Clean energy and mini-grid toolkit

Module 5

Cost-benefit modelling examples, Malawi

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1. General introduction

This Information Sheet presents calculations (done in Excel) to show the economics behind mini-grids with estimates of demand, size, costs and their profitability of mini-grids based on mini hydropower and solar power. Often case studies or reports present only part of the calculations. For example, a sizing study may estimate demand in a village and give an estimate of the size of the facility and some cost estimate, but not the tariff formulation and viability. Or a tariff study is made based on local ability or willingness to pay, but without clearly indicating what the influence is of the tariffs on the facility's cash flow, or how the tariff reflects realistic cost recovery.

The Excel sheet, used for the calculations in this Information Sheet, does not pretend to be a sizing tool (there are various models available to do detailed sizing and matching demand-supply, such as GIZ's Mini-grid builder and the HOMER model), demand forecasting model or a financial evaluation model. The purpose is to show what variables should typically be taken into account and illustrate this with figures. The Excel sheet can also be downloaded but is to show the reader how to make a model yourself in Excel rather than presenting a ready-to-use Excel tool where you put info in and certain output data will come out. Variables include the energy demand of households, shops, and machinery with load and energy consumption figures, total demand in MWh per year at the site, capacity of the energy generation as well as costs of generation equipment and distribution network, translating into cost per kW invested or cost per kWh generated. Based on the annual energy demand (and sales), tariffs and financial support (if available or needed), financial indicators can be calculated (cash flow, NPV, IRR, payback period).

The input data are as much as possible based on energy demand in rural villages in Malawi with data taken from reports on energy demand (see the Bibliography list in Information Sheet No.4). However, we do not claim that all the data are representative or are the average of a typical Malawian village or the average mini-grid in Malawi. The size of the plant in the villages (about 600 kW) may even be on the high side, but serves to stress the role of social and productive uses of energy in the daily load. The calculations do show how certain variations in variables impact other variables. For example, the level of subsidy on investment cost and the customer tariffs and actual demand in a year (revenues) will determine the profitability.

2. Demand

Energy and electricity are necessary in agricultural production for irrigation and drainage, food processing and storage. Household businesses and side-line activities need electricity. Electricity is as necessary for basic water supply in the house as it is for entertainment and communication.

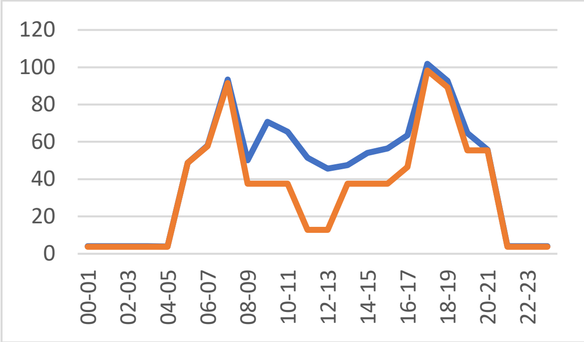
The daily and seasonal demand for electricity in a mini-grid depend on various factors, including:
- Number of inhabitants (families), the appliances they are using or want to use (with their energy consumption and usage per day), which is related to the available cash for consumer applications of electricity;
- The operation of small industries, businesses, farms, etc.;
- The energy demand will not be same over the year. Seasons will have influence, for example, on farming-related productive loads (e.g. irrigation, milling) that will only be used for a certain period in the year.

The mini-grid must be sufficiently flexible (mini-grid electricity supply has to meet electricity demand at all times. Yet, as mini-grids have fewer customers and less varied consumer types than national grids, the concurrency of demand is higher and load profiles are more volatile. The demand for electricity does not only need to be properly assessed but also sufficiently matched with energy supply (e.g. solar, or hydro) during mini-grid operation in order for mini-grids to

Table 1 Power demand in a hypothetical village with 500 households

	Number	kW	kWh/yr
Households	750	195.00	500,963
School	1	1.35	3,697
Clinic	1	1.52	3,584
Shops-offices	12	14.88	39,420
Maize mill	1	20.1	24,120
Water pumping	7	9	10,800
TOTAL		241.85	582,584

Based on sources given in table 2 and 3 (own elaboration)



be economically sustainable. The challenges are to assess the power demand for the near future in rural areas where people do not have personal experience with electricity, and then to accurately estimate demand growth over time.

For our calculation, we take a hypothetical village with 750 households, and which serves as a small development centre for the area (with a clinic, schools, shops and some productive uses). The energy demand is given by the product of the wattage of appliances and the hours of use. An estimation of the time of use of each appliance per day can then be used to evaluate the daily load profile (see Table 1). Not all households will be connected; it is assumed here that in year 1 20% of the households will be connected and then connections will increase over time to reach the full 500 households after 09 years (100% electrification). This is important, because of revenues from sales will be low in the first years and this will affect its profitability. The load (full demand) is given in Table 1, including a corresponding load curve (assuming that all are connected and all productive uses are in place by year 09). The curve does not show that some loads are seasonal, e.g. agricultural use machinery will only be used for a certain period in a year, but this has been taken into account in the annual energy demand estimates.

Typical appliances are lighting; most will have a radio and a charger for the mobile phone. Some households we have a TV and some limited electric cooking will be done. An example of a load estimate of an average household in the village is given in Table 2.

Table 2 Household energy demand assumptions

Household	Power (W)	Usage (h/d)	Amount	Distribution (%)	Power (W)	Energy usage (Wh/day)
Lights	15	7	4	100%	60	420
Radio	45	10	1	100%	45	450
TV	100	4	1	30%	30	120
Cookstove	1,200	6	1	10%	120	720
Mobile charger	5	24	1	100%	5	120
Total					260	1,830

Based data given in: JFY-RENEWAL (2016), Greenwing (2016). It is assumed that not all households will have and TV and only a few will use electric cooking (the latter has quite an impact on the power demand. Depending on the type of village and income levels, the usage per day can be changed, appliance removed or other appliances added. effective electricity demand is again only an estimate. Such calculations can be detailed further, e.g. by multiplying the assessed electricity demand with certain corrective factors, which take into account willingness or ability to pay.

