Martina Schäfer, Daniel Kammen, Noara Kebir and Daniel Philipp (editors)

INNOVATING ENERGY ACCESS FOR REMOTE AREAS: DISCOVERING UNTAPPED RESOURCES

Proceedings of the International Conference

University of California, Berkeley
April, 10th to 12th, 2014

organized by

Renewable & Appropriate Energy Laboratory RAEL

BREG Berkeley Rural Energy Group

Promotionskolleg Mikroenergie-Systeme

Technische Universität Berlin

in cooperation with

MICRO ENERGY INTERNATIONAL

Hans Böckler Stiftung

supported by

ada

giz

reeep renewable energy & energy efficiency partnership

PPAF

Trojan Battery Company

Frankfurt School of Finance & Management Bankakademie | HfB

Martina Schäfer | Daniel Kammen | Noara Kebir | Daniel Philipp (editors)

Innovating Energy Access for Remote Areas: Discovering Untapped Resources

Proceedings

Scientific Committee

Chair:
Prof. Dr. Daniel Kammen, University of California, Berkeley, USA
Prof. Dr. Dr. Martina Schäfer, Technische Universität Berlin, Germany

Sub-Chair for focus area Financing:
Frankfurt School-UNEP Collaborating Center for Climate & Sustainability Energy Finance

Committee:

Prof. Dr. Lucienne Blessing, Université du Luxembourg
Prof. Dr. Robert Brecha, University of Dayton, USA
Laura Foschi, ADA, Luxembourg
Prof. Marek Hudon, Solvay Brussels School of Economics and Management, Belgium
Dr. Michael Jakob, Mercator Research Institute on Global Commons and Climate Change, Germany
Noara Kebir, MicroEnergy International, Germany
Marlis Kees, GIZ, Germany
Prof. Dr. M. Rezwan Khan, United International University, Bangladesh
Prof. Dr. Johann Köppel, Technische Universität Berlin, Germany
Prof. Dr. Stefan Krauter, University of Paderborn, Germany
Prof. Dr. Walter Leal, HAW Hamburg, Germany
Prof. Dr. Inmaculada Martinez-Zarzoso, University of Goettingen, Germany
Ellen Morris, Ph.D., Columbia University, USA
Bruce Nordman, Lawrence Berkeley National Laboratory, USA
Shonali Pachauri, Ph.D., IIASA, Austria
Debajit Palit, TERI, India
Daniel Philipp, MicroEnergy International, Germany
Prof. Dr. Gisela Prasad, University of Cape Town, South Africa
Kilian Reiche, iiDevelopment, Germany
Christa Roth, FOODandFUEL, Germany
Dana Rysankova, World Bank, USA
Prof. Dr. Tomohiko Sakao, Linköping University, Sweden
Dr. Jan Steckel, Mercator Research Institute on Global Commons and Climate Change, Germany
Dr. Tania Urmee, Murdoch University, Australia
Prof. Bruce Usher, Columbia Business School, USA
Steven R. Wilson, Georgetown University, USA

Innovating Energy Access for Remote Areas: Discovering Untapped Resources

Proceedings of the International Conference
April 10th to 12th, 2014

University of Berkeley

Editors: Martina Schäfer
Daniel Kammen
Noara Kebir
Daniel Philipp

Universitätsverlag der TU Berlin

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.dnb.de/

Universitätsverlag der TU Berlin, 2014
http://www.univerlag.tu-berlin.de

Fasanenstr. 88, 10623 Berlin
Tel.: +49 (0)30 314 76131 / Fax: -76133
E-Mail: publikationen@ub.tu-berlin.de

Printing: docupoint GmbH

ISBN 978-3-7983-2693-4 (print)
ISBN 978-3-7983-2694-1 (online)

Published online on the Digital Repository of the Technische Universität Berlin:
URN urn:nbn:de:kobv:83-opus4-51851
http://nbn-resolving.de/urn:nbn:de:kobv:83-opus4-51851

Table of Contents

Foreword from the Chair

Tracking the progress of mobile phone coverage across the Global South has time and again been used to illustrate rapid technological and business change as proxies for a broader hope that we can innovate to achieve equitable access for the global poor and disenfranchised. At the same time, the global energy sector is scattered, and lacks rigorous efforts in innovation to sustainably cater services to the billions of people that continue to be deprived of it. For much of the last Century the energy sector was dominated by monopolies with partial or complete ownership of the regional grids and large-scale power plants. Research has shown that in areas with these monopolies the metrics of energy sector innovation are markedly low, perhaps because such monopolies are not required to publish results, or that they patent defensively or simply under-invest. This seems particularly concerning if we are to employ an innovation-based strategy to confront the major energy related challenges facing our society today.

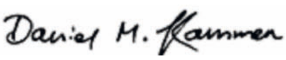
With the energy field evolving over the last decade to increasingly decentralized approaches, energy access movements have begun to refocus on the active participation of the people themselves through bottom-up initiatives. Hope for energy inclusion has regained momentum through the striving for further innovations triggered by more diversified actors in the field, seen for example in efforts to marry information and communication technologies with the energy sector.

It is in this spirit that this year's symposium has *innovation* as its focal point. *Innovating Energy Access for Remote Areas*: *Discovering untapped resources* has set off to bring together leading experts in the field to share their experiences on innovative approaches and to jointly drive new thought. The idea that innovative approaches can work with previously underutilized or unrecognized resources is central to this symposium, as this may lead to circumstances or cues for the development of successful and sustainable energy access programs. Such untapped resources may be seen in the discovering of synergies within areas such as pre-existing service infrastructures, supply chain and value chain management, natural resource availability, financing schemes, leap frog technologies, and more.

I particularly thank Microenergy Systems from the Technical University of Berlin and the Berkeley Rural Energy Group for jointly putting together this symposium. Only rigorous innovation will enable outreach to more geographically challenging areas. May this symposium serve as an inspiring platform to advance the innovations we need for success.

I warmly welcome you here at UC Berkeley and wish you a great time sharing your ideas and achievements on innovating for our common goal of achieving Sustainable Energy for All.

With best regards,



Daniel M. Kammen

Class of 1935 Distinguished Professor of Energy
Energy and Resources Group & Goldman School of Public Policy & Dept. of Nuclear Engineering
Founding Director, Renewable and Appropriate Energy Laboratory

Preface from Microenergy Systems Research Group

In 2001, at the Technische Universität Berlin, Institute for Energy Technology, two young researchers, Noara Kebir and Daniel Philipp, ventured out to Bangladesh to explore a seemingly simple question: How is it possible that in a country like Bangladesh, solar energy is implemented on a sustainable basis whereas in Germany it is considered a mere fancy dream. Intrigued by the example of Grameen Shakti, which since its founding in 1996 continues to successfully expand dissemination of solar home systems in rural areas of Bangladesh to this day, they founded a new research focus at the Technical University Berlin – Microenergy Systems (MES).

Microenergy systems are defined as *decentralized energy systems based on small energy appliances, which provide households, small businesses or farms with locally generated energy, enabling a spatial link between energy demand, supply and generation*. The systems provide solutions for single households or micro enterprises (e.g. solar home systems, irrigation pumps, biogas plants) as well as technologies for several households or communities (e.g. mini-grids). In recent years there have been growing expectations that microenergy systems can play an important role in shifting energy policy as well as creating co-benefits where development goals (e.g. reducing poverty) are combined with climate mitigation and adaptation actions.

A systemic perspective on microenergy systems stresses the need for a research approach to investigate across a variety of academic disciplines, including potential analysis, product development, manufacturing, planning, implementation, servicing, and use of decentralized energy systems, combining different perspectives stretching from end-users to policy decision makers. Therefore, the term "Microenergy System" refers to a broader understanding of the respective technical artifact in interrelation with its natural conditions, social context, economical system, organizational structures and political framework. The introduced research concept is demand-driven and deduced from practical needs rather than a product of pure theoretical consideration, and it consequently leaves the straight path of individual disciplines.

We feel that there is a strong need to consolidate the knowledge accumulated in the various fields of research focused on such solutions through regular exchange as well as through joint exploration and education. The aim of these efforts should serve to enable the transfer of strategies, programs and tools that can be tailored to myriad local contexts. This was the goal of the two researchers back in 2001 to share and disseminate the knowledge they gained from their field experiences in Bangladesh, and this continues to be our driving force for this 3rd event on decentralized energy supply, the MES-BREG symposium in 2014 at UC Berkeley.

We wish you a productive conference and an innovative outlook.

Sebastian Groh

Researcher
Microenergy Systems

Jonas van der Straeten

Researcher
Microenergy Systems

Foreword from the Organizers

It is a matter of great satisfaction for us at the Microenergy Systems Postgraduate School (MES) of the Technische Universität Berlin that we are able to bring together the international energy access community for the third time – this time with the *Berkeley Rural Energy Group* (BREG) for our co-organized *MES-BREG Symposium 2014 Innovating Energy Access for Remote Areas*: *Discovering untapped resource*. Our on-going biannual conference events began in 2011 and continued last year in 2013, when we welcomed more than 350 participants from around the world to join us in Berlin. We are enthralled to collaborate with BREG to begin our first in a series of smaller and themed symposia that will take place in new locations around the globe, staggered year-for-year with our major Berlin events.

