PRE-FEASIBILITY STUDY FOR PV ELECTRFICATION OF OFF-GRID RURAL COMMUNITIES

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Abstract **- A pre-feasibility study has been undertaken for the electrification of the rural off-grid village of Hurhudedanda, Nepal. PV solar was deemed most suitable after an assessment of local wind, micro-hydro, solar and biogas potential. To determine the most cost-effective PV configuration, different scenarios were simulated using RETscreen™. Decentralized Solar Home Systems (SHS) resulted in lower life cycle costs than centralized PV generation (1.25 $/kWh and 1.46 $/kWh respectively) and might be the best alternative for a first stage of electrification. A final study has been undertaken to assess the proposed system's ability to deal with a forecasted load increase.**

Keywords – Photovoltaic system, Rural electrification, Life cycle cost (LCC), Hurhudedanda, Nepal, RETscreen™

1. Introduction

Electricity is a critical input for the overall development of a country and one of the main infrastructure requirements for agricultural, industrial and socio-economic development in rural and remote areas. An estimated 2 billion people still lack access to electricity [1, 2]. While some of the rural energy users will be served by grid connections during the coming years, many will remain unconnected because of the high costs of grid extension in remote areas. In many cases, off-grid electrification can provide an economically attractive alternative for many low-demand users. It also provides new business opportunities for small scale rural energy service companies, thereby creating additional job opportunities [3].

Off-grid electrification can be achieved through different technologies (e.g., diesel-, biogas-, wind-, PV-, micro-hydro generators or hybrid combinations of these) and supplied through two different distribution options: village mini-grids or stand-alone systems.

Off-grid rural households typically spend a monthly energy budget of $3 to $15 in the form of candles, kerosene, battery charging and disposable batteries [4]. These expenditures often exceed the complete life-cycle cost (LCC) of an electricity generating system. However, due to an existing first-cost (capital cost) barrier, procurement of such a system is not possible without financial aid.

Because of the high risks involved (such rural communities lack any credit history) and low expected returns, the private-sector is often reluctant to invest in rural electrification projects. Credit is therefore more commonly extended by microfinance organizations or local development institutions [3]. Once the initial cost barrier has been overcome, a fee-for-service scheme is usually implemented where households are charged a fixed monthly fee, roughly equivalent to their conventional energy purchases.

Past experiences show that a large number of off-grid electrification projects fail because focus is generally given to technical installation without paying sufficient attention to the long-term sustainability of the project [5]. Every complete electrification process should therefore include the creation and training of an energy-service company to sustain the project.

A case study was undertaken for the electrification of Hurhudedanda village, located in Nepal. Hurhudedanda has a total of 46 households, 1 school, 1 medical clinic and 333 inhabitants,

Currently the village has a small electricity generating facility that is used only for emergency situations. However, it pursues the goal of electrifying the entire village, for which it receives the support of the NGO 'Practical Action'.

This paper describes the pre-feasibility study that has been undertaken for the electrification of Hurhudedanda via PV-modules.

2. Method

The following steps were taken to accomplish the objectives of this work:

- Assessing potential of local renewable energy sources
- Assessing the energy demand of the area of study
- Calculating current cost of energy in $/kWh
- Choosing energy-efficient appliances to minimize load
- Modeling 3 different scenarios in RETscreen^{TM} to compare Solar Home Systems (SHS), PV powered mini-grid and diesel gen-set powered mini-grid on total life cycle costs
- Checking the financial viability of each model, i.e. costs should not exceed current expenditures for energy (e.g., kerosene and batteries)
- Assessing potential for future growth of proposed system through forecasting of load increase
- Analyzing and discussing the results

Input information for the model was obtained from a site visit and from a survey conducted by the local NGO 'Practical Action Nepal'.

3. Renewable energy resource assessment

Our assessment of the potential of solar PV, wind power, micro-hydro and biogas has led us to the decision of focusing solely on solar PV. The main arguments for each technology are below.

Hurhudedanda has geographic coordinates 27°46'16.74"N, 84° 7'17.46"E. Average insolation of this location as given by the NASA climatologic database ranges from a minimum of 3.98 kWh/m^2/day in December to a maximum of 6.48 kWh/m^2/day in May with an annual average of 5.13 kWh/m^2/day [6]. This is considered good for the development of solar technologies. The fact that the village is located in a mountainous region, where the air is clean, also helps.

