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Mobilising Renewable Energy Investments

Zambia: Solar PV and Hydro Mini-Grids

Case Study: Solar PV Mini-Grid in Sinda District

SITUATION DESCRIPTION

This Case Study reveals the characteristics and potential viability of a solar PV mini-grid providing electricity to households and businesses in a village in Sinda District in Eastern Province, Zambia. The study is based on both information obtained from the project owner and estimates and assumptions. The study therefore does not necessarily reflect the actual mini-grid situation and performance. It does, however, provide indicative findings based on modelled analysis that may be useful for mini-grid developers and investors.

The Sinda project is the first private solar PV mini-grid in Zambia, commissioned in its current form in 2017, and is considered as a pilot project. The mini-grid is owned by Muhanya Solar Limited, a solar PV systems provider in Zambia. The village that the mini-grid supplies is in a rural area and was not electrified before the project was installed.

SOLAR PV MINI-GRID CONFIGURATION

The Sinda mini-grid is comprised of a 30 kWp solar PV system, a 20 kW inverter and 140 kWh of battery storage capacity with four 100 A charge controllers.[1] A 2.5 km, 230 V 3-phase overhead distribution network delivers electricity to 60 households and 5 businesses. The load per household is limited at 300 W.

Muhanya Solar intends to expand the system capacity and distribution network in the future to reach a total of 120 consumers including a school and a clinic.

Smart meters with remote monitoring capabilities are used. This helps achieve a collection rate of close to 100% on electricity bills. Payment can be made on a daily, weekly or monthly basis. Muhanya is also piloting the use of pre-paid electricity using mobile money.

1) A back-up 60 kW diesel generator may have also been installed but is not included in the Case Study as data was not available at the time of writing

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The project generation infrastructure is located on a plot of customary land obtained with the consent of the local administration and the community.

PLANT CHARACTERISTICS

The plant annual generation was estimated based on energy yield projections for a site with similar irradiation data. The expected operational period of the project is 10 years to account for uncertainties around main grid extension.[2] The solar PV plant has the following characteristics:

TABLE 1. Sinda solar PV mini-grid characteristics

PARAMETER	UNIT	VALUE
Approximate energy yield	kWh/kWp/y	1,747
PV system capacity	kWp	30
Annual generation year 1	kWh	52,410
Annual energy consumption year 1	kWh	42,979
Annual degradation	%	0.5
Distribution network	km	2.5
Number of customers year 1		65
Development & construction time	year	1
Mini-grid lifetime	years	10
Battery lifetime	years	7

The impact of system degradation, system losses, temperature, cloud cover and panel soiling is accounted for in the energy yield. Some of the excess PV production is stored in batteries to meet the demand during the evening and night time.

CAPITAL AND OPERATING COSTS

Capital expenditure (CAPEX) figures have been assumed based on the project investment cost as provided by Muhanya Solar. The mini-grid CAPEX includes the cost of the generation system (solar PV modules and inverters), the battery bank, balance of plant (mounting structures, cables, collection boxes, etc.), the low voltage distribution network and project development, design and installation costs. Equipment transportation costs are embedded in the CAPEX. A ZMW-EUR exchange rate of 0.08396 from May 2018 is used.

TABLE 2. Sinda mini-grid CAPEX

ITEM	COST EUR	COST ZMW
Solar PV generator	115,000	1,369,700
Battery storage	47,000	559,790
Balance of plant	39,000	464,507
Distribution grid	30,000	357,313
Development & installation	21,000	250,119
Total cost	**252,000**	**3,001,429**

The total project cost is about EUR 3,877 or ZMW 46,176 per customer connection.

Operating expenditure (OPEX) consists of generator and distribution network annual operations and maintenance costs, which were calculated as a percentage of the respective investment cost. Also included are staff salaries and wages for a manager, a technician and a security guard as well as administration expenses and insurance costs. The costs are based on reported expenditure incurred in the day-to-day running of the Sinda mini-grid. Regulatory costs are not included as the project did not have a mini-grid electricity licence at the time of writing, nor had the project undergone an environmental impact assessment.