The energy requirement estimates of Table 3 provide an indication of the peak demand for power in a health facility. Many or most devices and appliances are used at one time, but some devices that consume a lot of electricity may be used intermittently while others may remain on standby power mode for most of the day. Table 3 illustrates a simplified example of how average daily demand for power can be calculated in detail. It has been modelled on a 'tier 1 – health facility'. As mentioned earlier, the table does not claim to be an average or representative for the average Malawian rural clinic but gives the reader an idea what equipment is typically used and what energy amounts these consume.

It is further assumed that the village hosts a primary school and a number of shops (barbershop, shops, and a small centre for community purposes (e.g. church, guesthouse, youth centre). As main productive uses of energy, the village group has a maize mill, hosts another small agro-processing facility (e.g., coffee processing; other regions will have other productive uses, e.g. related to tobacco cultivation).

The productive use is important from a power load point of view. The figure next to Table 1 shows two peaks associated with household energy use in the early morning and evening (lighting in particular). The system has to be designed to accommodate this peak demand, but outside peak hours, the maximum power demand is less, and much of the capacity of the power facility will be idle (i.e. will have a lower load utilization factor). Having a number of machinery and equipment working outside peak hours means more energy is used that the power facility is able to meet and this means higher revenue from energy sales.

It does require some load balancing and the operator would have to ensure that the machinery would not operate at peak demand hours. Managing the electrical energy demand of the consumer can be achieved through various methods, such as financial incentives, shifting loads from peak periods to off-peak hours, but also changing behaviour through education and stressing the use of energy-efficient appliances.

Various groups of clients exist that are sometimes grouped according to the ABC model (anchor-business-community, in which households have low energy demand (as indicated in Table 2; see also Information Sheet No,.4), businesses and social services (higher energy demand, for example, shops or schools) and an anchor. The latter, with a high energy demand (e.g. a telecommunication tower, tourism lodges or a large agro-processing facility), will secure commercial operation of the power facility. It is assumed in the calculation that there is no real big anchor (to keep the calculations representative for most villages), but that some productive uses will be present (e.g., maize mill and agro-processing).

Different customers pay different tariffs, the calculations in this Briefing Note follow the tariffs as defined by MEGA in their mini hydropower operations, where a tariff for households is (around USD 0.10/kWh) and a tariff for businesses (USD 0.16/kWh); see Information Sheet No.4 and the Case study on the Mulanje mini-hydropower stations.

Table 3 Health facility energy demand assumptions

Social services - clinic	Power (W)	Usage (h/d)	Amount	Distribution (%)	Power (W)	Energy usage (Wh/day)
Lights	15	10	3		45	1,350
Security lights	30	8	2		60	960
Refrigerator-vaccine	60	10	1		60	600
Microscope	20	6	1		20	120
CD4 machine	200	4	1		200	800
Radio	80	2	1		80	160
TV	100	6	1		100	600
Notebook	60	6	1		60	360
Printer (inkt)	85	2	1		85	170
Mobile charger	15	24	1		15	360
Water pump	100	6	1		100	600
Fans	40	8	2		80	1,280
					905	7,360

Based on data given in: WHO-ESMAP (2015) and UNF (2015)

4. Supply options

We will examine four cases for power supply:

1. Mini hydropower plant
2. Solar PV facility
3. Grid connection
4. Diesel generator

For the scheme to be technically viable the amount of power available from the renewable energy should be greater than or equal to the desired demand. The energy facilities will be designed in such a way that these can peak load, annual energy demand and allow for some unexpected growth in the future (e.g. it is likely that after 10 years the number of households may have increased above the current 750).

Table 4 Energy demand assumptions, schools, shops, productive uses

Social services - school	Power (W)	Usage (h/d)	Amount	Distribution (%)	Power (W)	Energy usage (Wh/day)
Lights	15	4	8		120	3,840
TV	100	1	2		200	400
Computer	200	3	3		600	5,400
Printer	600	1	1		600	600
Fans	40	4	4		160	2,560
					1,520	10,240
Shops-offices						
Lights	15	6	4		60	360
Radio	80	8	1		80	640
TV	200	4	1		200	800
Utilities	1,800	8	1	50%	900	7,200
					1,240	9,000
Productive uses						
Maize mill	20,100	4	1		20,100	80,400
Agroprocessing	10,000	2	1		10,000	20,000
Water pumping						
Irrigation	3000	4	3		9,000	36,000

Based data given in: Based data given in: JFY-RENEWAL (2016), Greenwing (2016); NREL (1998), NREL (2000)

Hydropower

We assume a river is available with sufficient flow and head to generate sufficient electricity to meet the daily peak power demand and the daily energy demand. The net power demand is 242 kW, based on flow rates, head and system efficiency as given in Table 6. The 0.5 m^3/s figure is for the lowest flow in the dry season.

The figures for costs should be interpreted with caution. The figures are estimates that are based on Malawian studies (see note to Table 5) and on global data on costs per unit power. However, hydropower costs will usually be very site-specific, depending on length of penstocks, necessary infrastructure (e.g. road improvement) and civil works needed.

Solar energy

The design of the solar PV System is based on providing adequate energy matching the demand of the load, assuming monthly solar radiation data as given in Table 5. The 375-kW array with 2000 modules (of 1.3 m^2) can generate 690 kWh/yr, while demand is 583 kWh/yr. The solar plant is sized according to the lowest month of isolation (January in this case). Since the power generated will be used during the daytime for the productive use machines, but in the evening for the household lighting and even at night (at the clinic) storage provision is paramount. A system of 1000 batteries system (of 12V and 120Ah each) would meet the storage requirements. Three power conditioning units have been included (with inverters, converters, charge controllers) in the cost estimates of Tables 5 and 6.

Table 5 Solar radiation and sizing of the solar plant

Solar data	Wh/m2 per day			
Jan	4190	Array efficieny	15%	
Feb	4520	Lowest energy yield (january)	4,190	
March	4970	Area needed (to meet lowest energy demand)	2,540	m2
April	5160	Module area	1.3	m2
may	5250	Number of modules	1,954	
June	4680	Watt-peak per module	250	W
July	4370	Installed # of modules	2,000	
August	4890	Cost per module	250	
Sept	4860	Cost of module per kW	1,000	USD/kW
Oct	5250	Batteries (12V, 120 Ah)		
Nov	5410	Battery capacity	114,921	Ah
Dec	4650	Batteries needed	958	
		Batteries used	1,000	
		Cost per battery	120	USD
		Inverters	3	
		Cost per inverter	106,667	USD

Based data given in: Based data given in: JFY-RENEWAL (2016), Greenwing (2016); IRENA (2012a), Van den Akker (2017)

Grid extension

The cost for grid extension to supply power (or connecting the plant to the grid) is based on the length of a 33-kV line over a distance of 25 km (see Table 7). Cost is an estimated USD 1.1 million, based on the cost of the transmission line (USD 875,000), transformers (three at a cost of USD 20,000 each, circuits breakers and connecting switches (USD 21,500) to which the overhead cost is added (engineering and administrative expenses, 15%).

