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Energy for Sustainable Development

Mini-grid and Hybrid Systems

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Content

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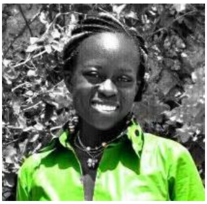

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Annika Groth studied Economics at the Freie Universität in Berlin and the Universidad Francisco de Vitoria in Madrid. She worked as a Research Fellow for the Prognos AG, the European Centre for Economic Research and Strategy Consulting in Basel and for Chile Ambiente, an environmental organization in Santiago de Chile. She also gained professional experience working with BITKOM, the German Federal Association for Information Technology, Telecommunications and New Media, GIZ, the Deutsche Gesellschaft für Internationale Zusammenarbeit, and DIW Berlin, the German Institute for Economic Research. Her main areas of research interests are renewable energy sources, economic development and public sector economics. She is currently enrolled in the PhD programme in Energy and Environmental Management for Developing Countries.

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Foreword

The present *Yearbook of Master Theses* from the two sister programmes Energy and Environmental Management at Europa-Universität Flensburg and Postgraduate Programme of Renewable Energy at the Carl von Ossietzky-University Oldenburg is the third in a publication series, which addresses issues of sustainable energy systems from a development-oriented, interdisciplinary approach originating in the technical sciences.

The cover page shows three parallel electricity infrastructures co-existing in a village in Bangladesh: solar home systems on individual homes; mini-grids operated with diesel-generators; as well as the national centralized grid. We chose this picture because it is a stark image for the development of electricity grids in many places of the global South, where a dichotomy exists between two different approaches in rural electrification: On one side the often inefficient, insufficient and interruptible central grid structures, and the other the emerging decentralized solutions based on renewable energy. The latter promise a faster, more flexible and less resource demanding answer to the problem how to deliver sustainable energy for the about 1.3 billion people on this planet without electricity access. But in between the national grid and the individual solar home systems there is another layer: mini-grids and hybrid systems, which play an increasing role in giving electricity access to rural communities. But more than often the installation of a mini-grid is a one-time intervention rather than a continuous process, and on an international scale, mini-grids have not been able to live up to the many expectations. Therefore, technical solutions, organizations and an economic model are needed, which reflect the great flexibility of mini-grids, which both can grow faster than centralized systems, and can be based entirely on renewable energy sources, while also offering economic and social sustainability.

The 2014 yearbook shows a selection of papers, which partly are based on recent Master theses of the EEM and PPRE programmes, but also some current contributions from the EEM group of PhD students. Among the presently 11 PhD students, several have chosen mini-grids as their subject of study, where technology, economy and organization of mini-grid and hybrid systems are being scrutinized.

Alexander Komakech-Akena, an EEM alumnus from 2012, presents a “techno-economic analysis of grid extension against stand-alone generation systems in Sezibwa, Uganda”. Rural electrification can be based on stand-alone or home systems; mini-grids; or the extension of the national, central grid. When having to decide about the technology to apply, effectiveness and economic cost are thought to be drivers for decision-making. The present paper sets of comparing the three alternatives against the background of the Ugandan power system. Then, it is elaborated if the country is ready for the development of decentralized energy systems; what the plans are for rural electrification; and whether government has the institutional capacity to implement such plans. For the village of Waswa as case study has been prepared, where resources and loads are described, and the willingness as well as the ability to pay for either type of system are being analysed. A stand-alone and a mini-grid are being designed for the village and the economy of either is being discussed. For the future decentralization of power supply in Uganda, the paper contributed with a proposed roadmap for the implementation of decentralized energy systems.

Jorge Núñez, an EEM graduate from 2013, contributes to this yearbook with an analysis of the regulatory framework of the energy sector of Honduras. Here, the share of renewables is to grow to 80% by 2038, which is a major challenge, particularly because the country is also experiencing substantial economic growth at present times. This calls for new policies in the field. After describing the power system of the country, the present institutional framework is presented and existing policies are described. Then, five options are presented: feed-in tariffs, net metering, programmes to promote distributed generation, standards for the grid-connection of such generation plants, and finally, and most interestingly for the subject of this yearbook, mini grids for areas too remote to be connected to the central grid. In order to assess the impact of each of these measures, the electrical energy system of Honduras is modelled using the Long-range Energy Alternatives Planning System (LEAP) software. The results point to economic advantages of distributed generation from renewable energy sources if these are significantly increased.

Michelle Paula Akute graduated from EEM in 2014 and describes aspects of her Master thesis in a paper on the potential of bagasse for cogeneration and for power supply enhancement in West Kenya. Here, insufficient power generation leads to poor and unreliable supply of electricity, while sugarcane processing plants have both the bagasse waste product as an alternative fuel, as well as the combined heat and power plants that could be retrofitted and expanded for power export to the region. By means of a case study of Mumias Sugar Company, an assessment of the existing cogeneration plant was made. An analysis of circumstances that favour or inhibit the development of cogeneration was carried out. Finally, different scenarios for power production from bagasse were analysed, from crop to end use. The results show that the present cogeneration plant is rather advanced compared to its competitors, possibly because of being financed through a Clean Development Mechanism (CDM) scheme. From four scenarios analysed in the paper it can be observed that investment in a high yielding cane variety and the expansion of the factories to crush more cane would result in better return of investment in the cogeneration unit. The study recommends that government, farmers and the sugar cane milling industry increase co-operation in order make use of the potential for power generation from sugarcane bagasse. In this respect, the paper demonstrates a good example for the need for institutional co-operation to improve the inclusion of alternative fuels by means of hybrid generation.

Dishant Saurin Parikh, a 2014 graduate from the PPRE programme, designs stand-alone and grid connected hybrid power systems, which are based on standardisation and solar energy, for rural as well as and urban applications in Uttar Pradesh and West Bengal, India. In his paper, the necessary steps are described to design sizes of photovoltaic (PV) power-based micro-grid systems. After a site analysis and a load profile analysis of existing systems, the technical and non-technical challenges in designing such systems are assessed and solutions to overcome the problems are applied. Interestingly, the results of the paper suggest that standalone solar home systems have advantages over utility power in grid-connected residential areas, where the stand-alone systems are observed to supplement erratic utility power. Furthermore, the proposed micro-grid systems are advantageous in areas without connection to the national grid. If the central grid is to be expanded into these areas, the author points out, existing micro-grid infrastructure may be built upon.

Ranju Pandey, a 2010 graduate of the EEM programme, contributes to this yearbook with a technical and socio-economic assessment of a community-based mini-grid system in the Baglung District, Nepal. Here, several micro-hydropower (MHP) systems exist, which experience imbalances between demand and supply. The present paper looks at the feasibility of interconnection of seven of such MHP systems, in order to exchange surplus generation and allow for expansion of the system in terms of geographical coverage as well as demand. Technical aspects of the interconnection of mini-grids are discussed, and a management model is being proposed, upon which the paper concludes with a financial analysis. It is found by means of hourly data analysis that surplus generation and excess demand to not correlate within MHP systems, and that an interconnection indeed may increase reliability as well as the overall utilization of the existing power plants. This may be very beneficial to foster economic growth, as small-scale industries may be the first benefitting from increased and more reliable supply. However, such investment will need capital from outside the rural areas.

Sebastian Groh entered the EEM PhD programme in 2014. His paper on Swarm Electrification addresses the problems of rural electrification from a system complexity view. In many instances, mini-grids may be unable to meet their commercial potential as well as the demand of users, probably because they are pre-engineered and supply-centred. Swarm Electrification is a newly developed bottom-up approach, where a swarm intelligence network is used to share information and exchange electricity. Neighbours are linked by a swarm net to form a non-pre-engineered and user-centred mini-grid. The idea is that people themselves start building a grid using the resources presently at their hands. For the case of Bangladesh, the inefficiencies of battery storage and of parallel infrastructures could be levelled out by adding system complexity through connecting many different stand-alone systems. A growing micro-grid with generation and storage, where so-called pro-sumers can buy and sell electricity to each other and possibly the national grid, is propagated to make synergies; to allow for re-programming in the event of changed loads; and achieve a more consistent and efficient local energy supply.

Patricia Kiarie is an EEM alumni from 2013 and is doing a PhD at the EEM programme on the socio-economy of grid-connected PV in Africa. Her present paper is a review of mini-grids in her home country, Kenya, where a distinction is made between the national grid and the off-grid networks, usually owned by the Rural Electrification Authority (REA). The paper addresses technology, ownership as well as implementation challenges. First, the paper looks at site-selection criteria, which range from distance to existing installations to energy demand based market surveys, which use purchase power as a main criterion, as well as socio-economic factors and security. Then the transition from diesel-based systems to ones with an increasing share of renewable energy sources such as wind and solar is being described. As regards their ownership, the origins in many such systems lie in development cooperation, but since 2006 their operation has been taken over by a governmental agency because of many cases of inefficiency, maintenance shortfalls and extension challenges. Recently the solar industry has found its way to replace diesel generators on the basis of market driven, low cost alternatives. Several institutional and organizational barriers remain for private actors to enter the scene and remain on it.

Annika Groth joined the EEM as a lecturer and PhD student in 2013. Her paper formulates the essence of her research by asking whether the institutional capacity of value-based institutions like rural electric cooperatives also may achieve a higher level of financial services such as access to micro-loans. Access to modern and reliable electricity services in rural areas, as well as financial inclusion, i.e. the participation of people in financial activities, comprise two main development goals, which will probably find their way in the post-Millennium Development Goal formulations. The field of rural electrification by means of mini-grids may be a great opportunity to address both of them, and a particular role is seen for value-based institutions such as co-operatives. But while both kinds of institutions have been studied frequently and in many locations, no assessment of the institutional capacities of e.g. Nepalese electricity cooperatives to also include financial services has been made yet. The proposed research therefore looks at answering how economic development can be spun by means of such hybrid institutions.

2014-2015 is a year of celebration at the Europa-Universität Flensburg, with the silver jubilee of the current EEM programme and its successors ARTES and SESAM. For more than 25 years the university has contributed to sustainable development by means of education and learning within the fields of energy and the environment. Wulf Boie, who has been lecturing at the programme almost since its very beginning, completes this yearbook with an account of the history of capacity building for sustainable development in Flensburg. This very strong tale of "meeting the challenges of climate change and energy poverty" – the motto of the EEM programme – guides the reader to continue her or his activities in strengthening and maintaining the links to the *alma mater* at Flensburg so that future education for sustainability in the Global South can continue to prosper.

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A techno-economic Analysis of Grid extension against Stand-Alone Generation Systems in Sezibwa, Uganda

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Abstract: Stand-alone systems, mini-grids and grid extensions are the three common technology options used for rural electrification today. Their effectiveness in escalating electrification is of particular interest to decision making for their deployment. This paper critically compares the three technologies considering different combinations and permutations and their economic feasibilities. Furthermore, the paper analyses the current status quo of the Uganda energy sector, highlighting such important aspects as readiness of the country to develop decentralised energy systems, government strategic plans towards rural electrification and the institutional capacity to implement them. A case study design is developed for a village in central Uganda called Waswa. Here the energy resource, load assessment, willingness and ability to pay, and overall economics of the resulting system are discussed and accompanied by the design of a standalone system and mini-grid. Basing on outcomes and observations, the paper concludes with a proposed path for Uganda to follow in implementing decentralisation of energy systems nationwide.

1 Background

Until 2014, electricity was only supplied to one sixth of Uganda's population. This current supply trend leaves a lot to be desired for electricity sector development. With some 28.1 million people having no access to electricity (IEA, 2011) and an energy per capita share of 80kWh, poverty is rampant, and a lot of pressure is being exerted on the natural environment for biomass feedstock as it is the readily available alternative. The status quo is further aggravated by the high electricity tariffs and prolonged delays in commissioning of the committed power plants planned. It is against this backdrop that a concerted effort was taken by Government of Uganda to promote decentralized energy programs, where locally available resources meet demand at points of generation. The program focuses on grid extension, capacity building and investment in clean electricity generation projects.

In 2011, the rural electrification program was reported to have yielded some positive results, notably a documented increase from 1% to 6% of the rural electrification rate from the year 2001 to 2006 (REA, 2006). However this success came at high investment costs as well as increased GHGs emissions in some cases, especially relating to the energy technologies employed.

This study was therefore conceived and undertaken to compare such technical and economical options as extending a Low Voltage (LV) utility grid, developing a Stand-Alone (SA) off-grid generation system or developing a SA with a mini grid network. It is a study case of a village in central Uganda called Waswa. The village is one of the many enclaves in Mabira Forest Reserve found in the Sezibwa region of Mukono district, at grid coordinates 0^o26' E and 32^o47'N. It has a population of 1,200 inhabitants with the approximately 225 households hugely dependent on agriculture as the economic activity. Even though the LV grid (33kV) is only 7 km away it remains unclear as to when it will be extended to the village. The research therefore had the aim of addressing the electricity penetration problem to the region using a bottom-up approach through the comparison of decentralized electrification technologies. Furthermore, it explores the various technological configurations that would achieve the most optimal system size at least cost.

2 Methodology

A combination of both quantitative and qualitative approaches was used to collect and analyse data. First, an assessment and review of existing literature such as project reports, academic papers, conference and workshop proceedings, design handbooks, and policies on electrification both locally and internationally was undertaken. The literature review phase was a desk study with periodic visits to the identified stakeholders. Second, came the survey studies of the proposed site (Waswa Village in Mukono), where primary data was obtained. During these survey studies, willingness and ability to pay, social acceptance, load assessment and market prices were determined, this with the help of questionnaires and guided interviews.

Third was the design and analysis of the different technology systems. Using HOMER software for the optimization modelling, planning, sensitivity and simulation of the three selected system configurations; the technical and economic designs were analysed. HOMER is especially suitable for addressing designs of potential electricity opportunities in rural communities and to investigate the technical and financial performance of hybrids given a village load and availability of the energy resource. Finally, the overall system cost was determined using financial indicators as Net Present cost (NPC), Capital cost, and levelised cost of energy (LCOE) etc.

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2.1 Micro hydro-Solar PV system (Hybrid) with Mini-grid

The *hybrid* option takes into consideration the designing and planning of micro hydropower, PV, inverter and a battery based system for electrifying the village. In this case the energy generated by the hybrid system is distributed through a distribution mini grid to all households.

2.2 Solar Home Systems

The *SHS* option considers the installation of PV panels, battery, and charge controller and inverter units for every household and commercial structure in Waswa. It utilizes roof areas of the buildings in the village. This system option is modular and calibrated to meet specific energy demands and loads of each individual household. No distribution is required. Table 1 shows the design parameters and optimisation sizes used in selecting appropriate SHS for the various load types in Waswa.

Table 1: Design parameters for SHS in Waswa

Parameters	Low	Medium	High	School	Dispensary
Considered panel size (kW)	0.1 to 0.3	0.15 to 0.5	0.75 to 3.0	0.2 to 0.65	0.15to 0.5
Lifetime	20 years	20 years	20 years	20 years	20 years
Tilt angle	0.433	0.433	0.433	0.433	0.433
Azimuth	0.0	0.0	0.0	0.0	0.0
Ground reflectance	5%	5%	5%	5%	5%
Derating factor	80%	80%	80%	80%	80%

2.3 Grid Extension to Waswa

The grid extension option assesses the costs implication of extending the LV 33kV transmission grid to the township of Waswa from within 7 km. Furthermore it analyses a breakeven distance for which the grid is more economical.

3 Findings

3.1 Energy Resources in Waswa

Hydro Resource: River Lwankima is the main hydrological resource available in Waswa. It has a mean annual flow rate of 682.99 l/s determined theoretically using the Turc and Solomon method[1] from a catchment area of 95.7 km^2. For hydropower design purpose, a residual flow rate for "non-Nile river" tributaries in Uganda was considered as 300 l/s (UN-WATER, 2005) represented by the horizontal line in Figure 1. Hence the available flow rate of the river is calculated as 382.99 l/s. The micro hydropower scheme was therefore designed and simulated using three design-flows; 120 l/s, 100 l/s and 90 l/s at a net head (H) of 30 m. A turbine efficiency of 65% and a PVC penstock of 150 m with 0.95% losses were selected.

Solar Resource: Country estimate of solar power in Uganda is based on the Renewable Energy Policy. The document may underestimate actual potential, given that only 1% of the suitable land area is considered available for solar. The mean solar radiation average of Uganda is 5.1 $kWh/m^2/day$ measured on a

[1] Turc analysed 254 drainage basins all over the world to provide a generalised calculation method and investigated the pragmatic use of rainfall and temperature to determine the annual evapotranspiration. The obtained flow duration curve may be considered as a reference, to be crosschecked with flow measurements. The computation of more sophisticated models (such as the TANK Model, catchment area ratio model etc.) is highly recommended.

horizontal surface (MEMD, Energy Policy, 2002). In Waswa, at the geographic grid coordinates 0o26' E, and 32o47'N, the recorded average daily insolation was 5.32 kWh/m^2/d. This meteorological data was retrieved from the NASA data accessed by HOMER and it was also used for PV system designs. Figure 1 and Figure 2 show solar resource in Waswa village and hydropower flow of Lwankima.

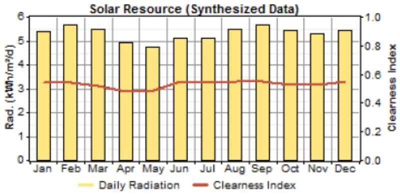

Figure 1: Solar Isolation in Waswa

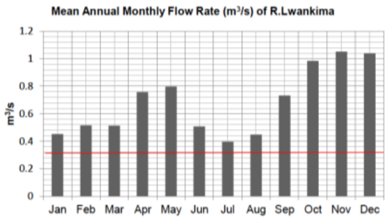

Figure 2: Monthly Flow of Lwankima

3.2 Energy Use and Load at Waswa

According to the survey findings, firewood is the predominant source of cooking energy. About 90% of the households use kerosene lanterns for lighting purposes. 69% use these kerosene lanterns on average of 5 hours per night. Furthermore, the survey results show that higher income households utilize 6V and 12V batteries (small battery-backup systems) and small solar PV lamps. Generators are being used to power the tourist camp around the Griffins falls.

The residents of this area especially appreciate the value of solar PV. At least 80% of the respondents felt that solar PV would contribute greatly to an improved lifestyle. Especially since energy services such as lighting, phone charging and radio (communication) were much desired the community at large. The high income rural households utilized batteries for watching television and listening to radio. Moreover, it was frequently observed that batteries connected to small inverters were being used for phone charging, which was also noted as an added source of income to the village. Electrification of the village by means an off grid system or grid extension would thus significantly improve quality of life, health and education for the dweller of Waswa.

Two load categories namely; domestic and commercial exist in Waswa. They were further divided according to facility of use namely; dispensary and school for commercial, and low, middle and high income households for domestic category. Table 1 and Table 2 show the occurring appliances and average time use of common appliances found in Waswa. The total coincidental daily load and installed power of appliances for each domestic category was calculated and used to project high, base and low growth in five years. For purposes of generating hourly data inputs for HOMER, a 24 hour consumptions of the load groups were reproduced. Table 3 shows the results of all summarised loads in Waswa.

Table 2: Author compiled from UEDCL and REA

Appliances	**Power Rating (W)**	**Use factor**	**Number of Appliances occurring in Rural households**		
			High	**Medium**	**Low**
Light bulb	20	0.9	6	4	2
Fridge	125	0.12	1	1	0
Flat iron	1000	0.17	1	0	0
Radio	50	0.60	1	1	1
Television	70	0.60	1	1	0
Fan	40	0.10	1	1	0
Phone charger	20	0.10	2	1	0
Hot plate	1200	0.20	1	0	0
Kettle	1200	0.20	1	0	0

Table 3: Hours of use

Appliance	Rural (High)		Rural (Middle)		Rural (Low)	
	Const.	Unconst.	Const.	Unconst.	Const.	Unconst.
Fan	6	15	5	15	0	0
Flat iron	0.5	0.8	0	0	0	0
Refrigerator	10	14	6	14	0	0
Hotplate	2	3.5	0	0	0	0
Lighting	4	8	2	6	3	6
Radio	4.9	7	3	6	2	6
TV	1.6	5	2	4	0	0

Table 4: Summary of loads in Waswa

Load category	Annual Energy	Numbers
Overall village (all commercial and domestic)	124825kWh/year	226
Dispensary	555kWh/year	1
School	686kWh/year	1
High income	1124kWh/year	23
Middle income	540kWh/year	66
Low income	284kWh/year	135

3.3 Willingness to Pay, Ability to Pay

Of the 117 households and 3 commercial enterprises surveyed in Waswa, 89.2% showed interest in obtaining SHSs. The survey grades show that, while higher income groups are willing to pay for grid electricity or large solar home system, lower income households are willing to pay for small solar home system. Basing on the outcome of the survey exercise, households generally demonstrated interest in having electricity. The lower income households however demonstrated an outstanding exception for electrification. All respondents in this category showed willingness to connect to a SHS system if a monthly billing is will be possible. Given, the economic activities such as agriculture, tourism and the fishing industry, Waswa village is comparatively wealthier than the average village in Mukono villages. Meaning sustainability of a monthly billing system can be justified.

3.4 Legal framework and Policy

A review of key documents in Uganda's energy sector, comparing effectiveness, sustainability and efficiency of each document for decentralisation development in Uganda was conducted. In the Ministry of Energy and Mineral development *Renewable Energy Policy (2007),* sustainability was analysed. The result of the reviewed policy revealed the semblance of a strong will towards a decentralised energy system for rural and/or remote communities. Moreover, existing legal frameworks establish strong enforcement mechanisms and plans. The *RESP 2001-2011* that is revised periodically after 10 years presents a work plan and schedule for investment into rural electrification with an emphasis on renewable energy systems.

3.5 Mini Grid

Figure 3 shows the layout of the proposed 415V three-phase delta mini-grid designed for Waswa. The mini grid network covers a total of 5.54 km with 124 creosote wooden poles placed a distance of 30m apart. Design and selection of the mini-grid specifications was based on electrical power calculations and principles such as line configuration, voltage drop and power loss. Using handbooks and design guides in practice in Uganda, allowable voltage drop of 15 to 17% was considered (Umeme, 2012). The key in the figure illustrates the different load types (households) with the respective power.

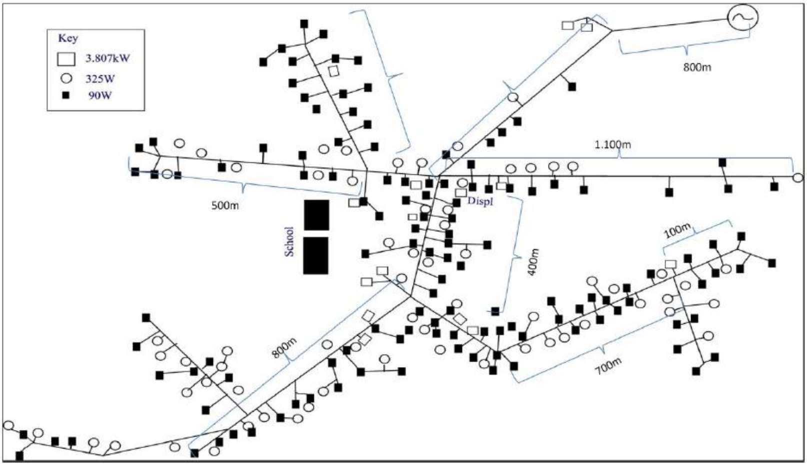

Figure 3: Mini Grid design for Waswa

Losses in the mini-grid network were found to be 16.46%, 4.0%, 0.56% and 5.03% in the main, second, third and fourth sections respectively. The main section had the highest loss because of its length and many interconnecting loads that generates a current build-up of 120.42 A at the last node. In that case, an AAC with cross-sectional area of 53.51 mm^2 was selected. The conductor has a current rating of 248 A (Product catalogue, 2012) that fits the design condition for the main section. AAC is the cheapest conductor category and is usually recommended for mini-grids (Inversin, 2000). Since the voltage drops in the other sections are relatively lower, an AAC with 21.15 mm^2 was found appropriate and economical for those sections as found in Table 6. Table 5 summarizes the designed mini grid components.

Table 5: Summary of Mini Grid components

Description of Material	Numbers
Creosote Wooden Poles	126
Conductor (AAC 25mm^2)	4 times 2,280m
Conductor (AAC 53mm^2)	4 times 1,440m
LT Hook N-95 & LT Insulator N-95	375 each
Galvanized wire	10
Flat Armour Aluminium	10
Aluminium Tie Wire	10

3.6 Grid extension

In the third part, an option of extending the 33 kV MV grid by 7 km to Waswa village was explored. This was guided by a rationale that grid power is typically the most cost effective electrification method if available, although at times the cost of extending a distribution grid to rural facilities can be prohibitively expensive. Simulation and analysis of the investment cost involved were based on actual project cost used by Umeme. Investment per meter for a 33 kV is US$ 30,000/km with US$ 450/km on Operation and Maintenance. Electricity tariff is then charged at the same domestic tariff of the distribution company.

The breakeven distance for constructing and extending the national grid to Waswa was found to be 3.67 km. The result was derived from an optimisation performed in HOMER. Breakeven distance is that distance for which grid extension cost is equal to the net present cost of the stand-alone system. For 7 km of the national grid the results showed that it is not economically viable to extend the grid to a small community like Waswa.

3.7 Economics of Systems

Hybrid with Mini grid: the hybrid option in Waswa meets the energy demand of the village at the lowest investment cost and tariff rate compared to the SHS and grid extension options. From the optimisation results in HOMER, setting up this system will require an initial investment of US$153,482.2. The resultant levelized cost of energy (LCOE) is US$ 0.11/kWh. It is appropriate for the village in the short run assuming population and demand do not increase beyond projected values. Otherwise, the hydro resource would be inadequate to supply Waswa and a solar PV park would also need to be added. This would mean an increase in cost of generation to meet the village demand.

Thus when investment cost crosses above US$ 210,000, then grid option becomes the best option. Figure 4 shows optimisation results of hybrid systems. As seen, a system constituting hydro, inverter and battery was found to be most economical. The cost of a mini grid is US$ 33,906.2; this figure was added to US$ 126,776.

Grid Extension: to extend the 33 kV line to Waswa an investment of US$ 210,000 is required for the LV distribution line. It is assumed that electricity would be provided to the villagers of Waswa at the same domestic tariff of Umeme which is US$ 0.21/kWh.

Solar Home Systems: the advantage of SHS over the two systems is the resource availability and elimination of a distribution network. Hence, it reduces the costs of installation when compared to the micro hydro and grid extension. For Waswa, if the SHS option is to be considered, it would be the most expensive of the three options. It would require a total initial investment of US$860,766. The aggregated cost of electricity for the different SHS installed on roofs in Waswa is 2 to 7 times more costly than that of a utility grid and hybrid with mini grid. Table 6 shows the number of components required in the different SHS configurations in Waswa.

Table 6: Summary of SHS units in Waswa

Optimised system size	Low	Medium	High	School	Dispensary
PV collector	0.25	0.5	1.0	0.55	0.5
Inverter/rectifier	0.2	0.2	0.75	0.3	0.2
Battery number	2	2	4	4	4

4 Factors challenging rural electrification and Decentralization

4.1 Hydropower generation sensitivity to rainfall variations

Reliance on a large hydrological power generation resources has its pros and cons. Because Uganda’s hydropower generation is highly dependent on the amount of water-flow in the rivers, seasonal changes in the amount of rainfall directly affect the power generated. In many cases, this causes load shedding and in certain instances has caused complete power cuts. Electricity production in Uganda is therefore highly vulnerable to climate variability.

4.2 Social capital

The benefits of energy services risk being sabotaged if there is no equitable share and sense of belonging among households. Due to an uneven income distribution in rural households, commercial losses in a distribution network of electricity is high, since many poor households will resort to power theft. On the other hand, because of strict monitoring and strong penalties imposed by the distribution utility company, those who cannot draw benefits from the installed system will vandalize it. Transmission and distribution losses in Uganda are as high as 28% (ERA, Sector Update, 2011).

4.3 Institutional support

A great deal of success in electrification programs arises from government support and commitment. A strong political will and good governance is needed to plan, strategize and implement decentralised energy systems. These will include, but are not limited to, good structures of energy project management, funding and capacity building or training.

4.4 High Investment Costs for the Large-Hydro Power Plants

Uganda is looking to build more large hydro power plants to further boost its power generation capacity. Much as this is a welcome development, the investment costs required to develop these power plants are massive, so much that the country cannot fund them. The alternative is international financing which attracts interest and hence a high cost per unit of electricity produced not to mention the extended time required for commissioning of these power plants.

4.5 Low income per capita and Electricity access challenges

The cost of extending the transmission grid remains prohibitively expensive. Even where the grid has been extend to some parts of the country, owing to low levels of economic activity and hence low incomes, the intended beneficiaries might not afford to pay for the electricity.