2) Note: PV modules typically have a longer lifetime of 20 – 25 years

TABLE 3. Sinda mini-grid OPEX

ITEM	UNIT	ANNUAL COST	
	%	EUR	ZMW
O&M costs plant	1.5	3,015	35,910
O&M costs grid	4.0	1,200	14,293
Staff & admin costs	—	6,850	81,586
Insurance	—	250	2,978
Total cost	**—**	**11,315**	**134,767**

It is expected that the battery will need to be replaced in year 7 of operations.

BASIS OF THE ANALYSIS

While Sinda mini-grid costs were mostly incurred in USD, the Case Study is based on an investment in EUR. The effects of currency exchange rate fluctuations are not considered in the analysis.

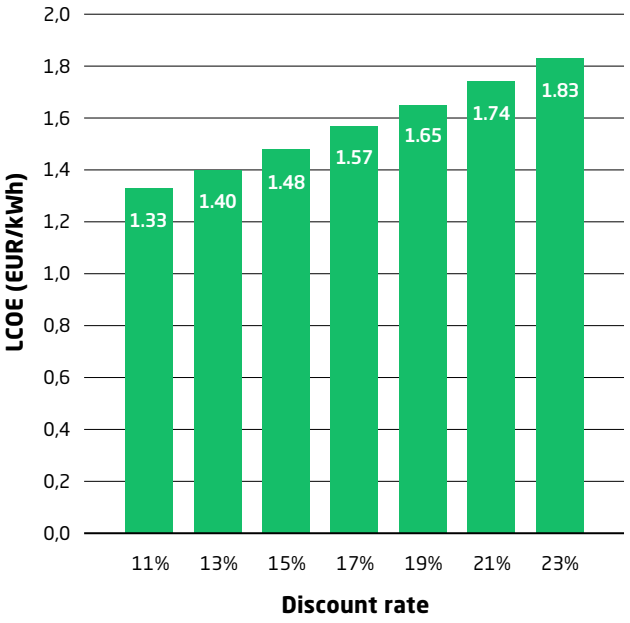
Value Added Tax at 16% is also not considered. This is because VAT is a throughput tax and not a cost item for businesses. In addition, the main solar PV project components are zero-rated for VAT (and customs duty) in Zambia. However, it should be noted that a mini-grid operator would usually need to add VAT and excise duty (at 3%) on electricity sales to customers

The base year of the calculation is 2017. The analysis considers 11 years (1 year development and construction, 10 years operation). At the Sinda mini-grid, all of the customers were connected in the first year. For the project Case Study, it is assumed that the initial system installation was somewhat oversized to allow for future demand increase, which is estimated at 1.5% per year. For simplification, the demand increase is expected to come from existing customers. No new customer connections are considered. Annual inflation of 7% is applied to operating costs as per recent rates in Zambia.

LEVELISED COST OF ELECTRICITY

The levelised cost of electricity (LCOE)[3] is calculated using a discount rate of 17% and determining mini-grid costs and electricity production for each year separately using the discount factor. The discount rate is based on an assumed required rate of return on equity. The division of the present value of costs by the present value of electricity production results in a project **LCOE of 1.57 EUR/kWh** (ZMW 18.86/kWh).

FIGURE 1. Project LCOE at different discount rates



MAXIMUM ALLOWABLE TARIFF CALCULATION

The Energy Regulation Board (ERB) of Zambia has electricity tariff determination guidelines for retail customers that use the revenue requirement methodology.[4] The guidelines are aimed at the national utility but are also broadly applicable to private mini-grids.

3) Levelised cost of electricity (LCEO) is the ratio of lifetime costs to lifetime electricity generation, both discounted back to a common year using an assumed discount rate

4) Also known as the rate of return or cost of service methodology. See the accompanying Developer Guide; accessible at www.get-invest.eu, for details

As per the guidelines, the revenue requirement is based on total costs for **a)** OPEX, **b)** depreciation, **c)** return on assets and **d)** taxation.[5] A return of 6% real is allowed on mini-grid fixed assets. It is not clear if this may be negotiated. Assets funded with subsidies or grants may be included but the project is not allowed to make a return on such assets or subsidized portion thereof. The Sinda mini-grid was financed with approximately 70% grant funding and 30% equity. The different funding sources were:

— Power Africa Off-Grid Energy Challenge EUR 84,000

— Musika Development Initiatives EUR 84,000

— Muhanya Solar Limited EUR 84,000 (EUR 71,400 in cash and 12,600 in kind)

Therefore, a return on assets is not allowed for a significant proportion of the mini-grid infrastructure.

