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Mobilising Renewable Energy Investments

Zambia: Solar PV and Hydro Mini-Grids

Case Study: Hydropower Mini-Grid at Lwakela Falls

SITUATION DESCRIPTION

This Case Study analyses the feasibility of a potential small hydropower mini-grid to provide electricity to rural customers in North-Western Province, Zambia. The Case Study gives indicative information on the project and the findings may also be useful for developers and investors considering small hydro mini-grids elsewhere in the country.

The Lwakela River is located 25 km to the north of Mwinilunga town on the T5 road to Ikelenge and the Angolan border at Jimbe, in northwest Zambia. The potential project is in an agricultural area with some fishing activity. Economic development is generally limited, largely due to the lack of electricity. Many businesses and health clinics rely on diesel or petrol generators and households use off-grid solar products for lighting. The main development nearby is the Sachibondu Mission, 6 km to the east of Lwakela village, where there is a primary school and a modern hospital completed in 2018. The mission has a self-built 20 kW mini-hydro scheme on the river for its own needs.

At the request of the local chief and community, a Zambian hydropower project developer — Hydro Electric Power Limited (HEP)[1] — began championing the development of a larger hydro scheme at the site of the Lwakela Falls in 2002. **Figure 1** shows the falls and **Figure 2** presents the project location.

1) Hydro Electric Power Limited (HEP) is a hydropower project developer and operator registered in Zambia since 2009. HEP developed and is operating the vertically integrated Zengamina Power Company in Ikelenge District of North-Western Province. Zengamina is a 700 kW run-of-river mini-hydropower scheme on the upper Zambezi River, supplying approximately 550 residential, commercial and institutional customers that are approximately 100 km from the national grid.

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FIGURE 1. View of Lwakela Falls[2]

FIGURE 2. Location of the hydro mini-grid

Currently, the national grid (ZESCO) ends at Mwinilunga. A future extension of the grid to Ikelenge or to Angola could allow for the expansion and interconnection of the existing Zengamina small hydro mini-grid located nearby (developed and operated by the HEP team). HEP has been developing the Lwakela project with an expectation of grid expansion from Mwinilunga. However, without such an extension, connecting the proposed Lwakela mini-hydropower project to the grid would require 23 km of high voltage transmission and would likely not be feasible.

HYDROPOWER MINI-GRID CONFIGURATION

As the extension of the national grid to the project site is not confirmed, the Case Study considers an off-grid electrification scenario for the Lwakela mini-hydropower project. Under such development, the project will connect two villages with a combined population of 4,500 people.

The hydro plant is anticipated to be located on a stretch of the river with an existing waterfall with a net head of 12 m. The scheme's layout includes a weir raising the water to an intake, from which the water will flow through a canal or penstock placed along the right bank and ending after the falls, to the powerhouse. After the power is stepped up, the two villages that are near the T5 road will be supplied via 6 km 33 kV distribution network.

The population resides in 643 households, of which it is assumed that 70% (451 households) will be connected. The area to be supplied has a hospital and three schools. Apart from a number of small businesses, productive enterprises or micro-industries such as maize grinders, saw mills and welders are expected to be present and become customers of the mini-grid. Based on a preliminary field survey and reference sources, households are estimated to have an average consumption of 1.54 kWh per day. The total mini-grid load may reach 250 kW and the 473 connected customers are projected to use more than 1 GWh of electricity in a year.

TABLE 1. Mini-grid customers and demand – year 19

CUSTOMER TYPE	NUMBER	TOTAL LOAD (kW)	TOTAL ANNUAL CONSUMPTION (kWh)
Households	451	92.0	252,849
Schools	3	3.4	8,585
Health centre	1	80.0	700,800
Micro-industries	11	61.0	89,790
Businesses	7	8.1	34,646
Total	**473**	**245**	**1,086,670**

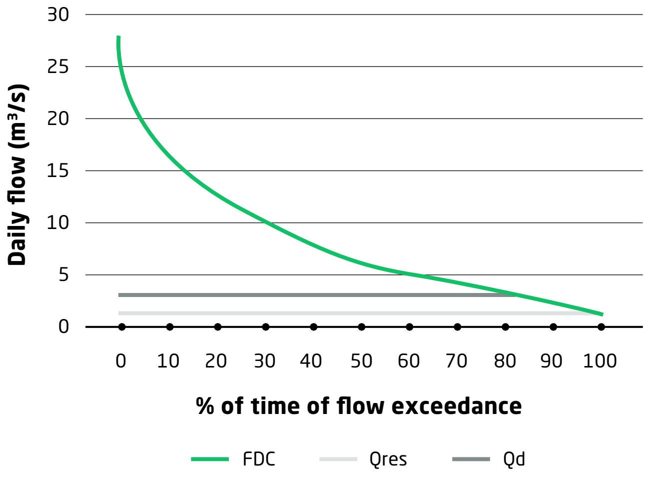
2) ©GIZ

HYDROLOGY, POWER OUTPUT AND ENERGY PRODUCTION

The water catchment area of the hydropower site at Lwakela Falls is 632 km² and the mean annual rainfall is estimated at 1,400 mm.[3] The maximum recorded rainfall in the district is about 2,000 mm, and the minimum is 960 mm. There is a gauging station installed at the envisaged location for the weir. Records for 36 hydrological years are available, but only years with less than 20 daily records missing were considered; reducing the number of annual records used to 22. The resulting flow duration curve (FDC) for Lwakela, showing the average water availability distribution during the year, is presented in **Figure 3**.