This year, there are a few developments of which we are particularly proud. First and foremost, we are excited about our partnership with BREG, and their teamwork in organizing this symposium in the incredible environment at University of California Berkeley. Second, we are extremely grateful to ADA, Luxembourg organization dedicated to inclusive finance, for its generous support of the symposium as well as for its continued dedication to helping researchers publish their work on the relationship between microfinance and the environment. Third, the symposium is being organized in coordination with Environmental Research Letters, which will publish select papers. Suitable papers may be also considered for peer-review in the International Journal of Innovation and Sustainable Development, in the International Journal of Progress in Industrial Ecology, and the International Journal of Sustainable Development. Furthermore, the publication of a book as part of the Climate Change Series with Springer is under discussion. As in the previous years, we thank our conference organization partner *MicroEnergy International (MEI)*, a Berlin-based consultancy active in Africa, Latin America and Asia, aiming for the provision of fair and sustainable energy for all. Without their continuous support these events would not be possible.

We would like to thank the authors who submitted more than 70 papers on innovations in energy access from across the world. Our sincere gratitude also goes to our distinguished Scientific Committee that took the time to review and provide feedback on these papers. We would like to thank the *Hans-Böckler Foundation* for their continuous financial support to MES, as well as *ADA, GIZ/Bangladesh, the Pakistan Poverty Alleviation Fund* for providing scholarships for researchers from the Global South to come to Berkeley and REEEP for supporting a workshop during the symposium. We also thank Trojan Battery Company and SEA-RAE for their financial support in hosting the poster session networking event and reception. Finally we are also grateful to *energypedia,* our media partner for this event, for making sure that the main conference take-away messages are accessible to the global energy access community.

Get ready for two days of presentation and discussion, including light workshop sessions, 30+ new papers presented in concurrent sessions and plenary, 20+ posters presentations, and networking events, all to take place in four different venues to be explored by participants across campus.
We wish everybody a successful conference.

Your organizing team,

Dimitry Gershenson	Brian Edlefsen Lasch	Sebastian Groh	Jonas van der Straeten	Liisa Andersson
Berkeley Rural Energy Group	**MicroEnergy International**	**Microenergy Systems**	**Microenergy Systems**	**MicroEnergy International**

Scientific Papers

I. ICT & Energy

Optimizing Device Operation with a Local Electricity Price

Bruce Nordman (BNordman@lbl.gov)
Lawrence Berkeley National Laboratory
1 Cyclotron Road, 90-2000, Berkeley, CA, 94720-8130 USA

MattiaBugossi (MBugossi@lbl.gov)
Lawrence Berkeley National Lab
1 Cyclotron Road, 90-2000, Berkeley, CA, 94720-8130 USA
UNIVPM - UniversitàPolitecnicadelle Marche
P.zza Roma 22, 60121 Ancona, Italy

Abstract

Making optimal use of available electric power is important for efficiency, functionality, and to reduce capital costs, particularly in developing countries.Thispaper shows the results from simulating the behavior of refrigerators and freezersthat vary their operation according to a local price and price forecast.The price is set to the availability of local photovoltaic power and is used to adjust the temperature setpoints of the devices. For off-grid systems, this can be used to concentrate consumption during times of PV availability, to increase efficiency and reduce battery size.Our simulations show a reduction of up to 26% of the energy used by the devices at night.

Keywords: Off-grid; nanogrid; local price.

Introduction

In electricity systems of many scales, matching supply and demand is a critical need.For energy access deployments, there are often significant limits on system capacities for energy and power, and these may vary from day to day.This paper demonstrates that a local price of electricity can be used to shape demand to use it more optimally.The context addressed is a system powered with local photovoltaic (PV) power backed up with a battery.Refrigerators and freezers are modeled to see how price can be used to better match their consumption to electricity availability.

Research Objectives

The purpose of this study was to explore the general principle of using local prices as a way to control devices — or rather, so devices can control themselves.This is a core principle of the technology of Local Power Distribution (LPD) (Nordman et al., 2013). LPD uses a network model of power, rather than the conventional single unitary grid.A network of local grids can be attached to a large scale utility grid, a small mini-grid, or a local microgrid.The basic unit of power distribution in LPD is the nanogrid, and each nanogrid has its own local price and price-forecast.This paper considers only a single nanogrid, including integral storage, plus a connection to local photovoltaic (PV) power.

Data Sources

With the purpose of this study being exploratory, it was not necessary to be detailed in our modeling.For example, the efficiency of storing energy into and out of a battery is assumed to be constant, and we do not consider the interaction between charge level and capacity to store or withdraw power.The details of compressor operation are not modeled; each minute of operation is assumed to have an identical effect on reducing temperature in our refrigerators and freezers.

For PV data, we used sample data from a convenient source[1].The load shape of produced power was simply scaled to match our system needs and the hourly output linearized. Figure 1 shows one day of PV system output, unscaled. For batteries, we assume that 10% of electricity is lost in the charge/discharge roundtrip.

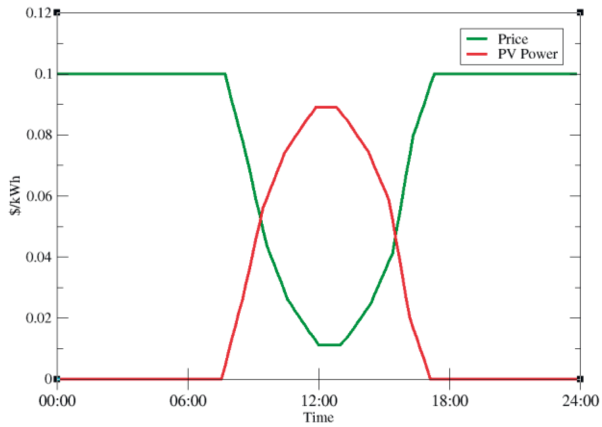


Figure 1. PV daily electricity loadshape and local price

Our base case of device operation was modeled on typical behavior of a recent models of refrigerators and freezers[2].Our units are manual defrost so there is no automatic defrost cycle to schedule (though these could be readily set to be at times of high electricity availability).We did not model door openings.

Prior Work

Matching supply and demand is not only of concern for off-grid systems, but arises in most electricity systems. For improved operation of conventional utility grids, a project at U.C. Berkeley (Taneja et al., 2011; 2013) demonstrated a phase change material used in the freezer

[1]Adapted from http://www.seia.org/research-resources/ potential-impact-solar-pv-electricity-markets-texas
[2] Personal communication from Lloyd Harrington, 2013.

compartment of a typical refrigerator (with integral freezer) to shift demand. Energy is required to "charge" the material as it freezes; it later absorbs heat as it melts. They considered how such a system would behave in the context of a fixed time-of-use price regime. They also operated it to follow renewable generation in the local utility grid and select among a few different temperature set points to shift energy demand to the desired times.

Our project builds on this concept but with different context and goals. We take the appliances as-is, without physical modification; a local price forecast is the only information considered; and the set point is directly manipulated in a continuous manner.

Individual Device Operation

Figure 2 shows a six hour period of our basecase freezer operation. There is a constant set point (-10 C) so that the compressor cycles do not vary, with compressor on-times and off-times of about 20 minutes each. The unit turns on the compressor when the internal temperature reaches 0.5 C above the set point, and turns off the compressor when 0.5 C below the set point is reached. Our basecase of refrigerator operation is similar. We assume that the freezer setpoint can range from -3 C to -18 C, and the refrigerator setpoint from 1 C to 6 C.These are to give the system maximum flexibility without compromising the integrity of the units function.

The units can change their setpoint in response to the local price. This can happen at any time, so that a setpoint change may lead to immediate change in compressor state, or may cause the expected duration of compressor operation (or period of non-operation) to be longer or shorter than would have occurred without the setpoint changing. Compressors have a 10 minute minimum cycle time as short cycles are energy inefficient.

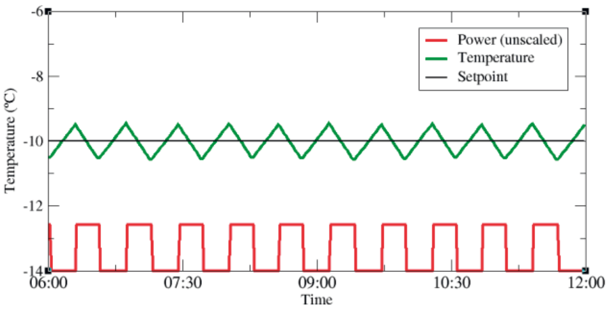


Figure 2. Constant price freezer operation

Optimizing Demand Patterns

When the sun is shining, power is more available than when it is not. Consuming at night requires storing power in a battery which entails capital cost for the battery and associated hardware, as well as energy losses from the round-trip through the battery. Thus, it is advantageous to concentrate electricity demand during the day, and to match as well as possible the loadshape of PV output. Doing this can reduce the size of the battery needed as well as the energy losses.

The context of our analysis is a system with a nanogrid controller which assesses available electricity supply (from solar and battery), current demand, and past history, to set a current price and forecast of future prices. The system reduces the price of electricity in accordance with actual and forecast solar output, with the lowest price corresponding to the highest output, as shown in Figure 1.Devices can use the price to concentrate their consumption in the middle of the day.

In general, the price and forecast can change at any time. Periods of constant price can be of any length and do not need to be the same as other periods. When the price or forecast changes, then devices may adjust their operation.

We used periods of 10 minutes for the price forecast, so that the setpoint for each unit also changed every 10 minutes. In our analysis, we did not change the actual price trajectory from that in the forecast; a nanogrid controller can change the forecast at any time. The shape of the price should match the supply/demand condition, so in this case it is simply the inverse of the supply.

