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Mobilising Renewable Energy Investments

Zambia: Solar PV and Hydro Mini-Grids

Model Business Case: Solar PV Mini-Grid for Rural Electrification

INTRODUCTION

This Model Business Case analyses the financial feasibility of a portfolio of investment of five solar photovoltaic (PV) mini-grids supplying power 24-hours a day to five to hypothetical communities of Rural Growth Centres[1] (RGCs) in Zambia, in a wider area that was not previously electrified and where national grid extension is not foreseen. For this Model Business Case, satellite imagery of a village in Luapula Province identified in the Rural Electrification Master Plan (REMP, 2008–2030) as an RGC was used to help determine distances. The analysis considers the potential sale of electricity to five customer types: households, small businesses, hammer mills, schools and health centres.

At the time of writing (mid 2018), there was no specific comprehensive regulatory[2] framework for mini-grids. However, a combined generation, distribution and supply licence can be obtained from the regulator (Energy Regulation Board — ERB) as part of a light-handed approached. A licence indicates (an) area(s) of supply, but does not usually assign site exclusivity. Mini-grids will also need to adhere to the 2013 Grid Code and 2016 Distribution Grid Code as well as various technical standards. There is no policy or regulation in place to address the situation where the national grid arrives at a private mini-grid site. The Government of Zambia and development cooperation partners such as the AfDB, EU Delegation, Sida, and the World Bank Group are working to improve the enabling environment for off-grid energy access.

In addition, at the time of writing, there were no tender procedures for mini-grid sites in Zambia. Private developers are able to identify and secure sites for mini-grids as they see fit. However, there are uncertainties around which sites are being targeted for electrification by public entities. A National Electrification Strategy under development that should be completed by 2019 will help address this issue.

1) Rural Growth Centers are defined as "rural localities with a high concentration of residential settlements and the centre of rural economic activities" according to the 2008 Rural Electrification Master Plan (2008-2030). Of the 1,217 RGCs identified in the REMP, 474 are considered to be of a larger size, having more than 400 households.
2) For a comprehensive summary of energy sector regulations and licensing in Zambia, please consult the accompanying Developer Guide; accessible at www.get-invest.eu

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Land for a mini-grid can be acquired if a developer meets certain conditions, such as being a permanent resident, being a company 75% owned by Zambians or being an investor under the Zambia Development Agency Act. Much of the land in rural areas is likely to be customary land (as opposed to state land), which requires the consent of local traditional authorities to use. Developers may consult with the Ministry of Lands and Natural Resources for more details.

TARGET AUDIENCE

— **Project developers**, who may be interested to pursue opportunities for solar PV mini-grid development in Zambia

— **Potential investors**, who may be interested to finance private renewable energy mini-grids

TECHNOLOGY OVERVIEW

Annex A provides more details.

ASSUMPTIONS AND MAIN PARAMETERS

Customers and demand

It is assumed that a private developer will invest in the package of projects — which is procured all at once and reaches an economy of scale that reduces investment unit costs — and will be responsible for mini-grid implementation and operations. The latter includes maintenance of the PV generator, maintenance of the distribution grid and connections and the sale of electricity to customers. Because the portfolio is hypothetical, the load forecast at each mini-grid site is assumed to be identical and all the five projects have the same design, installed capacity and costs. All five sites are located within a 100 km radius, which helps to reduce investment, O&M and administration costs.

The model was prepared considering load assumptions from the Rural Electrification Master Plan (2008–2030). For each mini-grid site the customer and demand characteristics found in **Table 1** were used.

TABLE 1. Solar PV mini-grid customers and demand in year 1 – per site

CUSTOMER TYPE	NUMBER	DEMAND PER CUSTOMER – YEAR 1	
		Max load (kW)	**Average daily consumption (kWh)**
Household (HH)	400	0.120	1.615
Small business (BE)	25	0.500	4.170
Hammer mill (HM)	2	15.000	105.000
Primary school (PS)	1	0.350	5.050
Secondary school (SS)	1	1.050	14.900
Health centre (HC)	1	0.850	13.250

In the first year of operations:

— 99 customers are assumed to be connected at each mini-grid (23% connectivity rate), including 80 households, 15 businesses, 1 hammer mill and 3 public institutions.

