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Mobilising Renewable Energy Investments

Senegal: Renewable Energy in Agricultural Value-Chains

Case Study: Solar Powered Irrigation – Micro-Scale Water Pumping for Onion Farming (0.5 Hectares)

SITUATION DESCRIPTION

The case study evaluates the costs and benefits of using solar PV powered water pumping for irrigation at a small-holder farm near Kayar town close to Dakar in Senegal. The case study is based on data collected during a field visit to two farm plots near Kayar and Potou in 2017 as well as other assumptions. The case study may be of interest to smallholder farmers, developers, equipment suppliers and potential financiers considering solar PV pumping.

The Niayes zone is a 180 km narrow stretch of land, running along the northern coastline of Senegal between Dakar and Saint Louis. The region is the centre for vegetable and legume horticulture in the country, with popular crops including potatoes and onions. Cultivation in the area is underpinned by smallholder farmers with an average farm plot size of between 0.5 and 10 hectares (ha).

In Senegal, irrigation systems for small private farm plots (PMPP — petits et moyen périmètres privés and MIP — micro-irrigation privée) are predominantly powered by diesel pumps[1] or manually via hand pumps or buckets.

Diesel pumps are perceived as being too expensive and unreliable while manual watering is labour intensive, resulting in sub-optimal production. In addition, there is an ever-rising year-round demand for fresh vegetables in the country, especially in Dakar. In 2013, 33% of the demand for onions was met by imports due to a production deficit. Farmers in the Niayes are consequently striving to meet this demand, increase production and turn a profit, whilst simultaneously searching for ways to reduce costs and labour requirements.

1) Petrol pumps may also be found

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Surface and groundwater can be found in the Niayes region, the latter being typically at a depth of between 3 to 9 meters. Wells are common in the area. These conditions allow for surface pumps to be applied, although for some micro-pumps (<1 kW) the equipment often needs to be positioned not more than 7 metres above the water level.

FIGURE 1. Local onion storage[2]

For this case study, the situation of a smallholder farmer growing onions on a plot of 0.5 ha is considered. Dry onions in Senegal may have a growing period of 110–150 days; for the case study a period of 137 days is assumed. With irrigation and the availability of shallow ground water year-round, two onion crops are assumed to be produced each year. In between the growing periods the land is left idle to allow for regeneration.

Three different water-pumping alternatives are evaluated: a) diesel pumping, b) solar PV pumping and c) pumping using grid electricity. In all scenarios, the irrigation system is assumed to deliver the same amount of water to the plot to meet the onionwatering requirements. In reality, the irrigation method (hose, sprinkler or drip) can have an important influence on water usage.[3]

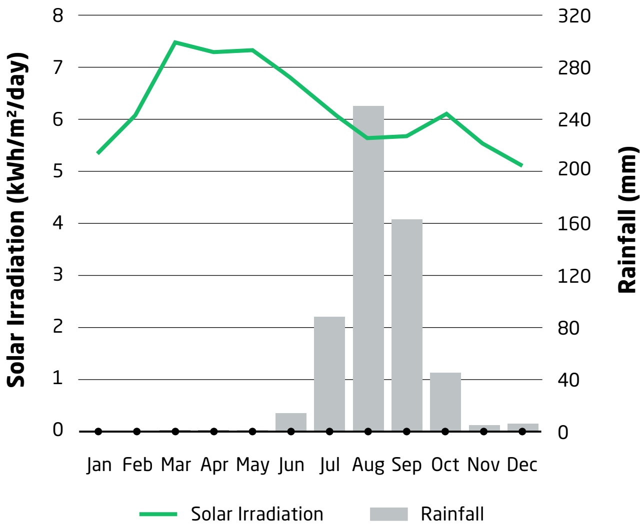
WATER REQUIREMENTS AND SOLAR IRRADIATION

The onion crop requires watering for 274 days of the year. For this case study, the growing days are distributed across two of the three Senegalese growing seasons:

— **Season 1:** Dry/hot season (Contre-saison chaude) from March to June — 122 days

— **Season 2:** Wet season (Hiverange) July to November — 152 days

FIGURE 2. Average rainfall and irradiation in the area[4]



The irrigation water needs of a crop depend on a number of factors including the climate (e.g. sunshine, temperature, humidity, wind speed and effective rainfall after accounting for deep percolation and run-off), the crop type and its growth stage. The Food and Agricultural Organization of the United Nations (FAO) indicates that in semi-arid climates such as that of Senegal an onion crop will require roughly between 6.6 and 8.5 mm of water per growing day depending on the season — the same as the

2) © GIZ
3) A comparison is found at the end of the study

4) Solar irradiation data from European Commission "Photovoltaic Geographical Information System – Interactive Maps", link: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=en and rainfall data for Dakar (nearest data to Kayar) from a source using data from the Agence Nationale de l'Aviation Civile et de la Météorologie, link: https://tinyurl.com/y9o3kear – both accessed January 2019

requirement for standard grass.[5] When adjusting for seasonality and rainfall, the irrigation need is estimated to be 852 mm in Season 1 and 959 mm in Season 2. Total irrigation water required over the two growing seasons is approximately 9,053 m³, which works out to an average of about 33 m³ per day.