5 Conclusions

Overall, preliminary findings of the study revealed that decentralized energy systems are the safest approaches for electrifying rural and remote communities. Developing such systems is more cost effective compared to grid extension programs, regardless of how near the grid exist. Grid extension varies in cost depending on the utility, the terrain, the distance to be covered, and the size of the load to be served. If the local grid is fairly reliable and within a few kilometres, obtaining an estimate for the capital cost of grid extension and the recurring cost of electricity will give points of comparison when considering other options.

The policy review revealed that Uganda is equipped with appropriate and adequate policy instruments to keep energy development on a sustainable path. However, there remain uncertainties in the strategies as to how to accelerate decentralised system deployment. And given the reliance of the country on biomass, the management of this resource will determine whether or not the country stays on course for sustainable energy development.

For the case study village, a hybrid system composed of hydro and battery bank with a mini-grid was found to be most suitable. This system is capable of delivering 218,770 kWh of annual energy to cover the demand estimate of 124,825kWh. Implementation of a hybrid option in Waswa requires an initial capital investment cost of US$ 153,482.2 with calculated net present cost of US$ 347,644.2. The cost of electricity derived from the hybrid and mini grid case is US$ 0.11/kWh. This tariff value is 50% cheaper compared to current tariffs offered by UMEME (the utility company).

Grid extension was observed to require a total capital investment cost of US$ 210,000 with a NPC of US$ 275,000. Electricity would then be sold at the nominal domestic tariff of US$ 0.21/kWh. The third option considered installation of solar home unit on the roof area of Waswa village. It was observed to be the most expensive and technically and economically not suitable for electrifying Waswa. The total investment required to set up SHS for the 225 households is US$ 860,916 with net present cost of US$ 1,184,766. The systems are modular and design to meet house loads only. On average the cost of electricity from a SHS installed is US$ 0.62/kWh. This is however specific to the household energy demand.

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Assessment of Distributed Generation Based on Renewable Energy Sources in Honduras

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Abstract: The present study aims to analyse the regulatory framework of the Honduran energy sector and evaluate the energy policies that could support distributed generation based on renewable energy sources in the country.

The growth of the Honduran economy over the past years indicates that a similar increase in energy demand is also likely. Hence, the electricity generation needs to fulfill the growing electricity demand. The government is pursuing an increase of the renewable generation share in the national energy mix to 80% by 2038. Currently, the share of renewable energy amounts to 44% inclusive of generation from large hydropower plants. If only plants smaller than 50 MW were considered, the share of renewable energy drops to 11.4%. The objectives of the Honduran Government could be reached if new options for policies were implemented. This research is structured in order to firstly describe the electricity context of the country. Next, the current regulatory framework and energy policies are identified. In this regard the study examines the main energy related policies of the country in order to identify the possible new options that can be carried out. It then provides five options that benefit distributed generation based on renewable energy sources. These five options are feed-in Tariffs, net metering/billing, distributed generation programmes, technical standards for the interconnection of distributed generation and mini grids. Finally, the country's electrical system is modeled to assess the impact of these policies.

1 Introduction

The economic situation of Honduras has been steadily increasing over the last years reaching values of up to 6.6% of GDP growth in 2007 (World Bank 2013). Economic growth is a driver of higher demand of electricity which necessitates building more power infrastructure in order to meet that demand.

The electricity sector in Honduras is dominated by the state-owned utility company National Electric Utility (Empresa Nacional de Energía Eléctrica, ENEE). This enterprise is the owner of the transmission lines, distribution system, end-customer sales, and a third of the generation capacity. The remaining power generation is owned by private companies but ENEE is the main purchaser of the electricity (World Bank 2010, 26; ENEE 2013, 3).

Honduras has a high economic vulnerability due to its reliance on thermal generation and the high and volatile prices of non-renewable fuel sources (Berríos 2009, 69). Thus, a renewable energy target of 80% in the energy mix by 2038 has been set since the share of renewable energy as of the year 2012 is only 44% (SEPLAN 2009, 135; ENEE 2013, 5). The national energy policy aims mainly at the development of renewable energy from large hydropower and biomass plants (Cálix 2010, 35). Consequently, a regulatory framework might be needed in order to promote small scale renewable energy generation projects. Distributed generation might help to reach national renewable energy targets while also helping to deal with the economic issues regarding electricity generation from fossil fuels. Distributed generation based on renewable energy sources has been steadily emerging in the international context. There are many examples worldwide such as in Germany, Spain, and United States of America based on the implementation of effective policies. In the Latin American region there are examples in countries such as Brazil and Costa Rica (ARECA 2011, 53-54).

2 Methodology

Firstly, the electricity sector of Honduras is assessed to identify the existing challenges requiring further consideration in the assessment of distributed generation based on renewable energy sources. Secondly, the current policy and regulatory framework is given as a background consideration in the proposal of policy options. Thirdly, some regulations and policy options are provided in terms of their suitability in the national context. Fourthly, the electrical system of Honduras is simulated, taking into consideration the possible influence of current and prospective energy policies on the future generation mix when intended as a means of increasing the renewable energy share. Finally, the impact of the policies is assessed in economic terms (see Figure 1).

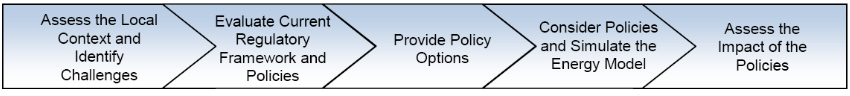

Figure 1: Research Methodology

Source: (Author 2013)

Doukas, et al. (2008, 364-365) express that there is a strong relation between energy policy and energy planning. Energy policy is mainly influenced by political decisions while energy planning uses the objectives, priorities and basic parameters provided by the energy policies. Then the results of energy planning inform the possible impacts of the energy policies. Consequently, policy making arises as an effect of the expected scenarios and the possible solutions. The interaction between energy policy and energy planning constitutes the foundation of the simulation of the electrical system of Honduras in this research.

2.1 Research Approach

A descriptive research is used to describe the existing energy situation of Honduras. It identifies and presents information on the characteristics of distributed generation based on renewable energy sources in the national context. The regulatory framework, energy sector policies and related issues are analysed. A literature review is carried out as well as an assessment of the international policies relevant to renewable energy technologies regarding distributed generation. A qualitative research is done through the use of semi-structured interviews. Quantitative data is then used to simulate the energy model of the power system of Honduras.

2.2 Research Scope

The intention of this research is to present the energy situation, regulatory and institutional framework, policy analysis, and opportunities of distributed generation deployment from renewable energy sources in Honduras. The analysis is conducted in the context of Honduras but compared internationally.

Through this research is analysed the current benefits for small power plants. They usually work with distributed generation on the demand side of the grid and under the current regulatory framework some policies that might support the deployment of renewable energy are identified.

Implementation of energy policies to support renewable energy has some impacts that need to be assessed in order to provide efficient solutions. In this study the economic impact of distributed generation is assessed along with consideration of the country's renewable energy targets, the current regulatory framework and the implementation of new policies. The tool "Long-range Energy Alternatives Planning System (LEAP)" is used to simulate the power system and to obtain long term results from different generation scenarios.

3 Description of the Electricity Sector of Honduras

3.1 Electricity Supply

In 2012, the installed capacity of the centralized grid of Honduras was 1,782.6 MW of which 1,005.4 MW were from fossil fuel power plants, 537.8 MW from hydropower plants, 137.5 MW from biomass power plants, and 102 MW from wind power. The electricity generation is shared by the private and public sector. Independent Power Producers manage fossil fuel power plants as well as renewable energy power plants. The fossil fuel power plants operated by the private sector, which require Power Purchase Agreements (PPAs) with the national electric utility, have an installed capacity of 880.8 MW while the public sector has 124.6 MW. The private sector accounts for 73.4 MW of total installed capacity of hydropower plants and the public sector accounts for 464.4 MW. The 137.5 MW of installed biomass power plants are totally owned by the private sector. The 102 MW wind farm is also completely owned by the private sector. The total installed capacity of power plants owned by the public sector is 589 MW while the private sector has 1,193.6 MW (ENEE 2013, 3). Figure 2 depicts the historical generation capacity added to the grid from 1995. It is seen that thermal power plants and hydropower plants have accounted for a large portion of the installed capacity. In addition, small hydropower plants and biomass power plants of 10 MW or less have been steadily added to the system for about the last ten years (ENEE, 2013, 3).

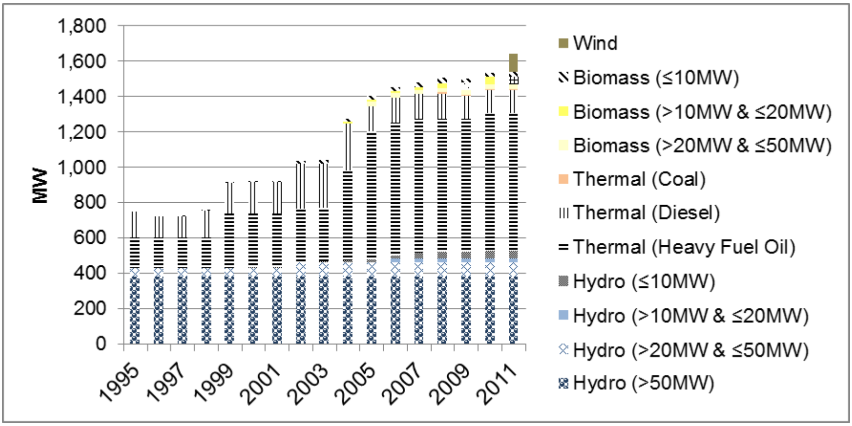

Figure 2: Historical Installed Capacity 1995 – 2011

Source: Author with data from (ENEE 2011)

The total electricity generation of Honduras was 7,565.8 GWh in 2012. The electricity generation based on renewable energy was 3,301.5 GWh while the fossil fuel electricity generation was 4,186.5 GWh. Hydroelectricity accounted for 2,786.4 GWh, biomass electricity generation for 180.3 GWh, wind electricity for 336.8 GWh, and electricity import for 75.8 GWh. The electricity supply mainly relies on hydroelectricity and fossil fuels since those sources represent 92% of the electricity generation (ENEE 2013, 5). There are some regions of Honduras with no access to the centralized grid but with isolated power systems based on diesel power plants. The Bay Islands (i.e. a group of islands in the Caribbean Sea) are of great importance due to its significant role in the tourism sector of the country. The electricity service of the Bay Islands is provided by the following companies:

- Roatan Electric Company (RECO) in Roatan Island,
- Utila Power Company (UPCO) in Utila Island, and
- Bonnaca Electric Company (BELCO) in Guanaja Island (ENEE 2012, 4).

The department of Gracias a Dios, located in the eastern region of Honduras, is one of the most remote areas of the country. It is the only department on the mainland that it is not connected to the centralized grid. Private companies provide the electricity service to the municipalities of Puerto Lempira and Brus Laguna in the department. The electricity service of Puerto Lempira is provided by Local Electric Power Company (ELESA) and Electrical Investments in La Mosquitia (Inversiones Eléctricas en la Mosquitia, INELEM). The electricity in the municipality of Brus Laguna is also serviced by INELEM. The remaining municipalities do not have access to electricity (ENEE 2012, 22).

3.2 Electricity Demand

The electricity consumption per capita of Honduras was 902 kWh in the year 2012 (ENEE 2013, 7; BCH 2013). There has been an upward trend in the electricity consumption per capita in the past years. Based on data from ENEE (2011), the total electricity demand grew between 1% and 2% in the past three years. In the year 2012, the total electricity consumption was 5,308 GWh of which the residential sector was the largest consumer with 41%. The industrial and commercial sector of the country combined for52% of the total electricity demand while the governmental, municipality and street lighting electricity consumption accounted for the remaining 7% (ENEE 2013, 7). According to ENEE (2013, 6), the peak demand of Honduras was 1,282 MW in May, 2012. Considering that the available generation capacity was 1,367.3 MW for the same period, the reserve margin was 7%.

4 Regulatory Framework Related to Renewable Energy

4.1 The Framework Law of Electricity

The Framework Law of Electricity (Ley Marco del Subsector Eléctrico, LMSE) was enacted in 1994 to regulate the generation, transmission, distribution, and commercialization of electricity in Honduras. An international standard model was followed to arrange the institutional framework of the electricity sector in the country. The main change brought about by the law was the beginning of private thermal power generation. Since then, the expansion of the generation capacity has been mainly carried out through private investment. It has been complemented by means of the development of renewable energy projects, small hydro- and bagasse-fired power plants.

4.2 The Renewable Energy Act

The Decree 70-2007 about "Promotion of Electricity Generation based on Renewable Resources," hereafter called the Renewable Energy Act, is the main law that rules the deployment of renewable energy in Honduras.

The Renewable Energy Act might be considered as a Feed-in Tariff (FiT) scheme due to its characteristics. Guaranteed access to the grid, long-term purchase agreements and levels of payment in accordance with the cost of the renewable energy technology are typically part of a successful feed-in tariff policy (Couture, et al. 2010, 6). Most of these elements are found in the Renewable Energy Act. A summary of the main benefits from the Renewable Energy Act to projects of less than 50 MW are mainly tax exemptions, financial incentives, and long term contracts. Small renewable energy power plants of less than 3 MW have the extra benefit of a streamlined process to obtain an operating license (GoH 2007, 4).

5 Prospective of a National Energy Policy to Support Renewable Energy

5.1 National Policy

In the year 2009, the Honduran Government created the "2010-2038 Country Vision and 2010 - 2022 Nation Plan" with the purpose of having a long term planning horizon that could be followed during the seven governmental administrations that are defined in the plan. With respect to the electricity sector, the strategic guideline no. 8 "Productive Infrastructure" of the plan sets the goal to increase to 80% the share of renewable energy in the national generation matrix by the year 2038 (SEPLAN 2009, 135).

The "National Competitiveness Strategy 2012–2022", which considers the "2010-2022 Nation Plan of Honduras", was created by the government as an instrument for the purpose to improving the position of Honduras in the global competitiveness index. In regards to the energy sector, the objective of the strategy is "to improve the quality and reliability of the electricity service maintaining a competitive price" (SEPLAN 2013, 42). The strategy sets to reach 60% of renewable energy in the generation mix, to reduce the electricity losses by 10%, and to increase to 95% the total electricity access by 2022.

5.2 National Energy Policy

In Honduras, the definition and formulation of energy policies is in the charge of the Energy Cabinet as stated in the Framework Law of Electricity. The document "Energy Policy and National Energy Plan 2030" was developed in 2010. This national energy policy identifies the main problems of the energy sector of Honduras with the purpose of establishing the objectives to be explored. Three out of nine identified main problems are related to the use of fossil fuel as primary energy. In addition, a high cost of electricity generation and inadequate electricity tariff structure are issues that hamper the economic development of the country. Besides, the high consumption in households in some cases and the lack of access to electricity in others are considered as hindrances to social and economic development as well. Additionally, the regulatory framework and institutional setup are intended to be addressed by the policy through the creation of a minister solely in charge of the energy sector (Cálix 2010).

5.3 Discussion of the National Policies

Firstly, the general vision of the country is to change the generation mix while setting a higher percentage of renewable energy. Secondly, the strategy to improve the competitiveness of Honduras also recognizes the need to reduce the electricity losses and to increase the electrification rate. Finally, the national energy policy mainly addresses national issues related to renewable energy, rural electrification and the institutional setup.

6 Options for the Development of Distributed Generation

6.1 Feed-in Tariffs

Feed-in Tariffs (FiTs) is the most widely used policy worldwide to promote renewable energy. By the year 2013, developing countries and emerging economies accounted for more than two-thirds of the countries that have implemented FiTs (REN21 2013, 72). The Renewable Energy Act is considered as a variation of a Feed-in Tariff.

Even though the Renewable Energy Act supports electricity generation from many renewable energy sources with incentives such as premium payments and long term contracts, these incentives are all the same for each type of source. Therefore it is suggested to consider a FiT design by technology, taking into consideration the size, in order to properly address the unique issues of each technology. Policy instruments to scale up renewable energy can be used in combination or individually. FiT and net metering policies are sometime differentiated since FiT policies refer to the purchase of electricity on the utility side of the meter whereas net metering refers to the customer side of the meter. However, some FiT models apply to the demand side as well the premium payments given to generators through net metering (UNEP 2012, 13).

6.2 Net metering or net billing

Net metering is defined by REN21 (2013, 134) as "a regulated arrangement in which utility customers who have installed their own generating systems pay only for the net electricity delivered from the utility." This means that the final payment of the customer is charged to the net difference between the electricity received from the utility and the electricity delivered. A variation of the scheme is that the payment for the electricity delivered to grid and the charges for the electricity consumed are counted separately at given prices (REN21 2013, 134). The proposed net billing scheme includes different premium payments that correspond to the respective cost of the technology as depicted in Figure 3. It can be seen that some premium payments might be over the purchase tariff of electricity while others might be over the retail tariff.

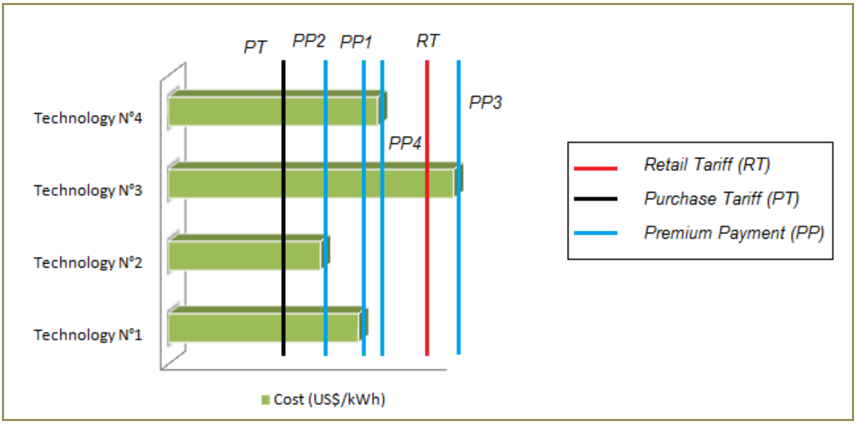

Figure 3: Net Metering/Billing Scheme

Source: (Author 2013)

Setting premium payments higher than the purchase tariffs and the retail tariffs will definitely increase the tariffs for ratepayers. Some options to control the total cost of this policy might be needed such as policy caps or bidding mechanisms.

6.3 Distributed Generation Programme

Since 2010, a distributed generation programme has been carried out in Costa Rica to promote the use of renewable energy technologies by customers connected to the grid. It is a regional programme named "Distributed Generation Pilot Plan for Self-Consumption" and it is intended to promote the installation of small scale distributed generation systems based on biomass, solar, wind, and hydroelectric sources[2]. A similar programme can be used in Honduras particularly to analyse the consequences of introducing net metering to promote distributed generation based on renewable energy sources.

While the Costa Rican programme is limited since the total cap of the policy is just 5 MW due to its regional application, a policy cap in Honduras can be higher. The programme can be implemented with extra financial incentives

[2] The regulations of the programme are available at www.grupoice.com/wps/portal/gice/elect_hub/Proyectos Energéticos/Plan piloto generación distribuida/, accessed on 02.08.2013

than the Costa Rican case for technologies with higher capital costs. Nevertheless, the introduction of FiT policies to promote the development of less cost effective technologies such as solar photovoltaic systems along with a regulation to encourage the use of net metering or net billing would increase the cost of generation of the utility. Therefore it is necessary that these policies combine total caps for entire installations with individual caps for more costly technologies in order to avoid unexpected consequences that result in higher cost of electricity for consumers. Then the combination of cap policies with FiTs and net metering may regulate the total cost of the policy.

6.4 Technical Standard for the Interconnection of Distributed Generation

The Author considers that a technical regulation is needed for the interconnection of distributed power plants on the load side to efficiently operate the electrical system, thereby smoothing the integration of small scale renewable energy power plants into the grid. This is very important as the lack of a regulation might prevent addition technologies with intermittent sources such as solar systems to get access to the grid. In Central America, a technical standard for interconnection, operation, control, and commercialization of renewable distributed generation was issued by the National Electricity Commission of Guatemala to regulate distributed generation based on renewable energy sources including customers with self- generation systems. Consequently, the author suggests the creation of a technical standard to facilitate the interconnection of renewable energy power plants into the distribution system similar to Guatemala’s regulation. This would include not only solar systems but also other renewable energy technologies such as waste to energy or wind.

6.5 Mini Grids

The Renewable Energy Act stipulates tax exemptions, financial incentives, and long term contracts for renewable energy projects connected to the centralized grid, but off grid and mini grid projects based on renewable energy are left apart from the act. There is the proposal for the implementation of mini grids in isolated regions of Honduras to promote the use of distributed generation based on renewable energy sources. The electrification rate of the country has reached a level of 86.4% in 2012 due to incentives the Honduran Government has placed on grid connected projects[3]. However, the World Bank (2010, 69) states “grid connection is not necessarily the most cost-efficient option.” Therefore, the author suggests the promotion of mini grids with renewable energy sources in order to electrify those regions where the centralized grid will never reach, at least, in the short term. A regulatory framework has to be set up to support this scheme.

Existing mini grids of the country, which are based on diesel generators, could be supported by the regulation in order to integrate renewable energy sources into their power systems. Hybrid mini grids are preferred to optimize the combination of technologies based on local resources and to guarantee that the load profiles of communities are properly met by the power system.

7 Impact of the Development of Distributed Generation

The power system of Honduras was simulated using the Long-range Energy Alternatives Planning System (LEAP) to assess the impact of the development of distributed generation in the country. LEAP is a software tool to assess energy policies and for climate change mitigation analyses (Heaps 2012). Through the simulation and further analysis the impact of the implementation of energy policies that support distributed generation was evaluated. For the purposes of this study, distributed generation refers to the electricity generation from power plants with an installed capacity of up to 15 MW. In this study distributed generation also refers to applications connected to the grid.

7.1 Modelling of the Power System

The simulation of the power system of Honduras is carried out using the year 2012 as the base year and 2038 as the end year. The projections of the power system are done considering the targets of the 2010-2038 Country Vision and 2010-2022 Nation Plan.

Description of the Scenarios

Moderate penetration of distributed generation is considered as the reference scenario. In this scenario, it is assumed that hydropower plants and

[3] Coverage of electricity service in Honduras is available at http://enee.hn/index.php/planificacionicono/184-cobertura-electrica, accessed on 05.08.2013

fossil fuel power plants are added to the system along with some biomass and wind power plants. The scenario is based on the current generating expansion plan of the system. Distributed generation from hydroelectric sources is added to the capacity of the grid as defined in this plan.

High penetration of distributed generation in which a combination of policies promotes a more diversified distributed generation from renewable energy sources rather than the added in the reference scenario. The renewable energy potential is partially developed: yearly increases until reaching 150 MW of solar by the year 2038, 111 MW of waste to energy by the same year, 31 MW of geothermal and an additional 200 MW of hydropower plants are added to the system by the year 2022. These additions are justified by the will to analyze a programme for distributed generation with policy caps.

Electricity Demand Assumptions: The electricity demand by sector in 2012 and the annual growth projection for the 2013–2038 period are shown in Table 1.

Table 1: Electricity Demand Projection

Consumer Sector	Base Year 2012 (GWh)	Annual Growth 2013 – 2038
Residential	2,155.8	6.11%
Commercial	1,326.5	5.02%
Industrial	597.8	6.08%
Large Industrial	828.4	4.74%
Others (Governmental, Municipalities and Street Lighting)	399.7	3.09%

Source: (ENEE 2013, 7)

The annual growth was calculated from the electricity demand projections of 2012 and 2027 in order to forecast the demand until 2038.[4] These projections assume that the electricity losses of 2012 decrease from 30% to 15% by the year 2027. Additionally, the projections assume that the reductions of the commercial losses, which are part of the electricity losses, are turned into energy sales.

[4] The "Demand Projection for the Years 2013 – 2027" is available at http://enee.hn/planificacion/ESC_BASE_PROY_DDA_2013_2027.pdf, accessed on 18.08.2013

Electricity Supply Assumptions: Regarding the generation side of the power system, some parameters and assumptions are considered for the simulation. The existing power generation plants in the system are introduced into the model considering data from the National Electric Utility for the year 2012. Furthermore, maximum availability and efficiency of the power plants are also assumed. The annual yield of each renewable energy potential was calculated, using data from different sources, to be used in the simulation of the power system (see Table 2).

Table 2: Annual Yield of Renewable Energy Sources

Renewable Energy Source	*Capacity (MW)*	*Annual Yield (GWh/year)*	*Source*
Hydro	5,000	21,900	ECLAC (2007, 58)
Biomass	61.46	307.32	Agüero (2009, 12)
Animal Waste[5]	71.56	532.84	Agüero (2009, 34-35)
Wood Waste	25.72	128.56	Agüero (2009, 18)
Solar[6]	8,689.95	20,616.90	Author (2013) based on SWERA (2008, 9-12)
Geothermal[7]	125	985.5	García Mansilla (2009, 12)
Wind[8]	1,334.30	3,506.54	SWERA (2008, 21)
Agriculture Waste	19.7	146.69	Agüero (2009, 26-31)
Municipal Solid Waste[9]	10.9	81.16	Agüero (2009, 41)
Bagasse[10]	163	713.94	Agüero (2009, 8)
Biogas	9.5	47.76	Agüero (2009, 13)

Source: Compiled and calculated by Author from sources as described above

[5] Agüero (2009, 34-35). Annual yield was calculated using a resource availability of 85%.

[6] The solar yield is estimated considering that 0.1% of the total solar radiation can be exploited with an efficiency of 10%. The technical solar capacity is calculated using 6.5 hours of sunshine duration per day to give a conservative perspective.

[7] García Mansilla (2009, 10) indicates that most of the geothermal power plants in the world are base load; the yield was calculated considering a resource availability of 90%.

[8] A resource availability of 30% was used to estimate the annual yield, which is less than the capacity factor of the single existing wind farm in 2012, in order to provide a conservative value.

[9] Annual yield was calculated with a resource availability of 85% considering that the municipal solid waste is produced throughout the entire year as it is mentioned by Agüero (2009, 41).

[10] Annual yield was calculated assuming 50% resource availability and considering a typical period of 6 month of waste production.

Costs: The costs for power plants are classified by LEAP as capital cost, fixed operation and maintenance cost, and variable operation and maintenance cost. The document "Analysis of the Honduran Renewable Energy Market," realized by the programme Accelerating Renewable Energy Investments in Central America (ARECA) in 2009, provides the data for most of the technologies used and expected to be used in the country. Some technology costs included in this research were derived from the cost analysis publications by the International Renewable Energy Agency (IRENA), which include cost of OECD and non-OECD countries. It is also assumed that the fuel costs change over the projections for both scenarios. Therefore, growth rates for diesel, residual fuel oil and coal were taken from the database of the Annual Energy Outlook 2013. This is a publication of the Energy Information Administration (EIA) of United States of America. See (Núñez 2013) for more details.

7.2 Findings and Analysis of the Results

Total Generation: Figure 4 shows the electricity generation for both scenarios during the period 2012 – 2038. By the year 2020, the generation from fossil fuels is drastically reduced. This trend continues until the year 2024 in the moderate scenario and until the year 2028 in the high scenario. Henceforth however the electricity generation from fossil fuels increases nearly along with the demand.

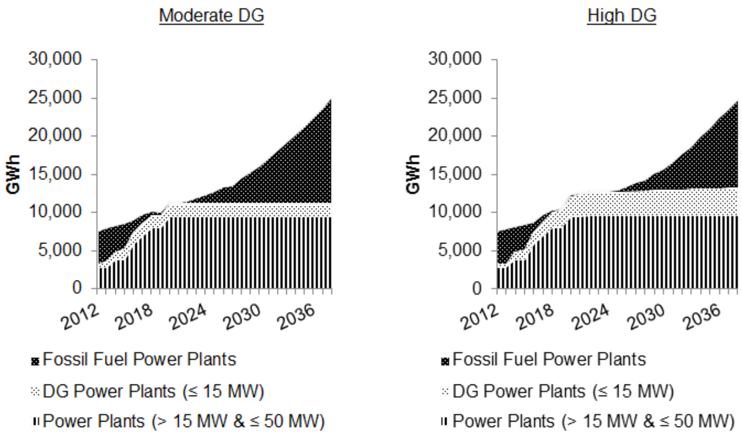

Figure 4: Electricity Generated 2012 - 2038

Source: (Author 2013)

Generation Cost: Figure 5 depicts the annual generation cost of electricity from 2012 until 2038. It is observed that the total generation cost of the high scenario is greater than the cost of the moderate scenario for the first years. However, for the last years of the period under study the total generation cost is higher in the moderate scenario.