— Daily consumption is assumed at 330 kWh with an evening peak load of 32 kW between 18.00 and 19.00 hrs.

— Monthly average household consumption is assumed to be 49 kWh, and 127 kWh for small businesses.

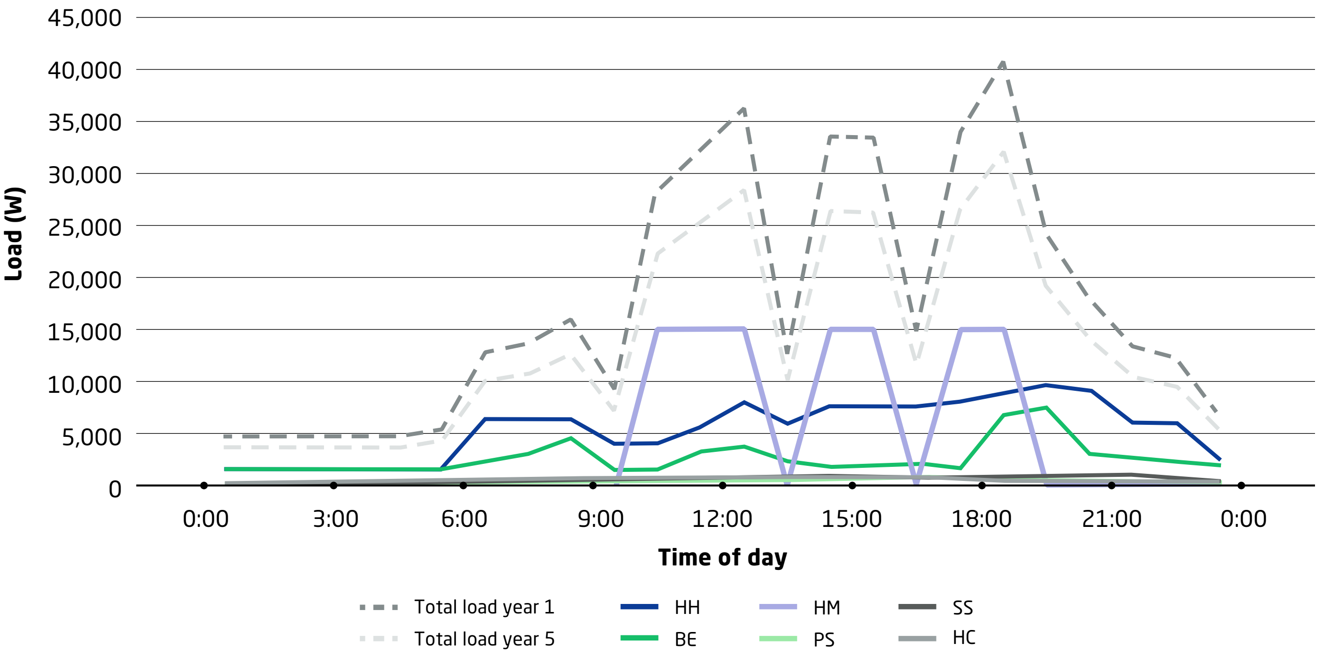
For years 1–5:

— An annual demand growth rate of 5% is assumed, after which demand remains flat.

— Consequently, daily consumption rises to 421 kWh with a peak load of 41 kW at the end of the fifth year of operations.

The daily load profile per customer segment in year 1 and the total daily load in year 1 and year 5 are shown in **Figure 1**.