As shown in **Figure 2**, the average solar irradiation on a horizontal plane at Kayar town ranges from 5.1 kWh/m²/day in December to 7.5 kWh/m²/day in March. Irradiation at an optimal inclination of 16° would be even greater. The average minimum of 5.1 kWh/m²/day is sufficient to power the PV micro-pump during the two growing seasons.

ASSUMPTIONS AND PARAMETERS

For the three water pumping alternatives — diesel, solar PV, grid electricity — a number of parameters were held constant for simplification. Thus the water irrigation system itself was excluded from the analysis. The assessment instead focuses on the pumping technology and the energy source.

For all three scenarios, it is assumed that a surface pump is used, the dynamic head is 3.5 m, the pump efficiency is 70% and that a maximum pump power of about 80 W is needed to deliver the annual irrigation based on the maximum volume requirement of 0.0016 m³/s that occurs in August and November.

— For the diesel pump scenario, it is assumed that the generator has an efficiency of 20%.

— For the solar PV pump scenario, the pump and the PV panels are bought as an integrated unit.

— For the grid electricity scenario, it is assumed that the national grid is available at the pump location and the farmer only needs to be connected. In addition, an electric surface pump needs to be installed.

The main system parameters for the three scenarios are presented in **Table 1**.

TABLE 1. Water pumping system parameters

PARAMETER	DIESEL	SOLAR PV	GRID
Average daily water requirement (m³)	33	33	33
Dynamic head (m)	3.5	3.5	3.5
Pump capacity (W)	300	300	300
Max demand (W)	80	80	80
PV panel (W)	—	150	—
Annual electricity requirement (kWh)	86.7	86.7	86.7
Annual diesel consumption (l)	43.6	—	—

CAPITAL AND OPERATING COSTS

For all three alternatives, supplier catalogue prices were used.[6] The pumps are somewhat oversized as suitable smaller capacity models may not be readily available on the market, in particular for diesel and PV. For solar PV, a purpose-designed portable unit was considered. The costs of the pumping units include suction hoses and spare parts.

For annual operations and maintenance (O&M), a percentage of the investment costs is assumed in all three scenarios: a) diesel — 15%, b) PV pump — 4% and c) electric pump — 4%. Furthermore, for diesel fuel a price of EUR 1.06/litre (about CFA 694/litre)[7] is estimated, adjusted upwards by 15% to take into account higher transport and retail prices for diesel in a more rural area. Annual operating costs for the grid-connected scenario assumes electricity billing in the low voltage, low power professional use customer tariff category (UD-PP — usage professionnel petite puissance), with energy charges based on consumption tranches ranging from EUR 0.196/kWh to 0.225/kWh (CFA 128.85/kWh to CFA 147.68/kWh).[8]

5) FAO (1986) Irrigation Water Management Training Manual No. 3: Irrigation Water Needs. **Table 2** and **Table 3**. Link: http://www.fao.org/docrep/s2022e/s2022e00.htm – accessed January 2019

6) The actual market price might vary depending on the distributor, location, etc. For the PV pump, the price was adjusted for a larger PV panel than what is usually sold with the unit to ensure the average daily water requirement can be met

7) For costs converted from local currency, the fixed CFA/EUR rate of 655.957/1 is used

8) See the accompanying Developer Guide; accessible at www.get-invest.eu for more information on tariffs in Senegal

TABLE 2. CAPEX and annual OPEX (EUR)

CAPEX

Item	Diesel	Solar PV	Grid
Pump	300	600	300
Connection charge	—	—	142
Total EUR	**300**	**600**	**442**

ANNUAL OPEX

Item	Diesel	Solar PV	Grid
O&M	45	24	18
Diesel fuel	46	—	—
Grid electricity	—	—	17
Total EUR	**91**	**24**	**35**

No equipment replacement costs are expected during the assumed operational period of 10 years for the three scenarios.

The case study is based on an investment in EUR. The effects of currency exchange rate fluctuations are not considered.

