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Mobilising Renewable Energy Investments

Senegal: Renewable Energy in Agricultural Value-Chains

Case Study: Solar Powered Irrigation – Small-Scale Water Pumping at a Group Irrigation Scheme (6 Hectares)

SITUATION DESCRIPTION

The case study assesses the potential financial viability of solar PV powered water pumping for irrigation at a small group irrigation scheme at a location near the town of Richard Toll along the Senegal River in the north of Senegal. The case study is based on a hypothetical project but uses data collected during a field visit to a number of farms in 2017 as well as other assumptions. The case study may be of interest to smallholder farmer group irrigation schemes, developers, equipment suppliers and potential financiers considering solar PV pumping.

Rural Senegal has a strong network of local village groups and associations, including for agriculture. Group irrigation — irrigated village plots (PIV — périmètres irrigués villageois) — is a model found frequently along the Senegal River and valley with average scheme sizes ranging from a few to tens of hectares (ha). Diesel generators are often used to pump water from the river or other surface water bodies.

For the case study, it is assumed that the group irrigation scheme is run under a village association and comprises 18 farmers with an average plot size of 0.34 hectares (ha), for a total area of about 6 ha. Tomatoes are the predominant crop grown and the produce is sold locally. A central diesel pump draws water from the river to a small reservoir and the plots are irrigated using a series of small hoses or pipes and sprinkler system.

Tomatoes in Senegal are expected to have an average growing period of around 137 days. Due to the availability of surface water year-round and the existence of an irrigation system, two tomato crops are produced each year. In between the growing periods the land is left idle to allow for regeneration.

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The association running the group irrigation scheme is interested in alternative water pumping systems due to the high cost of running a diesel pump. The potential financial feasibility of two different alternatives is compared to the option of continuing with the existing diesel pump: **a)** a solar PV pumping system and **b)** a grid-powered electric pump.

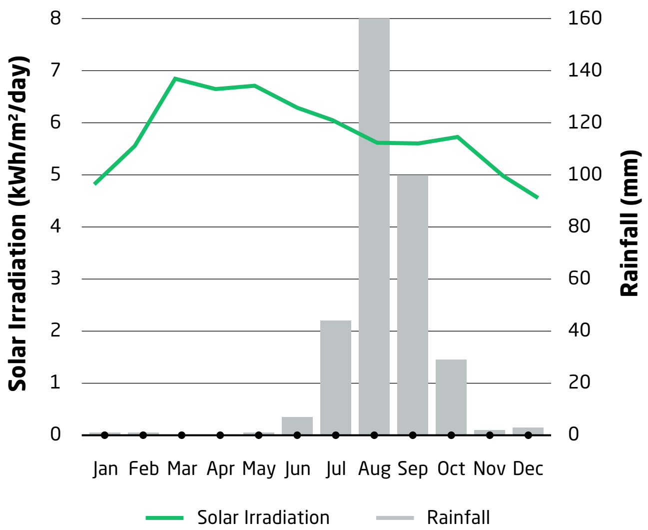
WATER REQUIREMENTS AND SOLAR IRRADIATION

The tomato crop requires watering for approximately 274 days of the year. For the 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 1. Average rainfall and irradiation in the area[1]



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 a tomato crop will require roughly between 7.15 and 9.35 mm of water per growing day depending on the season — 10% more than the requirement for standard grass.[2] When adjusting for seasonality and rainfall, the irrigation need is estimated to be 938 mm in Season 1 and 1,248 mm in Season 2. Total irrigation water required over the two growing seasons is approximately 134,775 m³, which works out to an average of about 488 m³ per day or 79.5 m³/ha/day.

As shown in **Figure 1**, average solar irradiation on a horizontal plane at Richard Toll town ranges from 4.6 kWh/m²/day in December to 6.9 kWh/m²/day in March near the height of the dry season. Irradiation at an optimal inclination of 18° would be even greater. The monthly solar irradiation data was used to help size and estimate the output of the PV system needed to power a PV pump during the two growing seasons.

ASSUMPTIONS AND PARAMETERS

For the three potential alternatives for water pumping at the group irrigation scheme — diesel, solar PV or grid electricity — a number of parameters were held constant for simplification. Thus the water irrigation system itself (e.g. pipes) 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 12 m, the pump efficiency is 70% and that a pump installed electrical capacity of about 4.6 kW is needed to deliver the annual irrigation based on the maximum volume requirement of 0.0275 m³/s that occurs in November.

1) 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 Saint Louis (nearest data to Richard Toll) 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

2) 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

For the diesel pump scenario, it is assumed that the generator has an efficiency of 25% and that the energy density of diesel is 9.94 kWh/l. The existing diesel pump will continue to be used.