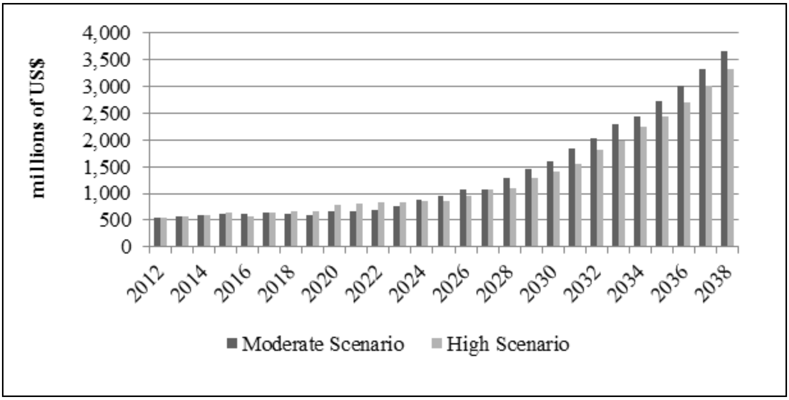

Figure 5: Historical Installed Capacity 1995 – 2011

Source: (Author 2013)

During the period from 2018 to 2023, the higher total generation cost in the high scenario compared to that of the moderate scenario might be explained as a result of an oversupply of electricity. This existing oversupply could be balanced through the Regional Electricity Market. A sample of unit costs of electricity generation in four selected years is shown in Table 3. By the year 2038, the unit cost of electricity in the high scenario is lower than in the moderate scenario.

Table 3: Unit Cost of Electricity Generation (Selected Years)

Variable	Scenario	2013	2022	2030	2038
Unit Cost of Electricity (US$/MWh)	Moderate Scenario	72.68	59.8	99.3	146.9
	High Scenario	73.13	65.2	89.6	133.9

Source: (Author 2013)

8 Conclusions and Proposed Options

It is concluded that distributed generation from renewable resources still has a large undeveloped potential. However, there are several challenges in the electricity sector that need to be overcome. The Renewable Energy Act promotes the electricity generation based on renewable resources. This law offers several incentives for renewable projects smaller than 50 MW and is considered a Feed-in Tariff scheme. Additionally, the national policies support renewable energy and access to electricity. The five options proposed in this study are a Feed-in Tariff design by technology and size, net metering/billing in combination with a Feed-in Tariff scheme, a distributed generation programme to promote small scale installations, the creation of a technical standard for the interconnection of distributed generation, and mini grids based on renewable energy for isolated regions.

The projections of electricity generation show that under the moderate penetration of distributed generation, electricity generation reaches lower values than in the high penetration by the end of the period under study. The electricity generation cost in both scenarios increases consistently during the period under study. Nevertheless, the generation costs in the moderate scenario rise above those in the high scenario by the end of the simulation. Therefore, the increasing trend of the unit cost of electricity is lower in the high scenario than in the moderate scenario. It is seen that distributed generation from renewable energy sources could be a means of stabilizing the unit cost of electricity in the long term while achieving the targets of the Government.

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Assessment of the potential of Bagasse for Cogeneration and for power supply enhancement in West Kenya

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Abstract: The West of Kenya suffers from poor and unreliable supply of electricity due to low generation. This is in spite of the existing untapped potential of power generation from bagasse, the waste product produced after crushing sugar cane. To contribute towards addressing these concerns this study investigated the feasibility of enhancing power supply from Cogeneration using Sugarcane bagasse in West Kenya with reference to a Case study of Mumias Sugar Company. Information gathering for this study was done in three parts: assessment of the operation of the existing Cogeneration plant owned by Mumias, investigating conditions that favour or inhibit the development of cogeneration, and modelling different scenarios for power produced from bagasse. The results for the three parts showed that first Mumias cogeneration plant was facing some challenges in operating its cogeneration plant. From four scenarios modelled it was observed that the best investment would be to introduce a high yielding cane variety and allow the factories to expand their capacity to be able to crush more cane. This study looked at various aspects of the sugar industry as a whole in relation to cogeneration from bagasse. It was then recommended that the Government, farmers and millers need to work together in order to realize the potential of power that exists from bagasse based cogeneration.

1 Introduction

Electricity is the third largest source of energy in Kenya contributing to about 9% of the total energy demand (IEA 2013). According to the World Bank only 18% of the total population in the country have access to electricity with the rural population being cited to have only 4% in 2009 (EIA 2014, FUAS n.d.). The country also relies heavily on hydro resources for its supply of electricity but this is susceptible to climate and weather changes. This has rendered the supply unreliable and has driven the country to depend on diesel powered plants to meet the shortage in generation of electricity. The result is an increased cost of electricity making it unaffordable. The West Kenya region has a population of about 9.8million people according to the 2009 Kenya county statistics. It has the second largest county in the country i.e. Kakamega county (KNBS 2014). The main economic activity in this region is farming with sugarcane as one of the major cash crops being grown (FAO 2001).

The West of Kenya is largely rural, about 70% of the population is located in rural areas. This means that a huge number of the people living in this region experience low standards of living and amenities like water and electricity (or continuous supply of electricity) are not available to them (IFAD, 2013). They also depend heavily on Agriculture for their income, most of them being smallholder farmers (IFAD, 2013). The region experiences a lot of power woes, characterized by blackouts and load shedding mainly due to insufficient generation. This generation is also largely reliant on hydro resources which are susceptible to climate changes. The Kenya Power Company, a utility that distributes electricity in the country, has had to buy electricity from Emergency Power Producer Aggreko; a diesel based Power Plant, to meet demand especially during drought periods. Supply of power also has to be imported from other distant regions to meet shortages in demand but this leads to poor quality of supply due to insufficient infrastructure and low voltages (Frankline 2011; Karambu 2014).

The West Kenya region has the largest sugarcane growing areas and highest number of sugar factories. Currently eleven of the country's sugar factories are located within this region. Mumias Sugar Company (MSC), located on Kakamega County, is the biggest sugar factory in the region producing about half of the country's sugar and is currently the only factory with a Cogeneration Plant (KIPPRA, 2010). These facts show that there is potential which remains untapped for producing power from co-generation and also to enable the factories to become self-sufficient in meeting their local demand for electricity. At the moment the sugar factories rely on grid fed electricity as backup power for their local electricity needs. This is however unreliable and the factories have substituted grid fed electricity with diesel generators to meet this demand for power (MoE, 2004; UNFCCC, 2013). The sugar factories have also over the years relied on the sale of only one product of sugarcane i.e. sugar and this is rendering the industry highly uncompetitive. The cost of production of sugar in the country is also quite high in comparison to the COMESA states. An example is that it costs 570USD to produce a tonne of sugar in Kenya compared to 215USD to produce the same in Malawi. This is now posing as a challenge to Kenya's membership in the COMESA Free Trade Area (FTA) States as it is obligated to allow duty free imports of such products. The Government has had to apply protectionist measures granted from the COMESA officials against these duty free imports to protect the sugar industry. The measures are however set to expire in March 2015 and the Government has set a platform to employ reforms to make the industry more competitive (J Barigaba 2014, S Mbogo 2014). Some of these include privatization of the government owned sugar factories, introduction of a new payment system to the sugarcane farmers based on the sucrose content in sugarcane rather than the weight and diversification of the product base from only sugar to bagasse based cogeneration and other biofuels like ethanol (KSI 2009).

It is for these reasons that the research study was carried out in order to address some of the issues raised above. This was done through studying the potential of power that exists from bagasse and ascertaining whether the same can be harnessed and used to increase the access to reliable electricity, firstly within the factories and then in the greater West Kenya region.

2 Research Objectives

The main objective of this study was to investigate the the feasibility of enhancing power supply from Cogeneration using Sugarcane bagasse in West Kenya with reference to a Case study of Mumias Sugar Company. This approach was however limited due to the operational constraints faced by the company at the time of the study. This study sought to address the following specific research questions:

- What are the methods used by Mumias Sugar Company to harness energy through cogeneration from Sugarcane bagasse?
- Can other sugar companies in the vicinity apply the same methods like Mumias Sugar Company to harness energy through cogeneration from Sugarcane bagasse?
- What are the challenges inhibiting the development of Cogeneration in the West Kenya region?
- What are the ways through which the factories in West Kenya can enhance power supply in this region through cogeneration?
- What are the impacts of Implementing Cogeneration in West Kenya?
- What are the policies in place for the development of cogeneration using bagasse?

3 Research Methodology

The various stakeholders involved in this study were identified and categorised as follows:

- *Key stakeholders:* included Governmental bodies i.e. Ministry of Energy (MOE) and Ministry of Agriculture (MOA)
- *Primary stakeholders:* they included the farmers and the millers
- *Secondary stakeholders:* included the Kenya Sugar Board (KSB), Kenya Sugar Research Foundation (KESREF), Kenya Sugar Manufacturers Association (KESMA) and Kenya Sugar Growers Association (KESGA). The Secondary stakeholders provided services to the primary stakeholders.

Information was obtained from these stakeholders and analysed through a series of steps as discussed below:

Field Visits: Primary data was first obtained through a number of visits made to various organizations and with the different stakeholders. Several interviews were then conducted with the stakeholders mentioned above accompanied with different field tours where field notes and observational methods of data collection were employed. Information was also gathered from email correspondences and informal conversations. Relevant documents from these institutions were also collected.

Literature Review: Secondary data was then obtained from various sources which included previous studies, journals, articles, books and reports relevant to this study. Other literature was also obtained from various sources on the Internet.

Data Analysis: The data collected was both qualitative and quantitative. The quantitative data was analysed using Microsoft excel. The qualitative aspect was first sorted and the useful information for this study extracted. This information was then categorized into the themes identified from the data using coding and memoing operations. Propositions were then developed based on the themes, after which several conclusions were drawn. This was done using the Miles and Huberman Framework for data analysis (Keith F Punch, 1998).

4 Results and Analysis

The qualitative and quantitative data was presented and analysed in a variety of layouts and scenarios using various tools. The linkages between the two types of data were noted where necessary.

4.1 Qualitative Data

The collected data was divided and analysed according to the following categories; from the sugarcane farmers, from the millers and the policies supporting cogeneration in the country.

Farmers: The objective for the interviews conducted with the farmers was to get an idea of the existing practices and conditions in Cane farming, to know the attitudes of the farmers in certain aspects affecting the Sugar Industry and to know the challenges faced by the farmers. Some of the different tools used to analyse the results are discussed below.

Goal Grid tool: A goal grid tool was used to analyse the attitudes of the sugarcane farmers to the introduction of a new cane payment system based on sucrose content rather than weight of the cane. This is shown in Table 1.

Table 1: Use of Goal Grid tool for analysis

Do we Want it? / Do we Have it?	Yes	No
No	Practices poor crop Husbandry and is not open to the New Cane Payment System **ELIMINATE**	Practices Good Crop Husbandry and is not Open to the New Cane Payment System **AVOID**
Yes	Practices poor crop Husbandry but is open to change to adopt the New Cane Payment System **PRESERVE**	Practices Good Crop Husbandry and is open to adopt New Cane Payment System **ACHIEVE**

Source: Author, 2014 based on (F Nickols & R Ledgerwood, 2005)

It was observed that there exist both negative and positive attitudes towards this new payment system. It also shows that the farmers engage in poor farming practices which may be affecting the yield of cane from this region. The objective is to work towards achieving the necessary steps to implementing this new system while simultaneously encouraging good crop husbandry that would eventually lead to an increase in the yield of cane. As such, the farmers would be more receptive through being made aware of the benefits of good crop husbandry in providing high returns based on the new system of payment.

Check Point/PEST Analysis: A Check Point combined with a PEST (Political, Economic, Social and Technological) Analysis was made based on the challenges in cane farming as identified by the farmers. The Check Point through a check list was used to identify the most prevalent challenges placing them in their various PEST categories. A Cause Effect Analysis was then performed to identify the reasons for these challenges which were also grouped into PEST categories. The total values for the causes were each multiplied by a weighted value equal to the number of times the particular reason was mentioned and the results fed into a Pareto chart as shown in Figure 1.

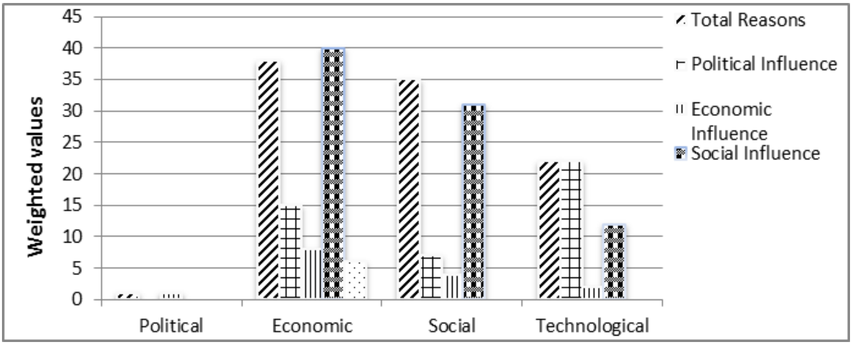

Figure 1: Pareto Chart Analysis for farmers' challenges

Source: Author, 2014

It was seen from the chart that most of the challenges are economic in nature with a high rate of social influence. An example of this given by the farmers is the persistent late and poor payments by the millers. This was attributed to factories lacking funds due to losses made on sugar sales as a result of cheap and illegal sugar entering into the country, which is a social factor. Another example is that most of the farmers are contracted by the factories to plant the cane and hence face high interest charges on the services rendered to them by the factories. This is because most of these farmers cannot afford to plant cane on their own due to poverty.

Millers: There are currently 11 sugar factories that exist in the West Kenya region. Out of the eleven sugar factories interviews were carried out in 6 of them for the purposes of this research. The interviews sought to ascertain how the factories are using the their Bagasse, whether they have any excess Bagasse and what existing challenges they are facing that would prevent them from using the excess Bagasse for power production either to meet their local demand or for commercial purposes. Some of the results are displayed below.

L matrix: A comparison was made of the type of technology that each factory interviewed uses for producing energy from Bagasse to the existing technology used in the Cogeneration plant in Mumias. This was done using an L matrix as shown in table 2 below.

Table 2: Comparison between Mumias cogeneration technology and other factories' cogeneration technology

	Boiler Parameters	Efficiency of Boiler	Type of Turbine	Efficiency of Turbine
Mumias	87Bar 170TPH with Economiser	80%	Condensing Extraction	90%
Nzoia	54TPH		Back pressure	
West Kenya	Pressurized Boiler with Economiser, 45kg/m^2 70TPH		Back pressure	92.8%
Butali	N/A	N/A	N/A	N/A
Muhoroni	Suspension burning & Heap burning with economiser 21Bar, 40TPH	80	Back Pressure	75%
Chemelil	Stoker Boiler with economiser 20TPH, 21 bar	80%	Back Pressure	60%

Source: Author, 2014

It was observed that Mumias cogeneration plant uses better technology in terms of a high pressure boiler and condensing extraction type of turbine. This facilitates electricity production in the Cogeneration plant. The other factories use low pressure boilers with the Back Pressure type of turbine meaning most of the steam is being used for process applications within the factory and not to produce electricity. There is therefore a need for the other factories to upgrade their technology to at least match the one in Mumias.

In relation to the above it was noted that Mumias sugar factory was able to acquire funding for its cogeneration plant through a loan from a funding organisation known as Proparco and as well from the sale of credit points to the Japan Carbon Finance through the Clean Development Mechanism (CDM) initiative by the United Nations (UN). The plant is a registered CDM project with the UN (UNFCCC, 2013; Senelwa, 2009). The sale of electricity generated from Mumias was negotiated through a Power Purchase Agreement (PPA) between Mumias and Kenya Power Company based on a capacity charge system of payment. This allows Kenya Power to fine Mumias if the availability of electricity goes below a certain fixed percentage for a period of time. The length of the contract in this case is also not fixed and in the case of Mumias a period of 10years was negotiated. The other factories in the region can employ similar methods in terms of funding for a cogeneration plant, however in terms of sale of electricity the Feed in Tariff system of payment is better and will be discussed in later this paper.

Check Point/PEST Analysis: A similar process as in the case of the farmers' challenges was used to analyse the challenges of cogeneration using bagasse identified by the millers interviewed. The check list provided a means to identify the most common challenges from the interviews so as to feed the data obtained onto a Pareto Chart. This is shown in Figure 2.

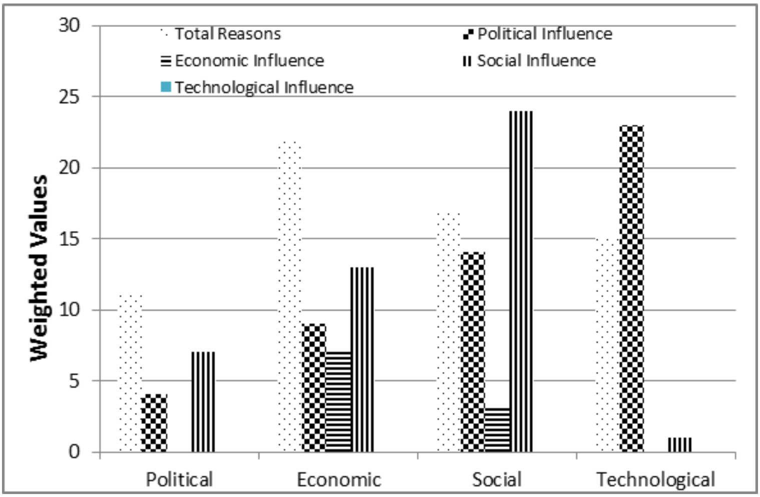

Figure 2: Pareto Chart Analysis for millers' challenges

Source: Author, 2014

It was observed that most of the challenges identified were also economic in nature with a high rate of social influence. An example of this is the millers lack funds to venture into cogeneration. This was also as a result of the cheap and illegal sugar entering the country. It then causes the sugar factories to have a huge number of unsold bags of sugar in their stores leading to poor and late payments and in some cases inability of the millers to buy cane from the farmers entirely (S Apollo, 2014). This causes a lack of raw material for consistent bagasse production. With the farmers not being paid well, they are now engaging in illegal cane poaching activities that cause factories to lose their cane investments to other factories in the region. This is a loss both in terms of finances as well as raw material.

Policies: There are several policies that exist both in the Sugar and Energy sub sector in support of bagasse based cogeneration. These are outlined as follows:

Kenya Sugar Industry (KSI) Strategic Plan 2010-2014: under the value addition and product diversification strategy the KSI strategic plan supports bagasse based cogeneration for sale of electricity to the grid. It also outlines the potential revenue the various factories can generate from sale of electricity produced from bagasse. The plan encourages the use of joint venture agreements and carbon credits sales to finance the cogeneration projects (KSI 2009).

Sessional Paper no. 4 on Energy, 2004/ Draft National Energy Policy: encourages the Government to engage in Public and Private Partnerships (PPP) for the accelerated development of cogeneration projects. It also promotes the introduction of fiscal incentives that reduce start-up costs for such projects, research and development of cogeneration technologies and initiation of capacity building programs and awareness of the same (MoE 2014, MoE 2004).

Energy Act no. 12 of 2006/Fourth draft of the Energy Bill 2013: encourages the Ministry of Energy and Renewable Energy Authority to promote the development of cogeneration technologies and the sale of electricity produced to the grid (MoE 2006, GoK 2013).

Least cost power development plan (LCPDP) 2013-2033: incorporates an 18MW cogeneration power plant i.e. Kwale International Sugar Company as part of the power plan for the country. It also encourages the Ministry of Energy to conduct studies for the potential of cogeneration from bagasse and other biomass waste to accelerate the transition from traditional wood fuel to a more modernized use of biomass for energy (GoK, 2013).

Feed in Tariff (FiT) policy: identifies bagasse as a type of biomass renewable technology. This attracts a tariff of USD 0.10/kwh of electrical energy produced which is higher than the current tariff of USD 0.06/kwh paid to Mumias Cogen plant under the negotiated PPA between the sugar factory and Kenya Power. The length of the PPA also under the FiT policy is stated to be 20years (MoE, 2012).

The above policies have laid out very ambitious plans for the development of cogeneration technologies from bagasse. There is however a lapse in some of the plans. An example of this is that the maximum capacity of a Biomass plant that can attract a FiT is 40MW. However the national energy policy encourages the realisation of 200MW cogeneration capacity from bagasse by 2017, 800MW by 2022 and 1200MW by 2030. The FiT policy does not state whether there are plans to increase the maximum capacity for these plans to be realized. It was also noted that the LCPDP only includes an 18MW power plant for the whole 20year period from 2013 which raises the question of how the Government intends to incorporate these huge capacities mentioned in the energy policy. More in depth information is thus required.

4.2 Quantitative data

The data collected in this case was mainly on the performance of the sugar industry in terms of sugarcane grown by the farmers and sugar produced by the factories. This was received from the Kenya Sugar Board Year Sugar book of 2012. The data was then used to model four different case studies for electricity produced from bagasse. In each case study two options were modelled. The first option was the generation alone i.e. for the factories to produce electricity and feed it entirely to the grid. The second option was both to generate and to distribute i.e. for the factories to produce electricity partly to feed it to the grid and distribute the rest to the area within the vicinity of the factories. The second option was modelled despite the country policies at the time of this study of not allowing for duplication of electricity networks[11]. It was observed that all the factories that were included in this research have an existing electrical network that served both the factories and the areas surrounding them.

The electricity produced was analysed within each of the three sugar belts that existed at the time of the study with one factory from each belt being selected as the point of production and sale of electricity (F K Ingara, 2013). The scenarios are discussed below.

Business as Usual Scenario: In this case study a business as usual scenario was modelled whereby the data on the amount of bagasse being produced by the factories till the year 2012 was used to project bagasse values for the years

[11] From interviews with Energy Regulatory Commission (ERC) Engineers

2014 and 2030. This was then used to calculate the potential amount of electricity produced from bagasse within each of the three sugar belts in the country.

In this scenario the amount of bagasse projected as produced within each belt will require a few factories to undergo an expansion of their crushing capacity. It was also noted that if the factories continue with this trend cane losses will be realized. This is because the amount of bagasse projected will require an amount of sugarcane that is below the current amount of sugarcane produced, calculated from the current yield in tonnes/ha and area under cane in ha.

Scenario 1: The case study was modelled based on the factories' rated crushing capacity i.e. the amount of sugarcane a factory can crush in a day or an hour at the time of the study. This meant that the amount of sugarcane crushed and hence amount of bagasse produced was equated to the factories' rated crushing capacity. In the scenario a similar situation was noted where the total amount of cane equal to the factories' crushing capacity was still below the amount of cane harvested from the fields at the current yield and area under cane. This also meant that cane losses will be realized.

Scenario 2: In this case study the scenario was modelled based on an introduction of a new cane variety with a higher yield. In this case it was noted that all the factories in each of the belt will have to undergo an expansion of their crushing capacities to cater for the extra amount of cane being harvested. The factories in the 3 belts could go through the expansion in two ways i.e. either for one factory within each of the sugar belts to undergo the expansion or for all the factories to undergo the expansion. It was observed that it would be better for one factory to undergo the expansion rather than all of the factories to do the same. This makes a better economic investment as is further discussed in the economic analysis.

Scenario 3: In the case study the scenario modelled was based on the projection of an increase in the area under cane for 2014 and 2030. The values were projected from the current area under cane (ha) and yield (tonnes/ha) from the 2012 Year Sugar book. A similar situation as was observed in scenario 2 was seen, whereby it will be required that some of the factories go through an expansion of their crushing capacities to accommodate the increase in sugarcane production. Similarly two alternatives were given in this scenario for the expansion and it was still noted that it is better for one factory in each belt to undergo the expansion.

Economic Analysis

A financial analysis was done for each of the scenarios to find out their economic viability. The FiT of USD 0.10/kwh of electrical energy produced was used for all the scenarios as the selling price of electricity despite the limit of 40MW for Biomass power plants. A separate analysis for the scenarios was made with a lower tariff discussed in the sensitivity analysis. The results are discussed below.

BAU and Scenario 1: In both scenarios positive Net Present Values (NPV) were observed as seen in Table 3 and Table 4. It was however noted that it is a better investment to go for the generation alone i.e. option 2 for the two scenarios in all the sugar belts. This is because of the higher NPV in this option. It was also seen that scenario 2 made a better investment than scenario 1 due to the same reason. This means it is better for factories to crush cane at their rated crushing capacities than to continue with the current trend of bagasse production.

Table 3: Table showing Economic analysis of BAU scenario for 2014 and 2030

Factory	NPV Option 1 (2014)	NPV Option 2 (2014)	NPV Option 1 (2030)	NPV Option 2 (2030)
Mumias Sugar	63,090,035.41	69,474,709.32	32,003,989.64	38,524,304.80
Chemelil Sugar	19,880,331.87	25,393,525.03	3,210,953.17	7,570,031.12
Sony Sugar	10,730,677.61	16,703,938.93	-337,613.82	11,011,762.57

Source: Author, 2014

Table 4: Table showing Economic analysis of Scenario 1

Factory	NPV Option 1	Payback period (Option 1)	NPV Option 2	Payback period (Option 2)
Mumias Sugar	80,574,223.33	12	89,875,433.68	12
Chemelil Sugar	44,409,986.76	13	50,643,929.70	13
Sony Sugar	47,264,135.53	12	51,970,910.53	11

Source: Author, 2014

Scenario 2 and 3: In these two scenarios it was again observed that it was a much better investment to generate alone (i.e. option 2) as was seen in the BAU and scenario 1 case studies. It was also noted that it was a better investment for one factory within each belt to expand their crushing capacities than for all the factories to do the same as was already mentioned. The two observations are seen from Table 5 and Table 6 where higher NPV values are noted in each case. It can also be concluded that scenario 2 is a better investment than scenario 1 from the higher NPV values, meaning it is better to introduce a higher yielding cane variety than to increase the area under cane. The financial analysis for Scenario 3 was also done for 2030 but the same observations were made for the two options of generating electricity and the two alternatives for the factories' expansion. It is safe therefore to make similar conclusions.

Table 5: Table showing Economic analysis of Scenario 2

Factory	NPV Option 1 (Alternative 1)	NPV Option 1 (Alternative 2)	NPV Option 2 (Alternative 1)	NPV Option 2 (Alternative 2)
Mumias Sugar	680,388,071.49	426,282,344.07	692,584,097.19	438,588,174.18
Chemelil Sugar	175,759,070.58	140,584,551.27	182,186,000.07	146,962,107.77
Sony Sugar	156,330,893.14	126,391,082.89	162,749,773.94	132,816,863.69

Source: Author, 2014

Table 6: Table showing Economic analysis of Scenario 3 for 2014

Factory	NPV Option 1 (Alternative 1)	NPV Option 1 (Alternative 2)	NPV Option 2 (Alternative 1)	NPV Option 2 (Alternative 2)
Mumias Sugar	209,967,025.37	131,995,495.69	216,530,266.83	138,558,737.15
Chemelil Sugar	67,828,985.74	59,679,770.73	69,444,154.85	66,175,939.84
Sony Sugar	42,323,668.66	49,827,990.62	59,698,776.38	56,316,111.05

Source: Author, 2014

When the four scenarios were compared it was seen that the BAU and scenario 1 had the minimum investment costs. The two however would involve cane losses and thus were the least in terms of maximum power production. It was therefore concluded that for the best results it would be better to go for scenario 2 and 3 regardless of the higher investment cost. In the end the best investment for maximum results would be scenario 2 as it yields maximum results and does not compete with the area for food production as compared to scenario 3.

Sensitivity Analysis: A sensitivity analysis was done using a lower tariff for the sale of electricity. The tariff used was USD 0.06/kwh of electrical energy generated which is the current tariff paid to Mumias Cogen plant by Kenya Power Company (Mugambi 2009). The analysis showed that none of the scenarios modelled will become economically viable. This is because at this tariff the NPV values generated for all the scenarios were negative. This shows that to make such an investment for a cogeneration plant a higher tariff has to be employed. There is thus need for Kenya Power to revise their tariffs or for the Government to incorporate higher capacities for Biomass plants in the FiT policy.

Cost to the Farmer: The costs incurred by the farmers were evaluated for scenarios 2 and 3. This is because in both scenarios the cane delivered to the factories increases. An economic analysis of costs to the farmer for both scenarios revealed that it is much better for the farmer to plant a high yielding variety of cane than increase the area under cane with the current cane variety. This means the yield obtained for cane planted has a higher influence over the returns compared to increasing the area under cane. The results of the economic analysis also showed that the current variety of cane being planted in this region has a low yield and is also late maturing. The farmers are not adopting the higher yielding, better cane varieties, which are early maturing, as most of the time the factories delay in harvesting. This has the effect of lowering the tonnage in the sugarcane which subsequently lowers the returns to the farmer (FAO, 2013). Scenario 2 is also a better option for the farmer as it does not compete with land for growing food as compared to scenario 1 where land for cane increases.

Impacts of cogeneration in West Kenya: The following are some of the impacts of bagasse based cogeneration in the West Kenya region.

Increase in power generation: as was already discussed, the West Kenya region suffers from insufficient generation of power. If implemented power generation can be boosted using bagasse in this region. Past reports from Kenya Power show evidence of load shedding in West Kenya due to unavailable generation from Mumias Cogen plant. There are also reports of the

Kenya Power company having to turn to fossil fuel based generation to cater for the low generation in this region. The fossil fuel makes the cost of power expensive in the long run as the country has to import it and therefore does not determine the market price for the fuel (Frankline 2011, Karambu 2014). These two aspects can be avoided if cogeneration using bagasse is explored.

