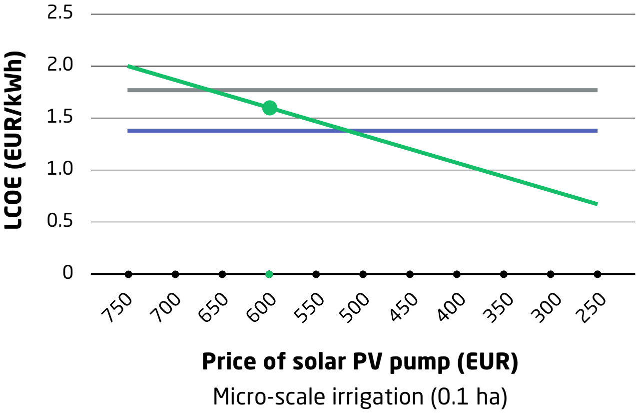
In order to gain a deeper appreciation for the significance of this variable it is useful to highlight the impact of irrigation needs across seasons and locations within the country. Considering the same plot under cultivation in the southern city of Ziguinchor, water needs per hectare decrease from an average of $63m^3$/ha/day to $55m^3$/ha/day during the wet season (July to November).

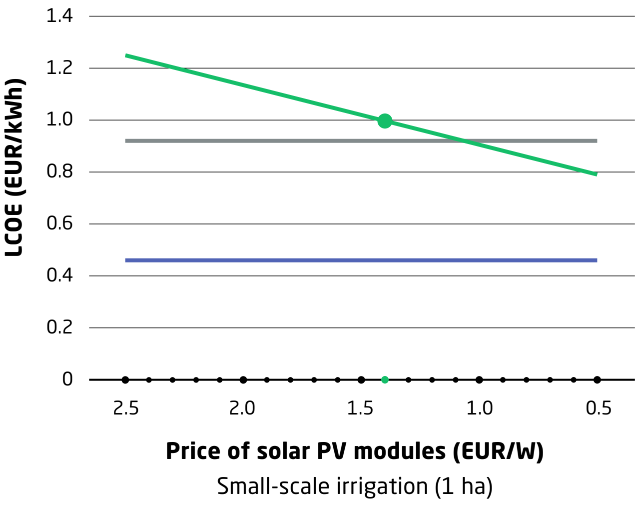
Variable 2 — Effect of PV module price on LCOE of solar pumps compared to diesel and grid-connected pumps

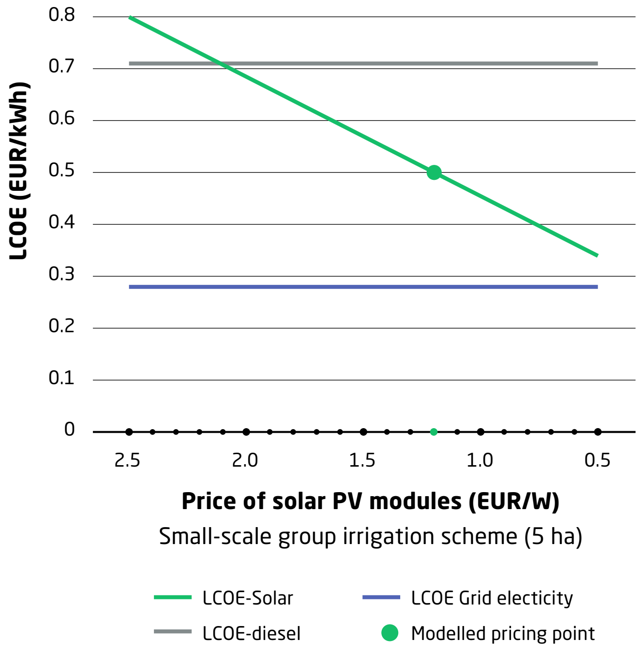
The costs associated with utilising a solar pump are directly correlated with the upfront expenditure required to procure the solar array. Despite global trends of declining solar PV costs, the price of the panels secured by an individual investment could be a critical variable. Therefore, the effect 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 the 1 ha case, a 30% reduction of PV panel price against a static diesel LCOE results in a positive case. On the 0.1 ha plot[20], a less than 20% decrease in the PV pumping unit price results in the solar option becoming attractive against the grid-connected alternative. This is considering a static tariff and no requirement for a back-up generator in the event of grid downtime.