For the solar PV pump scenario, the pump and the PV modules are assumed to be separate units pro-cured together. A PV array mismatch factor of 0.85 results in a PV system size of 5.5 kW.

For the grid electricity scenario, it is assumed that the national grid is in the near vicinity and the village association needs to pay for a 1 km low voltage line to connect to the grid. 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 (m^3/ha)	79.49	79.49	79.49
Dynamic head (m)	12	12	12
Pump size (kW)	4.6	4.6	4.6
PV capacity (kWp)	—	5.5	—
Annual electricity requirement (kWh)	4,395	4,395	4,395
Annual diesel consumption (l)	2,210	—	—
Grid connection (km)	—	—	1

CAPITAL AND OPERATING COSTS

Capital expenditure (CAPEX) for a diesel pump is not considered as it is assumed that the current pump was installed recently and can continue to operate for a number of years. For solar PV, the pumping unit should be able to respond to varying solar irradiation and hence changing power inputs at different motor speeds. There exist solar pumps with controllers for this purpose. Such systems, which are both more efficient and more expensive, are assumed for the case study.[3] PV modules are priced separately (at EUR 1.15/W). The figures also include the costs of a lockable security structure to house critical equipment, including the pump and control panel.

Grid extension costs are taken from a 2017 paper on electrification in sub-Saharan Africa.[4]

For annual operations and maintenance (O&M), a percentage of the investment costs is assumed in all three scenarios: **a)** diesel — 10% of the estimated installed cost of the existing pump, **b)** PV pump — 2% and PV array — 2.5% and **c)** electric pump — 2%. Furthermore, for diesel fuel a price of EUR 1.06/litre (about CFA 694/litre)[5] is estimated, taking into account higher transport and retail prices for diesel in a more rural area. Operating expenditure (OPEX) 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).[6]

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 or hedging costs are not considered.

3) The catalogue prices of applicable systems were used for the estimates. However, it should be noted that prices might be lower in Senegal depending on the distributor, brand, location, etc.
4) Mentis D. et al. (2017) "Lighting the world: the first application of an open source, spatial electrification tool (OnSSET) on Sub-Saharan Africa", Environmental Research Letters
5) For costs converted from local currency, the fixed CFA/EUR rate of 655.957/1 is used
6) The group irrigation scheme is located within the rural electrification concession operated by the company COMASEL. While COMASEL customer tariffs may differ from those of SENELEC, those of the latter are used because COMASEL tariffs were not obtained. See the accompanying Developer Guide; accessible at www.get-invest.eu for more information

TABLE 2. CAPEX and annual OPEX (EUR)

CAPEX

Item	Diesel	Solar PV	Grid
Pump	–	4,500	1,700
PV array	–	6,268	–
Grid connection	–	–	4,261
Total EUR	**0**	**10,768**	**5,961**

ANNUAL OPEX

Item	Diesel	Solar PV	Grid
O&M	170	247	119
Diesel fuel	2,339	–	–
Grid electricity	–	–	905
Total EUR	**2,509**	**247**	**1,042**

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)[7] or other such facility as may be available (e.g. via development cooperation partner support for microfinance institutions). Both financing scenarios have a 70/30 debt equity ratio and quarterly debt repayments:

Financing A

— 1 year loan term
— 3 month grace period
— 7.5% interest rate

Financing B

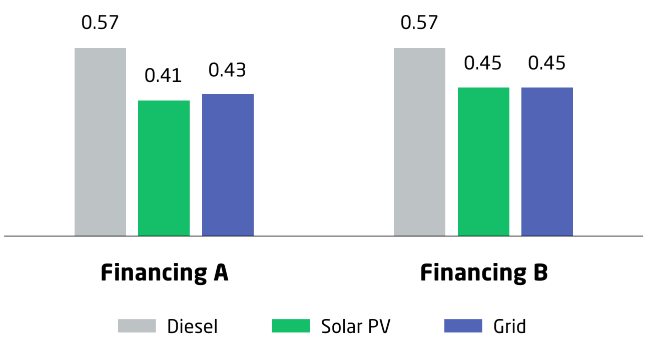
— 4 year loan term
— 1 year grace period
— 12% interest rate

For the village association responsible for the group irrigation scheme, a required return on equity of 17.5% (real) was modelled. This results in a Weighted Average Cost of Capital (WACC) of 9.24% (pre-tax, real) in the first financing scenario (Financing A) and 12.39% (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 (CAPEX and OPEX) by the discounted electricity generation for Financing A and Financing B. In both instances, a solar PV pump was found to have the lowest LCOE although in the second scenario there was almost parity with a grid-powered pump (EUR 0.448/kWh for solar versus EUR 0.450/kWh for electricity) (**Figure 2**).[8]