Lifetime of equipment

The design life for the mini-hydro scheme is 20 years, although technical life can in practice be longer. Solar PV has also been designed for 20 years, but assuming that batteries and inverters need to be replaced after 10 years (adding to the cost in year 10). The diesel generator is assumed to last 12 years provided regular overhaul takes place.

Table 6 Cost of diesel plant and of grid extension

Life		12	
Size		250	kW
Load utilization factor		27%	
Investment		100000	
Generator efficiency		34%	
Electricity demand		583	MWh/yr
Diesel consumption		178281	litre
Price of diesel		1.1	USD/litre
Capital cost		100,000	USD
Preparation and infrastructure		11,250	USD
Diesel cost		196,110	USD/yr
O&M	3%	3,000	USD/yr
Overhaul cost (3 yrs)	5%	20,000	USD
Annualised capital cost		20,426	USD/yr
Total annual cost		216,536	USD/yr
LCOE		0.37	

Grid extension

Investment	1,125,000
O&M	33,750
Annualised capital cost	98,083
Total annual cost	131,833
LCOE	0.23

Based data given in: Based data given in: Greenwing (2016); IRENA (2012a), Akker (2017), www.knoema.com

Table 7 Base data and cost and energy production estimates, solar and hydro

Base data			
Flow		0.5	m3/s
Head		150	m
Efficiency		75%	
Power		551	kW
Pipehead loss		7%	
Net power		513	
Hydropower			
Preparation and infrastruct (road)		50	
Civil works (inlet, forebay)		200	
Civil works (penstocks, support)		500	
Powerhouse		150	
Electromechanical equipment		450	
Contigency	10%	135	
TOTAL		1485	USD/kW

		Local grid	**Grid sales**	
Size		250	500	kW
Economic lifetime		20	20	yr
Electric energy demand		583	2409	MWh/yr
Load utilization		27%	55%	
Cost		1485	1485	USD/kW
O&M		4%	4%	
Discount rate		6%	6%	
Investment, hydropower plant		371,250	742,500	USD
Annualised cost of investment		32,367	64,735	USD/yr
Operation and maintenance (O&M)		14,850	29,700	USD/yt
Total annual cost		47,217	94,435	USD/yr
LCOE, hydropower plant		0.0810	0.039	USD/kWh
Distribution grid		85,000	85,000	USD
per km	10	8500		USD
Transmission		1,125,000	1,125,000	USD
per km	25	45,000		USD
O&M cost		3%	3%	

Solar			
Preparation; civil works		45	
Modules		1000	
Inverters		330	
Wiring, electical		240	
Rack, support		270	
Batteries		240	
Battery rack		175	
Contingency	10%	230	
		2530	USD/kW

	Local grid	**Grid sales**	
Size	375	750	kW
Economic lifetime - system	20	20	yr
Lifetime - batteries, inverters	10	10	yr
Electric energy demand	583	1381	MWh/yr
Load utilization	18%	21%	
Cost	2530	2530	USD/kW
O&M	1.5%	1.5%	
Discount	6%	6%	
Investment (batteries)	90,000	180,000	USD
Investment (inverters)	123,750	247,500	USD
Investment (rest of system)	735,000	1,470,000	USD
Operation and maintenance (O&M)	14,231	28,463	USD/yr
Annualised cost of investment	64,081	128,161	USD/yr
	58,084	116,167	USD/yr
Total annual cost	136,395	272,791	USD/yr
LCOE, solar facility	0.234	0.20	USD/kWh
Distribution grid	85,000	85,000	USD
Transmission line	1,125,000	1,125,000	USD
O&M cost	3%	3%	

Based on cost data given in: JFY-RENEWAL (2016), Greenwing (2016); EID-DFID (2013), IRENA (2012a), IRENA (2012b), WEC (2013), Akker (2017)

5. Economic comparison of the various supply options

Table 8 gives an overview of the costs of the four options in the framework of this particular case, i.e. initial investment cost (in USD and USD per unit of installed capacity), estimated annual operation and maintenance cost (in the case of the diesel generator, this includes the fuel cost) and the estimated 'levelised cost of energy'. The LCOE can be derived by annualising the capital cost (by applying a discount factor[1]) and adding annual O&M cost and dividing the total by the annual energy production. The example shows that the mini-hydro scheme offers advantages such as lower capital installation cost, lower unit cost of power generated and lower installation capital, in comparison with the solar facility or grid extension. A diesel generator will have minimum installation capital costs (compared to the other options), but a genset has very high operation and maintenance costs due to fuel and transportation costs (see Table 7).

Table 8 Overview of costs of energy generation options

Options	Investment (USD)	Cost per kW (USD)	Annual O&M (USD)	LCOE (USD/kWh)
250 kW mini-hydro plant	371,250	619	14,850	0.081
375 kW solar PV facility	825,000	825	14,231	0.234
Grid connection (25 km)	1,125,000	1,875	33,750	0.226
250 kW diesel generator	111,250	185	199,110	0.372

Table 8 needs to be interpreted with some caution, as the various examples are based on a range of assumptions, such as distance grid, investment cost per installed capacity (kW), customer tariff (differentiating between household and commercial tariffs), feed-in tariff (in case of delivery to the grid), operation and maintenance cost as well as size of demand for energy (kWh) and power (kW) and the level of subvention given to the initial investment (e.g. grants by NGOs or the government electrification programme). Varying all these assumptions will give different results.