FINANCING

The case study considers two financing scenarios based on a potential concessional loan from the National Agriculture Credit Fund (CNCAS — Caisse Nationale de Crédit Agricole du Sénégal)[9] or other such facility as may be available (e.g. via development cooperation partner support for microfinance institutions). Both financing scenarios have an 80/20 debt equity ratio and monthly debt repayments:

Financing A

— 1 year loan term

— 3 month grace period

— 7.5% interest rate

Financing B

— 2 year loan term

— 6 month grace period

— 12% interest rate

For the onion farmer, a required return on equity of 17.5% (real) was modelled. This results in a Weighted Average Cost of Capital (WACC) of 8.06% (pre-tax, real) in the first financing scenario (Financing A) and 11.66% (pre-tax, real) in the second financing scenario (Financing B), when the inflation rate forecast of 1.8% for Senegal is considered. The WACC is used as the discount rate for the financial analysis.

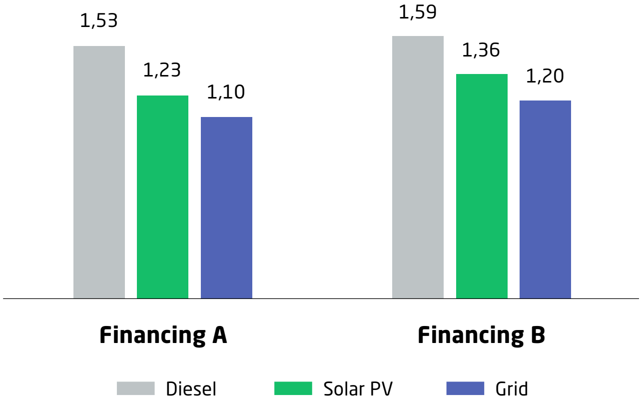
RESULTS OF THE ANALYSIS

The levelised cost of electricity (LCOE) for the three pumping alternatives was calculated as an indicator to compare the cost of electricity of different options. LCOE is calculated by dividing the total discounted costs of each system (investment and operating costs) by the discounted electricity generation. In both financing scenarios, a solar PV pump was found to have a lower LCOE than a diesel pump. However, an electric pump powered by grid electricity would have the lowest LCOE based on electricity tariffs at the time of writing (**Figure 3**).[10]

9) At the time of writing, the Fund provides a total amount of EUR 3 million per year in loans to farmer unions and individual farmers. Most of the fund is used for insurance and covers short-term loans of up to 9 months (7.5% interest rate). Long-term loans of 3-7 years have an interest rate of 12%. The fund requires a security deposit of 10-20%

10) LCOE is used in the case study as the indicator for comparing the cost of electricity of different options. See the accompanying Developer Guide; accessible at www.get-invest.eu for more information on tariffs in Senegal

FIGURE 3. LCOE (EUR/kWh) of pump alternatives



The net present value (NPV)[11] of the cost savings resulting from using solar PV compared to the other scenarios is presented in **Table 3**.

TABLE 3. NPV on saved costs of using solar vs. diesel and vs. grid

SCENARIO	SOLAR PUMPING NPV VERSUS (EUR)	
	Diesel	Grid
Financing A	186	–81
Financing B	130	–90

It should be reiterated that the comparison with the electric pump assumes that the onion farmer's plot is located close to the national grid (e.g. within 500m). At many farm plots in the Niayes grid electricity is not available and the connection charge may also increase due to the distance, meaning an electric pump would not be an option. In addition, in areas where the power grid is unreliable, network downtime could potentially negatively affect crop watering or necessitate a back-up generator.

The cumulative discounted costs are presented in **Figure 4** and **Figure 5**. For Financing A, by year 5 the cumulative discounted costs of a solar PV pump are lower than those of a diesel pump (Break-even point). When compared to an electric pump powered with grid electricity, the solar PV scenario does not break even during the 10-year period. For Financing B, the break-even with diesel occurs in year 6.