Compressor operation is based only on the setpoint value (and minimum cycle time) so is not directly a function the electricity price. Similarly, the setpoint is based only on the price so it not directly a function of the PV output (or supply/demand balance generally). Each step of the process is as simple as possible, to enable more complex systems while keeping the complexity contained.

Dynamic refrigerator operation is similar to that of a freezer, except that with a smaller temperature range available, the degree that consumption can be concentrated during the day is less.

Single Device Results

Figures 3 and4 show freezer operation with a dynamic price. Figure 3 presents the entire day. Figure 4 is a close-up to show incremental setpoint changes and the how the unit changes operation from night (compressor mostly off) to day (compressor mostly on).Figure 5 shows the power consumption of the freezer operation from Figure3; it is plotted as average power over each cycle of compressor on-time and off-time. For the variable price case, the freezer understands that there is a 'day mode' and 'night mode' of operation, where prices are lower during the day. It detects which mode it is in and for how long it will remain in that mode by looking at the trajectory of future prices. In night mode, it sets the setpoint to linearly move from its current point to its maximum point over the course of the night. In day mode, it adjusts the setpoint non-linearly, to have the greatest change in setpoint when the price is lowest, at the middle of the day.

Multiple Device Results

Nanogrids enable power to be exchanged locally within a building or community. Exchanges occur when prices are different in adjacent nanogrids, indicating different availability. Sharing power evens out the spikes of consumption that individual device operations produce.

To explore this, we simulated fifteen freezers (and fifteen refrigerators), with power levels and rates of temperature increase and decrease similar to our basecase units, but slightly randomized. The starting condition (internal temperature and compressor status) were also randomized. We did not want many units to change operation simultaneously, and so updates to the price/forecast was delayed by up to nine minutes to that at most two receive the update each minute. The compressor cycling of ten freezers is shown in Figure 6; the overall pattern is consistent—more on-time during the day—but their cycling details are random.

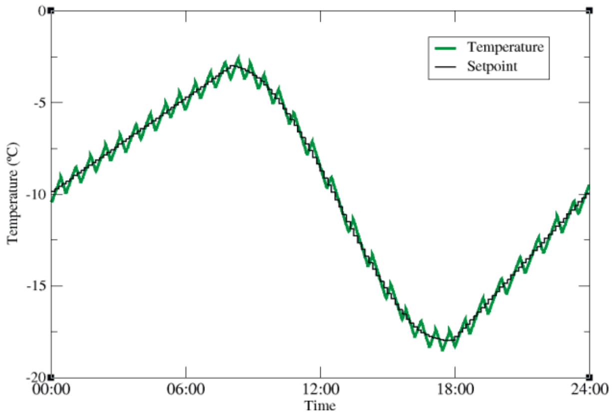


Figure 3. Variable price freezer operation – one day

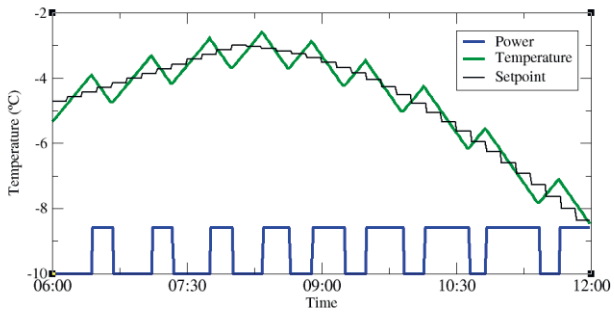


Figure 4. Variable price freezer operation – six hours

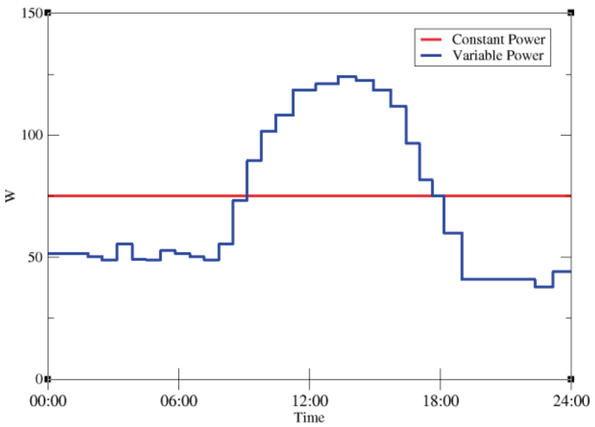


Figure 5. Variable price freezer operation – power

The total energy use for the fifteen units of each type are shown in Figures 7 and 8.These are plotted as averages for each hour to eliminate short-term variations which obscure the overall pattern. We simulate both a constant price a (and so constant setpoint) and a variable price. Also on these figures we show the PV output required for the constant price scenario. The power under the PV output curve but above each total power line is stored in the local battery, to be withdrawn for use in the night hours, minus the round-trip energy loss. There is a greater difference between the two cases for freezers since they have more ability to shift energy use.

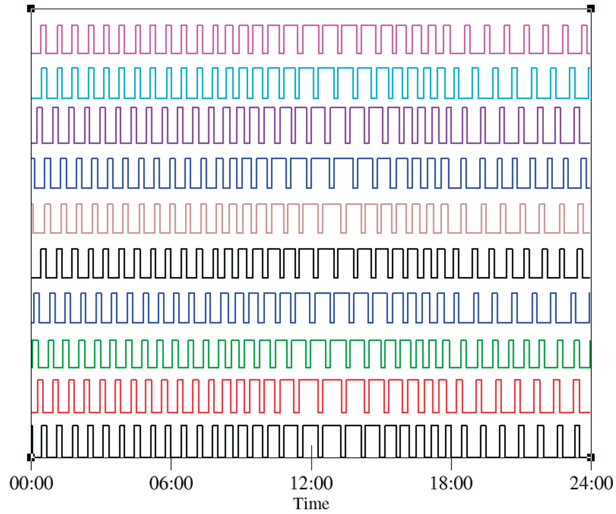


Figure 6. Compressor cycling for ten (of 15) freezers

Discussion

In principle, the night-time total power should be relatively flat from midnight until 08:00; we also did simulations with hundreds of freezers and refrigerators and produced that result. That the total in Figures 7 and8 is not flat is due to the small number of units. For the evening hours, the cycling of refrigerator power is a result of most units being in compressor off mode after the setpoint has stabilized, since most were on as the setpoint was dropping. Then, as the setpoint begins to rise, most of these start their compressors, creating the pattern. Further randomization could avoid this alignment.

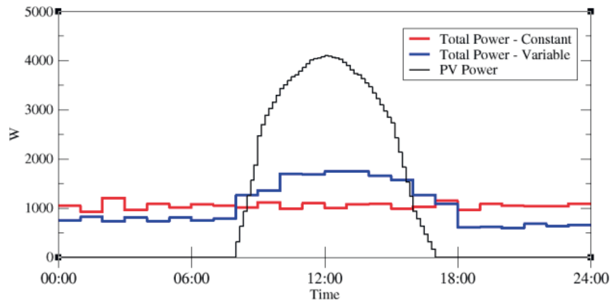


Figure 7. Constant and variable 15-freezer operation

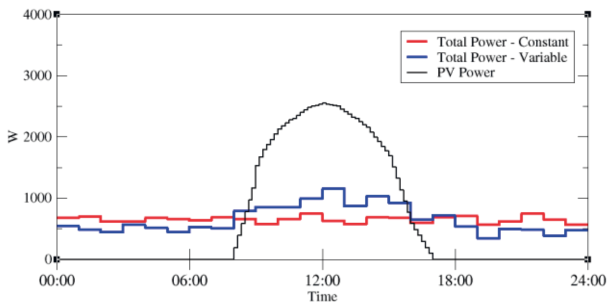


Figure 8. Constant and variable 15-refrigerator operation

Table 1 shows the primary quantitative results, which compare each constant price case with the percent change that occurs when variable prices are introduced. The table shows absolute energy values for the constant price case, and the percent change when moving to the variable case. Direct PV energy is the amount used directly from the PV panels by the units. Generation in excess of what the units consume is stored in the battery. Battery energy is the amount required from the battery. Excess PV consumption must be 10% greater than the energy drawn from the battery. The total unit consumption between the constant and variable cases is nearly identical.

With a time-varying price, the devices still consume power during the night and so rely on batteries, but less so than for the constant price case. With a constant price, about 35% of daily energy is consumed directly from the PV system.16and 10kWh of battery output are needed, with 10% of these values lost in the charge/discharge cycle. So, the PV system would need to be 1.4-1.6%larger in the constant price case to deal with the additional battery roundtrip losses. With a variable price, about 50%of energy is consumed directly from the PV system output, and the battery size (and corresponding energy loss) is reduced 21-16%.

These energy and battery capacity savings are the most obvious and valuable benefits of this change in device behavior, but not the only ones. The rate at which PV power must be absorbed by the battery is also reduced. For these cases, the maximum hour of excess PV power has is reduced by 24% and 21%.Battery chemistries have different limits on energy densities, charge rates, and discharge rates, so that being able to reduce this is an advantage.