Reduction in transmission losses: due to the low generation, the West Kenya region has to depend on power from other parts of the country. The electricity however has to be transmitted over long distances and suffers huge transmission losses. This then causes the end users to experience poor system voltages. The Kenya Power Company has laid out plans to introduce Reactive Power Compensation to improve the voltages along these lines. The cost of investing in these plans may seem to be one off when compared to paying annually for a bagasse based Cogen plant. However, as the demand for electricity increases the compensation has to be refurbished to meet the new demand meaning it will be done on a continuous basis. It is thus better in the long run to invest in cogeneration as it will avoid having to import power from other regions, as now the generation can be produced and consumed locally within this region.

Self-sufficiency in electricity by sugar factories: the factories are able to be self-sufficient in meeting their local demands for electricity. This is seen from the modelling of all the scenarios which factored in the local power demand for the factories with the excess being distributed or fed to the grid. It was noted from Kenya Power records that the factories are spending a lot of money on electricity and this can be reduced by implementing cogeneration plants from bagasse. The sugar millers will however need to upgrade their current old energy systems in the factories to more efficient ones for this to be realized.

Carbon emission reduction: bagasse is considered a carbon neutral fuel. This means that the electricity from bagasse can be used to calculate carbon savings from which the grid fed electricity will be displaced (IEA 2013, UNFCCC 2013). In this case however the amount of carbon savings calculated, using the International Energy Agency (IEA) figures, is much less in reality as other carbon intensive activities that use fossil fuels have not been considered e.g. cane production, cane milling, transport of bagasse and expansion of the factories (Govt of State of Sao Paulo, 2004)

The use of bagasse for electricity production also reduces the production of methane, considered a greenhouse gas (GHG), which is produced from the excess bagasse that is dumped by the factories and left to rot. This paper however assumes that the amount of methane produced in this case is equal to the amount produced in the burning action of bagasse to produce electricity. It is however not the case in reality.

Employment opportunities: the implementation of cogeneration plants opens up employment opportunities in two ways. One is through the setting up of the cogeneration plants themselves as people will be needed to run the plants. The second is through the expansion of factories' capacities as more people will be needed to run the factories.

5 Conclusion and Recommendations

5.1 Conclusions

The West of Kenya has great potential for the use of bagasse in electricity production. The sugar factories, most of which are located in this region have over the years depended solely on the production of sugar. The idea to now venture into cogeneration from bagasse is not only beneficial in terms of higher returns and self-sufficiency in terms of electricity production to the factories, but also in making the sugar industry competitive as a whole. This is due to eventual lapse of the COMESA safeguards that has protected the industry over the years. The promotion of electricity production from bagasse will also go a long way in curbing the problem of unreliable electricity in this region. This comes from the issue of low generation and transmission losses where the electricity is imported from other regions in the country to meet the shortfall in demand. The study tried to answer the research questions in the following way:

What are the methods used by Mumias Sugar Company to harness energy through cogeneration from Sugarcane bagasse?

Apart from Mumias Sugar upgrading their technical parameters for the cogeneration plant, they were able to finance the plant through a loan from the Proparco organisation. Furthermore the factory was able to finance the plant through sale of carbon credits through the CDM initiative (UNFCC, 2013). The company also has a PPA based on a capacity charge system of payment with the Kenya Power company. This has caused them to face losses whenever they have not been able to supply power due to the challenges in the sugar industry.

Can other sugar companies in the vicinity apply the same methods like Mumias Sugar Company to harness energy through cogeneration from Sugarcane bagasse?

Other factories in this region can use a similar approach in terms of funding and technology to invest into cogeneration. However in terms of sale of electricity it is better to take up the FiT as stated in the FiT policy rather than the capacity charge system of payment.

What are the challenges inhibiting the development of Cogeneration in the West Kenya region?

The potential for bagasse in producing electricity is not a new concept. However there are several challenges facing the sugar industry that has caused this potential not to be fully realised. The challenges were looked at in terms of those faced by the farmers and those faced by the millers. Some have been highlighted below.

Farmers: it was seen that most of the challenges were economic in nature with a high level of social influence. A major one highlighted by the farmers was the late and poor payments for sugarcane delivered to the mills. The main reason behind this was the poor returns made on sugar sold by the millers due to the cheap and illegal sugar entering the sugar market in the country. Another was the dependence of contracted farmers on the millers for inputs and services to plant the cane which exposes them to very high interest charges. This is because most of the farmers in this region are stricken by poverty.

Millers: the same scenario was noted with the millers whereby most of the challenges were economic in nature with a high social influence. A major challenge was lack of funds to invest in cogeneration. This is again due to the cheap and illegal sugar imports in the market causing the millers to have poor returns on sugar sales. The situation then leads to late payments to the farmers causing them to engage in illegal cane poaching activities. In both instances the millers loose the sugarcane which forms raw material for bagasse.

What are the ways through which the factories in West Kenya can enhance power supply in this region through cogeneration?

Power supply in West Kenya can be enhanced in various ways using bagasse. This was shown through four scenarios used to model bagasse based power plants, incorporating different aspects in the sugar industry. The scenarios involved two options for power production i.e. to generate and feed the entire electricity to the grid or generating and partly distributing the electricity while feeding the rest to the grid. The first two scenarios focused on the current trends of bagasse production and the rated crushing capacity both from the mills respectively. The last two focused on introduction of a new high yielding cane variety and increasing the area under cane respectively. It was noted from the economic analysis that first it was a better investment to generate and feed the entire electricity to the grid for all the scenarios. It was noted that for minimum investment it is better to go for scenario 1 which incorporated the factories crushing cane at the rated crushing capacity. For maximum investment it was better to go with scenario 2 which involved introducing a high yielding cane variety. In the end it was observed that scenario 2 achieved the best results as there will be no cane losses, it does not compete with land for food production and brings in higher returns for the farmers.

What are the impacts of Implementing Cogeneration in West Kenya?

If the potential for generating power through bagasse is realized it will have an impact in the West Kenya region. Some of these are listed below.

- There will be an increase in power generation & less reliance on fossil fuel based generation
- Transmission losses will be reduced
- Sugar factories will be self-sufficient in electricity production for their local demand
- Carbon emission will be reduced
- Employment opportunities will be generated

What are the policies in place for the development of cogeneration using bagasse?

There exist several policies both in the energy and sugar sub sectors that promote cogeneration from bagasse. It was observed however that the policies do not contain sufficient information as to how some of the laid out plans will be achieved.

5.2 Recommendations

The recommendations given for this study were done in two parts. Some of them have been mentioned as follows:

Recommendations to the farmers

Better methods of farming and harvesting cane should be made more accessible to the farmers. This can be facilitated by the Kenya Sugar Board (KSB) through increasing the funding and human resource capacity for research institutions like KESREF in the country. The relationships between farmers, out grower institutions and sugarcane research institutions should be strengthened. High yielding early maturing cane varieties suitable for the West region should be introduced, through the research institutions. These varieties should not compromise on either sucrose or fibre content in the cane.

Farmers should be empowered to plant sugarcane independently rather than depend on millers for this. This can be done through farmers' groups that can provide services like transport and harvesting the cane at a cheaper cost to the other farmers. The new cane payment system based on sucrose and weight of the cane rather than weight alone should be introduced on a pilot basis. This can be done across various field stations in each sugar belt and then monitored before being fully introduced.

Recommendations to the millers

The Government should introduce a comprehensive policy that lays out a better payment plan for the sale of electricity from bagasse.

A revenue sharing mechanism between the millers themselves and the millers and farmers should be introduced. This can be done as in the case of the cogeneration schemes in Mauritius (Deepchand, 2005).

The Government should also introduce tax incentives for the equipment used to set up a cogeneration plant to reduce on start-up costs. This also goes a long way in encouraging private sector participation in promoting cogeneration projects and as well obtaining funds from lending institutions. County officials should organise workshops and seminars that provide awareness and training on better and more efficient technologies for cogeneration plants

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Design of Stand-Alone and Grid Connected Hybrid Standardized Solar Power Systems for Rural and Urban Applications in India

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Abstract: The document demonstrates the steps taken to design the size of the Solar Photovoltaic Power Micro-Grid System for various projects in Rural India. The original thesis compared the implementation of Stand Alone Systems to Micro-Grids in Rural and Urban settings, but for this document, only Micro-Grid designs in rural areas are considered. The document describes the existing conditions for each of the sites followed by the analysis of the load profile of the active systems. The thesis describes the systems designed for each site based on the load profile, the existing conditions and the irradiation patterns of each of the sites. The thesis also narrates the technical and non-technical challenges faced during the design phase and the techniques applied to overcome the problems. The author concludes that Stand Alone systems work better for Residential areas that already have access to utility power. The Stand Alone system can supplement the utility power. Meanwhile, Micro-Grid systems work better for areas where the utility grid has not been extended. In such places, if the grid is extended in the future, the Micro-Grid transmission infrastructure, to some extent, can be utilized.

1 Introduction

India being a vast country, the government faces tremendous challenges in providing the population with affordable and reliable basic necessities. In this modern age, electricity is considered as a basic need. Projects in this document mainly focus on design of Solar Photovoltaic (Solar PV) systems in rural residential settings. Several sites in Eastern, Northern and Western parts of India were surveyed for this project. Climatic conditions, Industrial development and growth and Electrical Power scenarios in these different areas of the country are very diverse. Developing Solar PV solutions for each of the above settings required different approach and design considerations as detailed herein. All the projects in this thesis are performed for and on behalf of Sunkalp Energy. Sunkalp Energy is a start-up enterprise, an “Engineering, Procurement and Construction" (EPC) Company established in February 2012. The company is based in New Delhi and is a unit of BD Khanna Estates, a BDK Group company.

2 Site Conditions

Four village project sites spread across two different states are considered herein to represent rural electrification scenarios. Three of these villages are in Uttar Pradesh (UP) and one village is located in West Bengal (WB).

2.1 Existing conditions

Residential sector in rural areas is characterized by inconsistent electrical load patterns. There are several areas still deprived of the basic necessity such as electric power. Where power supply is available and there are people who can afford to pay for it, they face a high risk of theft or pilferage of system equipment. Establishing the load pattern itself was a challenging task due to the quality of inputs received from the village dwellers. The inputs can be considered as inconsistent and inaccurate at best.

2.2 Uttar Pradesh

The villages in UP surveyed for this thesis are located around the town of Anoopshahr. Pardada Pardadi Educational Society (PPES), a Non-Governmental Organization (NGO) was encouraged by the concept of Solar PV as an economical and reliable electrical power alternative for their infrastructure. Out of these 196 village sites, three villages namely Madargate, Karanpur and Durgaupur, were jointly identified for a pilot survey for a Solar PV project. All three villages are grid connected. Madargate is an extremely poor village where most of the people live below poverty level. The houses are made entirely out of straw and mud with no proper flooring or roofing. A family of approximately four to five people shares a small, one room house and use common bathrooms and toilets built by PPES. Karanpur village is just about 2 km from Madargate. It is a mid-size village with a mix of affluent and poor households. Most of the houses are a lot bigger and more spacious than the houses in Madargate, some are even built with bricks, mortar and concrete. Typically, each house has multiple rooms including separately designated kitchen, bathrooms/toilets and is equipped with lights and fans. Although they already have fans and lights installed, they cannot make enough use of it because of shortage of electricity. Typically, kerosene lamps are used for lighting during (frequent) power outages.

Durgaupur is the most affluent of the three. Most of the houses in this village are of bricks and concrete construction, each equipped with proper kitchen, bedrooms and bathrooms. Most households possess television set, lights, fans and refrigerators. Most of the farmers have electrically operated fodder cutters installed in the central open space within the house. Most of the villagers own inverters with battery banks for use during outages.

2.3 West Bengal

Sundarbans is a collection of islands, two thirds of which is in Bangladesh and about one third in Indian Territory. Brajaballavpur located on Patherpratima Island (India) of the Sundarbans is the village surveyed for this thesis project. Brajaballavpur is sparsely populated with most people dwelling in clusters of huts surrounding small ponds and using small pastures of fertile land in their backyards for farming. The island of Patherpratima is home to a population of over 200,000 residents with the village of Brajaballavpur hosting about 7,000 of them. Houses are made of mud similarly to the houses in Madargate with no proper flooring or roofing. The houses do not have toilets and there is no public toilet facility available in the village. The average monthly income of a family in Brajaballavpur is 1,500 Rupees (less than € 22 per month). There is no connection to electric power grid in Brajaballavpur or any of the nearby villages. Kerosene lamps are their only source of light.

3 Problem identification

3.1 Uttar Pradesh

During the visit to Madargate, Karanpur and Durgaupur, a field study was conducted in each of the villages to analyze the daily behavior of the population there and their energy use pattern. Although the villages are located within 5 kilometers of each other, they are vastly different. At the time of the survey, all three villages had schedule for power supply from 10.00 am to 5.00 pm but the villages received only three to five hours of electricity per day. The problems identified in each of the villages are listed below:

Madargate: In spite of the poverty, each house has a TV and a satellite dish connection, which is used during the few hours when the village receives electricity. Many girls in this village go to school but cannot study in late evenings because of insufficient lighting. The villagers expressed the need for better and longer duration of lighting.

Karanpur: The electricity supply is unreliable and the village often experiences unscheduled outages. Kerosene lamps are used by vendors in the village during power outages. The villagers identified that having enough energy to run a few lights and fans is essential.

Durgaupur: Even though many of the households have inverters with battery banks for use during power outages, the utility power supply is not enough to charge the batteries. Owing to the frequent and unscheduled power outages, the villagers have to be alert during the night as well to be able to cut the crop using fodder cutter whenever electricity is available. The villagers identified that having enough electricity to charge their battery banks, run their lights, fans and television sets was essential.

3.2 West Bengal

Some areas in the state do not have electricity because the grid has not been extended to those areas as yet. Almost all of these areas are located in the Sundarbans. The reason the grid has not been extended to these areas is that it is a collection of islands and building transmission lines is not economically feasible. The island of Patherpratima experiences heavy flooding during the monsoon months every year. In the absence of utility power, kerosene lamps are used in spite of the prevailing health and fire hazards associated with them. Diesel and other electricity generators are not affordable due to the meager income earned by the residents.

4 Solutions presented

Based on the existing conditions and the demands of the customers, customized systems were designed for each of the application sites. For the design of the systems, the following assumptions were made and the following equations were used for the calculations:

Assumptions

- PV wattage per m^2 = 120 W
- Efficiency of cables: η_{cables} = 0.9
- Efficiency of battery control unuit: η_{CBU} = 0.95
- Efficiency of battery: $\eta_{Battery}$ = 0.8
- Efficiency of inverter: $\eta_{inverter}$ = 0.95
- Efficiency of PV: η_{PV} = 0.175
- Performance ration (PR) = 0.7

- Factor of safety: FoS = 20%
- Efficiency of cables: η_{cables} = 0.9
- Overall cables and battery efficiency: η_{C+B} = 0.72
- Overall efficiency: $\eta_{Overall}$ = (η_{cables} * η_{CBU} * $\eta_{Battery}$ * η_{PV}) = 0.12
- Battery autonomy: 1 day (unless specified otherwise)

Different equipment has been designed according to equations below.

$$E_x[Wh] = N * \left[\sum_i^N P_{load,i} * [W] * equipment usage during x [h] \right]$$

Where P_{laod}: rated power of load in watts and N: number of households.

$$E_{autonomy} = E_{battery} * (1 + days\ of\ autonmy)$$

$$Battery capacity: C_{battery} = \frac{E_{battery}}{V_{System}}$$

$$Total battery energy: E_{battery} = \frac{E_{supply-battery}}{\eta_{B+C}}$$

$$Area of\ PV\ required [m^2] = \frac{E_{daily average for the month}}{I_{month} * \eta_{Overall} * PR}$$

4.1 Uttar Pradesh

For the design of the Solar PV system for Anoopshahr, data was acquired from NASA's Surface Solar Energy Data Set in HOMER software. The data set includes monthly average solar radiation data for any given location on earth. HOMER then uses the latitude information to calculate the clearness index for the location. Using the monthly average solar radiation data and the clearness index, HOMER builds a set of 8,760 solar radiation values, one for each hour of the year. HOMER uses the Graham algorithm to create the synthesized values, providing a data sequence that has realistic day-to-day and hour-to-hour variability and autocorrelation (Graham 1990). Based on this, and the data from NASA's Surface Solar Energy Data Set, the annual horizontal radiation data for Anoopshahr is acquired. The solar irradiance data for the villages was first analysed. Since they are very close to each other, the general irradiance pattern is assumed almost identical. The coordinates of Anoopshahr are used to acquire data for the villages. The daily radiation varies between 3.5kWh/m2/day and 6.75kWh/m2/day, the clearness index dips significantly in the months of July and August because of the monsoon season causing the effective irradiance to be low. It varies between 0.479 in August and 0.650 in October. Based on the existing conditions and the immediate requirements identified by the villagers, the following systems were proposed for each of the above-mentioned villages.

4.2 Madargate

Since Madargate's villagers identified economical and adequate lighting as their immediate need, the following Micro-Grid system was proposed for them. For the Micro-Grid, the primary options to be considered for this system are whether to build an AC system or a DC system. A DC system is chosen since the villagers do not own any AC equipment, other than a television set. The same DC LED lighting set and DC fan are chosen for the Micro-Grid system but one PV power plant would power 50 households. The general arrangement for the Micro-Grid system for Madargate is shown in Figure 1.

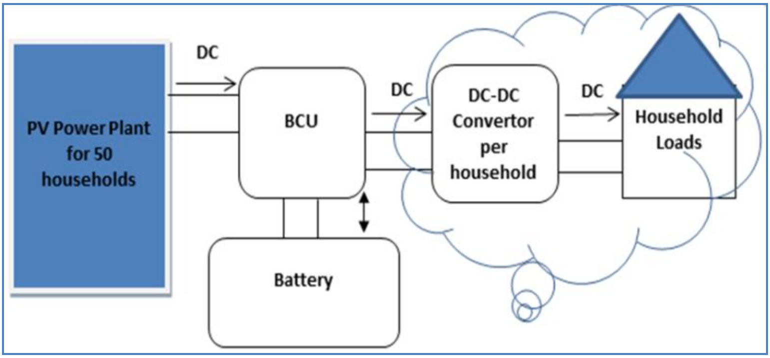

Figure 1: General Arrangement of the Micro-Grid System - Madargate, UP

The challenge in the Micro-Grid is that if the system voltage is kept at the equipment rating voltage (12V), then there will be significant losses in transmission, on the contrary, if the system voltage is kept high, a DC-DC converter will be needed to step down the voltage for use with the equipment rated for 12V. The DC system designed is based on the following calculations:

Battery Sizing

To size the battery, three scenarios were considered to identify the maximum energy expected to be supplied by the battery. Scenario one included the summer nights when the fans would be used. Since the summer days are very clear in this area, it was not deemed necessary to design extra days of autonomy for this case. Second scenario was that of the monsoon days, when the temperatures are still fairly high for the use of the fan but the days are not necessarily clear so one day of autonomy would be needed. The third scenario would be the months of March and October when the temperatures are high enough during the day for the use of fans but are low enough at night to not use them. Comparing the three scenarios and the sunrise and sunset patterns for the region, the monsoon months were identified to be the most demanding for the battery; hence the battery was sized to fit the monsoon needs. During the winter months, the daily energy usage is only for lighting purposes and is limited to 7 hours a day. This corresponds to 70Wh of energy usage per day which is significantly lower than the loads during summer and monsoon months. Taking battery and cable efficiencies and additional 5% losses for transmission into account, a battery size of 240V and 130Ah was chosen for the Micro-Grid application.

Solar PV Sizing

For PV sizing, the location specific synthesized data prepared by HOMER was first analysed. The irradiance was then coupled with the corresponding load and a monthly irradiation and corresponding load table was prepared; results are presented in Table 1.

Table 1: Monthly Average Radiation and Corresponding Load - Micro-Grid Madargate, UP

Month	Daily Radiation [kWh/m^2/day]	Daily Load [Wh]
January	3.808	3500
February	4.642	3500
March	5.611	13300
April	6.345	23100
May	6.787	23100
June	6.713	23100
July	5.374	23100
August	5.054	23100
September	5.496	23100
October	5.077	13300
November	4.135	3500
December	3.524	3500
Average	5.213	15000

Using Table 1, three scenarios are identified that need to be checked to identify the right size for the system. First, the months with the lowest irradiance such as December (3.524kWh/m^2/day), second, the month with highest load and lowest irradiance for that load; August (5.077kWh/m^2/day), and third, the average case. Since the load is lower in March and October compared to the load in August and the average irradiance is higher for these two months, the month of August is considered the worst case from March to October. After the analysis of all three scenarios, a 6530W PV system for Micro-Grid for Madargate is chosen because it provides the desirable amount of energy even in the worst case scenario. Since the charging voltage per cell of a 1V battery is 1.2 V, for a 240 V battery the charging voltage is 288V. Therefore the PV rated voltage is chosen to be in the vicinity of 288 V. 205 W_p panel from Moser Baer are chosen for this application.

Battery Control Unit Sizing

For the sizing of the BCU, it is essential to know the short circuit current rating of the PV system, the system voltage and the power rating of the load. For the PV module selected, the short circuit current is listed as 7.99A. Eight (8) modules will be connected in series and there will be four (4) strings. BCU rated for 350V and 40A on the source side and 288V and 7A on the load side is selected. Table 2 summarises the ratings for different suggested equipment for Madargate, while Figure 2 shows the estimated average daily output of the designed Micro-Grid system and the corresponding load.

Table 2: Micro-Grid System Specifications - Madargate, UP

Equipment	Power Rating [W] / Energy Rating [Ah]	Current Rating [A]	Voltage Rating [V]
PV Panels	6530W	I_{SC} = 31.96A	V_{OC} = 290V
Battery Sizing	130Ah		V = 240V
BCU Sizing		Source Side: 40A Load Side: 7A	Source Side: 350V Load Side: 288V

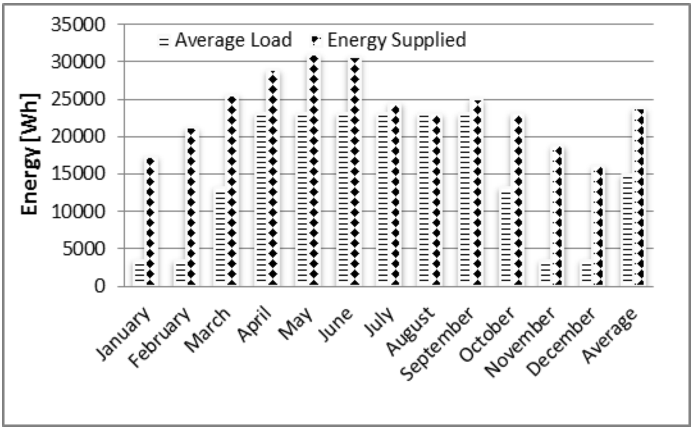

Figure 2: Average Daily Output and the Corresponding Load, Micro-Grid - Madargate, UP

4.3 Karanpur

Surveys indicated that adequate and reliable lighting was the immediate need of the villagers hence the following two systems are proposed. Once again, the primary options considered for this system are whether to build an AC system or a DC system. There is the option of either replacing all the existing lights and fans and provide a DC system or installing an inverter and continuing to use the AC equipment. While using the existing equipment would be a simpler choice, it consists of CFL lamps and big fans. These can be replaced with more efficient DC LED lamps with lower power ratings and DC fans with significantly lower power rating which will reduce the size of the PV system required and hence the installation costs. Keeping these facts in mind, a DC Micro-Grid System is chosen. The arrangement of the system can be seen in Figure 1. On an average, each house has two rooms and therefore two fans are assumed to be enough per household. Since it is a DC system no inverter is required. The lighting constitutes multiple lamps with a total power of 20W and two DC fans with total power rating of 36W. Based on the inputs from the villagers and the sunrise and sunset patterns for the villages around Anoopshahr, the usage pattern is identified as displayed in Table 3.

Table 3: Equipment usage pattern for Karanpur, UP

Equipment	Months	Times
Lighting (20W)	January, February, November and December	6.00-8.00 am and 6- 11.00 pm
	March, October	6.00-7.00 am and 7.00-11.00 pm
	April - September	8.00-11.00 pm
Fans (36W)	January, February, November and December	None
	March, October	9.00 am-9.00 pm
	April - September	24 hours

The Micro-Grid would supply power to 50 households. It is assumed that new infrastructure will be required for DC transmission. The arrangement of the Micro-Grid setup is similar to that of Madargate and can be seen in Figure 1. The load profile is the same as that of Madargate with twice the load requirement. Based on an identical approach to the Madargate Micro-Grid, the DC system designed is as follows:

Battery Sizing:

The overall battery sizing for the Micro-Grid for Karanpur is 240V and 260Ah.

PV Sizing:

After the analysis of all three scenarios, a 13060W PV system for Karanpur Micro-Grid is chosen with a charging voltage of 288V, therefore the PV rated voltage is chosen to be in the vicinity of 360V. A 220Wp panel from Moser Baer is chosen for this application.

Battery Control Unit Sizing:

For this system, six strings of 10 panels connected in series are used. The BCU is rated for 360V and 72A on the source side and 360V and 12A on the load side. Figure 3 shows the estimated average daily output of the designed Micro-Grid system and the corresponding load.

Table 4: Micro-Grid System Specifications - Karanpur, UP

Equipment	Power Rating [W] / Energy Rating [Ah]	Current Rating [A]	Voltage Rating [V]
PV Panels	13200W	I_{SC} = 48.84A	V_{OC} = 366.4V
Battery Sizing	260Ah		V = 240V
BCU Sizing		Source Side: 72A Load Side: 12A	Source Side: 360V Load Side: 360V

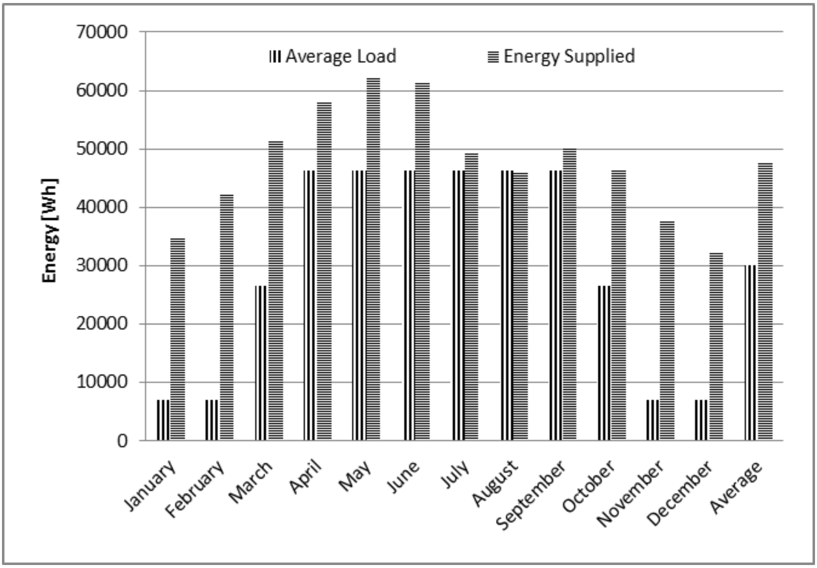

Figure 3: Average Daily Output and the Corresponding Load, Micro-Grid - Karanpur, UP

4.4 Durgaupur

Since villagers from Durgaupur identified providing energy to charge their inverter batteries to be their immediate need the following systems are proposed for them. Like the design approach for Madargate and Karanpur, the first decision to be made is whether to have a DC system or an AC system. Majority of the households in Durgaupur have several AC powered equipment. If an AC system is chosen, there is a very high possibility of uneven usage of energy. The villagers would try to operate their TV sets and washing machines on the energy from Solar and this would prevent other households from getting enough energy to charge their batteries. To prevent the uneven distribution of energy from Solar PV, a DC system is chosen. Since almost all households have batteries, it does not make sense to install additional batteries. The idea is to design a centralized solar power plant with DC transmission at approximately 312V. Each household will have a DC-DC converter followed by a BCU connected to the battery. The system is designed to supply enough energy to charge the batteries for 50 households. Figure 2 shows the general arrangement of the Micro-Grid system designed for Durgaupur.

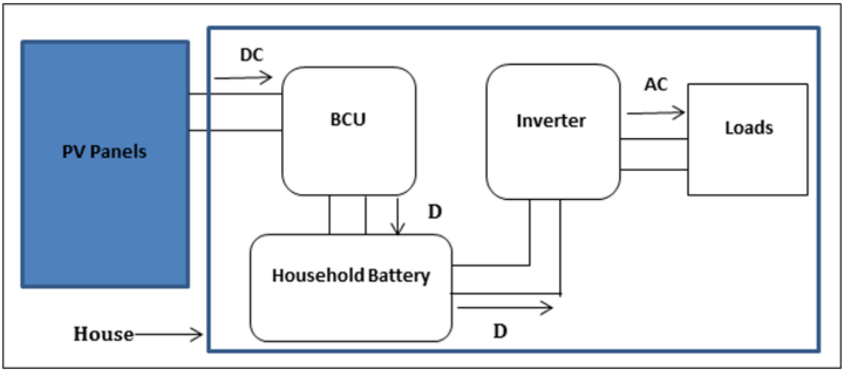

Figure 4: General Arrangement of the Micro-Grid System - Durgaupur, UP

PV Sizing

The PV panels are chosen so as to enable complete charging of the batteries even during the lowest irradiance, which is the month of December with 3.524kWh/m^2/day. The size of PV required to provide 52630Wh of energy to the battery is 21336W. 240W$_p$ panel from Moser Baer is chosen for this installation.