FIGURE 1. Mini-grid estimated daily load profile – per site[3]



System parameters

The configuration of the solar PV mini-grid system needed to meet the expected demand was carried out using HOMER Pro® software. A solar PV-battery generation option was selected to deliver electricity from 100% renewable energy, meaning that the mini-grid does not have a diesel generator. The system was designed as such because the logistics of regularly procuring, transporting and storing diesel fuel and operating and maintaining a diesel generator can be challenging in remote areas. In addition, in some circumstances a solar PV mini-grid using 100% renewable energy can also be the cheapest option. However, this is not always the case due to the higher upfront costs of solar PV including the need for significant battery storage. To give an indication of the impact of including a diesel generator on electricity costs, two hybridisation scenarios were also tested in the analysis.

The HOMER Pro® simulation results for the solar PV-battery design as well as other system parameters are found in Table 2.

TABLE 2. Solar PV-battery mini-grid system parameters – per site

ITEM	UNIT	VALUE
PV generator	kWp	100
Inverter	kW	100
Battery capacity	kWh	800
Autonomy	hours	47
Capacity shortage	%	15
Renewable energy fraction	%	100
Annual generation — year 1	kWh	153,844
Annual module degradation	%	0.5
Low voltage distribution network	km	2.0

The battery is sized to allow for almost two full days of autonomous run-time. However, it is expected that the charge in the battery may sometimes not be sufficient to meet demand and load management may be required.

3) Note: HH = household, BE = business entity, HM = hammer mill, PS = primary school, SS = secondary school, HC = health centre

The investment and operating costs for the entire mini-grid portfolio of five sites is provided in **Table 3**, along with the unit cost per kW installed.[4] The estimated costs were initially based on the project experience of a developer with mini-grids in different countries in sub-Saharan Africa. Then a discount of 20% was applied to a number of the cost components to account for efficiencies and economies of scale with investment and operations across five sites.

Capital expenditure (CAPEX) covers typical solar PV equipment and associated costs including for modules, inverters, mounting, the battery system, cabling and various balance of plant costs. Each site has a low voltage (400 V) distribution network of 2 km. Development costs include expenses for identifying and securing the site and obtaining regulatory approvals.

The bulk of annual operating expenses (OPEX) are staff and administration costs such as for project managers, technicians, security guards, back office and insurance. Parts and components for maintenance are assumed to be a percentage of the CAPEX for both the generation plant and the distribution grid. In the seventh year of operations the battery is replaced. The replacement cost assumes an annual price reduction of 3% compared to the initial investment.

TABLE 3. Mini-grid system CAPEX & OPEX for five sites

CAPEX	UNIT COST	PROJECT COST	
	EUR/kW	EUR	ZMW
Modules and inverters	760	380,000	4,525,960
Battery storage	640	320,000	3,811,340
Balance of plant	1,483	741,350	8,829,800
Total PV	**2,883**	**1,441,350**	**20,184,020**
Distribution grid	—	173,300	2,064,080
Development costs	—	80,000	952,830
Total CAPEX	**3,389**	**1,694,650**	**20,184,020**
Cost/customer	**—**	**3,424**	**40,776**

OPEX	VALUE	ANNUAL COST	
		EUR	ZMW
O&M costs – generation plant	2.0%	2,400	28,590
O&M costs – distribution grid	4.0%	6,950	82,780
Staff and office costs	—	144,000	1,715,100
Total OPEX	**—**	**153,350**	**1,826,460**
Battery replacement year	7	262,400	3,125,300

Mini-grid retail tariff determination

All electricity produced by the mini-grid is assumed to be sold to customers. An average tariff was considered across all customer types. In reality, it is likely that the tariff would be differentiated per end-user category.

Zambia does not have a national uniform tariff (at the time of writing) — private mini-grids may charge different tariffs subject to regulatory approval. In principle, cost-reflective tariffs may be proposed by developers. However, the tariff guidelines present some grey areas. Most important of these is that there is a benchmark rate of 6% return on assets and it is not clear if this is fixed or may be negotiated by private developers. In addition, while subsidised assets may be included in the revenue requirement calculation, a project is not allowed to make a return on such assets or subsidised portion thereof.

