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Mobilising Renewable Energy Investments

Senegal: Renewable Energy in Agricultural Value-Chains

Case Study: Solar Powered Irrigation – Large-Scale Water Pumping at a Melon Farm (350 Hectares)

SITUATION DESCRIPTION

The project case study assesses the potential financial viability of solar PV powered water pumping for irrigation at a large agricultural operation on the Senegal River near Saint-Louis, Senegal. While the case study is based on an actual farm from which data was obtained during a field visit in 2017, a number of assumptions have also been made in the analysis. The findings are therefore purely indicative. The case study may be of interest to agribusinesses and larger farms, developers, equipment suppliers and potential financiers considering such projects.

The farm has approximately 350 hectares (ha) of land on which melons are grown. There are a number of other farms of a similar size growing rice, fruits and vegetables in the wider area. The farm practices land use rotation every three to five years, meaning that only about 240 ha is under melon cultivation in any one year. Around 3,000 tonnes of fruit are produced annually, aimed at the export market.

The melons are watered using a centre-pivot (also known as water-wheel or circle) irrigation system. A main pipe of 2 km draws water from the Senegal River and secondary pipes deliver the water to the segmented farm plots. Three diesel-powered surface pumps (two in daily use and one on stand-by) raise the water from a low head at river level. The three pumps were manufactured in Italy and imported from France. The two pumps in operation each draw about 450 m^3/hr of water, each irrigating 120 ha. The centre-pivot system uses diesel-powered motors for the wheels, but it is not considered that these can be replaced with solar PV.

The case study assumes that the diesel-powered pumps are coming to the end of their useful life and assesses the potential impact of a) installing a solar PV pumping system or b) using grid power to meet the irrigation requirements instead of buying new diesel pumps.

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WATER REQUIREMENTS AND SOLAR IRRADIATION

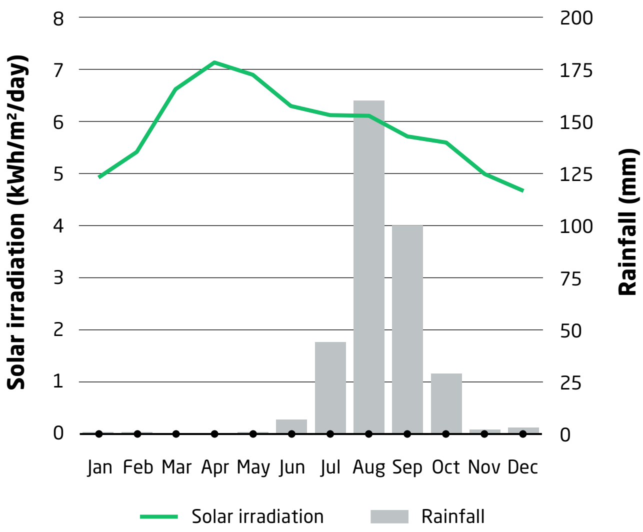
The melon farm is irrigated year-round. For the case study 364 operational days have been assumed, distributed across the three Senegalese growing seasons as follows:

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

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

— **Season 3:** Dry/cold season (Contre-saison froide) December to February — 90 days

FIGURE 1. Average rainfall and irradiation at St-Louis[1]



For melons with an approximate growing period of 120 days in warm climates, three crops will be produced each year. The relatively high production is considered realistic with intensive farming and given that about 1/3 of the total land remains fallow each year.

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 melon crop will require roughly between 6.5 and 8.5 mm of water per growing day depending on the season — equivalent to the requirement for standard grass.[2] When adjusting for seasonality and rainfall, the irrigation need is estimated to be 853 mm in Season 1, 1,118 mm in Season 2 and 585 mm in Season 3. Total irrigation water required over the year is approximately 6.13 million m³, which works out to an average of about 16,850 m³ per day or 69 m³/ha/day.

As shown in **Figure 1**, average solar irradiation on a horizontal plane in the Saint-Louis area of Senegal ranges from 4.7 kWh/m²/day in December to 7.2 kWh/m²/day in April near the height of the dry season. Irradiation at a 15° inclination would be even greater. The historical monthly solar irradiation data was used to help size and estimate the output of the PV system needed to power a PV pump over a year.

ASSUMPTIONS AND PARAMETERS

For the three potential alternatives for water pumping at the melon farm — 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 and associated costs common to the three scenarios (e.g. engineering, water usage fees) were ignored. 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 15 m, the pump efficiency is 70% and that a (total) pump installed electrical capacity of about 206 kW is needed to deliver the annual irrigation based on the maximum volume requirement of 0.9803 m³/s that occurs in November.