Subsidies for solar PV in Nepal depend on the size and remoteness of the location. For SHS over 18Wp in Hurhudedanda, as is the case in our study, subsidies amount to NPR 6,000 (~$81) per SHS [14]. No subsidies for PV mini-grids are available in the current policy.

Average annual wind speed measured at 10 m is ~4.27 m/s, which is greater than the 4 m/s rule of thumb to consider the technology viable [7]. However the village location in a mountainous region may result in a high variability in wind speed, no subsidies are currently given in Nepal and spare parts are not widely available.

Micro-hydropower (MHP) is a very promising technology in the hilly parts of Nepal. Nepal's total hydro capacity is estimated around 8300MW, almost 300 times of what is actually generated [9]. There is a small river near the community. However, since the flow rate during the dry season is close to zero, this source cannot be relied upon for electricity generation throughout the year.

The village has a fair amount of animals (over 200 heads of cattle, 200 goats and 370 poultry birds). A very rough estimation indicates that these would allow the production of about 8000 m^3 of methane-rich biogas per month to be used for electricity generation or reduce up to 70% of total fuel wood consumption (18 000 kg/month). However, cattle in Hurhudedanda is scattered and there is currently no animal manure collection.

The government sponsors this technology by the provision of $133 as subsidy for each biogas plant. Today there are more than 40 authorized biogas plant companies in Nepal [8]. Biogas could in the future be a potential replacement of the particulate matter emitting firewood.

4. Local energy demand and current cost of energy

Current sources of energy in the community are very limited. The primary uses are:

Cooking and boiling water: for which fuel wood is used. Certain problems are associated with the combustion of firewood, such as indoor air quality issues and deforestation. Efficient cooking stoves have been distributed by various national and international NGOs to avoid these problems. Many of the families in Hurhudedanda now have these types of improved stoves. Yearly expenditures for cooking purpose are reported to be $10,824 ($235 per household).

Lighting: for which kerosene lamps and battery-powered torches are used. These do not provide appropriate conditions for children's' homework or other activities requiring proper illumination, hence many activities are limited to daylight hours. Yearly expenditures in lighting (i.e., savings if replaced by solar generated electricity) are reported to be $5,004, or $109 per household.

Practical Action has already installed a small hybrid generation system consisting of PV panels (43Wp x 5) and wind mills (150W x 5), but this power is only dedicated to a battery charging station for urgent energy needs.

For the purpose of our study, only the load related to lighting and basic electric appliances shall be considered.

Kerosene lamps will be replaced by efficient 13W fluorescent bulbs and electricity has to be supplied for the currently owned electrical appliances, leading to the load as given in Table 1. The total energy consumption adds up to 186 kWh/month and its cost considering current expenditures results in 2.24 $/kWh.

5. Energy system design

The sizing of the system in the proposed scenario was done for a peak load of 2.40kW, calculated as a conservative 80% of the total available load of 3kW (Table 1). This can be configured as SHS, PV powered mini-grid or diesel gen-set powered mini-grid, now all briefly discussed. In each of the following cases, components were chosen based on local availability.

5.1. SHS

PV panels: SHS typically range from 10Wp to 100Wp [3]. Average installed capacity required per HH is 2.40kW/48 = 50Wp. An SHS of 60Wp (Sharp ND-T060M1) was therefore chosen to make up for the different losses in the system. The simulation was run with 48 installed SHS, adding up to a total capacity of 2.88kW. Slope of panels was set at 28° to maximize the annual average electricity delivered.

Battery bank: Vented lead-acid batteries are known to be the most suitable option for PV applications [10] and allow a depth of discharge of about 60%. Sizing was done based on the number of consecutive NO-SUN days for this location, which range from 2 to 6 depending on the month [6], days of autonomy for the battery bank was set at 3 as a good compromise between service and cost. The choice for our present scenario was of 12V/70Ah VRLA batteries (Unikor VT1270ES).

Charge controller: For this size of SHS a controller of 10A capacity has been chosen (GRE 10).

No inverter is required since in the current scenario all load is in DC.

Total estimated costs are given in Table 2.

5.2. PV mini-grid

In a centralized PV system, since there is no need to size systems to individual household consumption, there is more freedom in the sizing of components. Hence, PV panels, battery banks and auxiliary equipment have been chosen using greater sizes to obtain better efficiencies and lower costs per Wp.