Table 1. Results for one day for 15 units of each type all values except % are energy in kWh/day

	Freezer		Refrigerator	
	Const.	Var.	Const.	Var.
Device energy	25.1		15.5	
Direct PV energy	8.6	12.8	5.4	7.5
Direct TV fraction of total	34%	51 %	35%	48 %
change constant to variable	49%		37%	
Battery energy	16.4	12.2	10.1	8.0
change constant to variable	4.2		2.1	
change constant to variable	-26%		-21%	
Battery loss (kWh)	1.64	1.22	1.0	-.8
change constant to variable	0.42		0.21	

There are two ways to interpret these benefits. One is that less hardware is needed to accomplish the desired tasks—less generation, conversion, and storage. The other is that for the same infrastructure, more benefit can be obtained — more energy available, and more storage available.

This analysis is for simple and fixed variations in generation and hence supply/demand balance, but the ability of devices to respond to changing prices can be used in complex grid topologies with many sources and end-use devices. All that is required is for each local grid to set a local price to reflect its own conditions, and use that in exchanges with other grids to help shape the local prices of adjacent grids.

Further Work

Any local grid will have a variety of devices, with electronics and lighting being among the most common. All of these can take a price and forecast into account in their operation. Lights might dim as prices get high, and turn off entirely when a threshold is reached. Electronics can modulate consumption, such as dimming displays or powering down to sleep more quickly. Water pumps can similarly serve as storage, operating when electricity is inexpensive and storing the water in tanks for use at a later time. The local price and forecast will drive decisions about when to charge and discharge a battery, and battery capacity in turn can help shape the local price.

While this project had price a simple function of local PV power, the forecast can be more complex and variable. With more complicated price trajectories, a more sophisticated algorithm would be needed to shape demand across multiple periods of high and low price during one day. In addition, for units with automatic defrost, defrost cycles need to be scheduled about once a day and can be set to occur at a time of relatively low cost. To avoid many units defrosting at the same time, they should randomly select a defrost time across a range of times where the cost is reasonably low.

If power suddenly becomes scarce during the day, the local price and forecast will be changed to quickly rise in response. This could then cause refrigerators to stop dropping their setpoint so that units that have their compressor off will delay turning them on, and units that are on will turn off more quickly. When the situation reverses, devices will automatically change operation.

The refrigerator characteristics used were from commercial units in industrialized countries. In the energy access context with more expensive power, it could be beneficial to insulate the units to a greater degree; this would reduce energy use overall, and would also enable a higher proportion of concentrating energy use during the day due to less energy needed at night to maintain the setpoints.

Conclusion

A local electricity price is a simple and universal mechanism to reflect the local supply/demand condition. Our analysis showed that such a price can be used to change freezer and refrigerator operation to make better use of local generation, and reduce hardware needed for battery power and losses associated with using battery storage.

References

Nordman B. & Christensen K. (2013). Local Power Distribution with Nanogrids. *Proceedings of the International Green Computing Conference*.

Taneja, J. Lutz, K. & Culler, D. 2013. "The Impact of Flexible Loads in Increasingly Renewable Grids."

Fourth IEEE International Conference on Smart Grid Communications (SmartGridComm'13).

Taneja, J. Lutz, K. & Culler, D. 2011. "Demand Response for Everyone: Using Freezer Energy Storage to Balance the Grid, presentation to Local Summer Retreat.

An Optimized Load Frequency Control of a Decentralized Energy System Using Plug-in Electric Vehicles

Ali Ameli (ali.ameli@campus.tu-berlin.de)
Universität Paderborn,
Warburger Str.100, 33098 Paderborn, Germany

Hossein Ameli (h_ameli@aut.ac.ir)
Amirkabir University of Technology,
Hafez Ave. 424, 15875-4413 Tehran, Iran

Stefan Krauter (stefan.krauter@upb.de)
Universität Paderborn
Warburger Str.100, 33098 Paderborn, Germany

Rolf Hanitsch (rolf.hanitsch@iee.tu-berlin.de)
Teschniche Universität Berlin
Straße des 17. Juni 135, 10623 Berlin, Germany

Abstract

A micro-grid is a decentralized energy system consisting of distributed energy resources and energy storage systems which can operate either interconnected to the main grid or isolated mode. Diesel generators are one of the common energy resources in micro-grids that are also applied for control purposes by the system operators. With the inevitable increase of electric vehicles in the near future, it is of great importance to investigate the electric vehicles available capabilities for an optimized and more effective operation of a power network. The simulation results in this paper show that the electric vehicles can efficiently replace the diesel generators in case of availability for control objectives especially load frequency control of a micro-grid, which leads to a better controlling performance and less fuel consumption, CO2 and greenhouse gas emissions.

Keywords: Electric Vehicles; Micro-grids; Frequency Control; Particle Swarm Optimization; Aggregator; Smart Grid.

Introduction

The main objective in power system operation and control is to keep the balance between supply and consumption of the electric power. As it is known renewable energy resources like wind and solar power units, distributed energy resources such as diesel generators and energy storage systems like batteries are the main components of a micro-grid. In [1] an ESS[3] in a micro-grid is applied and indicates that simultaneously control of ESS and DG[4]s, improve the network stability, but the proposed method, requires a connecting link which has no performance in decentralized micro-grids. In the recent years, a lot of researches have been done in the field of power network control applying plug-in Electric Vehicles (EV). The EVs could offer distributed energy services like frequency and voltage regulation to the power grid because of their batteries fast response time [2],[3]. One of these researches demonstrates the effective impact of EVs for frequency control purposes in micro-girds regarding the vehicle owner's driving patterns [4]. Because of the uncertainty of the EVs mobility behavior and the small scale of the individual vehicles batteries for control services there is an intermediate management system, called aggregator, necessary to deal with the small-scale power of each vehicles to provide a proper large-scale control service [5],[6]. Smart Grid capabilities are inevitable for a faster precise data collection from the individual vehicles by the aggregator [3]. While the renewable energy production has increased in recent years in Germany and other developed countries, controlling the power grid is more difficult for system operators due to the uncontrolled power output of these units [7]. Electric vehicles could play an important role in integration of renewable energies due to their batteries fast performance [4]. Diesel generators are one of the useful energy resources in micro-grids that can be applied for control purposes beside power generation [8]. The fossil fuel consumption of these units has a harmful effect on the environment and causes CO2 and other harmful gas emissions. Thus, it is of great importance to find a suitable economic way to provide these kinds of control services in decentralized energy systems without any bad effects on the environment.

Research Objectives

As it was mentioned in the previous section, finding an environment-friendly solution for controlling micro-grids in an optimal and faster way could be very attractive for the system operators. The main objective of this paper is to show how applying the potentials of the aggregated EVs in fast charging and discharging of their batteries could replace the diesel generators at the times of availability and solve the load frequency problem of the micro-grids without any harmful gas emissions and less fuel consumption.

[3] Energy Storage System
[4] Distributed Generation

Methods

In this paper it is tried to present an optimal load frequency control (LFC) method in micro-grids using the available power capacity of the electric vehicles instead of diesel generators anytime the EVs are connected to the grid. The positive effect of this replacement is shown in the following sections. The studied micro-grid and the proposed control strategy are defined as follow.

Micro-grid Test System

The studied micro-grid is shown in Figure 1. This micro-grid contains RES[5]s and ESS[6]s with EVs and loads. The RESs are consisted of one or more energy generation units like WTG[7]s and PV[8]s. A battery energy storage system (BESS) is taking into account as an ESS because of the uncertainty of the wind generation.

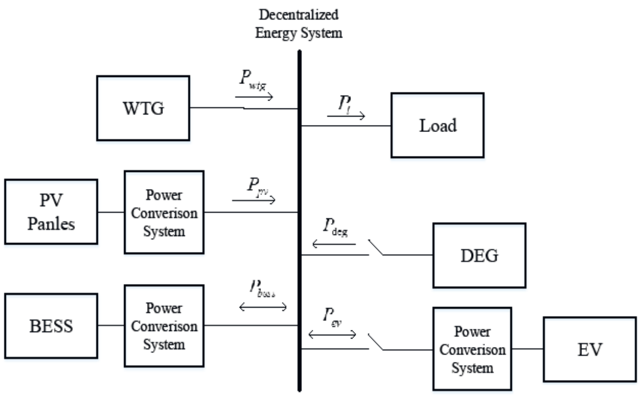


Figure 1: Micro-grid test system

It is worth to mention that the amount of the generation units is chosen from a study in [8] which is listed in Table 1.

Table 1: Installed DG and ESS capacities in the network

DG/ESS Technology	Capacity (kW)
WTG	225
EV	250
PV	30
DEG	250
BESS	250

In order to study a challenging mode, it is assumed that the micro-grid is isolated from the main grid in the following case studies and simulation. In other words, it means there is no injection power from the main grid to the network.

Proposed Micro-grid Operation Strategy

The algorithm of the proposed operation strategy is presented in Figure 2 the frequency of the micro-grid is measured at the beginning of the operation. The next steps present the optimized frequency control which is discussed in the following parts of the paper. The MATLAB/Simulink software has been applied for implementing the network.

Load Frequency Control

Maintaining the balance between the supplied and consumption power is the main aim of the LFC. The proper operation of micro-grids should be guaranteed by system operators in all operation conditions especially under contingencies such as RES outages. A stable frequency is one of the inevitable conditions of several industries [9]. It is not easy to keep the balance between power generation and demand in a micro-grid due to the slow reaction of the governors. Therefore the use of fast responding components like BESS and EVs for offering frequency regulation services becomes more important and is highly recommended for maintaining the stability of the grid in a higher level [1],[4]. As it was mentioned in the title of this paper, an optimal method called 'Particle Swarm Optimization' (PSO) has been applied to optimize the LFCs parameters of the simulation model.