For the Model Business Case, a ceiling average tariff was determined using the revenue requirement methodology described by the ERB's **Electricity Tariff Determination Guidelines for Retail Customers.**[6]

Value Added Tax

Value Added Tax (VAT) at 16% is not considered in the analysis. 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.

4) A ZMW-EUR exchange rate of 0.08396 from May 2018 is used
5) Including engineering, powerhouse and civil works, shipping and transport, installation and other costs and contingencies
6) Further information can be found in the the accompanying Developer Guide; accessible at www.get-invest.eu

Other financial analysis parameters

The Model Business Case is based on an investment in Euro. The effects of currency exchange rate fluctuations are not considered in the analysis. For the package of five sites, a one-year preparation, development and construction period and 10 years of operation is assumed. The 10-year time frame accounts for the risk of national grid extension, even though this is not foreseen. Annual inflation of 7% is applied to operating costs as per recent rates in Zambia. In reality, the effective rate of inflation is likely to be less because the bulk of OPEX is made up of staff and administration costs, which would not usually have an annual increment of 7%. Projects are subject to corporate tax at a rate of 35%. Smaller new enterprises in rural Zambia may be eligible for a 5-year tax holiday. Although it is not clear whether or not a mini-grid developer based in Lusaka would qualify, the tax holiday is included in the analysis.

For the analysis, revenues and costs from the five mini-grids are combined at the portfolio level. The division of the present value of costs by the present value of electricity production results in a levelised cost of electricity (LCOE) for the mini-grid portfolio. The LCOE is calculated using a discount rate of 17%, which is based on an assumed required rate of return on equity.

Financing[7] scenarios

Four financing structures were assessed[8]:

- **Base case:** assumes that no debt or viability gap funding (grant) is available
- **Option 1:** considers a structure of 30% equity (E), 30% debt (D) and 40% grant (G) funding. The loan is assumed to have an interest rate of 15%, a tenor of 8 years and a 1-year grace period
- **Option 2:** assesses the impact of significant grant funding at a level of 70%
- **Option 3:** assesses the impact of significant grant funding at a level of 90%

For each scenario, the loan and/or viability gap funding is applied to capital expenditures, reducing the amount required upfront from equity.

FINANCIAL ANALYSIS RESULTS

The results of the financial analysis for each of the four scenarios are presented in **Table 4**. The table indicates the LCOE on equity cash flows, the return on investment (project and equity internal rate of return (IRR)) and the net present value (NPV)[9] taking into account the investment, operating and financing expenses mentioned previously. For the second scenario, the minimum Debt Service Cover Ratio (DSCR) is also shown. The "ERB average tariff" is the maximum allowable tariff calculated using the ERB tariff determination methodology based on the revenue requirement approach. The "end-user tariff" — which is an average retail tariff that a developer could consider — was set to the minimum level that would **a)** provide a 17% return on equity, where possible, and **b)** not exceed the maximum allowable ERB average tariff.

As can be seen, in both the base case and option 1 scenarios, the portfolio is not a financially viable investment as the NPV is negative, although the second scenario is close to delivering the required return with an EIRR of 16.6% at a tariff level of EUR 0.59/kWh (ZMW 7.06/kWh). Option 1 also shows a minimum DSCR that is above the typical benchmark of 1.2 that lenders usually require to ensure that sufficient cash is available to repay the loan.

On the other hand, Option 2 and Option 3 provide the required return on equity of 17% at tariff levels that are lower than the maximum allowable ERB tariff. With 70% and 90% viability gap funding, respectively, this is achieved at EUR 0.47/kWh (ZMW 5.56/kWh) and EUR 0.36/kWh (ZMW 4.30/kWh).