Grid extension

One obvious question is whether it is not possible to extend the main grid (if not too distant) to link up the community. Table 9 illustrates the answer to the question., assuming a business case is sound if it has an IRR (internal rate of return on investment of about 10%). The cost estimates have included both the cost of the transmission line (33 kV) to the village as well as the cost of a small distribution grid (LV) in the village. Obviously, the cost will depend on the distance, so two cases are taken in the table, a distance of 10 km and a distance of 25 km. If the community would have to pay the extension cost, the tariff (given the household and commercial/social uses demand as given in Table 2 to 4) would have to be USD 0.18/kWh (10 km) and USD 0.40/kWh (25 km) for the household and USD 0.29/kWh (10 km) and USD 0.64/kWh for the commercial tariff. If a MEGA-type would be applied (USD 0.10 for household and USD 0.16/kWh for commercial, a grant (subsidy) would be required, 57% (10 km) and 95% (25 km) respectively. Would the ESCOM tariffs apply, even if fully subsidised, the extension of the grid over 25 km would be loss-making (in this case giving a negative IRR!).

Of course, this analysis depends on the size of the demand. If demand would be triple or quadruple the size, the sales revenue would increase accordingly, making the grid extension proposal much more attractive (i.e. yielding IRRs of about 10%, but with lower subvention and enabling lower customer tariffs). The example is to illustrate, why power distribution companies are reluctant to extend the main grid in cases there is no government support (e.g. grants or other subsidy) in combination with a generally low energy demand and limitation on the customer tariff.

Table 9 Cost estimates of grid extension

		10 km	25 km
	Subv	57%	95%
	IRR	10.1%	10.0%
MEGA tariff	Tariff	0.10-0.16	
	Subv	84%	100%
	IRR	10.1%	-13.1%
ESCOM tariff	Tariff	0.06-0.10	
	Subv	0%	0%
	IRR	9.9%	9.60%
Tariff no subsidy	Tariff	0.18-0.29	0.40-0.64

[1] Annualised capital cost = capital cost * $(1+r)^n/((1+r)^n-1)$, in which r is the discount rate (6% is assumed here) and n the lifetime of the facility.

Comparison of electrification options

This section illustrates the influence in variations in investment subsidy, size of the facility (normal size to meet the village demand, and double the size to favour sales to the grid in addition), customer tariffs (ESCOM-sanctioned tariff, MEGA-type of rural tariff and commercial tariff), feed-in tariff (in case of grid extension). The results of the analysis are summarised in Table 10 below, while for details on calculation of the IRR in each case, the reader is referred to the explanation in Annex A.

Let us first look at the **village grid system** (column 1 in Table 10). If there is no subvention, the tariffs would have to be USD 0.33-0.52/kWh (household and commercial tariff, respectively) in the case of the solar PV facility and USD 0.14-0.22/kWh) to yield an IRR of about 10%.

Note: filling in the spreadsheet a tariff (the same for both commercial and household) equal to the LCOE (hydropower, USD 0.081/kWh; solar power, USD 0.19/kWh) gives an IRR equal to the social discount rate (of 6%), assuming that energy demand is at full capacity from yr1. If demand is low in the beginning (20% of households) and increases over time, revenues will be less, resulting in a higher LCOE and thus a higher tariff would be needed to yield the same IRR.

The point the Table 10 wants to make is that *if tariffs to be charged are of a social nature* (i.e. less than needed for commercial cost recovery based on IRR of 10%), *a certain level of subsidy on investment will be needed*; in our specific example, a whopping 77% and 90% for the solar PV mini-grid (at MEGA and ESCOM-type of tariffs) and 35 and 72% for the hydro-powered mini-grid.

In this respect, the size of the facility is important. If for some reason, the mini hydropower facility would have been oversized (double the size, for example), the investment cost would be almost double, but revenues the same. We

Table 10 Comparison of hydropower and solar PV as stand-alone and grid-connected option, according to level of subvention, customer tariff, feed-in tariff and size of the facility (kW) at a 25-km distance from the main grid

HYDROPOWER		**Village grid**		**Village+distrib**		**Grid sales only**	
		250 kW	500 kW	250 kW	500 kW	250kW	500 kW
	Subv	35%	84%	80%	15%		
	IRR	10.4%	10.3%	10.4%	10.3%		
MEGA tariff	Tariff	0.10-0.16		0.10-0.16			
	Feed-in tariff			0.19	0.12		
	Subv	72%	100%	100%	30%		
	IRR	10.0%	4.60%	9.6%	10.2%		
ESCOM tariff	Tariff	0.06-0.10	-	0.06-0.10			
	Feed-in tariff			0.19	0.12		
	Subv	0%	0%	0%	0%	0%	0%
	IRR	10.5%	9%	10.4%	10.4%	10.6%	10.8%
Tariff no subsidy	Tariff	0.14-0.22	0.27-0.38	0.20	0.125	0.18	0.11
	Feed-in tariff			0.20	0.125		

SOLAR POWER		**Village grid**		**Village+distrib**		**Grid sales only**	
		375 kW	750 kW	375 kW	750 kW	375 kW	750 kW
	Subv	77%	94%		65%		
	IRR	10.2%	10.2%		10.1%		
MEGA tariff	Tariff	0.10-0.16		0.10-0.16			
	Feed-in tariff			0.42	0.25		
	Subv	90%	100%	-	72%		
	IRR	10.3%	7.30%	-	10.2%		
ESCOM tariff	Tariff	0.06-0.10		0.06-0.10			
	Feed-in tariff			-	0.25		
	Subv	0%	-	0%	0%	0%	0%
	IRR	10.0%	-	10.2%	10.4%	10.3%	10.4%
Tariff no subsidy	Tariff	0.33-0.52	-	0.47	0.31	0.42	0.30
	Feed-in tariff			0.47	0.31		

see in the Table, that the revenues would not be sufficient to cover a much higher subsidy (more than double), or if fully commercial, customer tariffs that would almost be double (USD 0.27-0.38 instead of the already high USD 0.14-0.22, household and commercial tariff respectively)

Grid-connected solar and hydropower (no village distribution)

Another case is formed by a mini hydropower plant or solar PV facility that exclusively delivers to the grid. It would have higher investment cost (the 25-km transmission line basically), but also higher revenues, because a) the feed-in tariff is higher than the social tariff the plant may be forced to sell to villagers, b) especially in the case of hydropower, the plant can run at a higher load utilization factor (55% instead of 27% in our specific examples). The last columns in Table 10 give the results. Obviously, the feasibility depends on the size of the plant. As the cost of the transmission line is much the same, it is better to have a power facility with a larger capacity.