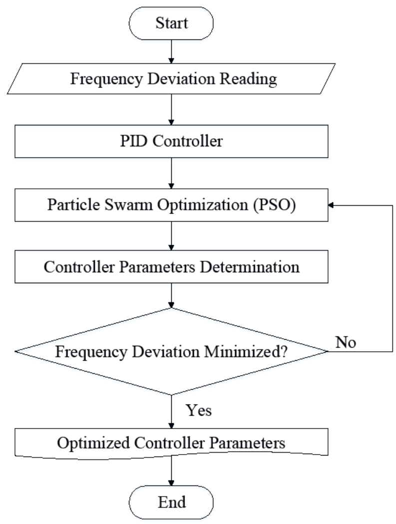


Figure 2: Proposed algorithm for LFC

Applying EVs for LFC

In this paper, it is assumed that the aggregator has a contract with the system operator and is able to provide 250 kW power form the EVs batteries anytime an accident happens. This amount of power can be provided through 100 EVs but there are more EVs in the micro-grid and the aggregator manages and chooses from the vehicles which are connected to the grid and are able to offer controlling services, regarding specific constraints. In [10] the simulation data and the control model of the EVs that are applied in this study are presented. How the cars are chosen and the structure of the contracts between the aggregator and the system operators and individual vehicle owners is out of scope of this study.

Figure 3 shows the implemented LFC block diagram. A part of the LFC is been supplied by the DEG[9]s next to generating power. In this paper it is proposed to use the

[5] Renewable Energy Sources
[6] Energy Storage Systems
[7] Wind Turbine Generation
[8] Photo Voltaic

[9] Diesel Engine Generation

available EVs in the micro-grid for LFC instead of the DEG. As it was mentioned before the EVs are environment-friendly in comparison to the DEG in the first point of view. It is shown and investigated in the next section how these EVs could be effective for the micro-grid's control procedure. It's good to mention that the DEGs are not completely replaced by the EVs because of the uncertain driving behavior of the vehicle holders. But it is tried to apply the EVs in case of availability, anytime a system fault happens.

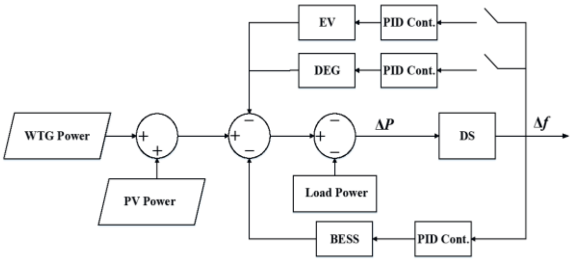


Figure 3: LFC Block diagram

Simulation and Results

In order to present the effectiveness of the control method and the EVs application, oscillations in wind turbine generation output are simulated by normally distributed random numbers around the mean values of forecast. To show the performance of the EV in the LFC method, two main cases are in isolated mode of the micro-grid studied. The first case study is defined, in order to show the normal operation of the micro-grid in presence of DEG or EV. In the second case study, the outage of the WTG is studied. It is worth mentioning that the time duration of the study is 60 minutes. The consumption of this system in this time interval is 360 kW. In summary, the case studies are divided to normal operation and contingency mode of the micro-grid.

Normal Operation

In this case study, the normal operation of the system in presence of DEG or EV is considered. Power output of the RES (WTG and PV) over a time of an hour is simulated, which is shown in Figure 4.

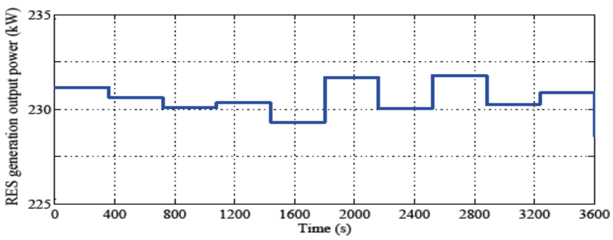


Figure 4: Output of renewable energy sources in kW

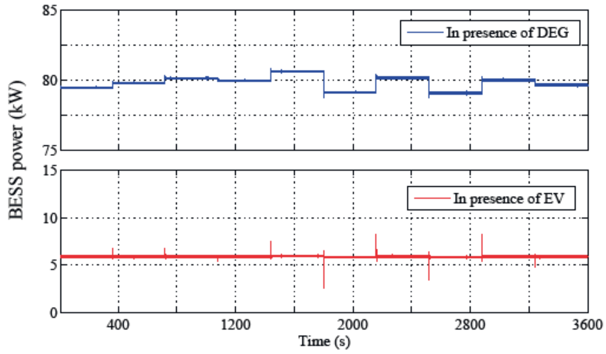


Figure 5: BESS in power in presence of DEG/EV in kW

Power output profile of the BESS is presented in Figure 5. It is shown that the BESS delivers about 80 kW in presence of DEG. In contrast, in presence of EV it is about 6 kW in normal operation of the micro-grid.
To indicate the performance of DEG and EV, the system frequency is shown in Figure 6.

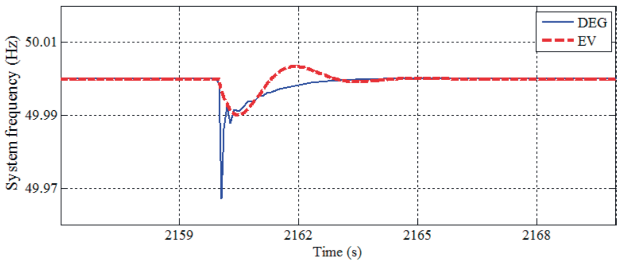


Figure 6: System Frequency in Hz

As it can be seen in the above figure, frequency drop in presence of EV is less than DEG.

Contingency Mode

In this case study, outage the WTGs is considered. This outage can happen either by failure of the turbine units or power line disconnection. This incident is happened at 1200 seconds. The output power of the generation in time of failure is shown in Figure 7.

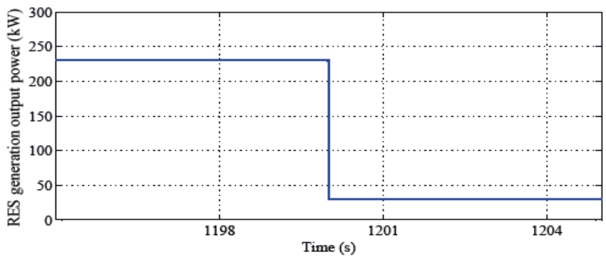


Figure 7: RES power in kW in time of incident

In this part the reaction of the BESS in both modes and the performance of DEG and EV are presented. In this figure the great performance of EV in participating in the LFC is considerable.

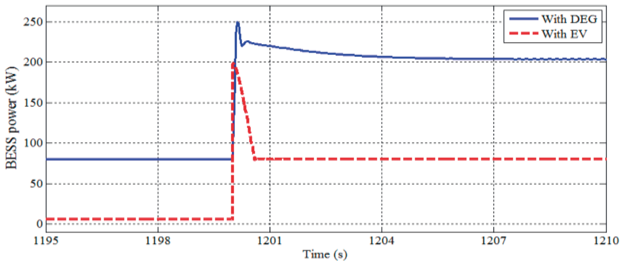


Figure 8: BESS power in kW after incident

In comparison to DEG, this performance of EV leads to the less participation of BESS in the frequency control which results in a higher lifetime and lower degradation cost of the battery. The system frequency in contingency mode indicates the efficient reaction of EV in comparison to DEG.

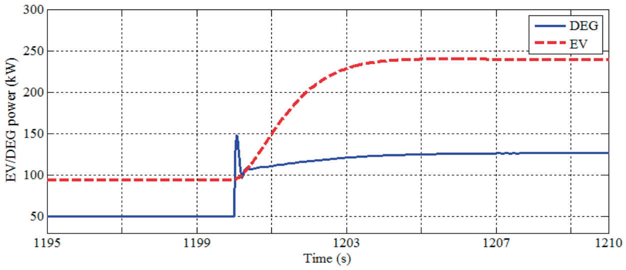


Figure 9: DEG and EV powers in kW after incident

This statement can be concluded from the less drop of frequency in time of incident (1200 s), which is about 3 Hz.

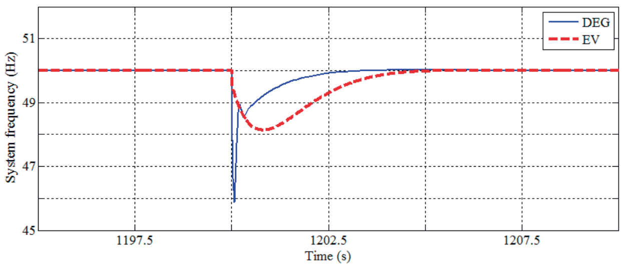


Figure 10: System Frequency after incident

The reduced slope of the frequency drop in presence of EV compared with DEG which is about 2 seconds is also another positive index of EVs. This improvement of frequency regulation in 10 seconds time interval in presence of EV in comparison to DEG is a significant index to show the effectiveness of applying this component in the micro-grids in cases, which their available capability is adequate.