7) Please refer to the accompanying Developer Guide; accessible at www.get-invest.eu, for more details on potential financing options
8) It is acknowledged that commercial financing conditions are currently not favourable for mini-grids in Zambia. The assessed scenarios are meant to provide the reader with a reference and comparison points
9) 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 4. Solar PV mini-grid portfolio financial indicators[10]

	FINANCING RATIO %			PIRR	EIRR	LCOE (/kWh)		EQUITY NPV	MIN. DSCR	ERB AVERAGE TARIFF (/kWh)		END-USER TARIFF (/kWh)	
	E	D	G	%	%	EUR	ZMW	EUR		EUR	ZMW	EUR	ZMW
Base case	100	0	0	4.5	3.8	0.84	10.05	−593k	0.00	0.63	7.48	0.63	7.48
Op 1	30	30	40	1.9	16.6	0.59	7.08	−4,541	1.69	0.59	7.06	0.59	7.06
Op 2	30	0	70	−10.4	17.0	0.47	5.56	0	0.00	0.57	6.82	0.47	5.56
Op 3	10	0	90	—	17.0	0.36	4.30	0	0.00	0.56	6.66	0.36	4.30

Tariff affordability

Solar PV mini-grid tariffs in Zambia need not only to be set at a level that is at or under the maximum allowable tariff (according to the state of regulation at the time of writing),[11] but also take into account what end-users may be willing and able to pay for electricity. Based on the user input tariffs from **Table 4**, and taking into account the assumed 49 kWh/month household consumption from the 2008 REMP, a household in this modelled case could be expected to pay between EUR 31 and EUR 18 per month for electricity, depending on the scenario. If a household in a rural area were to consume less electricity than assumed, say 50% less — but still pay the same tariff per kWh — the monthly bill would range from EUR 9 to EUR 15, depending on the scenario.

For this modelled case, it is evident that while the maximum allowable tariff would be sufficient to provide a 17% required return on investment in some scenarios, the typical rural household's ability to pay remains limited in comparison.

Thus, a developer of the hypothetical mini-grid package of sites would need to find ways to address the gap between revenue needed for viability and customer affordability, including for example by:

- Identifying higher potential sites with more businesses, productive use and institutional loads, or a few main anchor load customers, which often have a greater ability to pay.
- Reducing investment and operational costs. In particular, there is a possibility that inflation on OPEX could be controlled.
- Setting an energy daily allowance for certain customers to keep monthly electricity bills within ability to pay.

To test the impact of mini-grid hybridisation with diesel generation on end-user electricity costs, two additional scenarios were analysed with system sizing done in HOMER Pro®. The first (PV-battery-diesel) considered a slightly smaller PV generator and significantly less energy storage capacity. For the second hybridisation scenario (PV-diesel), the battery was removed and the renewable energy fraction dropped to 12%. The system parameters and main input assumptions used are found in **Table 6**.

10) Note: Op = option, E = equity, D = debt, G = grant, PIRR = project IRR, EIRR = equity IRR
11) 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 and the higher tariff is within customer ability to pay

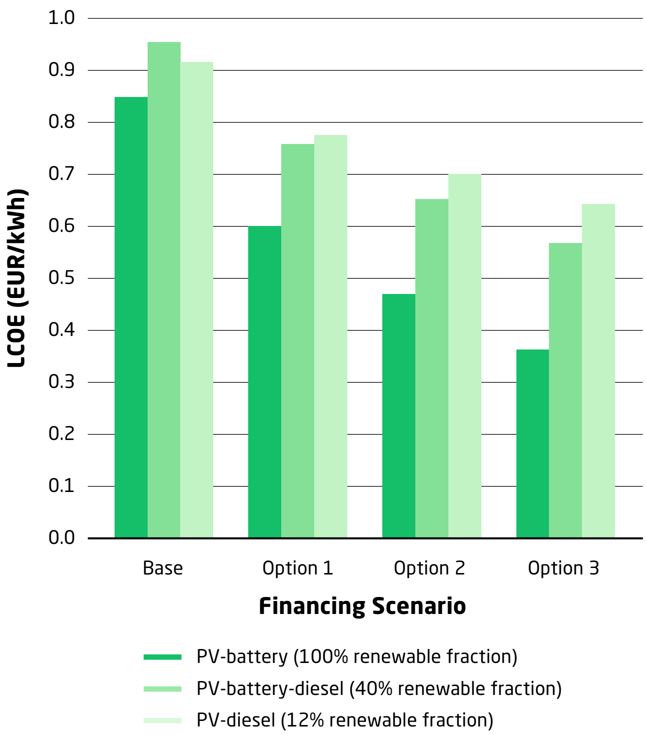
TABLE 6. Mini-grid diesel hybridization scenario parameters – 1 site