How does this work out for our specific example? To be viable (without any subvention, and aiming at IRR of about 10%), the power company (ESCOM) would have to offer feed-in tariffs of USD 0.30-0.42 (for 750 kW solar and 375 kW solar) and USD 0.11-0.18/kWh (for 250 kW and 500 kW mini hydropower plant).

Village-level power generation (solar or hydropower) and connection to the grid

The last case is a merger of the two cases mentioned before, in which a local energy company is connected to the grid and generates power from local sources (solar, hydro), distributes power to the village and delivers (or purchases) power from the grid. The grid connection means that power can be sold to the grid or bought from ESCOM. For the PV system, this has the advantage that the battery system (needed to meet demand during the night and with days with little sunshine) can be abandoned and thus investment cost can be reduced (compare cost of investment for solar PV in the table of Annex A for the cases with grid connection and the case of village distribution only).

To keep the calculation simple, the assumption that the local company buys and sells power to ESCOM at a same (feed-in) tariff, which in practice will not be the case. The purpose of the exercise is to show that if the company is forced to sell power at village distribution tariffs that are lower than the feed-in tariff (in case of sales to the grid) or lower than the tariff at which it buys power (in case local supply cannot meet demand), this is loss-making. So, a local energy facility (whether commercial, cooperative or private owned) will only be profitable (at IRR of about 10%) if the village tariff is the same at which it sells power to the grid.

In our calculation example, with no subvention on investment, the dual business of selling power to the village and excess power to the grid, becomes viable at a customer and feed-in tariff of about USD 0.125 kW (assuming the plant is double the size than needed to supply the peak village demand to take advantage that more power can be sold to the grid, while the cost of the transmission line remains the same, whether the hydropower is 250 or 500 kW in size; for a 250 kW the tariff would obviously be higher, USD 0.20/kWh). A similar calculation can be done for the solar PV facility.

If the village distribution is an add-on to a grid-connected scheme, this would not cost that much extra if commercial tariffs could be charged. Commercial tariffs (i.e. equal feed-in tariffs and customer tariffs) would not differ that much between the 'grid-only' case and the 'grid + village-distribution' case, e.g. for a 750-kW solar power facility, USD 0.30 and 0.31/kWh respectively.

The problem arises when the grid-only facility gets (or has to get) into the business of village distribution at below-cost customer tariffs. Then, we see such an enterprise can be undertaken, but only in a profitable way if some subvention is provided on the plant's investment[2]. Table 10 provides some examples. For a grid-connected solar PV facility (750 kW) to be profitable (at IRR of 10.1%), selling to the grid at feed-in tariff of USD 0.25/kWh, and selling part of its power production to the village according to their demand) would require a subvention support on investment of 65% (at the MEGA-type customer tariffs of USD 0.10 and 0.16/kWh, household and commercial tariff).

Similarly, a grid-connected hydro plant (500 kW), selling its power to the grid at a feed-in tariff of USD 0.12/kWh, would only find selling part of its power at the (below-cost) MEGA-type tariffs of USD 0.10-0.16/kWh) if supported with an investment subsidy of 15%.

[2] In all the calculation examples, it is assumed that the village distribution and power facility might get a subsidy, but not the transmission line.

ANNEX A Detailed analysis of supply options

A.1 Levelised cost of energy

The LCOE in tables 6, 7 and 8 is calculated by means of the simple formula given in footnote 1 to derive the annualised capital cost. The LCOE is actually defined as:

$$\mathrm{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

- I_t : investment expenditures in the year t
- M_t : operations and maintenance expenditures in the year t
- F_t : fuel expenditures in the year t
- E_t : electrical energy generated in the year t
- r : discount rate
- n : expected lifetime of system or power station

Let us use this formula to calculate the LCOE of the 600-kW mini-hydropower system. This gives the same result as the simplified formula of footnote 01, namely a LCOE of USD 0.081/kWh (see Table 6)!! However, this assumes that demand and cost do not change over time. Often this will not be the case.

Hydropower

250 kW	Connected:		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Energy sales	MWh		583	583	583	583	583	583	583	583	583	583	583	583	583	583	583	583	583	583	583	583
- Commercial			82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
- Residential			501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501
Energy sales (discounted)	MWh		550	518	489	461	435	411	387	366	345	325	307	290	273	258	243	229	216	204	193	182
Investment cost, plant	USD	-371,250																				
O&M	USD		-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850
Cost (discounted)	USD	-371,250	-14,009	-13,216	-12,468	-11,763	-11,097	-10,469	-9,876	-9,317	-8,790	-8,292	-7,823	-7,380	-6,962	-6,568	-6,196	-5,846	-5,515	-5,203	-4,908	-4,630
LCOE	USD/MWh	0.0810 (at 100% production, yr 1)																				

A.2 Influence of load utilization on the LCOE

In fact, in our calculation examples, the assumptions demand will change over time, because the plants will not be used at their designed maximum capacity right away. It is assumed here that only 20% of households will be connected in year 1 and then coverage will increase over time to reach 750 households after 9 years (100% electrification). It has been assumed that also productive uses increase at the same rate, although, in reality, these will not increase gradually but when the load is added. For simplicity, we assume that total demand (household and productive/social uses) however increases by 10% annually to reach full demand in year 9.

This has consequences for the LCOE as indicated in the table below. The reason is that in the first nine years, the plant will not operate at its designed capacity with less annual energy production and thus fewer revenues. In our specific example, the LCOE thus increases from USD 0.081/kWh to USD 0.115.

Hydropower

250 kW	Connected:		20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Energy sales	MWh		117	175	233	291	350	408	466	524	583	583	583	583	583	583	583	583	583	583	583	583
- Commercial			16	24	33	41	49	57	65	73	82	82	82	82	82	82	82	82	82	82	82	82
- Residential			100	150	200	250	301	351	401	451	501	501	501	501	501	501	501	501	501	501	501	501
Energy sales (discounted)	MWh		110	156	78	115	261	287	310	329	345	325	307	290	273	258	243	229	216	204	193	182
Investment cost, plant	USD	-371,250																				
O&M	USD		-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850	-14,850
Cost (discounted)	USD	-371,250	-14,009	-13,216	-12,468	-11,763	-11,097	-10,469	-9,876	-9,317	-8,790	-8,292	-7,823	-7,380	-6,962	-6,568	-6,196	-5,846	-5,515	-5,203	-4,908	-4,630
LCOE	USD/MWh	0.0810 (at 100% production, yr 1)																				
LCOE	USD/MWh	0.1150 (at 20% demand, yr1, increasing to 100% in yr9)																				

This means that if villagers would pay a tariff of USD 0.115/kWh, the IRR (internal rate of return) would be equal to the discount rate (6%). In reality, villagers will (able or only willing to) pay a lower tariff, while investors will demand a higher IRR, say around 10-11%.