Utilization of the BEST Solar 175Wp and 12V/160Ah battery VT12160EB was proposed.

Additional costs have been considered for the construction of a 1.3km electricity network with 48 electricity meters. Detailed costs can be found in Table 3.

5.3. Diesel gen-set powered mini-grid

Fuel in Nepal is currently heavily subsidized and a high fuel escalation rate can be expected as this measure is gradually ceased. Additional costs have been considered for transportation of the fuel to Hurhudedanda reaching a total of 0.90$/L.

The initial costs are shown in table 4. A small gen-set of 3 kW and appropriate shelter were estimated to cost $3000. Gen-set and mini-grid maintenance costs were considered high due to harsh operating conditions and inexperienced users ($500/year, including periodic overhauls and travel expenses). The costs for construction of the mini-grid are the same as for PV.

6. Results

The following financial assumptions were made:

- Project life is 25 years, which corresponds to the useful life of PV panels.
- Batteries require replacement every 4 years and charge controllers every 10 years, as indicated in the supplier's guarantee.
- The rates of inflation and fuel escalation were set at 8% and 10.6% respectively. The desired discount rate was estimated at 6.5% [12].
- Grants from the government amount to $3,800 [13] for SHS and $0 for mini-grid configuration.

Financial results are summarized in Table 5. The 3 scenarios can best be compared on their life cycle cost (LCC). With a life cycle cost of $71,300 for SHS, as compared to $82,800 and $84,700 for solar and diesel gen-set mini-grid respectively, SHS clearly leads to the best financial performance.

The life cycle savings (LCS) represent the savings on kerosene and disposable batteries throughout the life-time of the system and amount to 219,600. For SHS, this leads to an IRR on assets of 31.0%, an NPV of 152,100 and a pay-back period (PBP) of 4.5 years, as can be seen in the cumulative cash flow represented in Figure 1.

For solar mini-grid, IRR on assets amount to 21.8%, with an NPV of 136,800 and a PBP of 7.6 years, as can be seen in the cumulative cash flow represented in Figure 2.

By demonstrating that the LCC of diesel gen-set is highest, diesel gen-set technology can be discarded as an option for electrification.

7. Scalability

As an additional test for PV technology in the electrification of Hurhudedanda, a future scenario was modeled according to technology penetration rates and small-scale productive activities estimated by our local contact in Nepal (see Table 6).

A new base case (year 5) was created to account for the increased energy load, which was estimated at 1,680 kWh/month (9-fold of the base case of year 0) and the annual peak load at 10kW (4-fold of year 0).

Since modern appliances require modern energy services which could not realistically be met by kerosene and disposable batteries, the proposed case was put to compete against a diesel generator with an operational cost of 0.57 $/kWh (calculated considering previous fuel escalation rates).

Given that in this scenario 82.5% of the load is AC, the mini-grid of the base case will necessarily operate in AC220V and inverters will be required.

Potential cost reduction of PV technology in the next five years was not accounted for in this model due to lack of reliable information. The effect of this was simulated in a sensitivity analysis.

Larger-scale PV panels and batteries are not readily available in Nepal. Therefore, 175Wp panels and 12V/160Ah batteries, as used for the previously described PV mini-grid, were used in the modeling.

No subsidies are given by the government for this degree of expansion.

Table 7 shows the performance indicators of this future scenario. In terms of LCC, once again PV is a better option than gen-set technology. However, the margin is narrow. The main cash outflows that put the project at stake are those of battery replacements, which are by far greater than gen-set O&M costs.

An optimistic sensitivity analysis to account for cost reductions in PV technology (-20% in initial costs) resulted in a LCC_{PV} of 0.89 $/kWh which is more competitive than diesel generation. Still, the model was found to be highly sensitive to diesel cost, where a reduction below 16% of the estimated value would render the project unviable.

8. Discussion

SHS has numerous advantages other than cost, such as reliability of service (a problem in a grid would blackout several households) and modularity (expansion or reduction based on need and economic means).

In the same way, mini-grids also have several advantages, as are the potential to 'shave peaks and dips' of consumption of individual users, thus requiring a lower generation and storage capacity, and a larger potential to increase capacity when demand increases at a lower cost than SHS.