The revenue requirement should be met from electricity sales. To obtain the maximum allowed tariff for the Case Study, the calculated revenue requirement based on the modelled assumptions is divided by the billed consumption for mini-grid operational period.

At the time of writing, it was not possible to obtain detailed records of generation and consumption at the Sinda mini-grid. Furthermore, Muhanya has different business lines (e.g. solar home systems), the revenues and expenses of which were not separated. Thus, for this Case Study typical customer load profiles from the 2008 Rural Electrification Master Plan were used to estimate consumption. For the 65 Sinda mini-grid customers, the assumptions for the first year are:

— Households — 49 kWh/month

— Smaller business entities — 127 kWh/month

Over 10 years, the total billed consumption was estimated at 460,000 kWh. Based on the mini-grid financing structure and considering corporate tax at 35%, but ignoring a possible 5-year tax holiday — for which smaller new enterprises in rural Zambia can be eligible — the modelled 10-year revenue requirement is estimated to be EUR 460,000 (ZMW 5.5 million). This results in a maximum tariff of approximately **EUR 1.00/kWh** (ZMW 11.96/kWh).

ESTIMATED END-USER TARIFF AND AFFORDABILITY

At of the end of 2017, Sinda mini-grid customers were paying a flat monthly rate of between **EUR 12.60** and EUR 20.10 (ZMW 150 and ZMW 240). At the lower bound, based on the estimated average customer consumption for 2018 of 55 kWh/month[6], this works out to an average tariff of **EUR 0.23/kWh** (ZMW 2.72/kWh) in the first year of the Case Study. Based on the estimated 10-year average customer consumption (59 kWh/month), the average tariff would be **EUR 0.21/kWh** (assuming consumption increases over time while the calculated tariff remains flat).[7]

The following are notable examples of affordability for comparison:[8]

— Average monthly household income in rural areas of Zambia in 2015 was about EUR 68 (ZMW 810). Using a benchmark of 10% of income leads to an estimated ability to pay for electricity of EUR 6.80/month

— In 2016, it was reported that off-grid households were spending approximately EUR 8.50/month on lighting alone.

— For the public 60 kWp Mpanta solar PV mini-grid, a monthly charge of EUR 3.36 (ZMW 40) was approved by ERB. At a private hydro mini-grid in Zambia, customers on average pay about EUR 8/month, which may work out to a tariff of about EUR 0.03/kWh.[9]

5) In addition, deductible income is subtracted from total costs to arrive to the final revenue requirement. This is not applicable to the Case Study as there is no deductible income

6) Average of household and business customers

7) Note: Current connection charges are nominal at about EUR 8.40 (ZMW 100)

8) For further information on ability and willingness to pay, electricity tariffs and references please see the accompanying Developer Guide; accessible at www.get-invest.eu

9) It should be noted that the mini-grids were, respectively, funded with concessional loans and donations, and therefore their tariffs were not likely set on a commercial basis. In addition, it is reported that the Mpanta tariff does not cover O&M costs

In addition, in 2017, the World Bank assumed that new "last mile" national grid customers consume about 91 kWh/month, which works out to an electricity bill of EUR 2.75 before VAT and excise duty based on ZESCO Limited national grid tariffs.[10]

TABLE 4. ZESCO national grid retail tariffs 2017

TARIFF CATEGORY	CHARGE	EUR	ZMW
1. Small residential (R1)	Per kWh	0.013	0.15
— Up to 200 kWh	Fixed/month	1.53	18.23
2. Small commercial	Per kWh	0.045	0.54
— Up to 15 kVA	Fixed/month	8.09	96.41
3. Social services	Per kWh	0.041	0.49
— Schools, hospitals, etc.	Fixed/month	7.04	83.84

Note: values exclude 3% excise duty and 16% Value Added Tax

For the Case Study, it can be seen that the lower bound monthly charge (EUR 12.60) is likely to be at or above a level that is affordable for the typical rural household. Furthermore, the lower ZESCO tariffs imply a risk to the project in case of national grid extension to the project area.

SINDA MINI-GRID CASE STUDY MODELLED VIABILITY

The financial viability of a mini-grid depends on customers paying a tariff at a level that allows the operator to meet revenue requirements, including a return on investment. This usually means that the tariff must be equal to or higher than the mini-grid LCOE.