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







A note on backup diesel generation

In many cases, plot owners should consider the impact of backup diesel generator due to grid downtime. In a case where grid downtime is considered, the 5 ha plot grid-powered pump LCOE increases from EUR 0.28/kWh to EUR 0.34/kWh (15% downtime) and to EUR 0.43/kWh (30% downtime). This is compared to an LCOE of EUR 0.50/kWh for the solar PV pump. The difference between the solar PV and grid pump LCOE narrows even further if costs for a new grid connection are considered.

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20) The 0.1 ha scenario is based on a combined pump and PV panel unit where the PV modules are not priced separately. Therefore, the sensitivity test was performed on the pump unit cost

KEY TAKEAWAYS

— An individual decision to invest in a solar powered irrigation system is unique to each case. 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 cost for solar irrigation pumps remain a significant investment decision given the average farming household income levels in Senegal. For the three plot sizes modelled in this case, the approximate CAPEX requirements covering the pump and solar array are EUR 600 (0.1 ha), EUR 3,800 (1 ha) and EUR 9,500 (5 ha).

— Investment in solar PV pumping technology can be attractive when considering the discounted net savings compared to diesel pumps across a ten-year timeframe on plot sizes of 0.1 ha — EUR 70 and 5 ha — EUR 4,529. This is due to the solar pump low OPEX compared to the high fuel costs associated with the diesel option. Break-even analysis of the cumulative total discounted expenses (CAPEX and OPEX) further supports this with PV pumps becoming attractive within seven (0.1 ha) and five (5 ha) year time-frames.

— The sensitivity analysis demonstrates the role of critical parameters on the viability of different pumping alternatives:

a) The number of growing seasons (1 to 3) can significantly impact the economic feasibility of 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;

b) A drop in solar panel prices by 30% makes solar pumping attractive compared to a static LCOE for diesel pumps on a 1 ha plot;

c) This trend applies for grid-connected pumps, where a panel price decrease of 17% against current market rates generates a positive outlook for solar on a 0.1 ha plot;

For grid-connected pumps, in general terms, electricity network downtime and requirement for a backup diesel fuelled option already swings the situation in favour of solar. For example, the LCOE for a grid-connected pump on a 5 ha plot increases from EUR 28/kWh to EUR 0.43/kWh considering 30% downtime compared to EUR 0.50/kWh for the equivalent solar PV pump.

ANNEX A

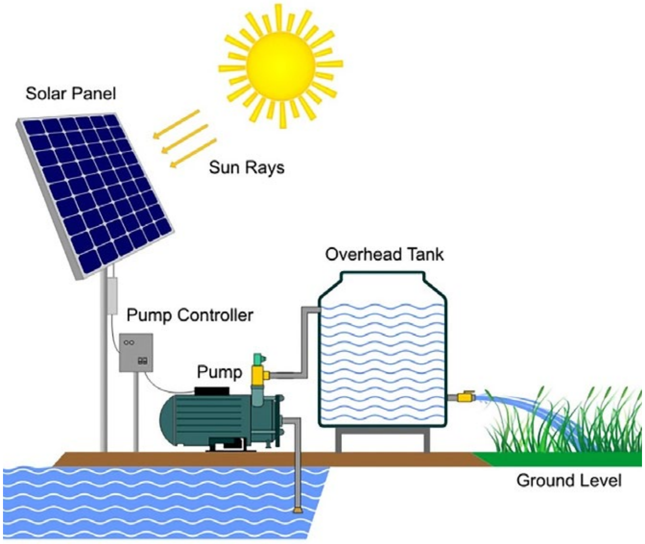
Technology overview

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.