Battery Control Unit Sizing

The BCU will be connected in series after the DC-DC converter. Therefore the maximum 'source' voltage for the BCU will be 15V. For the PV module selected, the short circuit current is listed as 8.24A. Ten (10) modules will be connected in series and 9 strings will be in parallel. Therefore the BCU should be rated for 18V and 42A on the source side. The Figur below shows the estimated average daily output of the designed Micro-Grid system and the corresponding load.

Table 5: Micro-Grid System Specifications - Durgaupur, UP

Equipment	Power Rating [W] / Energy Rating [Ah]	Current Rating [A]	Voltage Rating [V]
PV Panels	21600W	I_{SC} = 75.96A	V_{OC} = 376.5V
Battery Sizing	50Ah		V = 12V
BCU Sizing		Source Side: 42A	Source Side: 18V

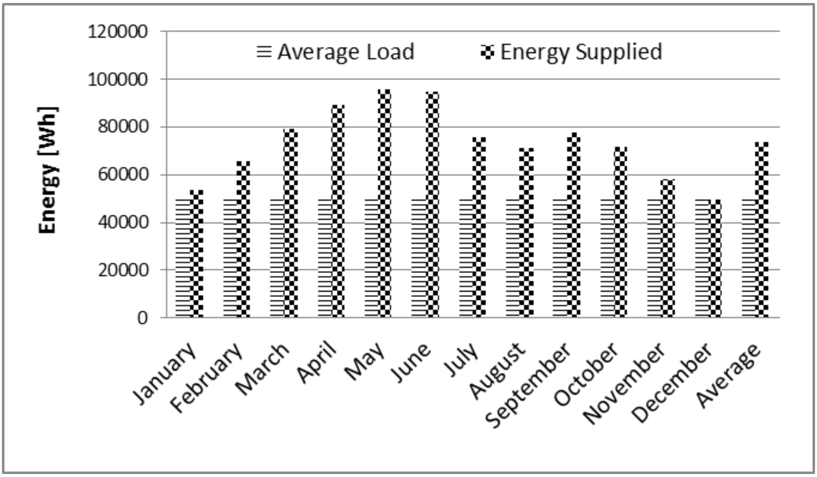

Figure 5: Average Daily Output and the Corresponding Load, Micro-Grid - Durgaupur, UP

4.5 West Bengal (WB):

Similar to the approach for the villages in UP, data for the island of Patharpratima was first acquired from NASA's Surface Solar Energy Data Set in HOMER software. The annual horizontal radiation data for the village of Brajaballavpur from HOMER is shown in Figure 6.

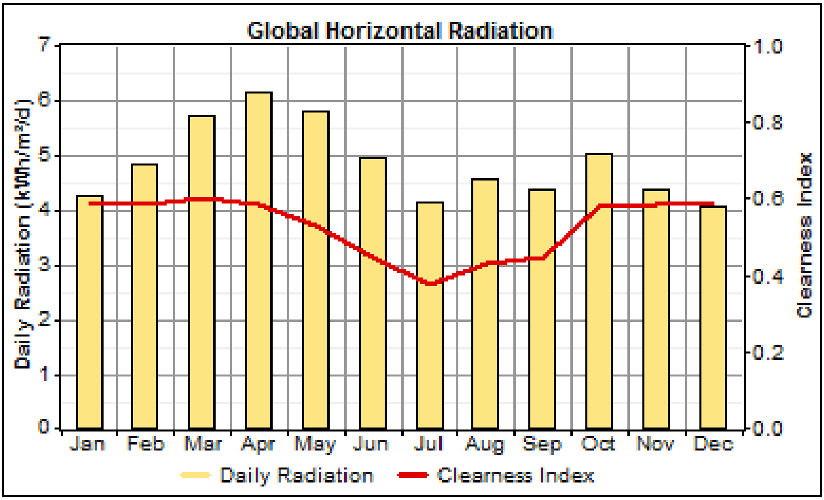

Figure 6: Average Global Horizontal Radiation and Clearness Index Variation for Patharpratima, WB

First the solar irradiance data for the village was analysed. While the daily radiation varies between 4.1kWh/m2/day and 6.1kWh/m2/day, the clearness index dips significantly in the months of June through September causing the effective irradiance to be low. The clearness index is constant throughout the year except for the monsoon months. It varies between 0.38 in July and 0.60 in March. Considering that the household income is very low, a Micro-Grid system is more appropriate for the village where an institution makes the initial investment to install the Micro-Grid and then charges as per use. According to the design specifications, each household has two 5W DC LED lamps for lighting. These lamps are expected to be used for four hours every day, identical to the usage pattern of kerosene lamps. A prepaid meter with a rechargeable card will be installed in each house. Once the credit on the rechargeable card is over, the villagers can take the card to a local recharging centre and replenish the balance to further use the electricity. For every unit of electricity, the villagers will pay a certain amount to the institution. In this manner, the villagers can choose to use as much electricity as it is economically feasible for them. The meters have the capability of limiting the power drawn so as to prevent usage of TVs and other high power consuming devices. The system will include high voltage DC transmission and individual DC-DC converters will be installed in the circuit to reduce the voltage to 12V for the household DC equipment. The arrangement for the system is similar to the

Madargate Micro-Grid system shown in Figure 1. The DC system designed is based on the following calculations:

Battery Sizing

Considering that this design is for a large system, an additional 5% is considered for losses due to decreased system efficiency including transmission losses. The voltage of the system is set high to reduce the transmission losses. The overall battery sizing for the Micro-Grid for Brajaballavpur is 72V and 100Ah.

PV Sizing

Considering that the battery is designed with autonomy of only 1 day and that there is no utility power backup, the lowest irradiation value is used in dimensioning the PV panels. Since all the energy will be eventually supplied by the battery, the efficiency of the battery has to be considered. Therefore, for the lowest irradiation, the size of PV required is 720W. The system voltage is set to 72V and the charging voltage of the system set in the vicinity of 90V. For this system, the 240Wp modules from Moser Baer are chosen.

Battery Control Unit Sizing

For the PV module selected, the short circuit current is listed as 8.49A. Three (3) modules will be connected in series. The BCU will be connected between the PV panels and the battery. Therefore the load side of the BCU will be connected to the transmission lines and the worst case scenario for the load has to be taken into accounti.e. all the households have the lights turned on and there are 5% transmission losses and 5% DC-DC conversion losses in the system. Therefore, a BCU rated for 140V and 11 A on the source side and 90 V and 10 A on the load side is selected. Figure 7 shows the estimated average daily output of the designed Micro-Grid system and the corresponding load.

Table 6: Micro-Grid System Specifications - Brajaballavpur, WB

Equipment	Power Rating [W] / Energy Rating [Ah]	Current Rating [A]	Voltage Rating [V]
PV Panels	720 W	I_{SC} = 8.49 A	V_{OC} = 112.95 V
Battery Sizing	100 Ah		V = 72 V
BCU Sizing		Source Side: 11 A Load Side: 10 A	Source Side: 140 V Load Side: 90 V

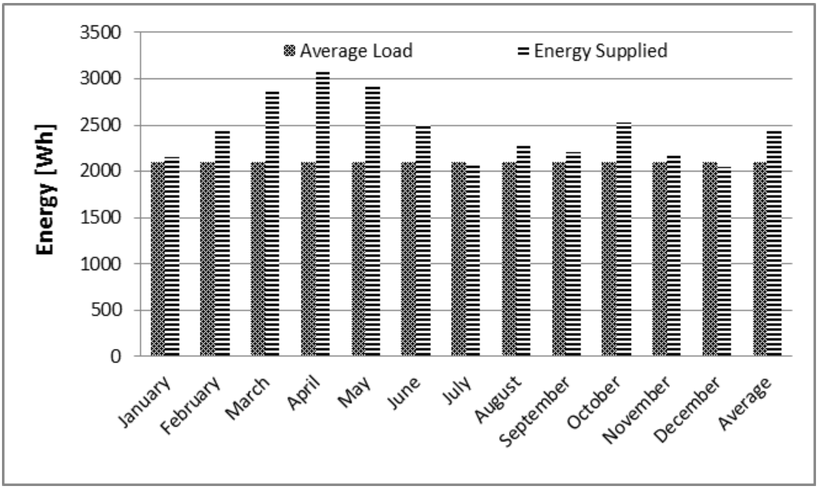

Figure 7: Average Daily Output and the Corresponding Load, Micro-Grid - Brajaballavpur, WB

A brief description of the overall findings in the Residential Sector for Rural Electrification projects is shown in Table 7.

Table 7: Stand Alone PV - Scoring Criteria for all Rural Residential Projects

Stand Alone PV					
Sites	**Available Space**	**Roof + House Stability**	**Financial Status**	**Designed System**	**Total**
Madargate	++	-	-	++	2
Karanpur	++	+	+	++	6
Durgaupur	++	++	++	++	8
Brajaballavpur	++	--	--	--	-4

Table 8: Micro - Grid PV - Scoring Criteria for all Rural Residential Projects

Micro-Grid					
Sites	**Available Space**	**Roof + House Stability**	**Financial Status**	**Designed System**	**Total**
Madargate	+	-	-	+	0
Karanpur	+	+	+	+	4
Durgaupur	+	++	++	-	4
Brajaballavpur	++	--	--	++	0

All the sites are scored for the existing conditions and the designed system. For each criterion, the scores range from "++" for 'excellent conditions' to "--" for 'not appropriate' conditions. The sum of the scores for all criteria is shown in the 'Total' column. For Madargate, Karanpur and Durgaupur, the scores for Stand Alone system are higher compared to the scores for Micro-Grid system. For Brajaballavpur, the score for Micro-Grid system is higher compared to the score for Stand Alone system. Therefore, the Stand Alone system is recommended for Madargate, Karanpur and Durgaupur while the Micro-Grid system is recommended for Brajaballavpur.

5 Conclusions and recommendations

This paper identified the existing conditions at all the sites, the problems each of the sites was facing and the reasons for them to consider alternative energy sources. Furthermore, the approach for the Micro-Grid Systems designed for the sites was presented and solutions and the possible outcomes were assessed.

For rural residential settings, for Madargate, Karanpur and Durgaupur, DC stand-alone systems are suggested. The systems are designed to cater to very few and specific loads. In the case of a Micro-Grid one consumer's carelessness can negatively affect all other consumers. Given the condition of the village and the equipment being used, there are very high chances of unfair and uneven use of energy from the Solar PV system. In addition, each household can be provided with a battery status indicator, a simple green light, which illuminates if the state of charge of the battery is above 95%. While the green light is on, the villagers can use the setup for additional equipment like charging of their mobile phones and radios. This provision is for effective use of the excess energy that the system produces during some of the months, especially since some of the systems are designed for the worst-case load and irradiation scenarios.

For the village of Brajaballavpur, having a stand-alone system is not as favourable because it is not economically feasible for the community. Instead, a DC Micro-Grid with the prepaid metering system is proposed for electrifying the village. Considering the yearly floods, a decision is pending on the possibility of having the system mounted 10 feet above ground and using overhead transmission cables. Since the wind speeds in this area are low, it could be possible to implement this approach. Another proposal under consideration is the installation of underground DC transmission lines because DC transmission is suitable for underground and underwater transmission and works even in case of floods provided there is adequate insulation. These projects will be visited on a regular basis for data collection and a more detailed analysis on their performance will be published after satisfactory amount of data has been collected.

This paper highlighted some of the details considered while designing the systems. The actual designing process involved site visits, client interviews, data collection, manual design, software simulations and some consultation from experienced individuals in the industry. I am not at the liberty to divulge much of the information and have included all the information possible to the best of my knowledge.

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Technical and Socio-Economic assessment of a community based mini- grid in Baglung District of Nepal

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Abstract: Many remote areas of Nepal are electrified by isolated Micro-Hydropower Plants (MHPs) distributed across the country. Some of the MHPs are not able to meet peak demand at specific time of the day while others produce more energy than required. To improve the reliability of the supply and to increase the utilization factor of the MHPs, it is important to think of interconnection of different power generation facilities located in the same region. This paper analyzed the technical and socio-economic feasibility of interconnecting into a mini-grid, seven MHPs in Baglung district of Nepal. It was found that power demand and production do not correlate in all the MHPs and this would be an opportunity for the MHPs which have surplus power to sell it to where it is needed through the proposed 11 kV line connecting the MHPs. To achieve this, management committee that would include representative from each MHP was recommended.

1 Introduction

Nepal is blessed with tremendous hydropower potential, estimated at 43,000 MW, but presently electricity access is limited to only 40% of the total population (NEA 2009, 17). Furthermore the country is still heavily dependent on traditional firewood to meet its energy needs. This has resulted in environmental problems such as soil erosion and deforestation in the country (Rijal 2000, 1). This is due to the inability to explore the resources available. Similarly, the increasing share of imported fossil fuels in the energy consumption in urban areas of the country has adverse effects on the national economy as well as on the environment. The ineffective energy management practices of the government has resulted in the production of a limited amount of electricity compared to the demand and this is causing even the grid connected electrified areas to face electricity shortages. In this current situation of electricity deficits, it is difficult for the government to extend the national grid to not yet electrified areas.

Decentralized energy technologies such as Micro hydro Plants, Solar Home Systems and Biogas Plants are presently providing electricity in the rural areas (Pandey 2009, 1). These renewable technologies have proven to be the suitable for supplying electrical power to rural areas of Nepal. Micro and small hydro plants operating in isolated and semi isolated systems are serving many remote settlements of Nepal and are isolating these settlements from the present electricity crisis. The rural population over the past two decades has been using electricity from these decentralized hydro power plants for only lighting purposes. The current availability of roads to the urban areas has increased the usage of modern amenities such as televisions and other electrical appliances among members of the rural population. They are however unable to fully utilize these electrical appliances due to limited electricity.

In such a situation of power shortage on the national grids it is almost impossible to supply adequate electricity from National grids to the rural areas. The rural people are dissatisfied with using electricity for only lighting purposes and as a result are exploring alternative energy sources. The effective usage of decentralized energy technologies can be a viable option in the already electrified settlements as a solution to the problems of the present local electricity crisis. Interconnection of the micro-hydro power plants is one option whereby rural electrified settlements can overcome the present local electricity crisis in a relatively short period of time.

This research is a case study carried out in four adjoining VDCs of the Baglung district in Nepal. It assessed the possibility of interconnecting the existing micro-hydro resources to the mini-grid networks. There is the possibility of harnessing the region's abundant micro hydro potential.

Decentralized micro hydropower plants have been serving these areas for more than 5 years. The interconnection of these power plants is one option whereby their reliability and load factors can be improved. A detailed look into the integration of all the MHPs was done since the goal of this study was to find the optimal technical solution that will result in the region's energy self-sufficiency. Additionally independent energy usage and a financial analysis were done in order to select the most suitable management model. The study focused on the technological, financial, managerial and social aspects of mini grid systems. The technical aspect mainly examines the quality and quantity of energy, load management and repair and maintenance issues. The financial aspect deals mainly with economies of scale, financial management and unit cost of energy transmitted. Similarly the managerial aspect mainly focuses on the quality of service and organizational model. Finally the social component of the study focuses on issues of ownership, level of participation and the social benefits to be derived from the project.

A technological analysis was conducted on the existing micro hydro power plants to ascertain the possibility of interconnection to the mini grid network. Similarly a socio economic assessment was done to determine the economic status of the local people, their opinions and reactions to the project, whether the project would be beneficial or a hindrance to the rural people. Through studying the technological, financial, policy and managerial options available a technical and socio economic feasibility assessment of project would be done. The present energy policies, pricing and role of Government were also briefly discussed to facilitate the successful promotion of mini grid technology at utility scale.

2 Methodology

In the beginning a literature review was done to obtain the background information relevant to the research and to understand the core of the study. Secondary data was collected from past studies, various reports, internet sources and books to gain insight into the core of the research. Literature research was done to prepare the relevant questionnaires which would be used for data collection during the field survey. The questionnaire was developed with the coordination of REDP and with the help of supervisor. The questionnaires for the MHPs were designed on the basis of the technical, financial and management aspects and were mainly for the manager/operator and management committee.

Similarly HHs questionnaires were designed mainly for the electrified household with standalone MHP. Checklists for each micro hydro power plant were prepared and a field survey was conducted. During the visit, face to face, semi-structured and telephone interviews, questionnaires and emails were used to collect required information. Apart from the mini grid site in Baglung other organizations like AEPC, NEA, REDP, ESAP DDC and the Baglung DRILIP office in Baglung were also visited. Questionnaires were distributed to some households while face to face interviews were done at others. Interviews with the operators, managers and chairpersons of the seven micro hydropower plants were conducted. All the seven MHPs were visited. Energy readings from each MHP were taken. Field research was conducted from 13th to 27th May 2010 in the Rankhani, Damek, Sarkaawa and Pauyanthanthap VDCs where the mini grid project is under construction. Seven micro hydro power plants with the total capacity of 129 kW were considered for the study.

During the field study, interviews were carried out in 290 households. The household interviews covered all the beneficiaries of seven micro hydro plants. This mainly focused on the energy consumption patterns, living standards of people, electricity requirement of households and their willingness to pay for electrical energy. The energy meter reading was also noted from the seven micro hydro power plants.

During the field visits observations of the local people's daily activities, culture, farming practices and use of available resources were made. Apart from the interview, informal discussions with the local people were carried out during the field visit and this was helpful in increasing the awareness of the community residence in relation to the objective of the study. During the interviews with the personnel of the seven MHPs information on the technical and financial status along with the energy meter reading were collected. Figure 1 shows the percentage of beneficiary households included in the survey from different schemes. This shows that coverage was made of the seven plant beneficiaries.

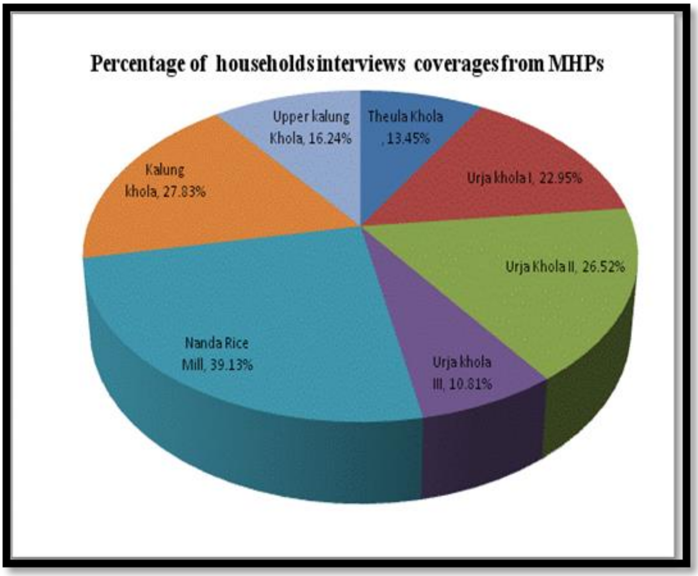

Figure 1: Percentage of household interviews coverage

(Source: author)

3 Description of Project site

Baglung is a famous district for small streams and rivers (DDC-Baglung 2009, 1). It is situated in mountainous region of western Nepal. Most of the district's rural VDCs were electrified by isolated MHPs with financial support from REDP and ESAP. Those parts of the rural areas which are in the vicinity of the national grid lines are electrified with community rural electrification from NEA. The nature of the geographical terrain causes long delays for grid interconnection of rural areas. In some case it takes several years. Instead of electricity from the national grid some people have resorted to the use of alternative forms of energy. The use of alternative energy sources like Solar Home Systems and Domestic Biogas equipment are common in the district. In hydropower generation, electricity is generated using the kinetic energy of falling water which runs the turbines connected to an electrical generator. The seven existing micro hydropower plants considered for this study are to be interconnected with an 11 kV transmission line. These micro hydro plants cover 4 VDC of the Baglung district, namely Rankhani, Sharkawa, Damek and Pauyanthanthap. The seven MHPS are Kalung Khola MHDS-12 kW, Kalung Khola MHDS-22 kW, Urja Khola I MHDS-26 kW, Urja Khola II MHDS-10 kW, Urja Khola III MHDS-25 kW, Nanda Rice Mill-12 kW, and Theula Khola MHDS-24 kW. The total households electrified from the seven MHPs are 1310. The single line diagram of the 7 micro hydropower plants is shown in Figure 2.

Among the seven power plants, six were established with the financial and technical support of REDP/UNDP during the first phase of the micro hydro demonstration programme. All of these MHPs are community based. The Nanda rice mill plant was privately owned but is now owned by community following negotiations with the owner. This plant is currently being reinstalled and will cover some wards of Damek VDC and ward 4 and 5 of Sarkawa VDC.

It is planned that excess electrical energy will be transmitted through an 11 kV transmission line within a distance of 7.5 km along the side of the river where the seven MHPs are located. The transmission line passes from each of the power houses along the river side starting from the Upper Kalung khola to Theula khola MHDS. Since the power is to be transmitted at a higher voltage than the previous micro hydro, adequate safety should be considered. There should also be possibility for expansion of the transmission line to cater for future demand. Therefore the technical specifications of the project need to be carefully designed. There should be sufficient power as well as optimization of the usage of the available power. Similar to technical aspects, the economic viability is also of equally essential. Finance is one of the key factors affecting technological adaptation. Therefore economic analysis is also considered as an essential factor for the establishment of projects.

Even though the project is technically and economically sound, if it is not accepted by the end users, then its success will be unlikely. The project should have a positive effect on the society in which it is implemented. Before construction of the mini grid thorough demand surveys, supply analyses, financial analyses, community benefit assessments and risk assessments should be conducted. These factors are discussed in detail in the section below.

3.1 Technical aspects of mini grid connection

The technical viability of the project is vital and should be a first consideration. Technically the mini grid should be safe, able to facilitate adequate expansion and operable in an efficient manner. Following the interconnection of the isolated micro hydropower plants to mini grid system, the complexity of the system is increased. Careful consideration and preparation must be made in the design and construction of hydro power plants for the reduction in discharge that occurs during the dry seasons. During these periods the generation capacity is reduced but the demand remains constant and sometimes increases due to the cooling needs. Because these affect the technical parameters of the system such as the voltage, frequency and the system stability, special care in choice of system equipment and operating parameters is essential. The physical arrangements of the components (cables, protective relays, synchronizing and measuring equipment) must be designed accurately (Shakya 2007)

Several factors affect the reliability of a power transmission and distribution network. These include frequency of trips, breakdowns, voltage in-balance and large frequency variations that negatively affect efficient system synchronization. The main technical considerations for a mini grid system are the governing, control and protection systems, metering equipment, the switchgears and so on.

PLC based ELC synchronizing panel has been proposed. PLC systems are commonly available from a wide variety of manufacturers. PLCs can form the basis of dedicated hydro control and protection systems. Many systems are available in modular format, with a wide variety of analogue and digital inputs and outputs. The systems can be tailored for specialized applications. PLC systems can be connected to SCADA systems for data logging and remote access and control. The use of standard PLC modules means there is a requirement to specify and program them to suit the particular application.

PLC software programming requires skill and experience. The software designer needs to understand the mechanical, electrical and hydraulic characteristics of the equipment that will be controlled – for example opening a main pipeline valve needs to be done slowly to avoid dangerous surge pressures. Software needs rigorous checking and debugging. Note also that specialist PLC based systems specifically designed for hydro applications are available. Such systems are pre-configured and programmed to operate a turbine and generator. For this reason, their use can save on system design and implementation time. However, such systems may not suit the requirements of the particular system and might be difficult to adapt to system requirements.

Multi-function digital panel meters can provide various types information from a single meter. Many digital meters can be connected directly to the PLC systems via Modbus or similar communication systems. This enables the PLC to monitor electrical parameters and make them available to SCADA systems for logging and remote monitoring. The typical parameters that can be monitored by a digital panel meter in the PLC are the peak values of current and voltage, harmonic distortion information, frequency, power and power factor.

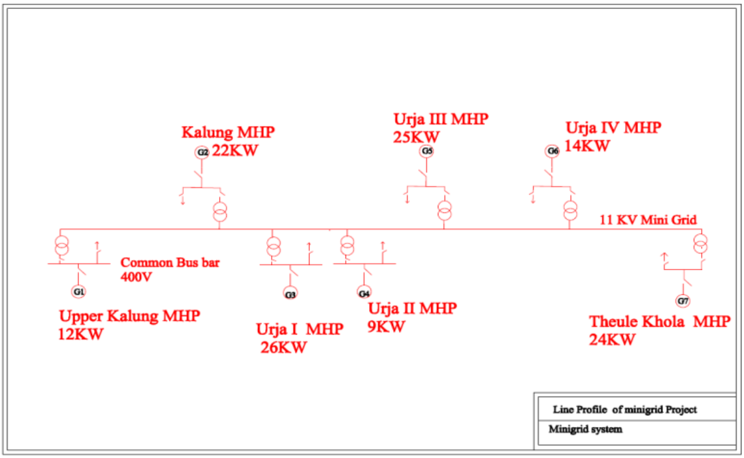

Figure 2: Single line diagram showing the major load centers.

(Source: author)

All the power plants are connected to the 11 kV mini grid network through the step up 0.4/11 kV transformer. There are other 400 V lines that connect each plant to its associated load centers. For the large power plants Theula khola , Urja khola II , Urja khola III and Kalung MHP a 50 kVA transformers are used whereas in the remaining two power plants 30 kVA transformers are installed .

3.2 Proposed Management Model

Initially a Mini Grid management committee has to be set up with the seven existing MHPs. The interconnection will cause the once independent MHPs to become a unit and will therefore require cooperation at the organizational level which should run for the entirety of the project. For effective operation, management and utilization of the mini grid and the micro hydropower plants connected to it, a mini grid working committee has been formed with the help of REDP. 12 representatives from the 4 large MHPs and 5 from the 2 medium MHPs form the management committee. In total there are 17 members within the steering board. This committee is fully responsible for solving disputes arising during and after the implementation of the projects.

Even within a single MHP plant there exist multiple disputes in Technical, Managerial, Financial and Social issues. When there is a mix of different communities to operate the mini grid there will be greater chances for disputes. After integration or completion of mini grid, any of the plant owners may attempt to disconnect or become isolated from the grid system if they feel they are being treated unequally.

Disputes may occur during dry seasons and peak periods when there will be less power to supply loads. Disputes may arise from system collapses. Disputes may be on issues of billing. In case of such future occurrences, they have to be resolved in proper manner. Disputes may be in any issues like technical, managerial, financial or social and need to be settled in a coordinated manner. Certain rules and regulations should be set up in regards to disputations.

After the interconnection of the MHPs, the responsibility and authority for the management committee would depend upon the management modality as whole system in relation to the categories into which the utilities are divided. These are the generation of electricity, transmission to the grid network and the distribution to the community. All the seven MHPs connected to a common mini grid network will be the transmission network with the 11 kV transmission line and supply power to all local communities connected previously to each individual MHP. Different management options have been suggested in order to better utilize the mini-grid.

Option A: - Management of the entire system by one committee

One entity is made responsible for the whole system. This option suggests that all the existing individual management committee would be replaced by a single committee that would be responsible for the generation, transmission and distribution of electricity from all the 7 MHPs. Generation planning, load management, load dispatching and repair and maintenance scheduling would also be handled by the same organization. Meter reading, revenue collection and the distribution of annual dividend from the profit will also be managed this entity.

With this type of management there will be a uniform tariff and same power quality to all beneficiaries. Income distribution among the MHPs is mainly done on the basis of the Present Value of capital investment in each project, the kW power installed and the number of households served by each MHP.

The advantages of this type of centralized management system are:

- Everything is managed by one committee therefore unit cost of operation will be low. O&M can easily be done without disrupting services.
- The entity will be able to hire adequate and appropriate human resources for technical and managerial activities and use them optimally.
- It will also be able to provide necessary facilities to the staff to retain them in the institution which will result in dedicated human resources.
- Efficient and easy coordination between all the utilities will be fostered since one utility has taken responsibility for all generation, transmission and distribution. This will lead to effective customer services and possibilities of quick decision making if required
- The size of the organization could enable better negotiations for national grid connection.

The disadvantages of this type of centralized management are:

- The problem of ownership may arise and the low sense of belonging may cause persons to become dissatisfied and lose interest in the project.
- Direct job opportunities may be low. Attention to perceived minor problems may also be lower in a centralized system.