ITEM	UNIT	HYBRIDISATION SCENARIO	
		PV-battery diesel	**PV-diesel**
PV generator	kWp	90	50
Inverter	kW	90	50
Battery capacity	kWh	200	0
Autonomy	Hours	12	0
Diesel generator	kW	48	48
Capacity shortage	%	0	0
Renewable energy fraction	%	40	12
Annual generation – year 1	kWh	153,844	153,844
Annual diesel fuel consumption	Litres	34,491	49,455
Diesel fuel cost per litre (wholesale)	EUR	0.69	0.69
Mini-grid CAPEX (5 sites)	EUR	1,352,750	953,200
Mini-grid annual OPEX including fuel costs (5 sites)	EUR	278,160	328,940
Genset replacement	Year	7	7

The two diesel hybridisation scenarios are characterised by lower upfront costs (compared to EUR 1.7 million for 100% renewable energy from solar PV) and much higher annual operating costs (compared to EUR 153,350). Based on the input assumptions and due to the cumulative effect of the operating costs over 10 years, including a diesel generation component did not result in a lower LCOE or end-user tariff.[12] The results of the analysis are shown for the four financing ratios in **Figure 2**.

12) Note: the two diesel hybridization scenarios are only indicative and are not based on an optimised LCOE

FIGURE 2. Mini-grid LCOE comparison with diesel hybridization scenarios[13]



The corresponding end-user tariffs ranged from EUR 0.56/kWh (ZMW 6.71/kWh) to EUR 0.81/kWh (ZMW 9.66/kWh) depending on the scenario, which are higher in each instance than those in the 100% renewable energy scenario (EUR 0.36–0.63/kWh).[14]