Similarly, the cost-benefit analysis for the solar PV facility can be calculated[3]:

Solar PV

	Connected:		20%	30%	40%	50%	60%	70%	80%	90%	100%											
	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Energy sales (village grid)	MWh		117	175	233	291	350	583	583	583	583	583	583	583	583	583	583	583	583	583	583	583
- Commercial			16	24	33	41	49	57	65	73	82	82	82	82	82	82	82	82	82	82	82	82
- Residential			100	150	200	250	301	351	401	451	501	501	501	501	501	501	501	501	501	501	501	501
Energy sales (discounted)	MWh		109.9	155.5	195.7	230.7	261.2	410.7	387.5	365.5	344.8	325.3	306.9	289.5	273.1	257.7	243.1	229.3	216.4	204.1	192.6	181.7
Investment cost, plant	USD	-948,750																				
O&M	USD		-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-104,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231	-14,231
Cost (discounted)	USD	-948,750	-14,021	-13,814	-13,610	-13,408	-13,210	-13,015	-12,823	-12,633	-12,447	-89,813	-12,081	-11,903	-11,727	-11,554	-11,383	-11,215	-11,049	-10,886	-10,725	-10,566
LCOE	USD/MWh	0.190 (at 100% production, yr 1)																				
	USD/MWh	0.245 (at 20% demand, yr1, increasing to 100% in yr9)																				

A.3 Role of the customer tariff in the plant's profitability

ESCOM charges tariffs that are about USD 0.06 for households and USD 0.10 for business customers (depending on the exchange rate used, see CEM, 2014). The MEGA facility in Mulanje area charges higher values (USD 0.10/kWh for households and USD 0.16/kWh for business clients). It is assumed in our calculation that similar tariffs will be charged (with social services, schools, and the clinic, paying the same as business clients). However, even charging at the MEGA tariff, the 250-kW mini-hydropower facility will hardly be a viable business, with IRR equal to the discount rate and a negligible NPV (net present value).

3 The more mathematically inclined among the readers will notice that in the case of the PV, the LCOE in the table above, USD 0.19/kWh does not correspond with the value of the LCOE calculated according to the simple formula in footnote 1, USD 0.234/kWh. The reason is that in the case of PV some of the investment takes place in year 10 (when batteries and inverters are assumed to be replaced). In the more sophisticated calculation of the table, that allows for different energy demand or cost values in different years, this investment is discounted with the discount factor $1/(1+6\%)^{10}$ and thus gives a lower cost which is reflected in the lower LCOE value,

Hydropower

CASE 01 Hydro Village distribution (250 kW)				20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Investment (plant+distrib)		USD	-371,250																				
Subvention		USD	0																				
Sales -at tariff:	0.100	USD/kWh		10,019	15,029	20,039	25,048	30,058	35,067	40,077	45,087	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096
	0.160	USD/kWh		2,612	3,918	5,224	6,530	7,836	9,142	10,448	11,753	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059
Connection fee	20	USD		3,060	1,530	1,530	1,530	1,530	1,530	1,530	1,530												
O&M				-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400	-17,400
Net benefits - costs		USD	-371,250	-1,709	5,627	11,942	18,258	24,573	30,889	37,205	43,520	48,306	48,306	48,306	48,306	48,306	48,306	48,306	48,306	48,306	48,306	48,306	48,306
			NPV (USD)	2,750	IRR		6.1%																

The tariff would have to be around USD 0.14-0.22/kWh (residential, commercial tariff respectively) to provide an IRR of about 10% (see Table 10). This implies that some subsidy must be provided to cover part of the capital cost. In the calculation example, a subsidy of 35% on the initial investment cost (plant, USD 371,250, and the village distribution, USD 85,000) gives an IRR of 10.5% (at the MEGA-type tariffs of USD 0.10/kWh and USD 0.16/kWh). It follows that, if forced to sell at ESCOM tariffs (USD 0.06-0.10/kWh), the subsidy need would be higher, 72% in our example.

In our examples, the solar PV investment is higher than the mini-hydropower. Obviously, the need for subvention will be higher. If selling power at the MEGA tariff (USD 0.10-0.16/kWh), the facility would need a hefty 77% subvention (or grants for the initial investment)[4]. If forced to sell at the ESCOM tariff, the solar PV facility would not be profitable (with an IRR only slightly higher than the discount rate).

Solar PV

Case 01 Village distribution (375 kW)				20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Investment (plant+distr)		USD	-1,033,750																				
Subvention	77%	USD	795,988																				
Sales at tariff:	0.100	USD/kWh		10,019	15,029	20,039	25,048	30,058	35,067	40,077	45,087	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096
	0.160			3,918	5,224	6,530	7,836	9,142	10,448	11,753	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059
	20	Connection		3,060	1,530	1,530	1,530	1,530	1,530	1,530	1,530	0											
Cost (inv, O&M)			-237,763	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781	-16,781
Total benefits - costs			-237,763	216	5,001	11,317	17,633	23,948	30,264	36,579	42,895	46,374	46,374	46,374	46,374	46,374	46,374	46,374	46,374	46,374	46,374	46,374	46,374
			NPV (USD)	117,704	IRR		10.2%																

A.4 Facilities involved in power sales to the main grid and to a village distribution system

One question is why an enterprise would not deliver to the grid rather than providing power to the village. In the case of hydropower, the load utilization factor could be higher (55% is assumed instead of 27% in our village case). Depending on the assumption that the additional cost of the transmission line (25 km distance) is balanced by the revenues (more kWh and at a higher tariff), the business proposition could be viable. In our calculation example of the hydropower facility (250 kW), at a feed-in tariff of USD 0.18/kWh, the facility would be considered viable (with an IRR of 10.6%). As the cost of the transmission line would be the same, it is better to have a larger facility. For example, doubling the size (500 kW instead of 250 kW) makes the hydropower facility feasible at a feed-in tariff of USD 0.11/kWh (at an IRR of 10.8%), NPV of USD 740,382 and a payback time of about 7.5 years (assuming full production already taking place in year 1), as shown in the table below.