Option B: Mini grid management by different committees

In this arrangement, the mini-grid would be operated by different entities. The grid receives only surplus power after supplying to the local communities. In this type of management system, all the management committees of the system will be responsible for generation and distribution of the electricity and tariff is set by the micro hydro committee themselves. Operation and maintenance of the micro hydro is also organized by this committee. Only the MV transmission line is manage by the mini grid management committee. This type of modality will require at least 8 organizations: 7 MHP owners and one mini grid operator. The mini grid operator will have to coordinate with the 7 MHP owners.

The advantages of this type of modality include:

- Communities have greater influence in the day to day operation and the sense of belonging to the system is higher in this type of modality. Local problems can be solved easily and issues can be handled more quickly.
- Grid-failure will have minor impacts on the communities
- Connection/disconnection with the grid is decided by the local authority
- Accounting transparency will be higher
- Quality of repair and maintenance of individual MHP will be different and this may affect the reliability of the system
- There will be non-uniformity in the tariff since they are being set by the MHs functional groups
- Financial viability of mini grid is low as revenue is collected by MHP functional groups

Option C: Generation plant is operated by a different entity (IPP model)

Load management and dispatching is controlled by the mini grid operator. All the transmission and distribution to local community is managed by the mini grid committee. The MHP will act as the IPP and is the standard model.

Community retains the ownership of each MHP but the mini grid as well as distribution is owned by a different organization. Each MHP is responsible for its own operation and maintenance as well as up grading of the individual plants. Scheduling for maintenance will however be in the control of the mini grid operator. It is easy for entry and exit of individual MHP on the mini grid networks. Flexibility in this case is high.

The advantages of this type of modality include:

- Quality of electricity is high due to the high system reliability as the MHP functions as the independent generation plants
- There is the uniform tariff system
- Strong ownership of individual plants and mini grid also exist
- O&M can be conducted without service disruptions

The disadvantage of IPP model is that the price of electricity may be high.

In this model, each plant owner would be responsible for the O&M of their MHP, as well for replacement of faulty equipment within the MHP. The operator is responsible for maintaining a log book (including the log of downtimes). The system boundary of an MHP includes (and ends on) the synchronization equipment (on the low voltage level) but the local distribution and the power transformer. MHPs owners receive a fixed share of the total monthly revenue. This share is calculated based on the power capacity and availability of the corresponding MHP.

Among these three modalities the IPP model is proposed. This is the standard model as the generation power plants are management by the owner and the transmission and distribution is managed by the mini grid committee. In this case new MHPs can be added and managed, with relative ease in handling of disputes as well. Any dispute in one MHP has less negative impact on the entire system.

3.3 Financial Analysis

The financial analysis is one of the main keys in decision making. It provides the means to determine whether to implement the project or not (AEPC/ESAP 2008, 47). The Financial analysis is conducted to check whether the mini grid project is economically feasible or not. Interconnection of standalone MHP plants as a means of improving the system reliability is a new practice in Nepal and the project should be technically and financially viable otherwise it will be unsustainable and difficult to replicate in other parts of the countries. Therefore, the economic evaluation of the projects using such indicators such as the Internal Rate of

Return (IRR), Net Present Value (NPV), Benefit Cost Ratio (B/C) Ratio and Payback Period were taken into consideration to ascertain the financial soundness or feasibility of the mini-grid technologies.

The investment required for the interconnection is estimated using the Nepali Rupee (NR). For the financial analysis of the mini grid connection, the following have been assumed:

a) There are no clear policies on interconnection of micro hydro power plants in Nepal with regards to royalty and energy tax payments. Hence a similar assumption as the community based electrification practices of the NEA is made.

b) Discount rate of the project is assumed at 10 %.

c) Lifetime of the micro hydro, transmission line, transformers and PLC Board is considered up to the 15 years.

d) Inflation rate is not considered in the calculation.

e) Depreciation is considered for 10 years.

f) The electricity selling price of the household sector is done on the same basis as the community based electrification done by NEA. This is the only possible way of performing the revenue calculation in the study area since there are no major industries or commercial loads in the area.

4 Results

This research highlights the present status of the MHPs, considers their technical status, financial and managerial conditions and suggests suitability for the grid interconnection. The analysis of the findings from households and the MHPs questionnaires has been performed. Load centres and power production do not mostly correlate in the MHPs. The MHPs which have surplus power do not have means to export it where it is needed. In addition MHPs with shortages do not have the possibility to import power from where there are surplus. Therefore, both challenges can be alleviated through the interconnection of the MHPs.

The analysis of hourly data on the demand side revealed that the interconnection of the plants would increase the reliability of supply as shown in Figure 3.

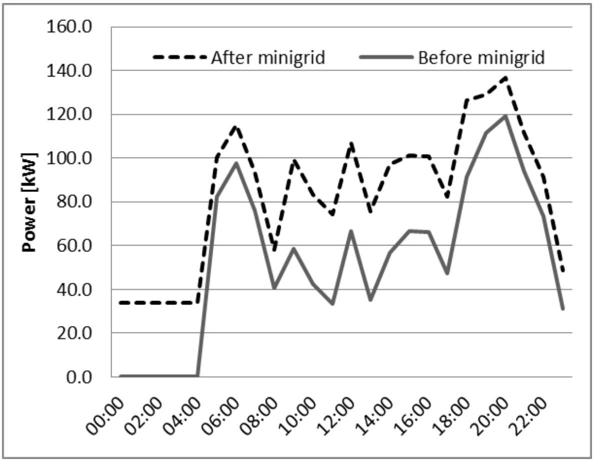

Figure 3: Daily load profile before and after mini grid network connection

Source (author)

The result of combining the energy meter readings obtained from the seven power houses during isolated operation as well as after interconnection is shown in Figure 3. Considering 24 hours daily operation of the Dairy Farm, 8 hour daily operation of the Grill Udogyo and 5 hour daily operation of the Crusher Machine then the load factor is increased to 64 %.

From the curve, it is clear that the domestic demand as well as commercial demand will increase and there will be optimum power utilization after the interconnection. Hence from the findings, it can be concluded that the interconnection of MHPs will provide extra power to the consumers.

The proposed mini-grid network is designed to transmit the excess electricity demand of the areas and to facilitate operation of the large motors during off peak periods. If the demand is not supplied by the MHPs energy is to be supplied via the mini-grid whenever power is available. Hence the unmet demand can to some extent disrupt the availability of power in the mini-grid if it coincides with the power available in the grid. Such an operation requires specially customized modifications and considerations.

Similarly during the off peak periods, required power is taken from the mini-grid network for running the enterprises. Large motors can be operated from grid fed electricity. The operation strategy of the system is shown in Figure 4.

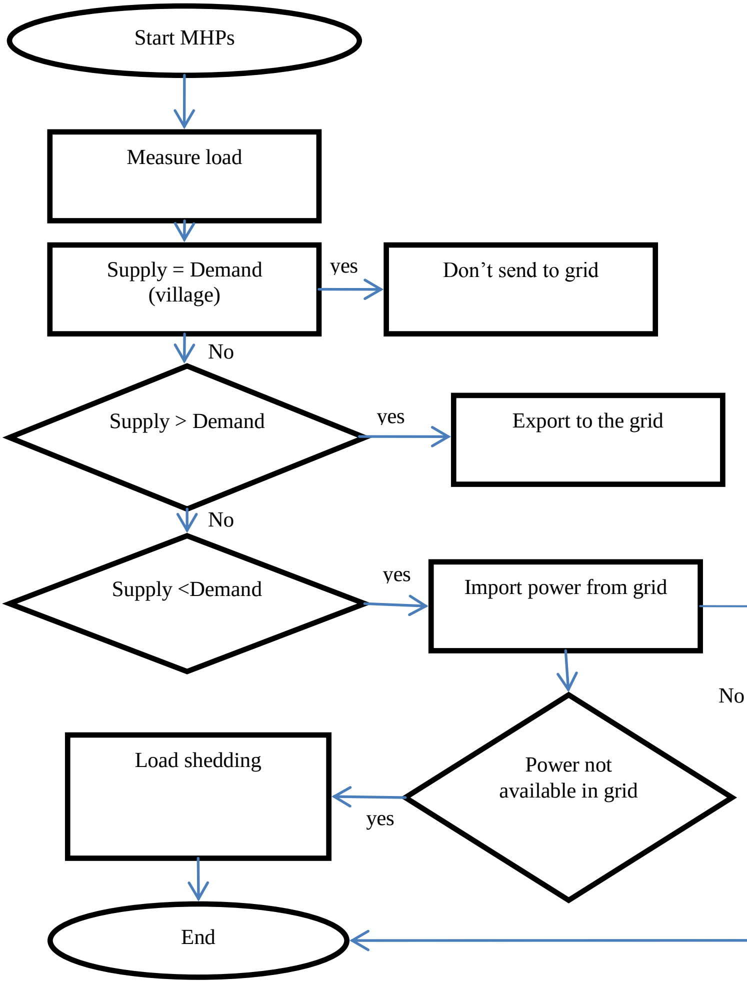

Figure 4: Operation strategy of the mini grids system

Source (author)

Similarly, technical and financial calculations regarding the mini-grid are performed and other technical studies necessary for the consideration of the mini grid network are conducted. In the financial aspects, the calculations related to the mini-grid network have also been performed. The management of the mini-grid network is one of the major problems faced by community owned MHPs as the later were built for the welfare of the rural people. As such various community based management modalities are proposed for the management of the mini-grid network and the micro hydro plants. Among these options, the IPP model is suggested. In this case the transmission and distribution are managed by one management committee and the MHP as a generating utility is managed by the previous MHP committee.

The analysis indicates that the 11 kV transmission line is required for the transmission of 129 kW power within the 7.5 km distance. Three phase weasel ACSR conductor is used for the present transmission and with the possibility of increased transmission in near future. Synchronization of the voltage and frequency is essential for the stability of the system. The ELC Board is replaced with the PLC board which is more advanced, consisting of the synchronization panel, metering system and controlling and communication system.

Furthermore, the financial analysis which examined the economics of the mini-grid connection was also done. The financial analysis showed that the main cost of mini grid is in the transmission lines, PLC board and the transformer. The cost per unit of transmission of electricity in mini-grid network is 5.25 NRs/kW. This is higher than the 3.5 NRs tariff currently offered by Nepal Electricity Authority (NEA) to the community based rural electrification (NEA 2009, 22). The financial analysis is done by separating the present revenues collected from that of the MHPs.

5 Conclusion

The implementation of proposed mini-grid project can be a timely and effective solution to the current regional electricity crisis. In the same way, given the availability of sufficient electricity from such a mini grid network new economic activities can emerge in this region. The local residents can reduce their fuel wood and imported fossil fuel dependencies and that will have positive impacts on both the local economy and environment. In a broader sense, such types of project will provide information for further development of mini grids in other parts of the country where there are a number of isolated MHPs in operation. Implementation of mini grid network would increase the load factor of the power generation plants. It will foster the establishment of enterprises that can improve the local economy. Possible impacts of the mini grid network are explained in details e.g. the availability of electricity 24 hours daily will foster greater income generating activities. Industries demanding large amounts of power can be established in the locality thus increase employment opportunities in the area. The impact analysis was done using the examples of success stories of rural electrification from various countries.

The establishment of an infrastructure for transmission lines requires large capital investment which is not economically feasible for to be undertaken by the rural people. This role is therefore reserved for the government, the NEA, the Alternative Energy Promotion Centre, the Agencies of International Development Cooperation and other stakeholders. They are crucial to obtaining a sustainable energy supply in Nepal. There are at present no certain policies regarding the mini grid networks. Any policy should therefore address key real time socio economic and environmental issues that will enable Nepal to make its energy system more sustainable.

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A system complexity approach to swarm electrification

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Abstract: The paper investigates the process of electrification and power systems from a systems complexity perspective. Contemporary approaches are found to have the tendency to be either unsuitable for some actors in the system or fail to provide the needed services in the long term to a large part, thus undermining its sustainability. Common, stand-alone system approaches, such as solar home systems, will not exceed providing a tier 2 level of electricity service. Mini-grids, on the other hand, are meant to fill this gap, but are yet unable to meet their commercial potential or the demand of users. Therefore in order to meet the needs of all agents involved, complex system behaviour ought to be embraced rather than shielded. Engineering and design should focus less on mere load estimations and supply side layouts and pay closer attention to the possibility of flexibility, upgrading, extension and stabilization of the system, regardless of its size or concrete appearance. The authors of this paper further evaluate the concept of swarm electrification, investigating its systemic properties against common electrification approaches, assessing Bangladesh as an exemplary case. By integrating existing resources with leapfrogging technology through the use of the convergence and innovations in ICT and energy access, more resilient and ultimately sustainable energy infra-systems become feasible.

1 Introduction

Across the Global South, infrastructure development, such as on the national electricity grid, scores high on the agenda in terms of gross national income invested (Dobbs et al., 2013). Simul Tenenbaumously, the UN Sustainable Energy for All (SE4All) universal energy access target by 2030 is looming large (Ki-moon 2011), indicating greater need for decentralized system options (OECD/IEA, 2011). The question therefore remains: what kind of electricity infrastructure systems should be developed considering past, present and future investments in micro and large-scale infrastructure (ranging from stand-alone solar home systems (SHS) to the national grid) in order to reach the set target.

For years, practitioners and researchers in the field of electricity access viewed energy as a utility that people either acquire or do not. This may be due to historic developments in the industrialised economies where centralised, state-supported electrification was the main mechanism, thus reflecting this dualistic view instead of a gradual process. As a result, the economic calculus for today's approaches is based on the (non-) viability of grid extension, which is measured by the distance-based cost of extension. Villages too remote and with very low demand are considered to only have a chance to be electrified with a "second class" solution through a decentralized approach (Mandelli and Mereu, 2013).

Without the ability to supply energy that is adequate, available when needed, reliable, of good quality, affordable, legal, convenient, healthy and safe, for all required energy services across household, productive and community uses (Bhatia and Angelou 2014, 2) the affected people's economic development is inhibited -or at least- delayed (Groh, 2014). The exact number of people lacking these electricity services remains unknown due to the fact that thus far there is no consensus on a measurement framework going beyond a binary assessment. However, the number of electricity connections (AGECC, 2010) is outstripped by population growth in large parts of the Global South (Pachauri et al., 2013), despite the increased rhetoric/studies on the need to change the lack of access to the national grid situation for 1.3 billion persons. On top of that, there is an additional billion persons with a severely intermittent supply. Discussions on electricity access are usually centred on two key players of development: the government and the private sector. However, this approach fails to take into account "the crucial third agent, in whose name development is carried out: people organized as communities and collectives, people seen not as 'beneficiaries' of the state or 'consumers' of private services but as drivers of their own destiny, empowered to self-provision of basic needs and to govern from below" (Kothari and Shrivastava, 2013).

Only recently, the scientific discourse on rural electrification has changed its dichotomous character of arguing for either centralized (e.g. national grid extension) or decentralized solutions (e.g. stand-alone SHS or isolated micro-grids) towards the questions of which level of access in a gradual process is present or which quality of service is provided (Tenenbaum et al. 2014). Therefore, this paper joins the effort to distance itself from a binary category of energy access towards a multi-tier framework in order to be able to measure a continuum of improvement (UN 2014; ESMAP 2014, Muench and and Aidun, 2014; Groh et al. 2014b).

The electricity supply's service quality through the main grid varies substantially (e.g. in terms of black- and brown-outs, voltage fluctuations, among others) in different countries, country regions and even parts of the same city. The quality of decentralized energy systems varies even more in terms of possible loads to connect, time and duration of usage. Thus, a mere measurement in the overall supply (electricity consumed) per household counteracts the strive for more energy efficient appliances that are supplied by those systems, thereby neglecting the importance of the load attached (wattage). These multiple access solutions, partly designed as transitional solutions or even running in parallel, need to be assessed reflecting these differences in service supply. With that said, appropriate reference is taken to the multi-tier approach of measuring energy access, distinguishing five tiers based on the six attributes of electricity supply, namely capacity, quality, duration, reliability, affordability and legality[12]. Nonetheless, the technology options presently discussed under the tier framework are all "engineered" in a certain size, with certain assumptions, for certain purposes. Space to act for the end-user remains very limited. Moreover, the future notion should not be centralized versus decentralized (nor access versus no-access) systems but on the question of whether systems provided are robust, adaptable, fast changing (self-organizing) infra-systems that use the involved complexity to their advantage.

System analysis speaks of the "prosumer" as the critical agent in a system of energy service supply, performing critical actions (Ritzer et al. 2013, 379). The prosumer is "an economically motivated entity that (1) consumes, produces, and stores electricity, (2) operates or owns a power grid, small or large, and hence transports electricity, and (3) optimizes the economic decisions regarding its energy utilization" (Grijalva and Tariq 2011, 2). The complexity lies here in both the physical/technical and the social/economic dimensions (Weijnen et al. 2008). Hence, Weijnen refers to infra-systems instead of infrastructures. They further argue that it is the socio-technical connection that crucially affects how the system performs. System performance is, therefore, precisely not dependent on the initial system design nor engineering from central entities who, can limit system performance if necessary during a declining stage. User-centred models usually draw on the particularities of the complexity of energy systems rather than trying to avoid them. For instance as in the use of patterns of self-organization and emergence to grow, the system

[12] Please refer to Bhatia M and Angelou N (2014) for further information.

by allowing for new business opportunities with a widening space of possibilities (e.g. prosumers). These infra-systems are characterized by the co-evolution of supply capacity and respective (economically feasible) demand that fits the overall system size. They achieve their robustness through usage of information and communication technology (ICT) (convergence) in order to communicate power, information and monetary flows that keep the physical system stable, constraining actions such as using devices with too high demand while signalling actors when new areas of opportunities open up (e.g. by integrating new storage or generation capacity that creates income for the actors; or uses cheap and abundant electricity for productive purposes, respectively) (Weijnen and Bouwmans 2006).

In certain scenarios, a paradigm shifts from an exogenously engineered approach to user-centric emergence schemes may lead to better system performance. Such a paradigm shift could improve on existing decentralized approaches for rural energy. A newly developed bottom-up concept, referred to as swarm electrification (SE), is discussed here against the background of system analysis (Groh et al. 2014a).

SE is based on nodes in a swarm intelligence network where information and electricity flows are shared among neighbours "to achieve a compounding network effect, in that they are linked together to form a micro-grid – to achieve a networked grid effect" (Groh et al. 2014a). The SE concept further envisions a readiness of the actors and infrastructure of the centralized track, namely utilities and the national electricity grid. The objective of this paper is, therefore, to investigate the feasibility of an approach where the people themselves start building upon their present resources in order to form a balancing network and prepare themselves for an eventual grid connection.

Given the unpredictability of system emergence, the underlying research question raised here is whether such a grid can be built from the bottom-up thereby avoiding path dependencies and leading to more resilient and ultimately sustainable infra-systems. In this paper, sustainability is not understood as a condition of stasis but "a process of continuous adaptation, of perpetually addressing new or on-going problems and securing the resources to do so" (Tainter 2011, 94).

2 Methodology and Conceptualization of Swarm Electrification

From the perspective of complex system theory, the authors analyse a bottom-up concept drawn from an approach that follows the basic principles of swarm intelligence in distributed information and communication technology networks (Unger and Kazerani 2012). In the swarm electrification scheme, individual nodes bring independent input to create a conglomerate of value even greater than the sum of its parts in the way that each node, in a swarm intelligence network, shares information with its neighbours to achieve a compounding effect (Groh et al. 2014a). For instance, individual stand-alone household energy systems could share electrical power. Hence, each node/agent acts independently as its action influence other agents and its own future way of acting (connected and interdependent entities in a dynamic environment). This opens possibilities for non-intended actions (non-predictable emergence) that benefit the system (or community, but finally feeds back to electricity system as well). Finally, a stable (and self-stabilizing) system component is attractive for connection to the larger system in order to create more overall stability and robustness. Figure 1 below illustrates the step-wise approach from a stand-alone system, over a network of systems, to a national grid access.

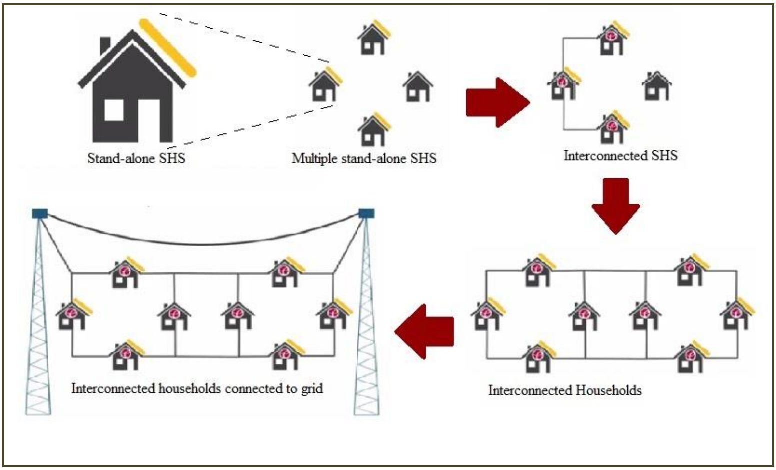

Figure 1: Stepwise approach for swarm electrification.

Source: Micro-Energy Int. 2013

In our understanding, a bottom-up approach is mainly characterized through its user-centricity. Figure 2 shows the main difference to a centralized-planned approach.

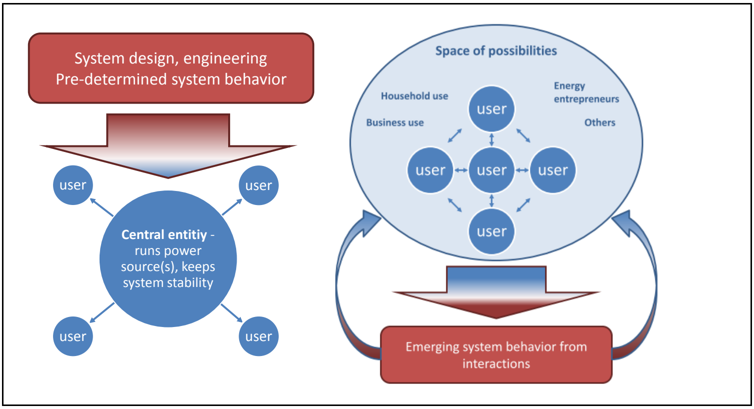

Figure 2: Central design of electricity infra-systems vs. the bottom-up approach

Whereas the latter is designed for a specific purpose and thus rigid and dependent on a single central entity to manage it, bottom-up systems ought to be:

- *non pre-engineered*, meaning it can adapt and reconfigure (through built-in ICT solutions), leading to greater path-independency and the avoidance of legacy infrastructure problems,
- *user-centred*, meaning it does not depend on a single entity or agent to run the system, meaning the user and clusters of users and their interaction will lead to a site-specific emergence[13] of overall system behaviour which in turn opens up new possibilities for the users to act as both consumers and producers of energy while constraining other actions.

When assessing infra-systems, public values come into play as the society itself is concerned beyond the directly affected stakeholders. For a user-centred model, the 4As scheme is a handy tool and is used in the present paper (Sheth and Sisodia, 2012). It consists of the following generic elements:

- Accessibility (e.g. to electricity services)

[13] Emergence draws on one of the main characteristics of complex systems. This is the differentiation between complex (where the behavior of the system results from unpredictable actions and interactions of agents) vs. complicated (driven from an external entity and thus predictable) systems.

- Availability (e.g. continuity of supply and quality and reliability of service)
- Acceptability (e.g. in terms of social and environmental goals)
- Affordability (people should be able to afford the use of the electricity services)

It is clear that the combined creation of these values will face trade-offs triggered by positive and negative feedback loops (as shown in chapter 4), reinforcing or slowing down changes in the system (Mitleton-Kelly, 2003). Furthermore, with increasing complexity, the infra-system consists of more sub-systems leading to more and more diverse interdependencies, again resulting in more feedback loops. The following chapter will further emphasize the concept presented above as well as investigate its systemic properties against common electrification approaches for the exemplary case of Bangladesh based on the 4A's principle.

3 The case of Bangladesh

Bangladesh is one of the most densely populated countries in the world with an estimated population of 156.5 million, 71% of which reside in rural areas (World Bank, 2013). The developmental challenges created by high population density and the acknowledged environmental threats are alarming enough to result in Bangladesh leading the list of countries in the global climate risk index (Harmeling, 2010).

In 1971, the year of independence, a mere 3% of the population of Bangladesh had access to grid electricity, but today that number is increased to almost 60%. In the last couple of years Bangladesh's GDP has been constantly growing at a rate of 6% to 7% (World Bank, 2013). In its development plan titled *Vision 2021*, dated half a century after its struggle for independence, the Government of Bangladesh (GoB) has made the provision for access to electricity and achieving economic and social well-being of all citizens through a low carbon strategy a central goal of this vision (GoB, 2012). Universal access to electricity by the year 2020 with improved reliability and quality is thus the declared goal of the GoB.

Even in the urban areas average grid failure time is 3.5 hours each day. With per-capita electricity consumption of 260 kWh the country ranks among the lowest in the world but is expected to increase significantly (World Bank, 2013). With this growing consumption throughout the country, the demand-supply gap is most likely to widen due to limited capacity and (accessibility of sites for grid extension). It has been acknowledged by now that the dispersed nature of rural settlements and the numerous rivers that crisscross Bangladesh make grid electrification in many areas too difficult, time-consuming and expensive. Decentralized schemes, such as the widely acclaimed SHS program have successfully started to provide basic electricity services (tier 1 and 2) to three million homes (IDCOL, 2014). Direct current (DC) SHSs, currently consisting of a 20 to 85 W_p solar panel, battery and charge controller are presently installed at a rate of 45,000 to 70,000 systems per month through a microcredit scheme carried out by the POs[14]. This significant progress which can be understood as a leapfrogging process, notwithstanding the challenge of rural electrification, remains in the country.

On the macro level, Goldemberg (1998) argues that, in theory, co-benefits in terms of energy poverty reduction and environmental protection can be realized through 'leapfrogging' to more efficient and cleaner technologies in the Global South. This implies that these countries need to skip "the middle rungs of the electricity ladder" that has been identified by Burke on a national level (Burke, 2010). On the micro level, the energy ladder refers to a model where a household's decision making process to substitute or to switch between available fuels varies based on its income (Baldwin 1986). It is important to note here that among the deciding factors is a desire to demonstrate higher socioeconomic status through the usage of technologies that emblematize it.

As a result, a linear transition is fairly unlikely but rather a multiple-fuel model is at play (Masera et al. 2000). This is especially the case where rural and urban perceptions submerge through the frequent movements between the two areas. This is the case in Bangladesh where "a rural-urban continuum" is increasingly becoming visible around the country (Lewis 2011, 22). Unemployment in rural areas, geographical density, high occurrence of remittances and combinations of those are examples that are likely to trigger/enforce this phenomenon. Whereas fuel stacking is based on a reluctance to let go of familiar patterns and habits in the case of cooking, as far as electricity is concerned the decisive factors beyond price seems to be readiness for an uninterrupted power supply (in terms of back-up solution) and compatibility with various end-use devices (complementarity).

Although the sunk-cost principle suggests that decisions should be taken independent of past investment where the cost has already been incurred and cannot be recovered (Mankiw 2000), the partnering organizations (POs), the institutions responsible for installation, payment collection and servicing in Bangladesh, report that users are prevented from adopting new technologies based on previous investments done (e.g. diesel generator; Solar Home

[14] Numbers are taken directly from the monthly PO meeting reports which are not disclosed.

System–when paid off) or future investments planned by third parties (e.g. political promise of grid connection). But then again, field results in Bangladesh speak a different language.

First, there is an increasing number of examples where parallel infrastructures are at play, e.g. new micro-grid connection overlaying diesel generators and SHS alike (Groh et al. 2014b) speaking in favour of the sunk cost principle. Second, records from POs show that the offer to return the SHS upon arrival of the national grid has hardly ever been exercised[15]. Therefore, an infra-system should be designed in a way to allow for non-linear trends in terms of energy source usage.

In addition, another important observation of the Bangladeshi case is that many households with a SHS do not fully utilize the electricity stored in their battery, resulting in a full battery by midday, and thereby limiting the generation potential of their systems by up to 30% (Kirchhoff, 2014). Assuming an average panel size of 50 W_p and three million systems in operation, this results in about 105 MWh of unused surplus electricity per year. At the same time, some households require electricity beyond what their systems can supply, especially during the rainy season, while others cannot afford a complete SHS at all and remain trapped in energy poverty.

A complexity view on this situation suggests that, provided the purpose of the infra-system is the matching of supply and demand, the two above contrasted inefficiencies may be equalized by adding complexity (Tainter, 2011) through connecting stand-alone systems. Other decentralized options comprise mini-grids[16]. Thus far, the only privately-operated large mini-grid in Bangladesh installed back in 2010 is a 100 KW_p solar power plant on Sandwip Island (Khan and Hugue, 2014). The system serves 250 customers and is backed up by a battery bank and a 40 kW diesel generator for supply of electricity during the night, mainly for shops in the market. However, the system has not performed according to expectations and so far lacks profitable operation. Due to its on-time intervention character, it is facing difficulties in adequately catering to different customer types given their heterogeneously emerging demand patterns. As a consequence, parallel infrastructure has started to

[15] Information is taken directly from the monthly PO meeting reports which are not publicly available.