Both PV configurations have the enormous advantage over a diesel gen-set of being better candidates for funding schemes aimed at overcoming the initial cost barrier, which is fundamental for this type of projects.

Some additional success factors for PV technology and Renewable Energy Technologies (RETs) in general, not accounted for in the models, are:

- PV technology costs are decreasing rapidly
- Larger, more efficient and longer lasting components (PV panels and battery banks) are not currently available in Nepal, but they will in the coming years, making a centralized mini-grid an attractive option for future growth.
- Since the most significant drawback of off-grid PV is the cost of battery replacement, other PV technologies such as solar water pumping (no battery storage required) could be worth considering for productive activities.
- Since most of modern appliances run on AC (75% of the load in the forecasted scenario), hybrid systems using other RETs which naturally generate AC (such as wind, hydro or biogas) may be more adequate to cope with future growth.

Finally, all calculations were done for the total energy load of the village and total current expenditures, assuming consumption and ability to pay will be the same for each household (i.e., $9/month/HH). However, we know this value actually ranges from 4 to 56 $/month/HH. This can be solved in a design stage by providing different sizes of SHS (ranging from 25Wp to 350Wp) to each HH.

9. Conclusions

The assessment of renewable sources led us to identify PV as the most promising technology for Hurhudedanda. Three types of configurations were tested for the electrification of the entire village: Decentralized SHS, Centralized PV generation and Centralized diesel fuelled gen-set. After contacting local suppliers and researching costs, RETscreen^{TM} simulations were run against the base case resulting in largely positive results for PV as replacement of their inefficient current sources of energy. In terms of LCC, SHS offered more attractive results than mini-grid distribution.

This study helps prove that renewable technologies, in particular PV, can be competitive for rural electrification against conventional fuels. It also shows that decentralized systems may be the best choice when the load is low (such as the case of lighting and simple appliances). However, if a quick load increase is to be expected in the coming years, a mini-grid is more appropriate.

The proposed methodology is simple and applicable to other regions with different renewable resources. Also, RETscreen^{TM} proved to be a very user friendly and complete decision support tool, what makes it very suitable for this kind of analysis.

10. Recommendations for future research

This project did not aspire to introduce new technologies or ESCO business structures, but was meant to apply existing simulation techniques (RETscreen^{TM}), RETs and business ideas to aid Hurhudedanda in achieving their goal of complete electrification. We believe to have supplied them with the right information to get projects started. However, further recommendations can be made on what steps to take in the near future and which fields we believe need further study to allow for continuous improvement.

First of all, we believe the project should be continuously monitored as the electrical load in the village is expected to increase as the village develops. A new study to deal with an increased load will be required in some years.

If the forecasts on the procurement of agro-processing equipment are correct, SHS will no longer be sufficient and centralized generation via mini-grid together with other complementary RETs should be considered.

Finally, if Hurhudedanda finds a way of collecting animal manure in the future, we see great potential in the biogas industry, which could possibly replace their current fire wood consumption. This can greatly reduce the health impact that is currently involved with the burning of firewood.

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Tables and figures

Table 1. Total monthly energy consumption in Hurhudedanda

Appliance	Power consumed (W/unit)	Amount (units)	Load (W)	Usage (h/day)	Consumption (kWh/month)
TL Lamp	13	192	2496	2	150
Radios	15	27	405	2	24
TV	100	1	100	4	12
Total			3001		186

Table 2. Costs of SHS for Hurhudedanda

Component	Quantity	Unit price ($)	Total price ($)	Life time (years)
PV-module (Sharp poly-Si ND-T060M1)	2.88 kWp	3 913	11 269	25
VRLA Batteries (12V/70Ah)	48	103	4 944	4
Charge regulator 10A	48	10	480	12
Support structure + installation materials	48	90	4 320	25
Transportation, installation & commissioning	48	50	2 400	-
Permits and approvals	48	24	1 142	-
VAT (1%)	-	-	210	-
Contingencies (5%)	-	-	1 238	-
Total Initial Cost			**26 004**	
O&M cost /year (estimated as 1% of capital expenditure)			260	