Discussion

In this paper an optimized LFC method is designed. In addition, the role of EV participation in LFC in case of availability instead of DEG is studied. The simulation results in this paper show that the application of the EVs is very effective for the micro-grids LFC. The EVs act faster than the DEGs and less frequency deviation happens during the normal operation condition and contingency mode of the micro-grid which indicates a better controlling performance of the vehicles. In addition, the BESS is also being operated at its lower capacity which, leads to the fewer charge and discharge actions and a higher lifetime and decrease in the degradation cost of the battery. As the balance between demand and generation is a very important operation issue in a micro-grid, therefore the subject of frequency control becomes especially more important in the stand-alone mode of a micro-grid which simulation results were shown in this research. Thus, the application of the EVs batteries potentials as fast storage systems could be very useful and effective for these controlling purposes. On the other hand the EVs do not produce harmful gases like CO2. This is very interesting and essential for any countries power system operator to apply environment-friendly methods for operating and controlling their power grids. There is also less noise pollutions and fossil fuel consumption using EVs instead of DEGs. The increasing application of the electric vehicles in the near future could help the system operators to maintain their power grids stability in a more optimal and effective way. Smart grid capabilities are inevitable for the better realization of these ideas and the aggregator's performance. Finally, the use of EVs is strongly recommended for system operation issues like LFC. Further researches should be investigated in the field of economic studies of this proposed method.

References

Kim, J.,Jeon, J., Kim, S., Cho, C., & Nam, K. (2010). Cooperative Control Strategy of Energy Storage System and Microsources for Stabilizing the Microgrid during Islanded Operation. *IEEE Transactions on Power Electronics, vol.25, no.12*

Wu, C., Mohsenian-Rad, H.,Huang, J.(2012). PEV- Based Combined Frequency and Voltage Regulation for Smart Grid. *Innovative Smart Grid Technologies (ISGT), IEEE PES* (pp.1-6).

Yilmaz, M.,& Krein, P. T. (2013). Review of the Impact of Vehicle-to-Grid Technologies on Distribution Systems and Utility Interfaces. *IEEE Transactions on Power electronics, vol.28, no.12*

Ameli, A., Krauter, S., & Hanitsch, R. (2013). Frequency Control Applying Plug-in Electric Vehicles Based on Costumer Behavior in Electric Power Networks and Micro-Grids. *Micro Perspectives for Decentralized Energy Supply, International Conference, 27 February –1 March in TU Berlin*

Han, S., Han, S., &, Kaoru., S. (2011). Estimation of Achievable Power Capacity From Plug-in Electric Vehicles for V2G Frequency Regulation: Case Studies for Market Participation. *IEEE Transactions on Smart Grid, vol.2, No.4*

Dallinger, D., Krampe, D., & Wietschel, M. (2011). Vehicle-to-Grid Regulation Reserves Based on a Dynamic Simulation of Mobility Behavior. *IEEE Transactions on Smart Grid, vol.2, No.2*

Kennel, F., Görges, D., & Liu, S. (2013). Energy Management for Smart Grids With Electric Vehicles Based on Hierarchical MPC. *IEEE Transaction on Industrial Informatics, vol.9, No.3*

Abbasi, E., Ameli, H., Strunz, K., Duc, N. H. (2012). Optimized Operation, Planning, and Frequency Control of Hybrid Generation- Storage in Isolated Networks. *3rd IEEE PES Innovative Smart Grid Technologies Europe, Berlin*

Senjyu, T., Nakaji, T., Uezato, K., & Funabashi, T. (2005). A hybrid power system using alternative energy facilities in isolated island. *IEEE Transactions on Energy Conversion, vol.20, no.2,pp. 406–414*

Ngamroo, I., (2013). Specified Structure Mixed H_2 / H_∞ Control-Based Robust Frequency Stabilizationin a Smart Grid By Plug-In Hybrid Electric Vehicles. *International Journal of Innovativ Computing, Information and Control, vol. 9, no.1, ISSN 1349-4198*

The Synergies between Mobile Phone Access and Off Grid Energy Solutions

Michael Nique (mnique@gsma.com)
GSMA – 5 New Fetter Lane EC4A 3BF
London, United Kingdom

Helene Smertnik (hsmertnik@gsma.com)
GSMA – 5 New Fetter Lane EC4A 3BF
London, United Kingdom

Abstract

Mobile connectivity has grown beyond the electricity grid in most emerging markets: the slow growth of grid access over the last 10 years compared to the rapid expansion of mobile networks has widened the existing gap between access to mobile and access to electricity. The GSMA estimates that this gap is equivalent to more than 643 million people covered by mobile networks without access to electricity, representing up to 53% of the global off grid population. According to five mobile channels, namely the off grid telecom tower infrastructure, mobile operators distribution networks, machine to machine connectivity, mobile payments and mobile services, the mobile industry offers innovative pathways to achieve reliable energy access for currently underserved communities.

Keywords: Mobile Phone; Mobile Payment; Off Grid Telecom Tower.

Introduction

1.2 billion People don't have access to electricity and 2.8 billion have to rely on wood or other biomass fuels to cook and heat their homes [1]. In order to reach universal, affordable and sustainable access to energy by 2030 (as stated by the United Nations), there is a need to accelerate the current pace of expansion of electricity access to keep up with the demographic growth but also develop innovative ways to provide decentralized and sustainable energy to off grid populations.

In a context of poor access to basic services such as electricity and water, mobile telecommunications have strived in the last ten years. The growth and increased maturity of mobile markets, based on ubiquitous population mobile coverage, extensive distribution networks and affordability of mobile services and mobile devices, is offering new market-based opportunities for energy practitioners.

Research Questions

- What is the current status of mobile availability and uptake in emerging markets?
- What is the size of the opportunity for energy practitioners to leverage mobile?
- What are the different mobile channels available to support energy access?
- How innovative business models such as mobile-based Pay As You Go solutions can disrupt the off grid solution market?

Methodology

This article was implemented based on the work the GSMA Mobile Enabled Community Services program carried out in 2013. The sections on the five mobile channels to support access to energy and the Pay As You Go example were developed from interviews with Energy Service Companies leveraging mobile infrastructure, technology and services part of their business model.

Related to the market sizing section, the energy addressable market is an estimate of the number of people who live within range of GSM networks and have no access to electricity, but could be hence impacted by the deployment of mobile-enabled services. For a total of 114 developing countries, the energy addressable markets were calculated by overlaying the following data in urban and rural locations on a country basis:

- The percentage of the population with access to electricity (2013 from IEA "electrification rate" and World Bank "access to electricity");
- The percentage of the population being covered by GSM networks (the most recent data available from mobile operators and GSMA GIS based estimates).

The ubiquity of mobile in emerging markets

As of 2013, more than 4 out of 5 people living in emerging markets were covered by mobile networks and 2.3 billion people had a mobile phone subscription, with an estimated growth of up to 3 billion in 2017[10]. The figure 1 illustrates how the global growth of mobile networks and unique mobile subscriptions has outpaced the expansion of the electricity grid, clean water and sanitation systems in emerging markets.

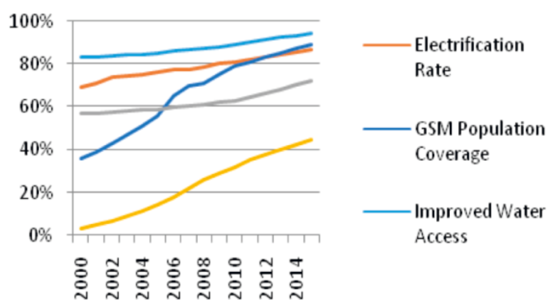


Figure 1: Mobile growth vs. utility access growth in emerging markets

[10] GSMAi 2013 on the number of Unique Subscribers

Leveraging this mobile ubiquity and increasing maturity of the mobile industry, and in conjunction with the cost reduction of renewable energy sources in recent years (PV module prices have fallen by 80% since 2008 and by 20% in 2012 alone [2]), there are strong opportunities for public and private players to leverage the mobile infrastructure, technologies and services to provide sustainable access to energy to current off grid communities, or communities with poor access to the grid.

A majority of the off grid population is covered by mobile networks

As of mid-2013, the GSMA Mobile Enabled Community Services program estimated the global energy addressable markets, e.g. the number of people covered by mobile networks without access to electricity, at more than 643 million people, representing up to 53% of the global off grid population [3]. Out of this total, more than 476 million people live in rural areas.

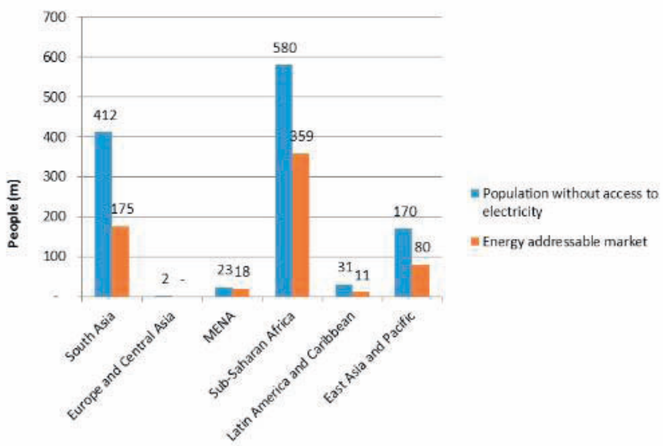


Figure 2: Energy Addressable Markets

As presented in Figure 2, the largest addressable market is Sub Saharan Africa (359 million people) where the reach of electricity networks remains limited (~32% of the population[11]) but where mobile networks cover more than 74% of the population. In East Africa, Kenya, Tanzania and Uganda accounts for more than 82 million people who could benefit from the access to mobile-enabled energy services.