FIGURE 2. LCOE (EUR/kWh) of pump alternatives



7) The Fund currently provides a total amount of EUR 3 million per year in loans to farmer unions and individual farmers. Most of the money 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%

8) LCOE is used in the case study as the indicator for comparing the cost of electricity of different options

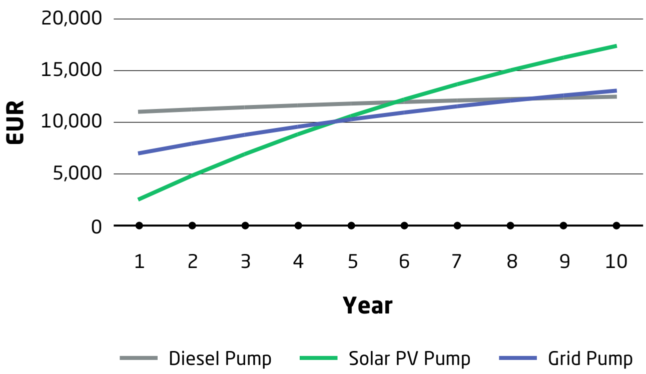
The net present value (NPV)[9] of the saved costs of solar PV compared to the other scenarios is positive:

TABLE 3. Solar NPV on saved costs

SCENARIO	SOLAR PUMPING NPV VERSUS (EUR)	
	Diesel	**Grid**
Financing A	4,926	586
Financing B	3,371	52

The cumulative discounted costs are presented in **Figure 3** and **Figure 4**. For Financing A, by year 6 the cumulative discounted costs of a solar PV pump are lower than those of continuing to use the existing diesel pump. When compared to an electric pump powered with grid electricity, the solar PV scenario does not break even until around year 9 of operations. For Financing B, the break-even occurs in years 7 and 10, respectively.

FIGURE 3. Break-even – Financing A



For the two loan scenarios, the equity investment by the group irrigation scheme (GIS) for the solar pump would be EUR 3,230. This works out to EUR 179 per farmer. If the solar PV pump or land cannot be used as collateral, the security deposit on a CNCAS loan would be EUR 754 at 10% and EUR 1,508 at 20%, or EUR 42 and EUR 84, respectively, per farmer. The maximum total upfront cash outflow is therefore EUR 4,738 for the GIS or EUR 263 per farmer. **Table 4** shows upfront equity contribution as well as the loan repayments (principle and interest) amortised over the tenor of 1 and 4 years. Even though the 4-year loan is more costly in total and reduces the financial performance of the solar pump, the longer tenor results in much lower quarterly payments for the individual farmers.