Under the assumed conditions, the design flow (Qd) necessary to generate 250 kW of power to meet the mini-grid load is 2.83 m³/s. This corresponds to a percentage of exceedance of 84% and 0.35 times the average daily flow of 8 m³/s. The corresponding average annual energy production is 1.09 GWh.

FIGURE 3. Flow duration curve at the hydro plant[4]



The hydrological analysis confirms that it is possible to meet estimated power and energy demand with the hydro resources available at the project site. However, on average, it will not be possible to meet peak demand 100% of the year. The flow duration curve shows that flows of less than Qd (2.83 m³/s) occur 16% of the time. The period during which the hydropower plant is not able to meet the peak power demand is increased by the need to maintain the reserve flow (Qres) of 1.23 m³/s. It is estimated that the maximum power output of 250 kW will be available, on average, during 70% of the year.

As such, the connection rate for the project will be progressive, with peak demand of 250 kW expected to be achieved at the end of the project lifetime. The limitations to power production will depend on demand and hydrological activity, as there is a natural variability of the flows within each year. Typical solutions to tackle potential gaps between demand and available power include load management and the use of an additional source of power. For simplification for the case study, it is assumed that the hydro plant will meet the demand.

TABLE 2. Hydro mini-grid system parameters

PARAMETER	UNIT	VALUE
Catchment area	km²	632
Average flow	m³/s	8
Design flow	m³/s	2.83
Installed capacity	kW	250
Average annual energy production	GWh	1.09
Overall efficiency	%	75
Development period	year	1
Construction period	months	12
Project lifetime	years	20
Civil works lifetime	years	40
Electro-mechanical equipment lifetime	years	20
Distribution grid 33 kV	km	6

CAPITAL AND OPERATING COSTS

Capital expenditures (CAPEX) cover the typical equipment and costs for a hydropower mini-grid project. These include civil works, the penstock, the powerhouse with turbine and generator, substation, distribution grid and additional miscel-

3) Hydrological data was provided by HEP
4) FDC = flow duration curve, Qres = reserve flow, Qd = design flow

laneous costs.[5] Due to the remote site location, a development and construction period of two years is assumed. For annual operating costs (OPEX), an average of EUR 68,000 is anticipated, being approximately 4% of CAPEX. These annual operating and maintenance (O&M) costs include management of sales and billing, maintenance, insurance and regulatory fees. The estimated costs are based on HEP experience. A ZMW-EUR exchange rate of 0.08396 from May 2018 is used.

TABLE 3. Mini-grid CAPEX and OPEX

COMPONENT	COST EUR	COST ZMW
Civil works	535,500	6,378,000
Penstock	42,500	506,200
Turbine and powerhouse	267,750	3,189,000
Substation	170,000	2,024,800
Grid and connections	136,600	1,518,600
Miscellaneous costs	442,804	5,274,000
Total CAPEX	1,595,154	18,890,600
O&M annual costs	67,850	808,170

The electro-mechanical equipment is expected to be overhauled in year 20 of operations at 50% of the cost of the original investment.

BASIS OF THE ANALYSIS

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. While VAT may be applicable on hydropower mini-grid plant and equipment, it is possible to defer VAT on some capital goods at the time of import. In addition, 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.

5) Studies, engineering, construction supervision, regulatory costs, access road, transport costs, land acquisition and 10% contingency

The base year for the calculations is 2018. It is assumed that consumption in year 1 will be 72% of the total potential demand, which will increase at 4% per year until year 6 and at 0.6% per year thereafter. In addition, energy sales are considered to equal the maximum forecasted energy demand.

LEVELISED COST OF ELECTRICITY AND ANALYSIS

The financial analysis considers a number of input parameters.

TABLE 4. Financial parameters

PARAMETER	UNIT	VALUE
Discount rate	%	16
Loan interest rate	%	15
Loan tenor	years	8
Grace period	years	2
Depreciation	years	10
Equipment salvage value	%	20
Income tax	%	35

For the Lwakela mini-grid, the levelised cost of electricity (LCOE)[6] is calculated using a discount rate of 16% and determining mini-grid costs and electricity production for each year using the discount factor. The discount rate is based on an assumed required rate of return on equity. In the base case analysis, a debt/equity ratio of 70/30 is assumed. The result is an LCOE of EUR 0.44/kWh (ZMW 5.27/kW) on equity cash flows.