FIGURE 6. Schematic diagram of a PV surface pump[21]



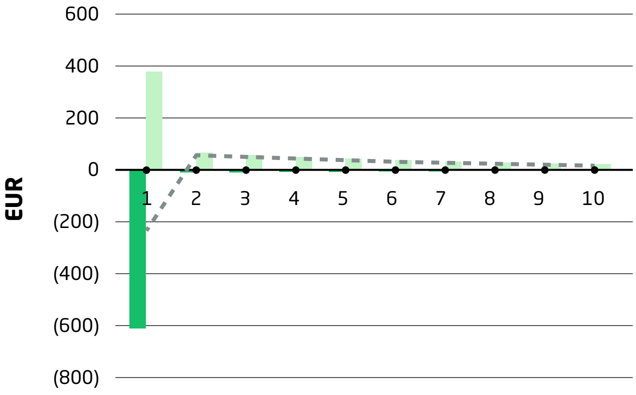
Solar water pumps are classified into three types according to their applications: submersible, surface and floating. A submersible pump draws water from deep wells, a surface pump from shallow wells, springs, ponds, rivers or tanks, and a floating pump from reservoirs being adjustable to the water height.

For utilising the pumped water three irrigation methods are commonly applied: hose, sprinkler and drip.

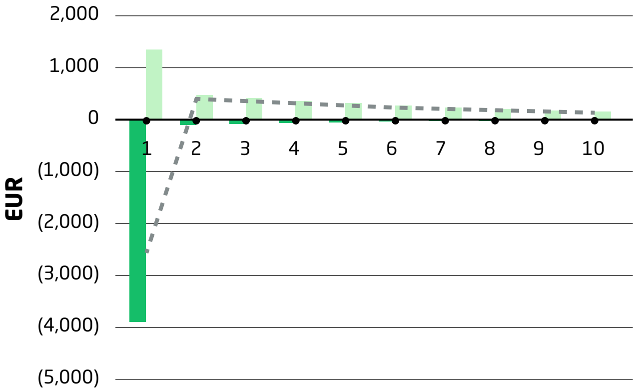
The reason for irrigating is to provide water to crops in the field with the aim of increasing yields. In this regard, hose irrigation is inefficient in that only a limited amount of the water spread onto the field is available to the growing crops. In comparison, sprinkler irrigation has a higher efficiency, whilst 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%. The latter figure indicating why hose systems are commonly paired with the diesel driven pumps that allow for a high flow over a short period of time.

ANNEX B

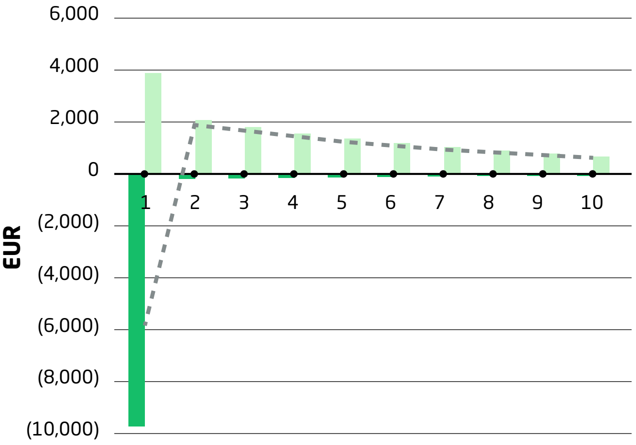
FIGURE 7. Net savings based on discounted costs of Solar PV versus Diesel irrigation pumps



Micro-scale irrigation (0.1 ha)



Small-scale irrigation (1 ha)



Small-scale group irrigation scheme (5 ha)

🟩 Investment cost 🟩 Saved cost – Diesel - - - Net

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

ABOUT GET.INVEST MARKET INSIGHTS

The first series of GET.invest Market Insights are published in early 2019 covering four renewable energy market segments in three countries, namely: renewable energy applications in the agricultural value-chain (Senegal), captive power (behind the meter) generation (Uganda), mini-grids (Zambia) and stand-alone solar systems (Zambia).

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.

GET.invest Market Insights therefore summarise a considerable amount of data that may inform early market exploration and pre-feasibility studies. It is recommended to cross-read all three products to gain a comprehensive overview. The products are accessible at www.get-invest.eu.

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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.

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