FIGURE 4. Break-even – Financing B

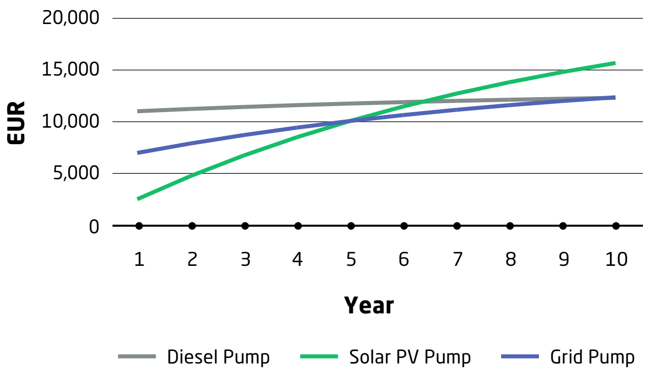


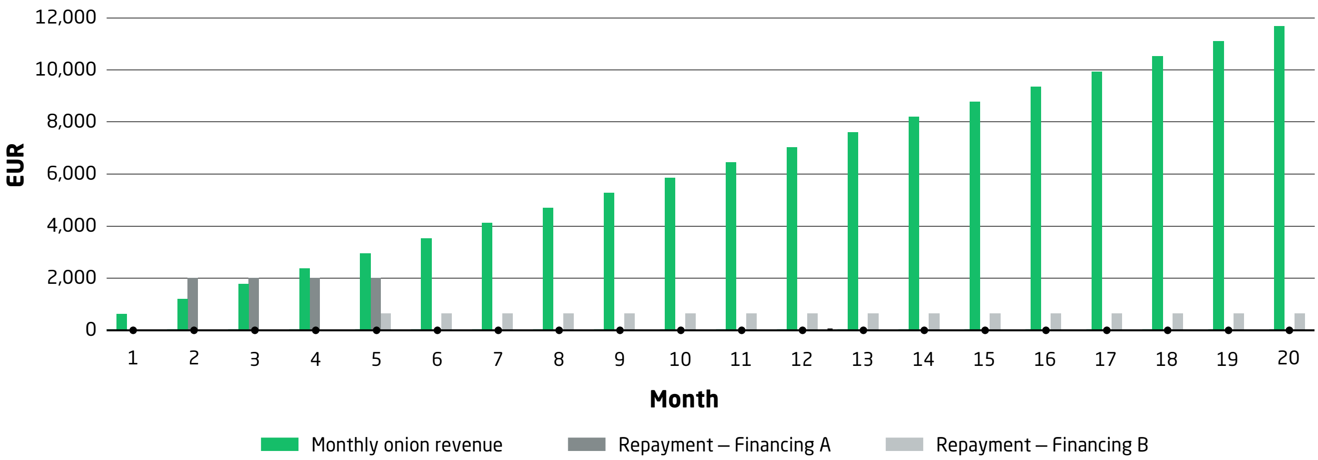
TABLE 4. Impact of the loan on the GIS & farmers

ITEM	SCENARIO (EUR)	
	Financing A	**Financing B**
Upfront equity GIS (30%)	3,230	3,230
Contribution per farmer	179	179
Quarterly repayment GIS	1,974	600
Contribution per farmer	110	33
Total repayment GIS	**7,894**	**9,601**
Total payment per farmer	**439**	**533**

The loan repayment amount at the GIS level can be compared to quarterly expenditure on diesel fuel costs in the scenario where the group scheme would continue to use the existing diesel pumps. **Figure 5** indicates that the loan can be paid of easily with the diesel fuel cost savings in Financing B. However, in Financing A, the cumulative diesel fuel cost savings are not sufficient to cover debt repayment in the first two quarters after the grace period.

9) 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

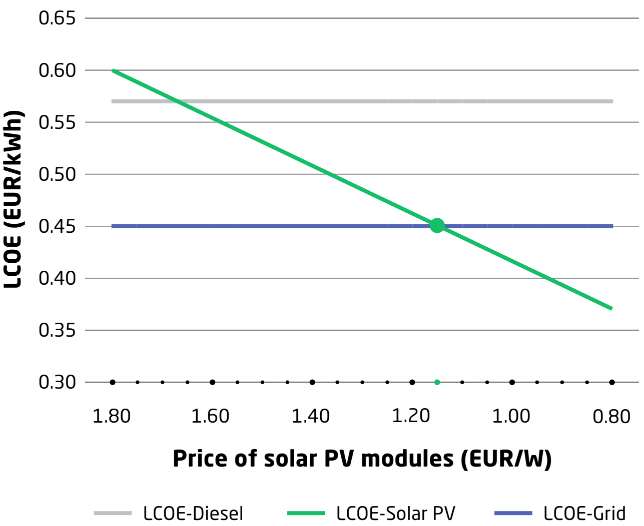
FIGURE 5. Debt service versus diesel fuel cost savings



SENSITIVITY ANALYSIS

A sensitivity test was performed on solar PV module prices for Financing B, with diesel fuel and grid electricity costs held constant. As per the results in **Figure 6**, if the module price increases above EUR 1.15/W, then the LCOE of a grid-powered electric pumping system would be lower than that of solar PV. However, the module price would have to go above EUR 1.70/W before diesel pumping would become more financially attractive.

FIGURE 6. LCOE sensitivity – PV module prices[10]



In another sensitivity test on Financing B, solar pump NPV of cost savings remains positive against diesel pumping even when the discount rate is raised to 18% (**Table 5**). However, the solar pumping scenario becomes less attractive when compared to grid-pumping as the discount rate increases.

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

DISCOUNT RATE	LCOE (EUR/kWh)			SOLAR NPV VERSUS ... (EUR)	
	Diesel	Solar	Grid	Diesel	Grid
8.4%	0.57	0.40	0.42	5,394	747
10.4%	0.57	0.42	0.44	4,318	377
12.4%	0.57	0.45	0.45	3,371	52
14.4%	0.57	0.47	0.47	2,523	–239
16.4%	0.57	0.50	0.48	1,722	–498

Other variables that would also have important sensitivities not assessed in the case study include **a)** the price of diesel fuel and **b)** the length of the power line (if any) needed to connect a pump to the grid.

10) The circle mark indicates the price per module used in the analysis (EUR 1.15/W)

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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).

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