[16] The term mini-grid is used here interchangeably with the term micro-grid. A micro-grid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A micro-grid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode [U.S. DOE, 2012, p. 4. Often mini-grids refer to larger sizes than micro-grids which in the framework of this paper does not appear intuitive as the capacity of the underlying concept is constantly growing.

emerge. As analysed by Tenenbaum et al. (2014), Bangladesh does not stand alone with this experience, so far globally mini-grids have not been able to live up to their expectations. In brief, the following observations have been made based on past and present decentralized system designs:

- not inclusive enough to reach down to the poorest segments (Samad et al. 2013);
- lack of flexibility in terms of usage patterns and payment methods (Chakrabarty et al. 2011);
- demand tends to grow once electricity is available and the pace of growth is hard to determine; productive use is enhanced with larger electrical loads (Mondal and Klein 2011);
- oversized systems are not economically viable; undersized systems might fail to adequately perform and therefore hinder social acceptance and economic development (Mondal and Klein 2011);
- productive use remains very limited, mainly due to a progressive increase in complexity (Rahman et al. 2013).

The latter point is discussed in more detail in Figure 3, focusing again on the three step approach of swarm electrification but this time in a graph indicating the degree of complexity on its x-axis and tier level on the y-axis.

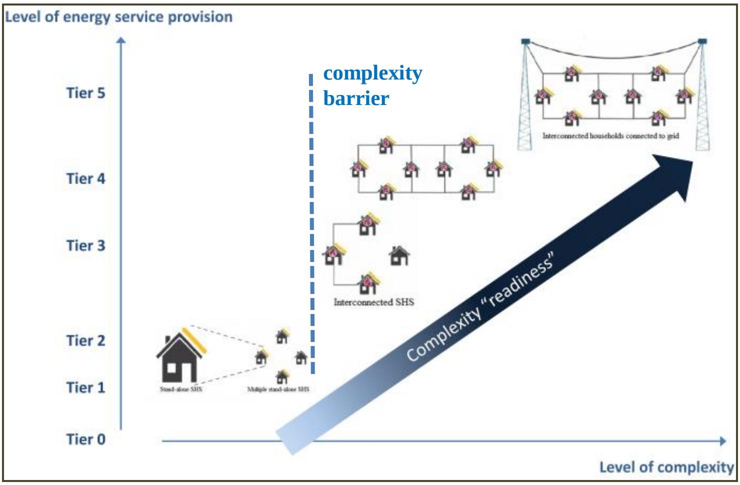

Figure 3: Swarm electrification steps in the context of tier based service provisions and added complexity

Single artefacts, such as a SHS, are usually affordable enough to access tier 1 and 2. The transition from tier 1 to tier 2 occurs with only little increase in complexity. To step-up to tier 3 and higher poses several challenges indicated here by the complexity barrier. It is often the step where single-device artefacts (single lamp for a tier one level) as well as slightly more sophisticated systems such as a SHS are no longer sufficient and need to be replaced by interconnected systems. This system interacts with the user layer, but the number of agents per system involved remains minimal.

In the given case of Bangladesh, this step has proven to be critical, as for the large amount of people that already possess a SHS. It should not be the goal to put additional electrical infrastructure layers but rather to aim for an integrated approach in which the existing resources are used for direct feed-in, thus avoiding the problems of a legacy infrastructure that is no longer in use. To stop using a SHS or at least to have it at most for backup purposes while simultaneously paying for a connection to a mini-grid, is in most cases economically inappropriate. Furthermore, interconnected systems such as mini-grids add not only technical complexity that has to be dealt with but also raise network and interdependence issues (distribution and usage, payment for maintenance, etc.) in the socio-economic sphere. Finally, the transition from tier 4 to 5 then has an even greater increase in complexity as decentralized and centralized infra-system are entering the same place with possible competition. Here, an overlay of networks with multi-role agents is at play.

In rural areas of Bangladesh, settlements tend to occur in different forms of clusters (Khan, 2012). The smallest type consists of very few households (3-5) surrounded by fields. The medium version comprises between 6-20 households with ponds, some open space surrounded by fields and wetlands. Larger clusters (>20) include a marketplace sometimes with one or two other additional structure(s) such as a school or a government office. Often a great part of these households have already acquired a SHS. This makes it an ideal environment for a swarm electrification scheme, as discussed in Section 4.

4 Drawing from the Bangladesh experience: implications for a complexity-embracing approach

The swarm electrification approach suggests interlinking multiple households with individual stand-alone energy systems and households with no electricity access. This creates a growing micro-grid where interconnected participants can buy and sell energy to each other, or to a local or national grid, according to their necessities, thereby becoming energy consumers and producers, so-called *prosumers*. Thus, swarm electrification advocates a bottom-up, demand-driven electrification approach with decentralized generation and storage. The resulting network is targeted to be a DC grid that can facilitate trade and increase usage flexibility and reliability beyond the status quo of one-off systems. The theoretical advantages such as better system performance due to better battery recharging cycles, more flexible usage of electricity, better system integration and opportunities for increased income generation through acquisition of larger capacity panels (and batteries) are reflected in the evolutionary development across the different tier levels. In terms of the ability to cope with the characteristics of socio-economic complexity increase, the concept aims to overcome the complexity barrier and incorporates the tier 2 systems for better economic viability of the new grid. These systems achieve their robustness through usage of ICT.

With the recent advances in smart grid technologies as a consequence of the convergence of energy and ICT, such a bottom-up interconnected electrification approach as described here can become feasible (OECD/ IEA 2011). Therefore, the ex-ante incorporation of complexity-handling ICT not only enables systems with respective controllers to connect to the grid but actually attracts the national grid (and thus the ultimate tier) to connect to them once they reach critical size. At all stages the agents in the model are empowered to consume electricity from the micro-grid as well as feed electricity into the micro-grid thereby generating direct income[17].

The interconnection has the potential to create synergy effects. The emergence of macro-patterns through the connection of people and technology triggers the conversion of the SHS from a mere energy source to a business-enabling vehicle, but at the same time, the process increases interdependence and may lead to more complex patterns. These aspects need to be taken into consideration at the device layer where smart devices can provide mechanisms for local control and as well as dynamism (Grijalva and Tariq 2011). This control unit can be referred to as the system communication controller, robustness controller, energy flow manager or monetary flow manager.

The key aspect here is that it can be easily (re-) programed in order to account for unpredictable behaviour which may cause instability. Unlike traditional micro-grid approaches, there is a dynamic participatory inclusion of community members based on their existing equipment assets. A new system is built based on a myriad of existing sub-systems. As each agent can also act independently, varying degrees of the quality/health of the systems do not interfere. Utilizing systems that are already existent in a particular household or business helps to minimize challenges associated with generation and

[17] For the details of the swarm electrification approach, especially regarding the financial and delivery model, please refer to Groh et al. 2014, p. 5-9.

storage sizing basically taking it from a complicated task to a complex system, while allowing the agents in the infra-system to share power, thereby balancing out mismatches over time.

By forming a village-scale micro-grid connection through the network of electricity-sharing homes, the agents make use of their differentiated energy generation, storage capacities and consumption patterns to allow for a more efficient and consistent electricity service for all involved: both for SHS-equipped as well as non-equipped households and businesses. This again adds complexity but also a significant amount of benefits in terms of energy inclusion.

Village-level micro-grids that were built from the bottom up can generally be able to serve high-power appliances for productive use. However, they face the problem of legacy infrastructure (electrical wiring) due to the assumable concentration on low-investment equipment in the first development stages of the system. As such, unlike traditional micro-grids, the swarm model might need to tackle the challenge of limitations that occur when the technical system remains dependent on the existing SHS cabling and voltage levels, thereby retaining the instantaneous power draw limits of the SHS even if the overall energy availability and system performance increases. This represents the downside of the usage of existing resources and infrastructure, even though in this case the infrastructure investment is considerably lower.

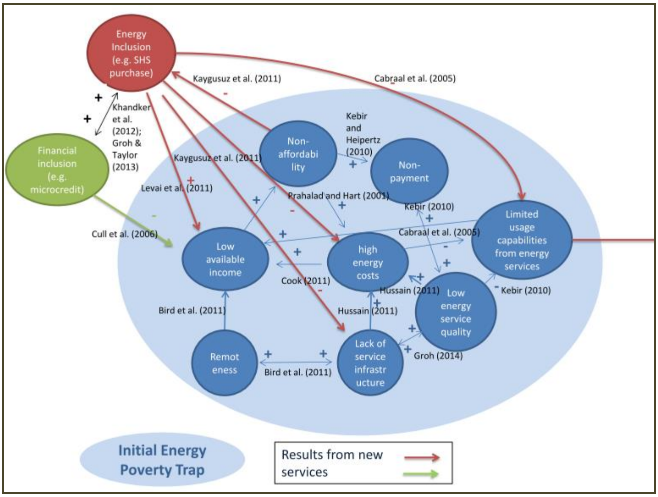

Figure 4: Household and microbusiness based feedbacks loops

By applying the 4As criteria to the concept, a central public value comes into play set out by the GoB in its Vision 2021 to achieve universal electricity access. In order to be able to adequately assess the swarm concept against this goal, feedback loops are analysed through graphical illustration in Figure 8 which illustrates the impact of a combined energy and financial inclusion measure, which seems to be mutually related as debated in Khandker et al. (2012), as well as in Groh and Taylor (2013), on an existing vicious cycle of a low income combined with high energy cost and limited usage capabilities from poor energy services, in short a “energy poverty penalty” (Groh 2014, 83).

Tier 1 and 2 provision of electricity services cover basic needs but also give the people *a taste for electricity*, resulting in higher electricty demand patterns as shown in Figure5 as well as observed by various authors. A SHS case study in Zambia displayed that energy demand in the household increased with time, leading to over-usage of the systems (Gustavsson 2007). For mini-grids the same applies: a study in India demonstrated that "people gradually started to look for more electricity" (Ulsrud et al 2011, 299). Another study from China demonstrated a significant drop in service time from 12 to 3 hours per day due to over-usage (Shyu 2013).

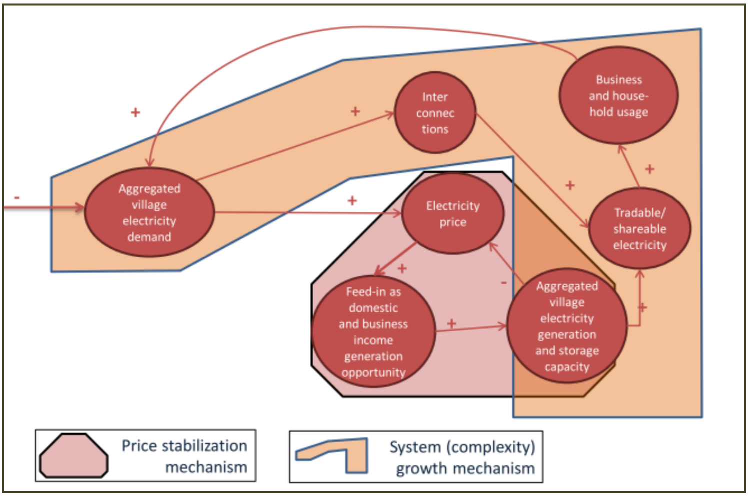

Figure 4: System feedbacks on village level

Figure 5 distinguishes between a system complexity growth mechanism which has been earlier described along the tier framework in Figure 4 and a price stabilization mechanism. In the latter, it is important to note that depending on the incentives set through dynamic pricing there are two possible dynamics. First, it can stimulate higher demand which can be realized system-internally but also through extension to new consumers which translates into additional electrification. Second, it can trigger entrepreneurial behaviour aiming for surplus generation capacity that can be traded. In order to comply with the 4A's scheme, it is, therefore, crucial, to manage the trade-off between electricity prices low enough to comply with inclusion targets but also high enough in order not to stall the entrepreneurial activities of net producers following a type of distributed energy services company model (Bardouille and Muench 2014). In order to account for this, supply and demand patterns should be monitored closely. The complexity growth mechanism may lead to catastrophe (e.g. the breakdown of social ties and the subsequent breakdown of physical connections) unless prevented which may be possible through the option of an independent island mode that can avoid harmful positive feedback loops.

The system intends to build on current systemic properties of SHS as the core subsystem of the swarm approach counting on various convergence trends. First, it builds on a mobile retail network in order to facilitate trade and exchange of electricity[18]. Second, it further spurs innovation in the converging trend of energy access and ICT by smart grid design. Third, local system management may be taken over by the partnering organization of the existing scheme (job market convergence). These proposed convergence trends attempt to lead to a high degree of *accessibility*, and *acceptability* as the approach builds on existing and familiarized technology and service delivery concepts for the communities.

A key argument in favour of *accessibility*, though, is the evolutionary process of grid-readiness. In the mechanism presented, the micro-grid is based on organic growth, in the sense of a usual tendency of the (sub-) systems to grow as long as the right price signals and economies of scale are in place. Hence, once people become a critical mass, representing a stable subsystem and have reached close enough to the national grid, win-win situations can be created where previously, individuals were deemed too 'economically unfeasible' to obtain grid connection.

Adding a stable subsystem (with embedded generation and storage capacities) to the grid implies more robustness to the grid itself, and additional power sold through only one connection node whereas the swarm agents climb to a tier 4

[18] Refer to (Groh et al. 2014a, p. 8f.) for details.

or 5 level. *Acceptability* beyond familiarity of the existing subsystems can be increased through a modicum of on-site controls to decide when they are operating in grid-connected mode or island mode. This further avoids interpersonal conflicts.

Money exchange is organized through a system of digital credits and debits managed by the network of swarm controllers and with payments handled only by neutral mobile phone retail points. The swarm approach may indeed increase *availability* by climbing up the tier stages at the same time introducing further complexity into the system and increased access to daily and seasonal energy through a balancing network. *Affordability* is crucial in terms of a dynamic pricing scheme but can equally be addressed through existing and largely successful microfinance schemes for high upfront payments for electricity equipment. This also implies that the ownership of the growing network is with the people themselves, as well as management which may be performed by a democratically legitimized community authority acting as safety regulators. The compliance with the 4A's scheme is not considered as static in this scheme but as a process of continuous adaptation, as described earlier by Tainter as the key aspect of a sustainability criterion (Tainter 2011).

5 Conclusion

The authors look at the process of electrification and power systems from a systems complexity angle. Contemporary approaches do not seem suitable or viable for actors in the overall system (especially grid operators) or fail to provide the needed services in the long term. At current, SHS as individual power producing units show lack of scaling capacity in the long run. They are unlikely to exceed energy services marked as tier 2 of the UN framework. On the other hand, mini-grids, meant to fill this gap, are struggling to meet the potential and the demand of the users in a sustainable manner. Overall, describing these different approaches as complex systems and analysing their characteristics using infra-systems terminology, we conclude that both, centralized and decentralized approaches have some main patterns in common:

- Current systems are engineered to meet a specific demand. This follows the rules of engineering design as we know it. However, this does not take into account the inherent dynamics of the process of energy access, that is, rising demand over time. This demand increase does not follow rules, contrarily it remains (as typical for complex systems) unpredictable. Stand-alone systems are unable to cope with this for the reasons provided throughout this paper, unless they are designed for upgradability. Micro-grids can be designed for a high assumed demand in the future. However, this way of designing a grid conflicts with expectations for financial sustainability.

- Complex systems, as the national grid as well as mini-grids, that are exogenously designed have to cope with legacy infrastructure when they want or need to adapt to new circumstances. This inhibits change by making it prohibitively expensive to upgrade or extend.
- As complex systems are critically determined by interactions of agents in it and the emergence that arises from this, they would need to incorporate flexibility in operation as prediction is impossible. This seems not to be the case in present schemes.

Consequently, we found that a sustainable electrification approach that aims at meeting the needs and capabilities of all agents involved should be embracing complex behaviour of the system rather than shielding against it. Engineering and design must focus less on load estimation and supply side layout and rather move towards incorporating the possibility of flexibility, upgradability, modular extension and stabilization into the system, no matter its size or concrete appearance. Concretely, for a future power system this requires the ability to:

- use legacy infrastructure (such as old SHS , diesel gen-sets, etc.) in order avoid production of sunk costs, where applicable;
- let users act in multiple spheres, as prosumers of energy and its services, thus putting the core agents into the core positions with core responsibilities;
- stabilize itself through constraining and incentivising user actions (through built-in ICT), this includes the communication of monetary, information and power flows;
- grow the system without a single central entity to manage processes, thus reducing the need for exogenous input while ensuring the users can climb up the energy ladder gradually and possibly in a non-linear way;
- act as a stable subsystem in the national grid, for the benefit of both the users (which will access tier 5 probably only through this) as well as the grid (which connects to a self-stabilizing subsystem).

In a next step, we analysed the concept of swarm electrification (SE) through the lens of complex systems and its potential power to meet the systemic properties laid out above in a theoretical case study for Bangladesh. The findings are as follows:

- SE can use existing infrastructures and increase the efficiency of its use (better usage of production and storage capacities) through the interconnection of SHS households (approx. 3.5 million in Bangladesh). Therefore, adding value to single agents by connecting them (physically, socially and economically) in a network system. This shows that embracing complexity can indeed yield positive outcomes while the “negative” effect of increased coordination effort is limited through convergence with ICT solutions in a micro-controller and existing mobile payment infrastructure;
- SE is able to provide added value and access by establishing a subsystem of trade and exchange, which then places the agents at the core of the system, enabling them to act as prosumers;
- SE, to a certain extent, is able to grow the overall system for the benefit of accessing the higher energy tiers available. However, we found that the original cabling and the respective possible load attachable, is likely to delay or even inhibit a direct jump to tier 4/5 levels (high loads for productive use) and thus poses a legacy infrastructure problem;
- SE incorporates the possibility to attach and detach loads and sources to the respective controllers, hence opening spaces of possibilities in a dynamically changing environment (unpredictable emergence of system behavior is not problematic for system performance).
- SE reflects the need of non-linearity in energy usage patterns, especially in terms of energy source neutrality.

Although the concept has a built-in opportunity for scalability, the issue of replication potential for other less densely populated areas and countries needs further research. However, in general, the concept seems to be applicable in all off-grid areas where a certain density of social and economic activity is present. Due to SE remaining a theoretical model thus far, as a next step, dynamic growth models testing the assumptions need to be computed as well as field tests conducted with close monitoring.

Looking at energy access efforts through the lens of system complexity can reveal strengths and weaknesses of approaches ex-ante and ex-post. In the light of many unsuccessful approaches in the past, there is a strong need to avoid similar pitfalls in the future. The authors hope that this is rather a starting point in a new discussion than a final statement. Based on our analysis, we argue that future infra-systems must be treated complex rather than complicated. The need for the incorporation of complexity with all its characteristics might indeed be larger than the need for precise system layout from the beginning.

Therefore, systems need to be built bottom up avoiding "unhelpful forms of top-down intervention" (Lewis, 2011, p. 196). This indicates that the electricity infra-system in the Global South has the chance to use the convergence of ICT and energy, coupled with innovations in both areas, as well as leapfrog technology by avoiding legacy infrastructures. The tools and concepts to design adaptable, robust, decentralized, democratic and socially just electricity systems are in place.

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A review of mini-grids in Kenya

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Abstract: With only 35 % of Kenya's population connected to an electricity supply (MoEP 2014), the country is utilizing different strategies to increase this figure. Challenges of grid extension, particularly in rural areas, have created a market for mini-grids. Potential sites for mini-grids in the country have already been mapped (both Off-grid and Greenfield). Since most of the existing mini-grids are owned by the Rural Electrification Authority (REA), there is need for fast tracking of the implementation by incorporating new players into the market. This paper analyses existing literature on mini-grids in Kenya and focuses on technological change (site selection criteria and examples of hybrid systems), ownership structures and implementation challenges.

1 Introduction

Kenya, like most countries in sub-Saharan Africa, has a low electrification rate. Only 35 % of the population is connected to an electricity supply (MoEP 2014).The electrification rate is much lower for rural areas which face a myriad of problems and challenges and as a result lag in electricity access. Various planning frameworks to increase electricity access are being used. These are integrated rural development (electricity is combined with infrastructure such as roads, schools and health facilities), area coverage (reaching as many customers as possible), grid extension (focusing on households near the grid), isolated generation (mostly for remote regions) and intensification (increasing connections in electrified areas) (Kirubi, et al. 2009; Parshall, et al. 2009).

While some authors advocate the extension of the grid in rural areas of Kenya due to high population density (Parshall et al. 2009), this is proving to be a challenge. The constraints; dispersed rural population, low purchasing power, high cost of rural electrification projects and high operating costs of rural grids make grid extension in remote areas uneconomical. This is compounded by the high connectivity fee which, though subsidised by the government, is still beyond the reach of many rural people (MoEP 2014; Kirubi, et al. 2009; Yadoo 2012).

Mini-grids have been used for a long time as an alternative to electrify such remote regions. According to Tenenbaum et al. (2014) mini-grids are traditionally defined as "a stand-alone, low-voltage distribution grid that is supplied with electricity from one or more small generators connected only to the isolated mini-grid." Mini-grids can also be interconnected with the utility grid but have the ability to operate autonomously. The MoEP (2014) mentions only two types of grid network: the national grid and the off-grid network. As such mini-grids have been categorized under off-grid networks.

This paper analyses existing literature on mini-grids in Kenya and focuses on technological change, ownership structures and implementation challenges. The first part reviews technology in terms of site selection criteria followed by examples of hybrid systems. The second part looks into the ownership structure and implementation agency whereas the final part highlights some of the challenges in implementing mini-grid projects.

2 Technology

2.1 Site selection

Proper selection of the mini-grid site is essential if the project is to be sustainable. Murunga, et al. (2014) advocates that new mini-grids in Kenya be constructed at sites greater than a 50 km radius from existing or planned power sources since within this radius it is cheaper to use grid-power. Energy demand is also an important part in site selection. Da Silva, et al. (2011) illustrates a fundamental analysis of the market, showing the demand target. The market pyramid in Figure 1 shows income classes in which the target demand for the mini-grids can occur. The income classes are subjective and depend on the region being analysed. According to Da Silva, et al. (2011), the target for most energy services is the Middle-class or the Rich while the extreme poor at the bottom of the social pyramid are being neglected.

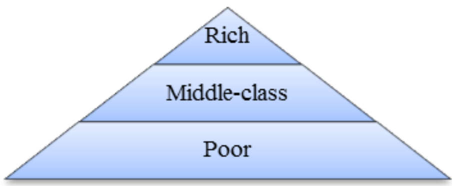

Figure 1: Social Class

Source: (Da Silva, et al. 2011)

Socio-economic conditions of the communities help to determine the ability and willingness to pay. This also helps in identifying income generating activities that will assist in ensuring productive use of electricity; a key factor in ensuring cost recovery of the project. Mini-grids with low productive use of electricity have lower load factor since electricity is mostly used in the evenings (Da Silva, et al. 2011; Kirubi, et al. 2009). Security is another key aspect of site selection and parameters in the Kenyan context including clashes, cattle rustling and ethical issues involving common property also need to be analysed (Murunga, et al. 2014; Da Silva, et al. 2011).

2.2 Shift to hybrid system

Before 2010 most of the mini-grids in Kenya used diesel to generate electricity. As of 2013 there were 15 mini-grids operated by Kenya power having a capacity of 13.6 MW. The high operating cost of these systems caused by fluctuating and high diesel prices, local pollution, GHG emissions and the challenges of transporting the diesel to remote areas resulted in the mini-grids being unsustainable. Thus there was advocacy to convert them to hybrid systems by incorporating renewable resources, especially wind and solar, to 30 % (SREP 2011). Therefore to reduce operational costs, seven mini-grids have so far been converted to hybrid systems (Gichungi 2013). The installed capacity for the systems are shown in Table 1 with calculations showing renewable energy (RE) share being less than 15 % against an initial target of 30 %. The energy mix for each mini-Grid is shown in Figure 2.

Table 1: Installed mini grid hybrid system

Station	Capacity Diesel (kW)	Capacity Wind (kW)	Capacity Solar (kW)	No. of customers	Capital Cost (USD/kWp)
Lodwar	1440	0	60	1610	5.103
Mandera	1600	0	300	3270	7.114(plus 11 kV line)
Marsabit	2400	500	0	2194	
Hola	800	0	60	1300	6.75
Merti	138	0	10	287	10.433
Habaswein	800	50	30	779	8.263
Elwak	360	0	50	535	7.343

Source: (Gichungi 2013; AHK 2013)

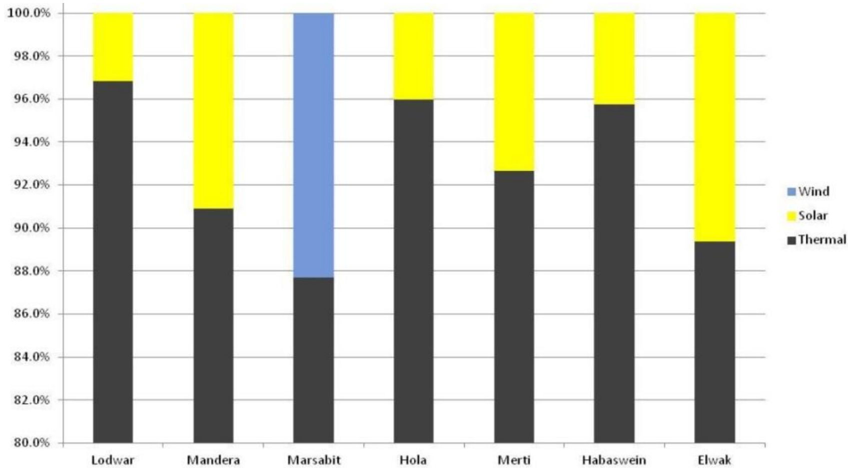

Figure 2: Energy mix for the hybrid mini-grids

Source: (Gichungi 2013)

A complete shift to green mini-grids, that is the use of only renewable resources, is a new phenomenon yet to be implemented in the country. Potential sites for the mini-grids and green mini-grids in the country have so far been identified.

3 Ownership structure/implementation agency

Different institutional structures have been used in mini-grid provision in Kenya. Community based mini-grids which are mostly funded by development agencies such as GiZ, DANIDA and JICA exist in other particularly off-grid regions of the country. These have the advantage of community involvement in the operation and maintenance of the system thus creating a sense of ownership and empowerment in the communities. Thiba, a 135 kW mini-hydro supplying 180 households, has a cooperative management structure. The Kipini mini-grid serves 120 households the power supply is limited to 4.5 hours per day but usable for major applications. Kathamba, a micro-hydro that serves 55 households is mainly used for lighting (CAMCO 2010).

The rural electrification authority (REA) set up in 2006 to accelerate rural electrification, is in-charge of the public mini-grids. REA took over some of the community based micro-grids such as the Mpeketoni micro-grid. The benefits of REA management were highly subsidized, 24 hour reliable electricity supply. Before the ownership change, the mini-grids operated from 5 am to midnight (Kirubi, et al. 2009).There have been other instances where non-governmental organization (NGO) micro-grids have requested the main power utility to take over the management due to poor grid network and maintenance and expansion challenges (Gichungi n.d.).

Nevertheless the solar industry, which is market driven, has thrived in the country with minimal governmental support. The recent call by the World Bank for the study of the mini-grid potential in the country and involvement of the private sector shows the need for a complimentary shift in the implementation of mini-grids (The World Bank 2015). Mainstreaming private sector involvement in mini-grid projects through e.g. public-private partnerships can fast-track the implementation and thus the provision of electricity in the off-grid regions.

4 Implementation challenges

4.1 Market barriers

Solar energy has been perceived as a source of power for the off-grid poor and according to AHK (2013) this has two repercussions, namely (a) putting a ceiling on the development of Solar PV for commercial markets and (b) the current low-cost access market has promoted the use of lower quality products in the country.

4.2 Frequent breakdowns

Frequent breakdown of the mini-grids is a major problem that affects their sustainability and acceptance by local communities. For example, the Thiba mini-hydro has been experiencing turbine problems since its inception. This has been causing frequent blackouts and the need for constant repair work exhausts most of the generated revenue (Yadoo 2012). At the Mpeketoni mini-grid long lead times of up to seven months before the generator set was repaired caused the power supply to be unreliable (Kirubi, et al. 2009).

4.3 Information barriers

There is a lack of adequate information on RE opportunities and financing options available to investors. The information is scarce for local communities located far from towns, thus their involvement in local RE projects is limited.

Benefits of community involvement has been highlighted by numerous authors (Kirubi, et al. 2009; Barnes and Foley 2004; Da Silva, et al. 2011) but the degree of involvement and the role played by the communities has been left ambiguous.