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4 It assumed in the calculation example, that the replacement of batteries and inverters takes place without subsidy, i.e. paid for by the revenues accrued in the previous nine years. Practitioners know this is a reason why solar PV (stand-alone and mini-grids alike) fail. At the moment of needing to replace the batteries (between 7-12 years), the plant’s cumulative cashflow is not sufficient to be able to make this large investment.

Hydropower

CASE 03 Sales to the grid only (500 kW)				20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Investment			-742,500																				
Transmission line			-1,125,000																				
Total costs			-1,867,500	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750
Sales to the grid - at	0.11	USD/kWh		264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990	264,990
Total benefits - costs			-1,867,500	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240	231,240
			NPV (USD)	740,382	IRR		10.8%																

For the solar PV facility, the feed-in tariff would have to be higher, given its larger investment cost (and larger cost per installed capacity, kW). To get an IRR of 10.4% to connect a 750-kW facility (over a 25-km transmission line) would require a feed-in tariff of USD 0.30/kWh.

Solar PV

Case 03 Grid sales (750 kW)				20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Investment (no storage)			-1,717,500																				
Transmission line (plus O&M line)			-1,125,000	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750
Total costs (plus O&M plant)			-2,842,500	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-307,013	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513	-59,513
Sales to the grid - at	0.30	USD/kWh		414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304	414,304
Total benefits - costs			-2,842,500	354,792	354,792	354,792	354,792	354,792	354,792	354,792	354,792	354,792	107,292	354,792	354,792	354,792	354,792	354,792	354,792	354,792	354,792	354,792	354,792
			NPV (USD)	1,027,102	IRR		10.4%																

Another question then is if and how investors can be enticed to deliver to a village grid, while at the same time taking advantage of selling power to the grid. The table below describes the economics of this case. The only way to have a private investor to build a facility to produce to a nearby grid and provide power to a nearby village, would be to offer a subsidy (for the investor to do so) or have the villagers pay a tariff which is the same as the feed-in tariff.

The examples in the tables below are to show that only if some subvention is offered can an enterprise (whether social or full profit-oriented) provide power for rural electrification with mini hydropower and at the same time maintaining 'social' tariffs (i.e., below the cost of energy production). The subsidy is 15% in the calculation example of the mini-hydropower plant and 65% in the case of the solar PV facility. It is assumed here to get some economies of scale (the cost of transmission is not dependent on the capacity of the power facility) that the size of the plant is doubled in comparison with the capacity needed for village distribution only (hydropower: 500 kW instead of 250 kW; solar PV: 750 kW instead of 375 kW).

Hydropower

CASE 02 Distribution and grid sales (500 kW)				20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Investment (plant+distrib)		USD	-827,500																				
Subvention	15%	USD	124,125																				
Sales -at tariff:	0.100	USD/kWh		10,019	15,029	20,039	25,048	30,058	35,067	40,077	45,087	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096
	0.160			2,612	3,918	5,224	6,530	7,836	9,142	10,448	11,753	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059
Connection fee	20	USD		3,060	1,530	1,530	1,530	1,530	1,530	1,530	1,530												
O&M				-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250	-32,250
Net benefits - costs		USD	-703,375	-16,559	-11,773	-5,458	858	7,173	13,489	19,805	26,120	30,906	30,906	30,906	30,906	30,906	30,906	30,906	30,906	30,906	30,906	30,906	30,906
Transmission line		USD	-1,125,000																				
				-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750
Feed-in tariff grid	0.120			275,098	268,107	261,116	254,125	247,134	240,143	233,152	226,161	219,170	219,170	219,170	219,170	219,170	219,170	219,170	219,170	219,170	219,170	219,170	219,170
Total benefits - costs			-1,828,375	224,789	222,584	221,908	221,233	220,557	219,882	219,206	218,531	216,326	216,326	216,326	216,326	216,326	216,326	216,326	216,326	216,326	216,326	216,326	216,326
			NPV (USD)	645,245	IRR		10.3%																

Solar PV

Case 02 Distribution and grid sales (750 kW)				20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Investment (plant+distr, no st)		USD	-1,717,500																				
Subvention	65%	USD	1,116,375																				
Sales at tariff	0.100	USD/kWh		10,019	15,029	20,039	25,048	30,058	35,067	40,077	45,087	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096	50,096
	0.160			2,612	3,918	5,224	6,530	7,836	9,142	10,448	11,753	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059	13,059
	20	Connection		3,060	1,530	1,530	1,530	1,530	1,530	1,530	1,530												
Cost			-601,125	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-273,263	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763	-25,763
Distrib benefits-costs			-601,125	-12,683	-9,204	-4,194	816	5,825	10,835	15,845	20,854	24,334	-223,166	24,334	24,334	24,334	24,334	24,334	24,334	24,334	24,334	24,334	24,334
Grid sales at tariff	0.25	USD/kWh		316,124	301,560	286,995	272,430	257,866	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607	199,607
Investment transmission			-1,125,000																				
				-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750	-33,750
Total benefits - costs			-1,726,125	269,691	258,606	249,051	239,496	229,941	176,692	181,702	186,711	190,191	-57,309	190,191	190,191	190,191	190,191	190,191	190,191	190,191	190,191	190,191	190,191
			NPV (USD)	522,519		IRR	10.1%																

It is interesting to note that linking energy production for village distribution with the option of sales to the grid improves the viability in the calculation examples with the revenues of additional sales (making more use of the power facility's maximum capacity, especially in the case of hydropower and be able to sell this even at a higher feed-in tariff than the 'social' customer tariff) outweighs the cost of transmission (over 25 km in the calculation example). So, in the calculation examples, the subsidy on initial investment cost of 35% for village distribution only (hydropower, 77% in the case of solar PV) can be lowered to 15% and 65% for hydropower and solar PV respectively for a grid-connected local company that is willing to sell part of production to power the villages. At these subsidy levels (and assuming MEGA-type customer tariffs), the profitability of the local energy enterprise of providing part of the power to the village distribution grid instead of selling all to ESCOM would be equal (i.e., same IRR of around 10%). In order to get the subsidy, the company would need to sign a contract with an obligation to provide power to the village first (at the social tariff) before selling it to the grid (at the higher feed-in tariff)!