Five Mobile Channels to Enhance Access to Energy

Based on the current footprint and maturity of the mobile industry, five mobile channels can support access to energy solutions (Table 1 summarizes impact of these channels):

- **Mobile Tower Infrastructure**: The mobile tower infrastructure has grown beyond the electricity grid by relying on its own power solutions, mainly diesel generators. At the end of 2011, more than 346,000 towers[12] were operating in off-grid environments. In a context where diesel costs are rising, leading to high operational charges, increasing synergies exist between operators and Energy Service Companies willing to provide stable energy to telecom towers and communities under an energy hub or micro-grid model.
- **Mobile Operator Distribution Network**: The mobile operator's airtime distribution channels and mobile money agent networks are becoming national distribution networks providing last mile access to mobile communication solutions. For example in Kenya, there were more than 96,000 mobile money agents across the country in April 2013 [4]. These kiosks and shops carry a trusted brand, reach remote communities and can scale-up responsively to the needs of potential customers.
- **Machine to Machine Connectivity**: Machine to machine (M2M) connectivity enables point to point communication thanks to embedded wireless chipsets within the utility system. With GSM networks serving as the communication backhaul, decentralized energy solutions can be remotely monitored, allowing real time information to be channeled directly from energy solutions to service providers and enabling an on/off switch function, critical for the Pay As You Go (PAYG) business model.
- **Mobile Financial Services**: More than a money transfer platform, mobile financial services are now enabling subscribers to buy products, pay their bills and save money through their mobile phone. As of the end of 2012, there were more than 30 million active mobile money subscribers worldwide with more than 150 live deployments in 72 countries [5]. The ability to leverage mobile phones for energy payments is now enabling the development of PAYG solutions tailored to low-income customers.
- **Mobile Services (SMS, USSD, Apps):** Mobile handsets are increasingly available and affordable in the developing world through formal and informal distribution channels. In Kenya, the monthly total cost of ownership[13] of a low cost mobile handset decreased from EUR10.11 in 2009 to EUR2.83 in 2011[14]. This pervasiveness of mobile phones in rural and underserved locations can be leveraged in different ways to enhance sustainable access to utility services and products.

[11] According to the electrification rate in 2012 from the International Energy Agency
[12] GSMA Green Power for Mobile

[13] The Total Cost of Ownership of a mobile handset refers to the amount a mobile user has to spend per month to own and use a mobile handset. This include the price of the mobile handset and an average use of mobile services (voice, SMS, data)
[14] Source Nokia from GSMA MDI website: https://mobiledevelopmentintelligence.com/statistics/70-monthly-total-cost-of-ownership-usd#

Table 1: Five Mobile Channels Impact Summary

Channels	Impact
Mobile Tower Infrastructure	Increase sustainability of decentralized micro-grids by providing power for consumptive and productive use
Mobile Operator Distribution Network	Support last mile delivery services for off grid products (e.g. home solar systems); Improve customer awareness and trust in emerging energy solutions by co-branding products
Machine to Machine Connectivity	Improve maintenance through remote monitoring; Enable Pay As You Go functionality, improving energy solutions affordability; Improved user centric design thanks to consumer usage patterns collection
Mobile Financial Services	Increasing system affordability through Pay As You Go solutions; Improving payment efficiency; Enabling private energy connection finance; Proposing smart tariffs based on customers energy usage or time of usage
Mobile Services (SMS, USSD, Applications)	Improve utility agents business capability through mobile tools usage (e.g. customer relationship management); Enable the collection of crowd-sourced information directly from customers; Improve supply chain management through mobile platforms

Emerging mobile-based energy business model – the Pay As You Go example

While underserved populations spend an important proportion of their income on hazardous energy solutions (up to 30% of their yearly income [6]), part of the same population cannot afford to buy clean energy solutions due to their high upfront costs. There are however evidences supporting the hypothesis that offering payment plans to customers increases the rate of adoption of solar products as they become more affordable[15].

The Pay As You Go model, developed on the brink of mobile financial services deployment, are now allowing entrepreneurs to offer home solar systems under a micro-financed or a “solar as a service” scheme, enabling low income customers to pay for energy directly via their mobile phones:

1) **Lease to own (micro-financed):** An Energy Service Company (ESCo) offers a micro-loan solution to their customers to afford a home solar system; customers first have to make a down-payment to have the home solar system installed at their house and then repay for the full price of the unit part of their energy consumption via daily, weekly or monthly installments. Once they repay for the full cost of the product, they own the home solar system and can use it freely (if the unit is GSM enabled, the unit internal switch will be permanently unlocked without any agent intervention). Products usually come with a warranty of 1 to 3 years according to contract terms.

2) **Solar as a Service:** an Energy Service Company provides a service to its customers while the home solar system remains the property of the service provider. An installation fee is charged to new customers and the service is then provided on a prepaid basis (amount according to the solution capacity). Energy prices are usually lower than in the “lease to own” model as the solar system and other products provided by the ESCo (lights, TV, fridge,…) remain its property. Full maintenance is also ensured under the service agreement with the end user.

Adding a GSM component to an energy system is the most seamless solution for PAYG, as remote monitoring and credit update on the unit meter can be done over the air, without an agent or a user intervention. Service providers receive real time information under a SMS format about the unit operations (power consumption, battery charge/discharge), customers’ payments (frequency of payments, credit) and any maintenance/theft issues. ESCos are also building extensive databases on unit operations, which are then analyzed to offer better products and services from a user centric perspective. M-KOPA, providing home solar systems under a Pay As You Go model in Kenya, has been to date the most successful Pay As You Go provider, reaching 50.000 units sold as of January 2014. The deep integration of mobile technology in their business model (as seen in Figure 3), M2M connectivity coupled to mobile payments, added to their distribution partnership with leading mobile operator Safaricom, has enabled this emerging ESCo to provide reliable products and stable services.

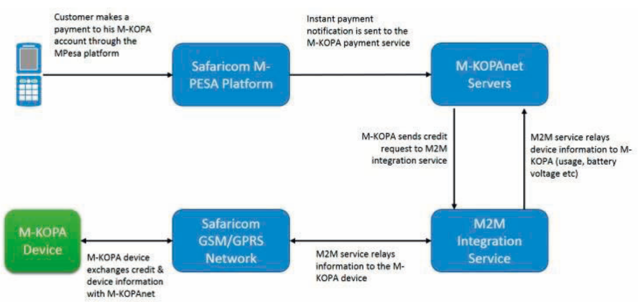


Figure 3: M-KOPA Pay As You Go Model

Most of the PAYG solutions are currently available in East Africa as shown in the Table 2; with poor access to electricity, good mobile penetration and increasing mobile money services traction, this region has become the cradle for mobile-based energy PAYG solution deployments.

[15] Information collected from several Energy Service Companies providing Energy Pay As You Go solutions

However, the opportunity to deploy and scale PAYG is real and important in most of the global off grid regions, provided the right ingredients are present: quality energy products, mobile payments capability (using mobile money but also mobile airtime), working capital available to energy entrepreneurs financing the risk of customers default and an efficient distribution network.

Table 2: Energy Pay As You Go Providers (as of the end of 2013)

Companies	Country Operations	Service Model	Payment Type
M-KOPA	Kenya, Uganda	Lease to Own	Mobile Money – flexible fee*
Mobisol	Tanzania, Rwanda	Lease to Own	Mobile Money –fixed fee*
Off Grid Electric (OGE)	Tanzania, Ghana	Solar as a Service	Mobile Money – flexible fee*
Angaza Design	Kenya, Tanzania	Lease to Own	Mobile Money – flexible fee*
Econet Solar	Zimbabwe, Lesotho, Burundi	Solar as a Service	Airtime Billing – fixed fee*
Simpa Networks	India	Lease to Own	Scratch cards or mobile payments

(*by introducing the terms flexible fee and fixed fees, we wanted to give a sense of the payment granularity of these different models; a flexible fee would indicate a possibility of daily payments, whereas fixed fee refers to weekly or monthly installments)

Challenges of such mobile enabled solutions

- Financing – while pay as you go solutions improve energy affordability, the financing burden falls on Energy Service Companies providing such products or services. Entrepreneurs have to wait for the duration of the payback periods to recoup their sales revenue, a period that can be as long as 36 months for some providers. This puts an important pressure on cash flow availability, especially for customers with high default risks. Without debt financing tools and working capital, companies might be unable to expand or ensure efficient after sales services.
- Availability of mobile financial services – even though mobile money services are increasingly gaining traction across markets, their growth and how they can be leveraged by energy entrepreneurs will vary on a market basis. The convenience of mobile payments should not be made at the expense of higher fees charged to consumers each time they pay via their mobile phone. In complement to mobile money services, airtime billing represents another interesting opportunity for customer energy payments.

Discussion

The success of mobile telecommunications in emerging markets is enhancing the opportunity for energy practitioners to develop innovative access models tailored to off grid and underserved communities' ability to pay. According to the GSMA, five mobile channels, based on the reach and impact of the mobile infrastructure, technologies and services, appears key to support such innovation. The development of Pay As You Go (PAYG) solutions under a micro-loan or solar as a service model, where units can be remotely monitored through machine to machine connectivity over mobile networks and where customers can make payments directly via their mobile phones, can act as a paradigm in displacing hazardous fossil fuels for the off grid households with access to mobile. As mobile markets mature and mobile financial services get more traction, most PAYG pilots could move in a commercial phase in 2014, with new entrants in different parts of Africa, Asia and Latin America. Still at a nascent stage of development, technology and business models innovation should lead to the emergence of more synergetic models, coupling mobile, energy but also water, some of the key pillars to socio-economic empowerment.