While a tariff at or around this level would provide for a project internal rate of return (IRR) of 4.8% and a return on equity of 30% with 70% financing, it may not be possible to obtain regulatory approval for such a tariff. This is because when applying the Energy Regulation Board (ERB) methodology for tariff determination for retail customers,[7] which uses the

6) LCOE is the ratio of lifetime costs to lifetime electricity generation, both discounted back to a common year using a discount rate reflecting the average cost of capital

7) See the accompanying Developer Guide; accessible at www.get-invest.eu for more information

revenue requirement approach,[8] a maximum allowable tariff of EUR 0.24/kWh (ZMW 2.85/kWh) is calculated. In the case that the maximum tariff cannot be negotiated upwards,[9] the project may not be attractive for a developer or investor without viability gap funding.

With viability gap funding of 25% and 50%, respectively, on capital expenditure that replaces the same portion of debt financing, the calculated LCOE for the mini-grid reduces to EUR 0.35/kWh and EUR 0.26/kWh (ZMW 2.62/kWh and ZMW 2.33/kWh). However, the maximum allowable tariff also reduces because the ERB methodology does not allow a return on assets that are subsidised.

TABLE 5. Hydro mini-grid financial indicators

SCENARIO[10]	FINANCING RATIO %			PIRR	LCOE	INPUT TARIFF	ERB MAX TARIFF
	E	D	G	%	EUR/kWh	EUR/kWh	EUR/kWh
Base Case	30	70	0	4.8	0.44	0.40	0.24
Op 1	30	45	25	10.3	0.35	0.40	0.22
Op 2	30	20	50	21.9	0.26	0.40	0.20

Tariff affordability is discussed in the accompanying Developer Guide; accessible at www.get-invest.eu.

SENSITIVITY ANALYSIS

Figure 4 and **Figure 5** show the impact of different tariff levels on project viability for the three funding scenarios. As seen in **Figure 4**, in the base case without viability gap funding the project IRR reaches 10% and a positive project net present value (NPV)[11] at a tariff level of EUR 0.50/kWh (ZMW 5.96/kWh).

FIGURE 4. Tariff effects on project IRR for each scenario

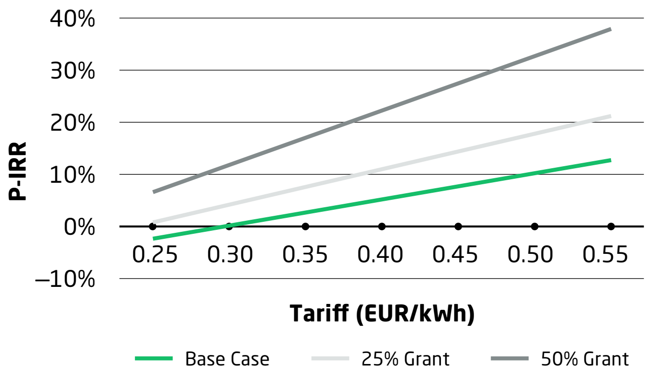
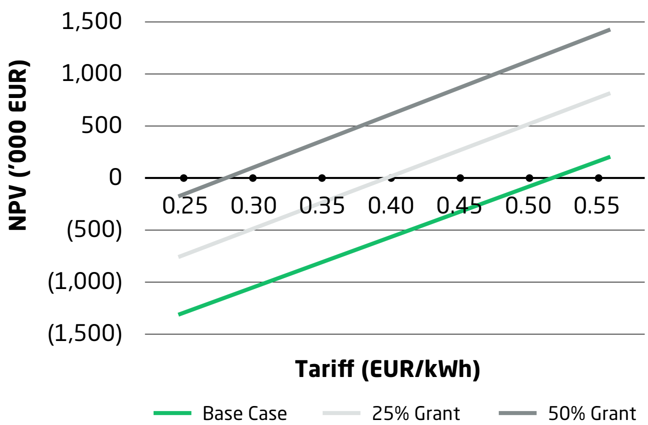


FIGURE 5. Tariff effects on NPV for each scenario



8) Also known as the rate of return or cost of service methodology
9) Note: it is unclear if a tariff above that calculated using the methodology could be approved in the case where the mini-grid developer has already agreed on a higher tariff in discussions with the target community
10) Op = Option, E = Equity, D = Debt, G = Grant, PIRR = Project IRR. LCOE is based on mini-grid equity cash flows. In all scenarios, the average debt service coverage ratio is sufficient for bank financing. End-user tariff is user defined ("Input tariff") or calculated based on the ERB methodology ("ERB max tariff")

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

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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.

ABOUT GET.INVEST

GET.invest is a European programme which supports investment in decentralised renewable energy projects. The programme targets private sector business and project developers, financiers and regulators to build sustainable energy markets.

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.

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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We welcome your feedback on the Market Insights by sharing any questions or comments via email at info@get-invest.eu.

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