FIGURE 4. Break-even – Financing A

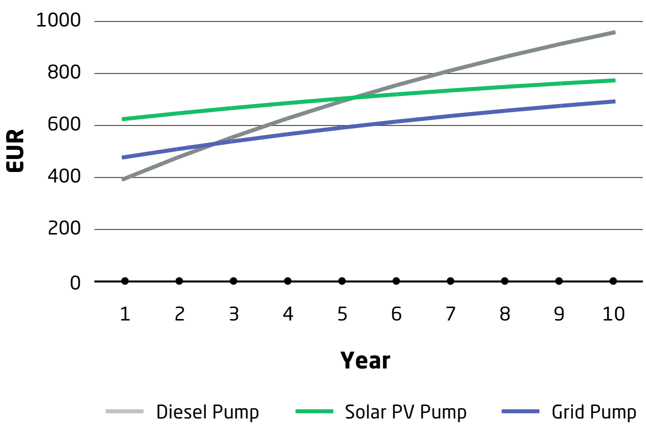
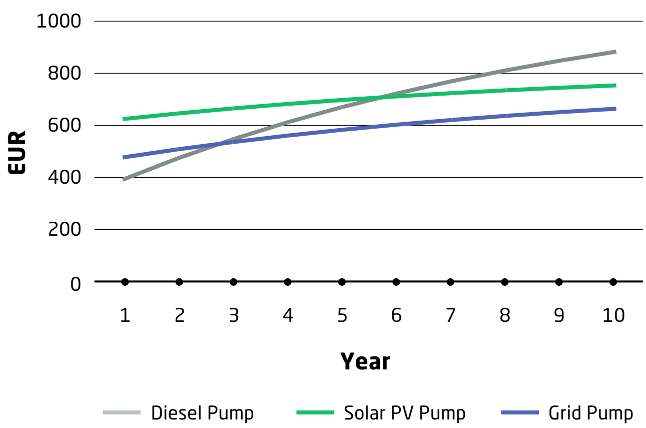


FIGURE 5. Break-even – Financing B



For the two loan scenarios, the upfront investment to be made by the farmer for the solar pump would be EUR 120. If the solar PV pump or land cannot be used as collateral, the security deposit on a CNCAS loan would be EUR 48 at 10% and EUR 96 at 20%. The maximum total upfront cash outflow is therefore EUR 216. **Table 4** shows upfront equity contribution as well as the loan repayments (principle and interest) amortised over the tenor of 1 and 2 years. Even though the 2-year loan is more costly in total and reduces the financial performance of the solar pump, the longer tenor results in much lower monthly payments for the onion farmer.

11) 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

TABLE 4. Debt repayment by the onion farmer

ITEM	SCENARIO (EUR)	
	Financing A	Financing B
Upfront equity (20%)	120	120
Financed amount	480	480
Monthly repayment	55	29
Total loan repayment	495	527

The loan repayment schedule can be compared to onion farm revenue over the loan tenor. Revenue from onion sales and timing of the income varies depending on the season, yield, market prices, spoilage and other factors. At an assumed marketable yield of 5,084 kg for the 0.5 ha plot per season and market price of EUR 0.175/kg (CFA 115/kg), the plot would generate approximately EUR 891 in gross income each season. If the income is divided equally over two consecutive harvest and sale months (i.e. EUR 446/month), this results in four months of onion revenue per year with 4–6 month gaps in between due to a lack of storage (Figure 6). Although net revenue was not assessed, gross revenue indicates that the farmer would likely be able to repay the loan from onion sales as long as a flexible payment schedule could be agreed.

SENSITIVITY ANALYSIS

A sensitivity test was performed on diesel fuel prices for Financing A, with PV pump and grid electricity costs held constant. As per the results in Figure 7, if the diesel fuel price were 50% lower than the base price (EUR 0.92/l) or 65% lower than the price assumed in the case study (EUR 1.06/l), then the LCOE of diesel would be on part with that of solar.