A.5 Financing of the energy supply options

It is important to understand not only the mini-grid economics, but also the available financing options and sources for mini-grid investment. In this section, we will discuss how one of the particular cases of the previous section 5. can be financed, namely the case "mini-hydropower, case 02, village distribution and sales to the grid". In this particular case, feasibility is augmented by sales to the grid, but the plant will (have to) sell to the villages at MEGA-type customer tariffs (i.e. USD 0.10/kWh residential and USD 0.16/kWh commercial tariff) meaning at level higher than the ESCOM tariff, but lower than what is fully cost-reflective. This is the main reason to justify the need for grant funding (15% of the plant and distribution investment cost in this specific case), lowering the total investment cost (plant, distribution, transmission) from USD 371,250 to USD 241,313.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Cashflow projections (pre-financing)																					
Capital expenditures	-1828																				
Earnings EBITDA	-1828	225	223	222	221	221	220	219	219	216	216	216	216	216	216	216	216	216	216	216	216
pre-tax NPV 645																					
IRR 10.3%																					
payback (yrs) 7.5																					
Depreciation		-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91	-91
Earnings EBIT (before interest and tax)		133	131	130	130	129	128	128	127	125	125	125	125	125	125	125	125	125	125	125	125
Cost of finance				-161	-156	-150	-176	-165	-153	-139	-123	-105	-85	-62	-35	-4	0	0			
Earnings before taxes		133	131	-30	-26	-20	-47	-37	-26	-14	2	19	40	63	90	121	125	125	125	125	125
Tax		0	0	0	0	0	0	0	0	0	0	-2	-5	-8	-11	-30	-31	-31	-31	-31	-31
Net income		133	131	-30	-26	-20	-47	-37	-26	-14	1	17	35	55	79	91	94	94	94	94	94
Plus:																					
Depreciation and interest		91	91	252	247	241	267	256	244	230	215	197	176	153	126	96	91	91	91	91	91
Cash flow (after tax)	-1,828	225	223	222	221	221	220	219	219	216	216	214	211	208	205	186	185	185	185	185	185
IRR 10.0%																					

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Financing activities (w/ soft loan)																					
Equity	274																				
Soft loan	549						-75	-75	-75	-75	-75	-75	-75	-75	-75	-75					
Bank loan	1,006			-193	-193	-193	-193	-193	-193	-193	-193	-193	-193	-193	-193						
Change in cash	0	225	223	28	28	27	-48	-49	-49	-52	-52	-54	-57	-60	-63	112	185	185	185	185	185
Cumulative cash balance	0	225	447	476	504	531	482	434	384	332	281	226	170	110	47	159	344	529	714	899	1,084
Financing activities (w/o soft loan)																					
Equity	274																				
Bank loan	1,554			-287	-287	-287	-287	-287	-287	-287	-287	-287	-287	-287	-287						
Change in cash	0	225	223	-65	-65	-66	-67	-67	-68	-70	-71	-73	-75	-78	-82	186	185	185	185	185	185
Cumulative cash balance	0	225	447	383	317	251	184	117	48	-22	-92	-165	-241	-319	-401	-214	-29	156	341	526	711

Financing requirement

	Amount (USD 000)	Annual repayment	Share	Interest	Grace period	Repay period
Equity	274		15.0%			
Soft loan	549	-74.53	30.0%	6.0%	5	10
Local loan	1006	-193.49	55.0%	16.0%	2	12

Corporate tax rate	
yr1-4	0.0%
yr5-13	12.5%
yr14-	25.0%

It is assumed that the project owner(s) cannot provide more than USD 274,000 in equity. This means that the remainder of the finance needed (USD 1.55 million) is assumed to come from debt financing (85%) in addition to the equity (15%). The remaining 70% would come from debt financing. However, in our particular example, having conventional loans (say, at 16% interest rates) would give a negative cumulative cash balance as the cost of loan repayment start weighing in.

It is assumed that the commercial loans are lowered and that some soft loan (at lower interest rates 6%) bridges the gap between the equity available and the commercial loans. In our particular example, with a soft loan of 30% (and consequently the share if the commercial loan in the financing package lowered to 55%), the cumulative cash balance is markedly improved, i.e. gives positive values at any given year, So, this can be one extra argument for applying for such a soft loan, e.g. to climate funds or development banks.

Upscaling

For many commercial (and also institutional lenders), the size of the investment (USD 2 million) would be considered quite small. If 10 ten times the size, these might become interested and this implies bundling various possible hydropower and solar PV mini-grid proposals in *one* programme. The table below gives an example of such a bundling of individual mini-grid projects, some are hydropower (village distribution and grid connection) and solar (village distribution only). In this particular example, the cost of the 40 projects would be about USD 48.5 million. The package can be financed by equity (community, project developer, investor), grants (e.g. government through is Electrification Fund, donors, charities), soft loans (development banks, such as African Development Banks), climate funds (e.g., the Green Climate Fund can provide equity and loans) and commercial loans (banks, investment funds). An example of such a financing scheme is given in the table below.

Financing of a programme of 40 mini-grids

(cost in USD)	Hydropower Village grid & main grid	Hydropower Village grid only	Solar grids Village grid only	Total
Number of mini-grids	15	10	15	40
Grant	1,861,875	1,299,375	11,939,813	15,101,063
Equity	4,113,844	361,969	534,966	5,010,778
Soft loan	8,227,688	361,969	534,966	9,124,622
Commercial	15,084,094	1,689,188	2,496,506	19,269,788
TOTAL	29,287,500	3,712,510	15,506,265	48,506,290
Connected households	11250	15000	22500	48750

Finance sources, example		USD
Grants		
- Climate fund	10%	4,850,629
- Government		5,399,805
- Other	10%	4,850,629
Soft loan (dev.bank)		9,124,622
Commercial		9,634,894
- Climate fund	25%	4,817,447
- Banks	25%	4,817,447
Investors/partners/local		5,010,778
TOTAL		48,506,250

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