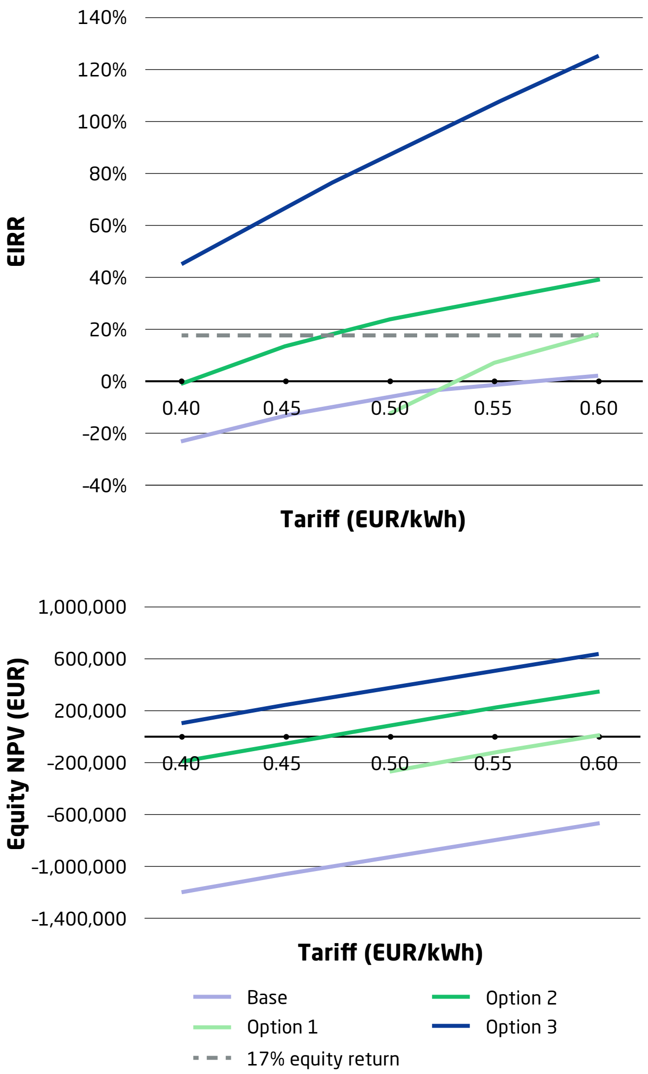
SENSITIVITY ANALYSIS

A sensitivity analysis was performed varying the potential retail tariff for the project to study its effect on EIRR and NPV. The assumed commercial debt terms were not changed, as shown in **Figure 3**.

13) Note: Base = 100% equity, Option 1 = 30% equity, 30% debt, 40% viability gap funding, Option 2 = 30% equity, 70% viability gap funding,
Option 3 = 10 equity, 90% viability gap funding

14) Two key factors influencing the results should be pointed out:
a) battery storage costs in the 100% renewable energy scenario are on the lower side (meaning that the impact of their replacement is not as much as if higher investment costs had been estimated) and
b) even with a low diesel fuel price, the compound effect of assumed inflation at 7% on operating expenditure is significant

FIGURE 3. Effect of tariff variation on EIRR and NPV



The effect of viability gap funding on the EIRR and Equity NPV is significant given the assumptions of this modelled case. Option 2 at 70% grant funding hits the required EIRR at a minimum retail tariff of 0.47 EUR/kWh.

KEY TAKEAWAYS

— An investment decision in a solar PV mini-grid or portfolio of sites is highly dependent on the characteristics of the site(s) and community (or communities) in question and should be taken only after a detailed assessment combining technical, commercial, social and regulatory analysis. For example, the location, the initial and anticipated future load, the number of larger consumers and customer ability to pay and expectations for the level of electricity service are important considerations for mini-grid sizing and design, including for the amount of energy storage and the option of diesel hybridisation.

— This modelled case of 100% renewable electricity from solar PV with 30% debt financing and 40% viability gap funding resulted in an equity IRR of almost 17% at a tariff of EUR 0.59/kWh. With a capital subsidy of about 70%, the project would meet the assumed required return on equity at a tariff of EUR 0.47/kWh.

— There are uncertainties around retail tariff determination for mini-grids in Zambia that should be clarified by developers for their circumstances. These include whether or not the 6% return on assets as per the tariff determination guidelines of the regulator is negotiable and if a tariff at a level that is higher than the calculated maximum tariff would be allowed if mini-grid customers had agreed.

ANNEX A: TECHNOLOGY OVERVIEW

Solar photovoltaic (PV) electricity generation systems consist of three main components:

— **Modules** which convert solar irradiation to Direct Current (DC) electricity

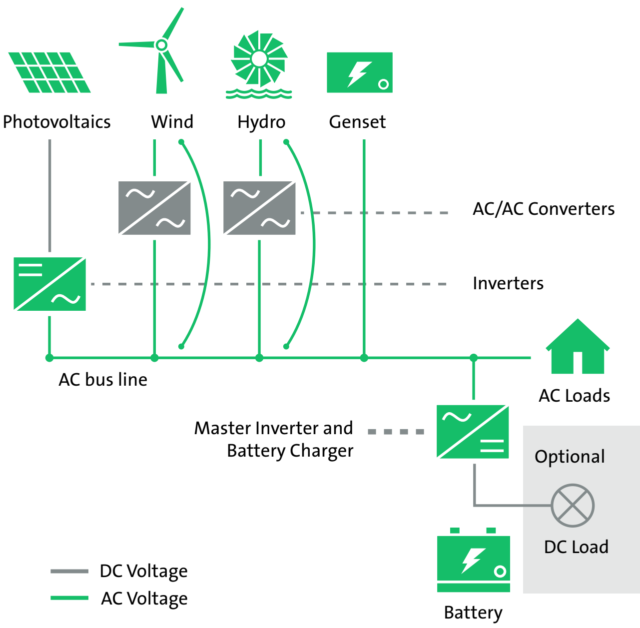
— **Inverters** which convert DC to Alternating Current (AC) electricity for normal use