Table 3. Relevant costs of a PV powered mini-grid for Hurhudedanda

Component	Quantity	Unit price ($)	Total price ($)	Life time (years)
PV-module (BEST Solar 175W)	2.80 kWp	3 733	10 452	25
VRLA Batteries (12V/160Ah)	19	244	4 636	4
Charge regulator	1	500	500	12
Support structure + installation materials	-	-	3400	25
Mini-grid (low voltage)	1320m	6	7 920	25
Meters for mini-grid connection	48	100	4 800	25
Transportation, installation & commissioning	-	-	2380	-
Engineering & Development (Permits & approvals	-	-	400	-
VAT (1%)	-	-	317	-
Contingencies (5%)	-	-	1 740	-
Total Initial Cost			**36 546**	
O&M cost /year (estimated as 1% of capital expenditure)			365	

Table 4. Relevant costs of a gen-set powered mini-grid for Hurhudedanda

Component	Quantity	Unit price ($)	Total price ($)	Life time (years)
Diesel Gen-set (+ back up)	2	3 000	6 000	5
Mini-grid (low voltage)	1320m	6	7 920	25
Meters for mini-grid connection	48	100	4 800	25
Transportation, installation & commissioning	-	-	500	-
VAT (1%)	-	-	187	-
Contingencies (5%)	-	-	970	-
Total Initial Cost			**20 378**	
O&M cost /year			500	

Table 5. Financial data of 3 proposed technologies

Indicator	SHS	PV mini-grid	Diesel gen-set mini-grid
Life Cycle Savings (LCS)	$ 219 600 (3.87 $/kWh)	$ 219 600 (3.87 $/kWh)	$ 219 600 (3.87 $/kWh)
Life Cycle Cost (LCC)	$ 71 300 (1.25 $/kWh)	$ 82 800 (1.46 $/kWh)	$ 82 700 (1.46 $/kWh)
IRR on assets	31.0%	21.8%	30.5%
Net Present Value (NPV)	$ 152 100	$ 136 800	$ 136 800
Simple payback time (years)	4.5 years	7.6 years	5.1 years

Table 6. Penetration rates of technology in the following 5 years

Equipment	Penetration Rate (% referred to number of HH)
Television	+20% each year
Refrigerator	+5% per year
Computer	+5% per year
Agro processing mill	~5 kW, operated 4 h/day
Workshop	~2 kW, operated 3 h/day

Table 7. Financial performance for PV system dealing with forecasted load

PV Solar	
IRR on assets	9.3%
Net Present Value (NPV)	$ 54 900
LCS = LCC_{GENSET}	$ 553 200 (1.08 $/kWh)
LCC	$ 486 800 (0.95 $/kWh)
Equity payback (years)	14.4 years

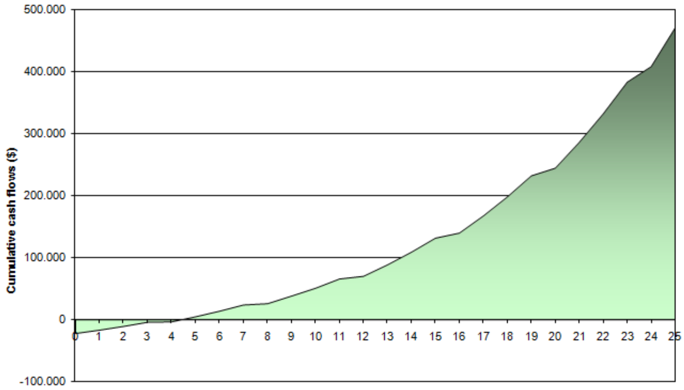

Figure 1. Cumulative cash flow of SHS system

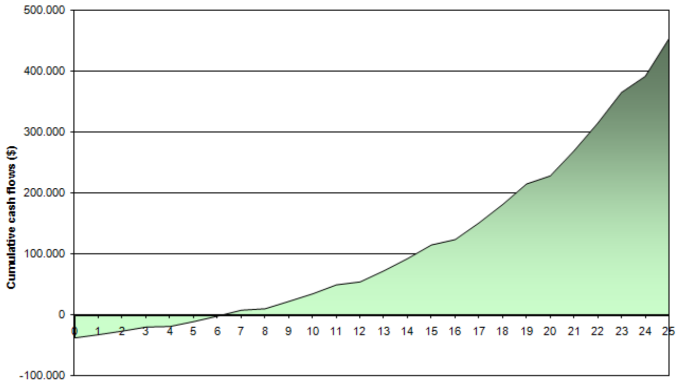

Figure 2. Cumulative cash flow of PV mini-grid