1) Solar irradiation data from the 2017 Solar Electricity Handbook, link: https://tinyurl.com/qg6rybt and rainfall data 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 generators have an efficiency of 25% and that the energy density of diesel is 9.94 kWh/l

- For the solar PV pump scenario, the pump and the PV modules are assumed to be separate units procured together. A PV array mismatch factor of 0.80 results in a PV system size of 258 kW.

- For the grid electricity scenario, it is assumed that the national grid is in the near vicinity and the farm owner needs to pay for a 2 km overhead line at 33 kV and transformer to connect to the grid. In addition, an electric pumping system 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)	69.48	69.48	69.48
Dynamic head (m)	15	15	15
Pump size (kW)	206.3	206.3	206.3
PV capacity (kWp)	—	257.8	—
Annual electricity requirement (kWh)	251,672	251,672	251,672
Annual diesel consumption (l)	101,236	—	—
Grid connection (km)	—	—	2

CAPITAL AND OPERATING COSTS

Capital expenditure (CAPEX) for diesel pumps are based on the original installation costs as reported by the melon farm owner.

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 0.45/W) and are based on recent landed costs for systems of a similar size. 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%, **b)** PV pump — 2% and PV array — 2.5% and **c)** electric pump — 2%. Furthermore, for diesel fuel a price of EUR 0.92/litre (about CFA 603/litre)[5] is estimated.

Operating expenditure (OPEX) for the grid-connected scenario assumes electricity billing in the medium voltage customer tariff category (livraison en moyenne tension), which includes both a monthly fixed change per kW and an energy charge per kWh based on time-of-use. It is assumed that all pumping can be done during the off-peak time-of-use band (23:00–19:00).[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 melon farm 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

TABLE 2. CAPEX and annual OPEX (EUR)

CAPEX

Item	Diesel	Solar PV	Grid
Pump	60,000	220,000	100,000
PV array	—	116,030	—
Grid connection	—	—	19,173
Total EUR	**60,000**	**336,0308**	**119,173**

ANNUAL OPEX

Item	Diesel	Solar PV	Grid
O&M	6,000	7,301	2,383
Diesel fuel	93,166	—	—
Grid electricity	—	—	47,297
Total EUR	**99,166**	**7,301**	**49,680**

FINANCING

The case study assumes that the 350 ha melon farm will be able to secure a loan from a commercial bank to implement the new water-pumping project. The same loan terms were applied to each scenario:

— 70/30 project debt equity ratio

— Interest rate of 14.25% (nominal), based on the average commercial bank rates in Senegal from 2016

— Loan tenor of 7 years

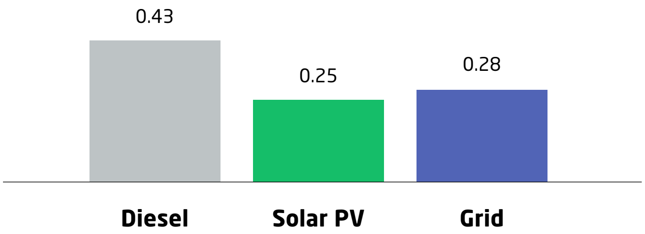
— Grace period of 2 years

For the farm owner, a required return on equity of 17.5% (real) was modelled. This results in a Weighted Average Cost of Capital (WACC) of 13.97% (pre-tax, real), 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. A solar PV pump was found to have the lowest LCOE (**Figure 2**).[7]

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



The net present value (NPV)[8] of the cost savings resulting from using solar PV compared to the other scenarios is positive in both instances:

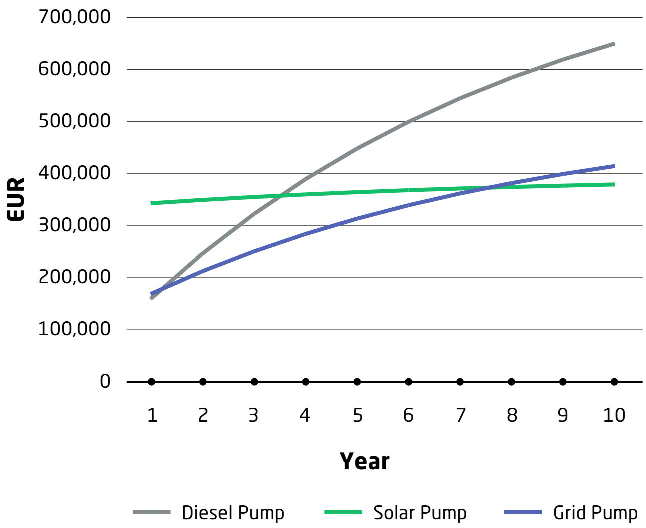
— Solar pump versus diesel — NPV of cost savings is EUR 270,811

— Solar pump versus grid — NPV of cost savings is EUR 35,412

The cumulative discounted costs are presented in **Figure 3**. This shows that by year 3 the cumulative discounted costs of a solar PV pump are lower than those of a diesel pump. When compared to the electric pump powered with grid electricity, the solar PV scenario does not break even until around year 8 of operations.