— **Batteries** (and their charge controllers) save PV electricity for later use

Solar PV systems range from micro to large-scale. A solar PV system can power single- or three-phase loads and can be installed on the ground or on the roof of a building (approximately 10–15 m² of space is needed per kW). Fixed-tilt systems are the most common.

Mini-grids are electricity supply networks that can operate in isolation and provide power to relatively concentrated, often rural or remote, settlements.[15] Mini-grids are comprised of a generation system, an electricity distribution network and an end-user metering and billing system. A control system manages the interaction between various generation components and the distribution network. **Figure 4** provides a schematic diagram of a mini-grid. Mini-grids may be designed to supply electricity 24 hours a day or for a shorter period. At some mini-grids customers may have a maximum daily usage allowance. If customers are found in close proximity (2–3 km) a low-voltage distribution network may be sufficient whereas a medium voltage grid may be needed where longer distances are involved.

FIGURE 4. Schematic of a mini-grid with battery storage and diesel generator[16]



Solar PV generation by its nature undergoes cyclical intermittency within a day and seasonal variations across a year. A solar PV system for a mini-grid must be designed to generate at an optimal level and supply electricity to meet the current and forecasted demand, bearing in mind that system sizing and components have implications for both the cost and quality of electricity produced. There are four typical design options for solar PV mini-grids:

- PV-battery
- PV-battery with back-up diesel generator
- PV-battery-diesel integrated system
- PV-diesel generator

Each configuration has different implications for implementation and operation. For example, energy storage comes at a higher upfront cost and so the appropriate sizing of battery should be carefully considered. The frequency of periods without solar irradiation, combined with the necessity to maintain a state of charge above 45%, determines the sizing of the battery capacity.

Because the conditions and needs of villages or rural centres targeted for electrification differ, mini-grid system design should be based on a site specific and detailed demand assessment. Alongside electricity demand data, financial and economic considerations (including ability to pay) are crucial in choosing the design option.

Performance considerations

A number of factors can affect the technical performance of a solar PV mini-grid in Zambia. These should be taken into account in modelling project performance and for design and planning:

- Variation in solar PV energy yield. Modelled performance is usually based on long-term irradiation data. From year to year, there can be differences of up to 15–20% in total energy yield. In addition, electricity production can vary day-to-day depending on the weather — e.g. heavy precipitation and cloud cover can reduce sunlight hours. This needs to be accounted for if 24-hour electricity supply is planned. The season variation in solar irradiation in Zambia is shown in the accompanying Developer Guide; accessible at www.get-invest.eu.

- Dust and dirt. Projects in dry land rural areas and near unpaved roads may be particularly affected.

15) For mini-grid implementation models, please see the the accompanying Developer Guide; accessible at www.get-invest.eu
16) European Union Energy Initiative Partnership Dialogue Facility (2014) Mini-grid Policy Toolkit: Policy and Business Frameworks for Successful Mini-grid Roll-outs, p. 123. Link: www.euei-pdf.org/en/recp/mini-grid-policy-toolkit – accessed 06/06/2018

— Temperature. High temperatures reduce the performance of solar PV modules.

— Improper battery operation and maintenance can drastically reduce a normal battery lifetime of 6–8 years, thereby increasing replacement costs.

— Theft of system components.

— Insufficient maintenance and lack of spare parts.

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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