4.4 Regulatory barriers

Currently the country does not have a specific regulatory framework for mini-grids. The current PPAs are designed for large projects with an approximately three years licensing time. This is prohibitively long for small projects. Procedures for the connection of mini-grids to the national grid when grid extension occurs are not yet in place thus risk of uncompensated takeover is a major deterrent for investors (ECA ;TTA;Access Energy LTD 2014).

4.5 Financial barriers

There is low return on investment. In the case study of Mpeketoni mini-grid the cost recovery for 12 years was approximately 79% with the operating deficit being covered by the main donor (GiZ/GASP) (Kirubi, et al. 2009). There is lack of diversified business models to address the high upfront investment costs of the mini-grids. Energy Service companies (ESCO) which can either supply useful energy or energy savings to the end user are yet to take be implemented in the country. Engaging ESCO helps in outsourcing the upfront investment cost of the project as shown in Figure 5.

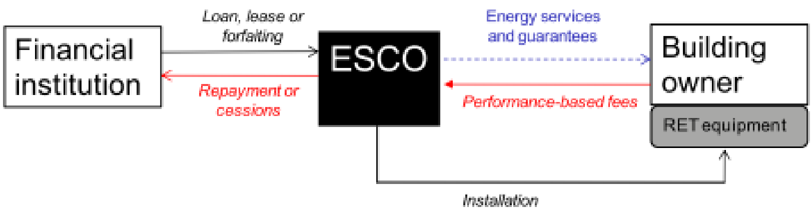

Figure 5: ESCO business Model

Source: (Würtenberger , et al. 2012)

5 Conclusion

This paper described mini-grids and highlighted the challenges of grid extension that have made this form of network access strategy uneconomical.

This has created a market niche for off-grid electrification using mini-grids. Key aspects of site selection for the mini-grid were reviewed and it has been advocated that mini-grids are constructed outside the 50 km radius of national grid. The market segment showed that most renewable energy projects target the middle-class. Successful case studies of diesel projects converted to hybrid system were highlighted. Ownership structure revealed that Kenya implemented various models but the private ownership model is yet to take root due to the highlighted challenges.

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Institutional capacity of rural electric cooperatives-does it also meet financial inclusion?

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Abstract: Financial inclusion and access to electricity are high on the political agenda of the post-2015 development priorities. Mini-grid systems attract a lot of attention regarding their potential contribution to rural electrification and development. Value-based organizations such as community-based organizations or rural cooperatives can occupy an important position in empowering information and catering for the needs of rural people without access to electricity and formal financial services. The proposal describes a research project that will analyze the institutional capacity of community-based organizations or rural electric cooperative of renewable energy based mini-grid systems to meet two major major development objectives at the same time: enabling access to electricity and expanding their services towards formal (micro-) financial services. The research will be based on a case study in the Baglung district in Nepal with information drawn from structure reviews and capacity assessments. Needs and strategies for the desired future capacity will be identified.

1 Introduction

Access to reliable modern energy services is crucial for sustainable economic development. It is therefore high on the political agenda of many countries in the world. In 2015, the target year of the United Nations Millennium Development Goals, access to electricity is still a major challenge. More than 15% of the world's population needs to be supplied with electricity. In developing countries one in five persons lacks access to electricity. In rural areas the situation is even worse; more than a third of the population lacks access to electricity (IEA 2014). By 2030, the target date set by the UN to achieve universal electrification, there will be more people with access to electricity. However the IEA estimates that even then more than 10% of the world's population will not have access to electricity (IEA 2013). Besides conventional grid extension, off-grid technologies play and will continue performing an important role in rural electrification. Village-scale energy systems, mini-grid systems, are especially predestined for rural electrification and development (Bhattacharyya 2014).

Financial inclusion[19] is another important post-2015 development priority on the agenda of global and national policy makers because of its potential to promote economic growth and to reduce poverty and income inequality (Bruhn et al. 2009); UNCTAD 2014). The reasons for financial exclusion and lack of electricity are diverse. Lack of information regarding the creditworthiness and behaviour of financial services customers and long-term profitability of rural power supply is one of the main challenges causing the hesitation in investment in rural areas in developing countries (Valencia, et al. 2008; ESMAP 2001; Allen, et. al 2012).

Value-based organisations such as community-based organisations or rural cooperatives can occupy an important position in empowering information and catering for the needs of rural people without access to electricity and formal financial services (UNCTAD 2014). In 2012, the cooperative model caught global attention because the UN announced the year of cooperatives. However, the attention to their role in meeting the triple bottom line of sustainable development (economic development, social justice, and environmental protection) still remains limited (Wanyama 2014).

This article describes a suggested research project that intends to analyse the institutional capacity of community-based organisations or rural electric cooperatives of renewable energy based mini-grid systems to simultaneously meet two major development objectives: enabling access to electricity and expanding their services towards formal (micro-) financial services. The research will provide details based on a case study in the Baglung district in Nepal (see also Pandey in the present publication) with information drawn from structure reviews and capacity assessments. Further, SWOT-Analyses will allow identification of the main Strengths, Weaknesses, Opportunities and Threats (SWOT) of electric and financial cooperatives in Nepal to meet access to electricity and financial inclusion. Needs and strategies for the desired future capacity will be identified. It is expected that this research has a significant practical implication for planners, regulators and investors. Additionally, fertile ground for future research is identified.

2 Background

Remote areas in developing countries that are structurally weak and difficult to access are especially affected by lack of electricity. High investment cost, difficult terrain, small scale operation, dispersed population and low purchasing power very often impede rapid extension of the national grid.

[19] The World Bank (2013) defines financial inclusion as „the proportion of individuals and firms that use financial services".

Nonetheless, main grid extension is still the most favoured way of rural electrification in developing countries (Bhattacharyya 2012, 264). However grid extension alone will not be sufficient to make progress towards the universal access goal by 2030. In fact, contributions to be made by off-grid energy systems are projected to be around 60% (IRENA 2013, 14). The estimations from the IEA are even higher, forecasted to be up to 70% (IEA and OECD 2011, 21). This highlights the importance of off-grid systems in rural electrification. Off-grid solutions are differentiated between two forms of power supply: stand-alone systems and mini-grid systems. Individual product-based systems such as SHS (Solar Home Systems) usually meet a smaller scale of demand (e.g. for household purposes such as lighting) and are particularly suitable for scattered households.

In contrast to these solutions, mini-grid systems can vary in scale and offer more reliable access to electricity since the power generated comes from a diverse range of small local generators. They can offer sufficient power for both household and productive activities. Additionally, where based on renewable energy sources, these systems can support climate change mitigation efforts without threatening long-term development objectives (Jakob 2014). Therefore, mini-grid systems are becoming increasingly important in promoting sustainable economic development (Bhattacharyya 2014).

Generally, different business models can be applied for mini-grid systems. In many cases utilities do not want to invest in mini-grid systems because they fear the high transaction costs (Bhattacharyya 2012). Thus, lack of financial resources to establish a mini-grid system is a frequent problem. Village electrification committees or rural electric cooperatives can play an important role in implementation, operation and maintenance of mini-grid systems. Being the consumer and supplier (prosumer) as well as non-profit oriented facilitates understanding and addressing the communities' needs more easily (Williams, et al. 2006). Electric cooperatives "can be a willing, efficient and effective means of extending and managing rural electricity services" given certain circumstances (e.g. regulatory framework, appropriate tariff structures, administrative controls, significant amount of guidance and training) (Yadoo, et al. 2010; Suwannakum 2007). This type of business model for rural electrification has been successfully implemented in several developing countries (e.g. Bangladesh and Costa Rica) as well as in developed countries (e.g. the United States) (Barnes 2007).

On the other hand, financial inclusion is crucial for sustainable economic development because of its potential to promote economic growth and to reduce poverty and income inequality (Bruhn, et al. 2009; UNCTAD 2014). Half of the world's adult population has no relationship with formal financial networks (The Worldbank 2014a). In rural areas of developing countries the share of people that lack access to formal financial institutions is higher than in urban parts (UNCTAD 2014). The reasons for people or firms not using financial services are diverse. Among these are the lack of regular and substantial income, costs, travel distance and documentation and/or collateral requirement (Lakshmi, et al. 2013; The Worldbank 2014a).

Financial cooperatives can be a key driver of financial inclusion and local development because of their proximity to the local community, their organisational structure, relationship with the informal economy and the development of innovative products or services (e.g. microfinance) to meet “unbanked” segments of the population (Ojong 2011).

3 Research Problem

The Nepalese finance sector started to liberalize in the 1980s (Ozaki 2010). Notwithstanding, Nepal is still one of the poorest countries in the world with a per capita gross national income of $730 in 2013 (The Worldbank 2014b) and one of the lowest values and positions (value 0.540 and rank 145 out of 187 countries) in the UN Human Development Report (HDR) 2014. Since the beginning of the liberalization, the finance sector has developed and despite the small size of the economy it is nowadays relatively diversified (Ozaki 2014). There are more than 30 microfinance institutions; thereby the major part of microfinance lending is attributed to rural banks. Although the cooperative sector in Nepal is huge the share of cooperatives in the gross loan portfolio of the microfinance industry (ca. 5% compared to more than 50% of rural banks in 2011) is much smaller compared to the share of rural banks, but this has been growing steadily in recent years (Kumari, et al. 2012, 6)). However although under the “deprived lending scheme”, all banks are obliged to allocate 3.5% of their total portfolio on loans to micro and small borrowers (Ozaki 2014, 25), approximately 75% of the population lacks access to financial services (Demirguc-Kunt, et al. 2012, 51)).

The electricity sector also faces many challenges. Difficult terrain, poor socio-economic development, an on-going energy crisis and weak policy environment complicate rural electrification projects (G.K. Sarangi, et al. 2014). Therefore, conventional grid extension is very expensive (Mainali, et al. 2012). Although the Nepalese electricity sector underwent several important reforms since the 1980s (Ozaki 2014), lack of electricity is still a major problem in Nepal. Only 76% of the population has access to electricity. In urban areas there is nearly total access to electricity (97%), whereas in rural areas 28% of the population is yet to be supplied with electricity (IEA 2014).

However, it should be considered that reliable electricity access is constrained to less than 8hours per day (Sovacool, et al. 2013). Therefore, off-grid electrification models such as micro- (or pico-) hydro, solar or wind based systems are of essential importance.

Micro-hydro based systems are not a new phenomenon in Nepal. Their history goes back to the 1960s. Earlier micro-hydro based systems were built to support small-scale loads, e.g. for agricultural activities. Since then these systems have developed steadily, also in terms of load. Today, there are approximately 1000 micro-hydro based systems, offering altogether about 19 MW. The major part (about 95%) is owned by communities, whereas 5% are owned by the private sector and a few by the National Electricity Authority (NEA) (Ghale BB, 2013).

One of the most important developments in the electricity sector has been the legalization of community-based organisations (CBO’s) into electric cooperatives by 2003. Since then, with formal registration as cooperatives, CBOs were allowed by law also to lend and to “use the profits generated from electricity sales to offer their members micro-financing for small-scale income generation activities” (Yadoo, et al. 2010, 4). Since grid extension is very expensive especially when approaching the off-grid system, the business model or investment in off-grid projects is threatened and new approaches for rural electrification are indispensable. For this reason, the government, international donors and other stakeholders support the creation of mini-grid systems. When interconnected to the main grid, the mini-grid is able to optimize electricity generation, counterbalance (main) grid instability and generate income (Shakya 2013, 6). The income generated could be used to offer microfinance services and thereby contribute to financial inclusion.

In Nepal, the first interconnected mini-grid system was implemented in 2012 in the Baglung district. Six micro-hydro power based systems were connected along the Kalung Khola River and the system is operated and managed by the local community. It is planned to connect the mini-grid system to the main grid, and a power purchase agreement with the National Energy Authority (NEA) is also envisaged (Shakya 2013, 7-8)).

4 Rational of the Research

A literature review revealed that electric and financial cooperatives in developing countries (including Nepal) have been the subject of many research studies and publications. But the major part studied the social, (socio-) economical, institutional and organisational aspects of these organisations separately (e.g. Yadoo, et al. 2010; Jamison 2005; Zeuli, et al. 2004; Turtiainen

2008; Bezboruah, et al. 2014). Additionally, there is vast literature on the role of (micro-) finance in financing rural electrification projects based on renewable energy (e.g. Altawell 2012; Bhattacharyya 2013; Moner-Girona, et al. 2012; Ottinger, et al. 2014; MacLean, et al. 2007) and different business models of mini-grid systems adopted across the world have been discussed extensively in many studies (e.g. Tenenbaum, et al. 2014; Bhattacharyya 2014; Zerriffi 2007; Krithika, et al. 2013). The assessment of the institutional capacity of Nepalese community-based organisations or the electric cooperatives of renewable energy based mini-grid systems to expand their services towards (micro-) financial services is still pending.

5 Theoretical Foundation

According to the neoclassical theory of finance capital, markets are characterized by their perfection. Acting economic agents do not have personal, spatial or temporal preferences in product supply and demand. Perfection allows them to make funding decisions fully informed and rationally (Dietrich 2007, 66f.). Market structures are designed such that homogenous goods can be changed under perfect competition, complete market transparency and without barriers to entry. Information symmetry and efficiency allow the exchange of goods without costs incurred for information gathering, contract design and enforcement (Schefzyk 2000, 103ff).

The price mechanism, in a credit market the interest rate mechanism, matches supply and demand. Thus market equilibrium is achieved. The match of supply and demand is attributed to maximize social welfare (Petersen 2007, 309). In particular, the underlying assumptions of full competition and information lead to the enforcement of the “good qualities” and to the suppression of the “inferior qualities” in the market (Cf. ibid). At this point, the “pareto principle” is often applied to evaluate the allocative efficiency of the market.

In the sense of the first fundamental theorem of welfare economics, a resource allocation of a market under full competition, where externalities are absent, is called “pareto efficient” when no “reorganisation and action in the market could increase the benefits or the satisfaction of an individual without sacrificing the benefits or satisfaction of another individual” (Samuleson, et al. 2005, 1022). By assuming a perfect credit market according to the neo-classical theory of finance, one can conclude that these conditions are met. Therefore, in an economy equipped with such a perfect credit market, the existence of financial structures is said to be “irrelevant” for the aggregated activity of the economy. There is a pareto efficient allocation of credits on the market if the underlying assumptions of a perfect market have been met and the competition forces in the credit market results in those market participants receiving the credits, who have the best investment opportunities in the market. Simultaneously, it is impossible to reallocate lending in favour of another individual, without sacrificing the benefits of other market participants (Besley 1994, 29ff.).

However, in reality credit markets have characteristics that indicate a renunciation of the neo-classical theory of a perfect market. On the contrary, imperfect credit markets exist. Many credit markets are characterized by the presence of transaction costs and limited rationality of market participants, which are especially caused by the imperfect information situation between the acting economic agents (Besley 1994, 30). In fact, the lender lacks information about the creditworthiness and behaviour of the client.

The existence of asymmetric information could probably result in costly information gathering required for the completion of a transaction. In reality, a perfect market transparency as stated by the neo-classical theory of finance is unlikely to be met. For this reason, efficient lending appears extremely improbable. Economic transactions affected by asymmetric information indicate market imperfections. According to the neoclassical equilibrium theory the price mechanism is not able to establish an equilibrium situation. Furthermore, the neoclassical theory of financing delivers no explanation for the existence of financial institutions and financing instruments such as banks, mortgaging etc. (Perridon, et al. 1999, 512).

The new institutional economics theory tries to fill this gap by assuming more realistic conditions when explaining economic relationships. This includes in particular the assumption of the existence of asymmetric information, which is assumed responsibility for the appearance of (market) imperfections. In contrast to the neo-classical approach of financing, the new institutional economics theory takes into consideration the information and intensification problems. Asymmetric information hereafter justifies the existence of institutions (e.g. contracts or financial intermediaries). These are considered as "reactions to the information and market-related operational problems". It is assumed that institutions are able to counteract asymmetric information and thereby reduce transaction costs (Schmidt 1981, 142f.).

Therefore, market participants can diminish trade-inefficiencies on markets through the establishment of incentive compatible structures (Lähn 2004, 71). To sum up, institutions are considered to have a decisive role in minimizing asymmetric information and transaction costs or optimizing (contractual) relationships (Kuhn 2005, 151). Properly functioning financial markets are of essential importance for sustainable economic growth (Levine, 1997). Through their financial intermediation it is possible to channel financial resources to those economic agents that have the most productive investment opportunities. The solution of the underlying information asymmetries is thereby important.

In developing countries, financial transactions face extreme conditions. The lack of legal claims to land or property and acceptable collateral complicate the establishment of formal financial relationships (Allen, et. al 2012). However, the history of financial (or economic) development showed that innovations can lead to improvements in the quality of information. Thereby new financial products, services and markets have emerged. One of these innovations has been the development of the microfinance industry in the wake of the liberalization of financial markets in many developing countries during the 1980s (Mishkin 2008). Microfinance institutions (which also include financial cooperatives) manage to solve extreme information asymmetries and enforcement problems by relying on innovative technologies. These mechanisms allow them to reduce the costs of screening and monitoring. In this way, formal capital access for low-income segments that previously had been seen as "unbankable" becomes possible.

While in the initial stages of the microfinance industry development, micro financial intermediation relied heavily on international donor or governmental funds, a paradigm shift happened in the course of the 1990s. It intended to reconcile sustainability with poverty reduction and recognized the need of diversified financial services. It became evident that even serving poor people allows financial intermediation to be profit-oriented and to achieve break-even status. To sum up, microfinance has the "integrative capacity" to build bridges between the formal financial sector and the informal economy, which contributes to the "integration" or "convergence of markets" and counteracts the "fragmentation of an economy" (Gonzáles-Vega 2002, 13ff).

6 Research Objectives

The aim of this research is to analyse and assess the current capacity of community-based organisations or electric cooperatives to expand their services to microfinance in order to meet two development goals at the same time: access to electricity and financial inclusion.

6.1 Specific research objectives include:

- The assessment of the institutional characteristics of electric and financial cooperatives in Nepal

- The study of techniques applied in electric and financial cooperatives to address extreme market conditions in Nepal
- The assessment of the policy framework

This study will pave the way to understanding the difficulties cooperatives might face when expanding their services towards micro financing. It will show that there are many institutional similarities between financial and electric cooperatives, which help electric cooperatives to expand their business towards finance. On the other hand, it is expected that institutional limitations (e.g. flexibility in responding to market changes or capacity that raise capital) will be detected which should be addressed by planners, policy makers and other stakeholders to promote rural electrification and financial inclusion in the long run.

6.2 Research Questions

- What are the institutional characteristics associated with electric cooperatives that experience long-term success?
- What are the institutional characteristics associated with financial cooperatives that experience long-term success?
- Do these characteristics overlap and/or can an electric cooperative expand its services to financial services?
- What affects the success of electric and financial cooperatives? (e.g. limited access to financial resources, acceptance of local population, policies, …)
- What policies promote the long-term success of these cooperatives?
- What has to be done in order to support the success of these cooperatives?

6.3 Hypothesis

It is possible to show that electric cooperatives that manage and operate renewable energy based mini-grid systems in Nepal have the institutional capacity to face market imperfections and to expand their services towards microfinance.

7 Methodology

This study will assess the institutional capacity of electric and financial cooperatives in Nepal by applying a mix of capacity assessment tools (e.g. as proposed by UNDG (UNDP 2008) or FAO (FAO 2010a). The term “capacity” is hereby understood as the ability of cooperatives to perform effectively to meet their objective.

The capacity assessment includes different “institutional characteristics” of the cooperatives such as motivation, strategic, organisational and management functions, operational capacity, human and financial resources, knowledge and information as well as infrastructure (FAO 2010b, 6).

The electric cooperative of the mini-grid system in the Baglung district in Nepal will be chosen for a case study because it is the cooperative of the first mini-grid system that has been established in Nepal. Additionally, a Power Purchase Agreement (PPA) with the National Energy Authority (NEA) is envisaged, the potentially generated income could be used to expand its business towards microfinance services. A sample Nepalese financial cooperative will be selected by retrieving data from mixmarket.org, whereby it is intended to screen the database in terms of legal status, size, products and services provided, segments targeted and financial performance.

The assessment includes identifying already existing key capacities and additional capacities needed by electric cooperatives to achieve the successful expansion of their services. In order to get there, data will be collected from primary and secondary data sources, which include a field study in Baglung, Nepal. Interviews with key informants and stakeholders will generate primary information. Secondary data will be obtained by reviewing relevant documentations and reports. Further, SWOT-Analyses will enable identification of the main Strengths, Weaknesses, Opportunities and Threats of electric and financial cooperatives in Nepal to meet access to electricity and financial inclusion. The results of the SWOT-Analyses will be compared and the option of the electric cooperative to include microfinance in their portfolio will be discussed. Needs and strategies for the desired future institutional capacity will be identified.

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25 years of capacity building for sustainable development at the University of Flensburg

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In 1989 the first students from Africa, Asia and Latin Amerika arrived in the far North of Germany to study in a new Master Programme called “ARTES” at the then University of Education in Flensburg. ARTES stood for “Appropriate Rural Technology and Extension Skills” and was one of the first study programmes in Germany specifically designed for professionals from the South, the so called “developing countries”. The implementation of the programme was supported by the federal government of Germany, the government of the federal state of Schleswig-Holstein and the German Academic Exchange Service (DAAD).

The ARTES programme followed a very broad approach. In one sentence the objective of ARTES was to train professionals for rural appropriate technologies. ARTES graduates where trained to support the rural population in so called developing countries to improve their lives by ameliorated rural infrastructure, housing, water supply, small industries or provision of basic energy services. Hosted by the University of Education not only technology but also adult education played an important role in the curriculum.

The ARTES Master programme from 1989 till 2000 was part of the “Appropriate Technology Movement”. In 1973 Fritz Schumacher was one of the first who, in his book “Small is beautiful”, developed a concept of an intermediate technology, a technology that could be managed on a local level and that was environmentally and economically sustainable. He made clear that fossil resources are a capital that is finite and that we need to move towards a world that is not dependent on fossil resources. For Schumacher nuclear energy was not a solution. He called nuclear energy an “environmental and ecological problem of a monstrous magnitude”. He also made clear that sustainable development requires a change towards a “life-style designed for permanence” (Schumacher 1973).

Others followed his approach and the concept of appropriate technology became very popular, in particular in international development organisations. In the eighties many of these organisations had their appropriate technology units. Published in 1987 by the World Commission on Environment and Development (WCED), the Brundtland report called for a sustainable development which allows meeting the "needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987, 16)." The Brundtland report also made clear that this "requires that those who are more affluent adopt life-styles within the planet's ecological means - in their use of energy, for example (WCED 1987, 16)."

However, neither Schumacher's concept of a "life style designed for permanence" nor the call of the Brundtland report for "life-styles within the planets ecological means" had large impact on politics in Western societies. When Uwe Rehling and Dieter Klein started to develop the ARTES programme in 1985 it was part of their concept to focus on the interdependency between development in the South and in the North. It was therefore another aim of the ARTES programme to make the German public aware of development issues in the South and the North and their interdependency. One of the outcomes of this approach was the artefact centre in Glücksburg, where also most of the ARTES teaching activities took place.

In Germany the development of renewable energy technologies had its origin in the movement against nuclear power plants, perceived by a large part of the population as an uncontrollable technology with a long lasting impact on future generations. Supported by the upcoming public discussion on climate change, renewable energy technologies and opposition against nuclear energy became a mainstream in Germany in the Nineties, resulting in the governmental decision to phase out nuclear energy in 2000 which was later withdrawn and finally repeated after the Fukushima disaster in 2011.

Also in the ARTES programme the energy topic became more and more a focus in the late nineties. The question was no longer only how to provide, in a sustainable way, basic energy services for cooking, lighting, communication and small scale economic activities in rural areas but also how to employ renewable energy on a national, large scale. The fast growing energy demand, especially in the emerging Asian countries and the growing maturity of renewable energy technologies made it obvious that Renewable Energy Technologies had to play a much bigger role in the so called developing countries than just the role of a small scale decentralized niche technology in rural areas. In 1973, when Schumacher's "Small is beautiful" was published, China consumed just 7 % of the world's primary energy. In 2012 its consumption had increased to almost 20% (IEA 2014) and China is now the world's largest CO_2 emitter. India has also doubled its energy consumption in the past 20 years.

Employing renewable energies to cope with the increasing energy demand is not only a requirement to mitigate climate change, it also offers economic chances. Today China and Taiwan supply almost 70% of the global demand for PV modules (Fraunhofer Institute for Solar Energy Systems 2014) and China produced 77% of the global demand for solar water heating systems in 2010 (APCO 2010). Rural electrification through extension of national grids offers rural communities not only the opportunity to develop economic activities; it can also offer the chance to generate income from electricity sales to the national grid.

That was the starting point of the SESAM programme in the late nineties. SESAM stood for "Sustainable Energy Systems and Management" and like the ARTES programme, the SESAM programme followed a multidisciplinary and practical approach that made it unique in Germany. Apart from engineering courses in the field of renewable energy, also management, energy economics, energy policy and energy planning became part of the curriculum.

The shift from ARTES to SESAM came along with some other major changes in Flensburg. In 1994 the University of Education got the status of a full University and new study programmes in management and economics were introduced in cooperation with the University of Applied Sciences, the second University in Flensburg, and the Syddansk University in Sønderborg, Denmark. The University moved from an old building to a new campus and SESAM moved from Glücksburg to Flensburg. This was not just a physical change. It led to a stronger integration of the programme and the international students into the University.

Of particular interest for the further development of SESAM was the new Diploma Engineering Programme on Energy and Environmental Management that started in 1996. From the beginning the two programmes shared a number of courses and finally merged in 2009 when new regulations required all study programmes in Germany to become Bachelor and Master Programmes.

The EEM programme is now divided into two specialisations, one of them addressing mainly German students and the other one addressing international students from so called developing countries. This division is justified mainly by the different educational backgrounds of the students: German students usually enter the Programme with a Bachelor degree in Energy and Environmental Management of the Flensburg University of Applied Sciences while the international applicants have Bachelor degrees in different engineering disciplines and at least two years of professional experience. Therefore engineering topics have got less weight in the new programme and there is a stronger focus on energy economics, energy politics and energy planning. Some of the classes in the EEM programme are joint classes with German EEM students who are trained for a career in the German Energy Industry. The exchange between the German and the international students is a major strength of the EEM course compared to its predecessors: The international students learn more about the attitudes and perceptions of future young German energy professionals, the German students benefit tremendously from the professional background of the international students and are exposed to international experience without leaving Flensburg.

Most of what Schumacher wrote 40 years ago still holds true and is considered in the EEM programme. We need a shift of our lifestyles in the North towards permanence, as he expressed it, but we need it much faster than 25 years ago. We need to secure the energy supply for the 1.5 Billion people who are still without electricity and the almost 3 billion people who still rely on wood fuel for cooking. And at the same time we have to reduce our greenhouse gas emissions and our resource consumption.

This is reflected in the motto of the programme: “Meet the challenge of climate change and energy poverty”. The objective of the EEM programme is nothing less than qualifying professionals for this challenge. Such professionals need the skills and the sensitivity to understand the social, political and economic environment, they need communication skills, they need to think and act strategically and they need to be able to work in teams with people from different professional and cultural background, in Einstein's words: "We cannot solve our problems with the same level of thinking that created them".

EEM offers a specialization in energy management. It is a multidisciplinary programme, neither a pure engineering programme nor a pure management programme. Specialisation and multidisciplinarity is not a contradiction. Energy is a multidisciplinary topic in itself. EEM students are already specialists when they come to Flensburg. They have their engineering background and are professionals in their particular field. The small student groups, usually not more than 15 students, have a very diverse professional and cultural background. This diversity is one of the assets of the programme. It allows students to learn from each other professionally, to gain intercultural experience and to develop team skills.

The international class, which was already part of the SESAM programme and is still part of the EEM programme, is an exercise where the students practice such skills and competencies. It follows the approach of problem based learning: For five weeks the students work in a team in a rural community on a real live energy related problem proposed by the community. After these five weeks the student team has to submit and present their findings to the community. For the past 14 years this exercise has been organised in Scottish communities in collaboration with a Scottish NGO "Community Energy Scotland". This learning experience is highly appreciated by both, the students and the communities who are involved. Future curriculum revisions will see an even stronger implementation of the problem based learning concept in the programme.

In the future the pressure to meet the energy and climate challenge will increase. There will be a high demand for energy professionals with a holistic view and a multidisciplinary qualification in the future. The interest of applicants for the programme confirms that: From about 100 applications per year in the nineties the number of applications has steadily increased to more than 200 in 2014.

In autumn 2015, the 25th batch of students will graduate from the International Master programmes at the University of Flensburg. We will celebrate this with an international alumni workshop in Flensburg. Among the successful students will also be the 300th graduate. He or she then becomes a member of a strong and active international alumni community with registered alumni associations on the African and Asian continent and national alumni organisations in Nepal and India.

Many of these alumni of the past 25 years now work in senior positions in the public sector, NGOs and private business, supporting the transition towards a world that is not dependent on fossil resources and that allows present and future generations in the North and the South to meet their needs.

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