Table 5 summarizes the results of various modelled financing and tariff scenarios, where the internal rate of return (IRR), LCOE and net present value (NPV)[11] are all based on mini-grid equity cash flows:

Base 1: Assumes no debt and an equity/grant ratio of 30/70% and sets the end-user tariff at the estimated average rate for Sinda customers over the project lifetime of EUR 0.21/kWh (see section "Estimated end-user tariff and affordability" for details).

Base 2: Sets the end-user tariff at the maximum allowable tariff using the regulator's revenue requirement methodology.

Base 3: Sets the tariff equal to LCOE, which is the minimum level at which the 17% required return on equity is met.

Debt 1: Assumes a bank loan (15% interest rate, 8 year tenor, 1 year grace period) and a financing ratio of 30% equity, 30% debt and 40% grant.

Debt 2: Assumes no grant and increases the debt contribution to 70%.

Debt 3: Assumes a lower inflation rate of 3% (vs. 7% applied elsewhere).

Debt 4: Assumes inflation at 3% (vs. 7% applied elsewhere) and a lower loan interest rate of 10%.

For the Case Study, when considering the 70% grant funding for the Sinda mini-grid, the LCOE on the equity cash flows drops by more than half to between EUR 0.73/kWh (ZMW 8.69/kWh) and EUR 0.77/kWh (ZMW 9.15/kWh) — see the base cases in Table 5 as compared to the project LCOE shown in Figure 1. The mini-grid tariff must meet or exceed this to provide the 17% required rate of return on equity (assuming no further viability gap financing).

With the estimated end-user tariff at about EUR 0.23/kWh in 2017, the Case Study mini-grid's annual revenue in year 1 is approximately EUR 9,900 (ZMW 118,000), which is lower than its OPEX of EUR 11,300 (ZMW 135,000). Based on the input assumptions, the mini-grid is making a loss and will continue to do so over the 10-year timeframe. Unless the situation changes, it will not be able to sustain its operations.

10) ZESCO national grid tariffs are subsidized. And at ZESCO diesel mini-grids, the cost of generation was between EUR 0.29/kWh to EUR 0.34/kWh

11) Net present value (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 5. Financing & tariff scenarios[12]

SCENARIO	FINANCING RATIO %			EQUITY IRR	EQUITY LCOE	EQUITY NPV	INPUT TARIFF
	E	D	G	%	EUR/kWh	EUR	EUR/kWh
Base 1	30	0	70	—	0.73	–93,000	0.21
Base 2	30	0	70	35	0.77	42,000	1.00
Base 3	30	0	70	17	0.73	0	0.73
Grant	10	0	90	17	0.49	0	0.49
Debt[13] 1	30	30	40	17	1.03	0	1.03
Debt 2	30	70	0	17	1.49	0	1.49
Debt 3	30	30	40	17	0.99	0	0.99
Debt 4	30	30	40	17	0.91	0	0.91

It can be seen that the proportion of viability gap funding (grant) has the biggest influence on the end-user tariff. However, even with maximum viability gap funding (90%), the tariff remains on the higher side vis-à-vis the typical household customer based on the assumptions applied. Adding debt to the mix to reduce viability gap funding increases the LCOE versus the base case (70% grant) and hence the required end-user tariff.

A combination of measures may help to improve the modelled financial viability of the Case Study:

- Assessing consumption and ability to pay to identify opportunities to bill at a higher tariff
- Connecting new customers that will pay a higher tariff, such as large agricultural households, industries and institutions, although the potential may be limited by the small size of the village, the potential connection costs and the possible impact of more customers on mini-grid reliability
- Promoting productive use activities, which may result in increased ability to pay
- Significantly reducing operating costs, including controlling OPEX against inflation
- Reducing expectations for return on equity

It is worth emphasising that the results of this Case Study may not be considered representative of the viability of solar PV mini grids in Zambia, but rather a specific case. Where the investment costs are lower, sites have larger businesses and economies of scale could be reached with a portfolio of sites instead of one, viability will improve.

12) E = Equity, D = Debt, G = Grant
13) In all "debt" scenarios, the minimum debt service coverage ratio is sufficient for bank financing

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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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