FIGURE 7. LCOE sensitivity – diesel fuel prices

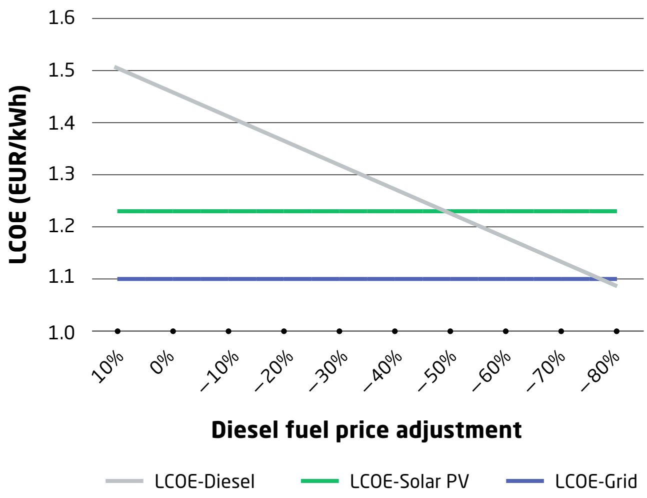
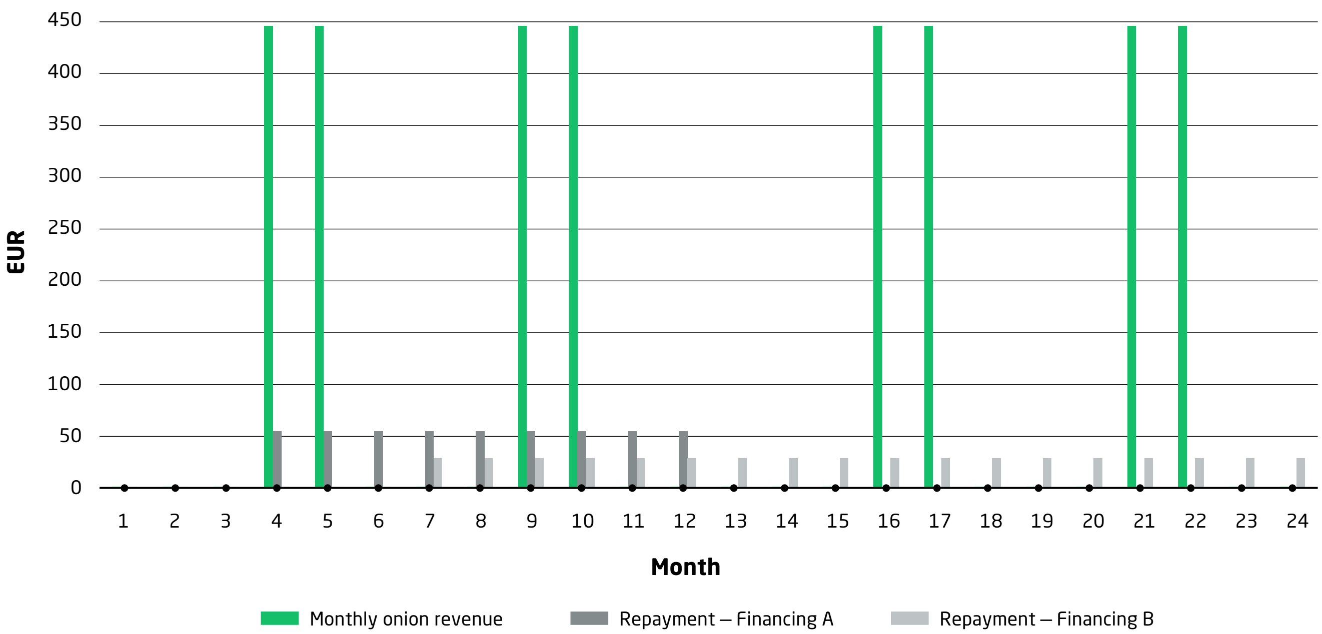


FIGURE 6. Debt service versus onion revenue



In another sensitivity test on Financing A, solar pump NPV of cost savings remains positive against diesel pumping even when the discount rate is raised to 12% (**Table 5**).

TABLE 5. LCOE & NPV on saved costs of using solar vs. other alternatives at various discount rates

DISCOUNT RATE	LCOE (EUR/kWh)			NPV OF SOLAR SAVINGS VERSUS … (EUR)	
	Diesel	Solar	Grid	Diesel	Grid
4%	1.46	1.10	1.00	266	−68
6%	1.49	1.16	1.05	224	−75
8%	1.53	1.23	1.10	186	−81
10%	1.56	1.30	1.15	154	−86
12%	1.60	1.37	1.21	125	−90

A NOTE ON IRRIGATION METHODS

The type of irrigation system used (hose, sprinkler or drip) can also have an influence on water usage. In water consumption terms, if irrigation methods are compared against the same outcome, with drip irrigation set at 100%, sprinkling would require 133% and the use of hose 250%. The latter explains why hose systems are commonly paired with a diesel pump that allow for a high flow over a short period of time. If the onion farm in the case study uses drip irrigation, **Table 6** presents a comparison with other methods in terms of water usage.

TABLE 6. Water use under different irrigation methods

ITEM	DIESEL	SOLAR PV	
Irrigation method	**Hose**	**Sprinkler**	**Drip**
Surface area (ha)	0.5	0.5	0.5
Water usage (m^3/day)	83	44	33
Operation time (hour/day)	2 – 3	9 – 12	9 – 12

The use of a diesel pump coupled with a hose can result in significant water and fertiliser runoff and can diminish crop yield and quality. In addition, the labour requirements of hose irrigation are usually higher than those of sprinkler or drip irrigation.

ACKNOWLEDGMENTS

GET.invest deeply appreciates the time and effort spent by the farm owners to share data and information towards this case study. GET.invest expresses gratitude to all staff and individuals who reviewed the case study and provided valuable insights, guidance and feedback.

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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.

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Place and date: Brussels, June 2019
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