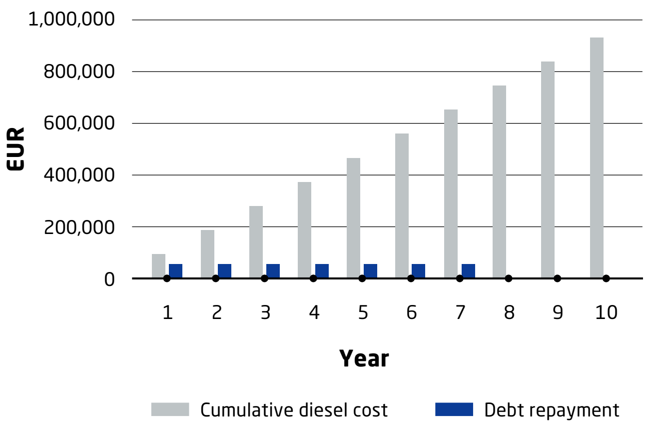
7) LCOE is used in the case study as the indicator for comparing the cost of electricity of different options
8) NPV is the difference between the present value of the project future cash flows and initial investment. The present value is the current worth of a future sum of money or stream of cash flows given an assumed discount rate representing the investment risk

FIGURE 3. Break-even of different pump alternatives



After the two-year grace period, the melon farm owner must start to pay off the bank loan. Annual debt payment (principal repayment and interest) is calculated to be EUR 55,271 over the amortisation period of 7 years. This amount can be compared to annual expenditure on diesel fuel costs in the scenario where the farm owner would select to install diesel pumps instead (or would keep the existing diesel pumps and continue to pay the estimated diesel fuel costs that are currently being incurred). **Figure 4** indicates that the loan can be paid easily with the diesel fuel cost savings.

FIGURE 4. Debt service versus diesel fuel cost savings



SENSITIVITY ANALYSIS

A sensitivity test was performed on solar PV module prices, with diesel fuel and grid electricity costs held constant. As per the results in **Figure 5**, if the module price increases above EUR 0.55/W, then the LCOE of a grid-powered electric pumping system would be lower than that of solar PV. However, even at a module price of EUR 1.30/W, solar pumping still has a lower LCOE than diesel pumping.

In another sensitivity test, solar pump NPV of cost savings compared to other alternatives remains positive even when the discount rate is raised to 18% (**Table 3**).

FIGURE 5. LCOE sensitivity – PV module prices[9]

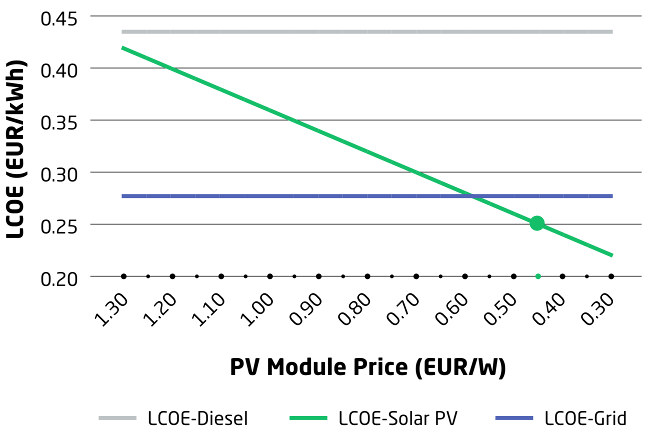


TABLE 3. LCOE & NPV on saved costs of using solar vs. other alternatives at various discount rates

DISCOUNT RATE	LCOE (EUR/kWh)			NPV OF SOLAR SAVINGS VERSUS ... (EUR)	
	Diesel	Solar	Grid	Diesel	Grid
10%	0.43	0.23	0.27	345,000	70,000
12%	0.43	0.24	0.27	305,000	51,000
14%	0.43	0.25	0.28	271,000	35,000
16%	0.44	0.27	0.28	239,000	21,000
18%	0.44	0.28	0.29	211,000	7,000

9) The circle mark indicates the price per module used in the analysis (EUR 0.45/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).

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 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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