References

Banerjee, Sudeshna Ghosh; Bhatia, Mikul; Azuela, Gabriela Elizondo; Jaques, Iver; Sarkar, Ashok; Portale, Elisa; Bushueva, Irina; Angelou, Nicolina; Inon, Javier Gustavo. (2013). Washington *Overview. Global tracking framework. Sustainable Energy for All* DC; World Bank.

Liebreich, Michael. (2013). *Scaling up financing to expand the renewable portfolio*. Bloomberg New Energy Finance.

Nique, Michael. (2013). *Sizing the opportunity of mobile to support energy and water access*. GSMA Mobile Enabled Community Services.

DiCastri, Simone; Gidvani, Lara. (2013). *The Kenyan Journey to Digital Financial Inclusion*. GSMA Mobile Money for the Unbanked; Bankable Frontier Associates.

Penicaud, Claire. 2013. *State of the Industry – Results from the 2012 Global Mobile Money Adoption Survey*. GSMA Mobile Money for the Unbanked.

Hammond, Allen; Kramer, William J; Tran, Julia; Walker, Courtland; Katz, Rob. (2007). *The next 4 billion – Market Size and Business Strategy at the Base of the Pyramid*. World Resources Institute.

End-Use Load Monitoring of a Micro Hydroelectric-Powered Community Microgrid: A Case Study in Rural Malaysia

Kyle Weber (kweber@masdar.ac.ae)
Masdar Institute of Science and Technology
P.O. Box 54224, Abu Dhabi, UAE

Dr. Scott Kennedy (skennedy@thecenter.mit.edu)
The Dalai Lama Center for Ethics and Transformative Values at MIT
Cambridge, MA, USA

Dr. Peter Armstrong (parmstrong@masdar.ac.ae)
Masdar Institute of Science and Technology
P.O. Box 54224, Abu Dhabi, UAE

Abstract

Rural electrification modeling and planning, especially for microgrid-connected communities, requires quality data to verify results. This data can be difficult to locate in current literature. Case studies which show not only the types of loads encountered in rural off-grid installations, but also the variation of loads and the daily load profile in the context of a limited output system are extremely useful in enabling further research in this field to expand the current pool of knowledge. This paper describes the end-use load monitoring work that has been performed in Kg. Buayan since 2010 and the challenges associated with data gathering and processing in a rural setting.

Keywords: End-Use Load Monitoring; Microgrid; Microhydro; Microenergy; Kg. Buayan.

Introduction

Rural electrification has come a long way in the last few years, especially in the areas of community off-grid, renewable powered microgrids. Such systems, which 20 years ago would have been considered impractical are now at the forefront of future energy access. As the UNDP states, “Energy is the fundamental prerequisite for achieving the millennium development goals (MDGs) and access to energy, especially in the form of clean and affordable electricity that can help achieve sustainable and economic development” (Takada & Fracchia, 2007). Because of these reasons, having quality data that can be used for modeling and planning is extremely important, as it has been noted that a gap exists in rural energy pattern data (Howells, Alfstad, Cross, Jeftha, & Goldstein, 2002) and detailed descriptions of rural household energy needs (Cross & Gaunt, 2003)

In the larger rural villages of Penampang, outside of Kota Kinabalu in the Malaysian state of Sabah, the issue of rural electrification has been addressed to some extent over the last few years through the installation of community-sized micro grids powered by micro hydroelectric generators. One village in particular, Kg. Buayan, a traditionally subsistence farming community which has been electrified since 2008, has partnered with Masdar Institute of Science and Technology in Abu Dhabi over the last four years to allow researchers to enter the village and conduct studies which contribute to better understanding of the system to determine ways that the electricity generated can be used more reliably.

The village of Kg. Buayan stretches along the Papar River with homes located on both sides as shown in Figure 1 below.

Figure 1: GPS Image of Kg. Buayan, 2010[16]

One of the most potentially useful projects to come out of the Kg. Buayan – Masdar Institute partnership to date has involved end-use load monitoring of the buildings connected to the microgrid. The project is encouraging partly due to the robustness of the data loggers which have been proven to survive the harsh environment that has prevented many more sophisticated technologies from fulfilling their duties, but also because the loggers have been integrated into the community through training and capacity building of individuals. Masdar Institute has relied on the community to retrieve and send data for processing, as well as alert researchers whenever problems occur to enable remote troubleshooting if possible, or mobilization if necessary. Results are then passed onto a community-based organization who can advise the community on best practices and ways to optimize the system for the maximum benefit of its users.

[16] The purple, blue and green dots signify homes on certain phases, the red dots signify distribution poles.

Research Objectives

The objective of this research is to develop Kg. Buayan as a case study for end-use load monitoring in rural Malaysia and thus fill a gap in the current available research on actual energy use in a recently electrified village including usage patterns and specific electricity loads.

Methods

Installing the end-use load monitoring equipment (Onset HOBO U12-006's) in Kg. Buayan was straightforward. After gaining permission from the households, and installing a current transducer (CT) on the incoming electricity line, the logger was mounted nearby and launched with a laptop. Data was collected on a semi-regular basis by either researchers or villagers who were trained in data gathering. To ensure that batteries could be replaced infrequently and that data collection could occur at the longest possible interval, approximately every 6-8 months, the loggers were set to record instantaneous current measurements every 10 minutes. It was assumed that this interval could be shortened in the future once a reliable collection schedule was established, but this has not yet been tested.

Results

The average results of this data can be found in Figure 2 below. Using quantitative logger data as well as qualitative household device information taken from surveyed homes, four distinct load groups were identified based on average consumption over the four month sample period.

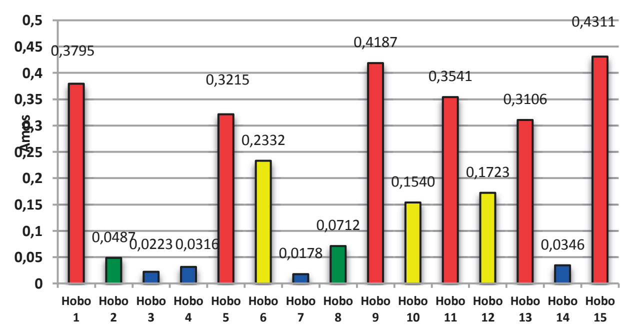


Figure 2: Average Current Values for 15 homes from July 2010 to November 2010.

The color red corresponds to load group A. Homes in this category contain at least one refrigerator or washing machine and all of the appliances found in the subsequent load groups. The color yellow corresponds to load group B. Homes in this category contain at least one television and related equipment and all the appliances found in load groups C and D. The color green corresponds to load group C. Homes in this category contain at least one radio or table fan and the appliances found in load group D. Homes in load group D utilize only lights and mobile phone chargers.

The appliances utilized in homes during this period were very similar in both size and power consumption, enabling accurate grouping of devices, as shown in Table 1 below. The largest differences were found in the lighting category as most users utilized high-watt compact fluorescent lights (CFL's), with a few using incandescent.

Table 1: Average Load of Various Devices found in Kg. Buayan and their corresponding Load Categories

Appliance	Watts (or other)	Load Category
CFL Lights	14 W (105mA), 18 W (130mA), 20 W	A, B, C, D
Phone Charger	100-240V, 50-60Hz, 150 mA	A, B, C, D
Portable Radio	220V, 50Hz	A, B, C
Table Fan	39 W	A, B, C
TV	45 W – 180 W	A, B
Satellite Receiver	30 W	A, B
DVD Player	20 W	A, B
VCD Player	20 W	A, B
Refrigerator	100 W (0.48 kWh per 24 hours)	A
Washing Machine	280 W (wash) 140 W (spin	A

The loggers have also been able to record system down time during the same period as recorded above, although given the 10 minute logging interval constraint, this estimate is only accurate within 10 minute increments and may thus be underestimated. The downtime is shown in Table 2 below.

Table 2: Average Outtage Duration from July 2010 to November 2010.

#	Start Date/Time	End Date/Time	Down Time
1	7/12/10 19:20	7/13/10 6:10	10 hours 50 minutes
2	7/13/10 23:30	7/14/10 6:30	7 hours
3	7/19/10 17:00	7/23/10 20:40	4 days 3 hours 40 minutes
4	8/26/10 20:30	8/26/10 22:00	1 hour 30 minutes
5	8/27/10 17:30	8/27/10 19:40	2 hours 10 minutes
6	8/28/10 7:00	8/28/10 15:10	8 hours 10 minutes
7	8/29/10 7:50	8/29/10 12:50	5 hours
8	8/29/10 18:40	8/30/10 6:40	12 hours
9	8/30/10 13:40	8/30/10 15:30	1 hour 50 minutes
10	8/31/10 4:30	9/3/10 17:10	3 days 12 hours 40 minutes
11	9/11/10 8:10	9/11/10 14:30	6 hours 20 minutes
12	9/22/10 20:10	9/22/10 21:10	1 hour
13	9/23/10 22:40	9/24/10 19:30	20 hours 50 minutes
14	9/28/10 20:50	9/29/10 10:40	11 hours 50 minutes
15	10/2/10 8:50	10/2/10 12:10	3 hours 20 minutes
16	10/15/10 18:50	10/15/10 20:00	1 hour 10 minutes
Total Down Time			11 days 13 hours 20 minutes

Finally the average daily load profile of the buildings in various load groups can be determined as shown in Figure 4.

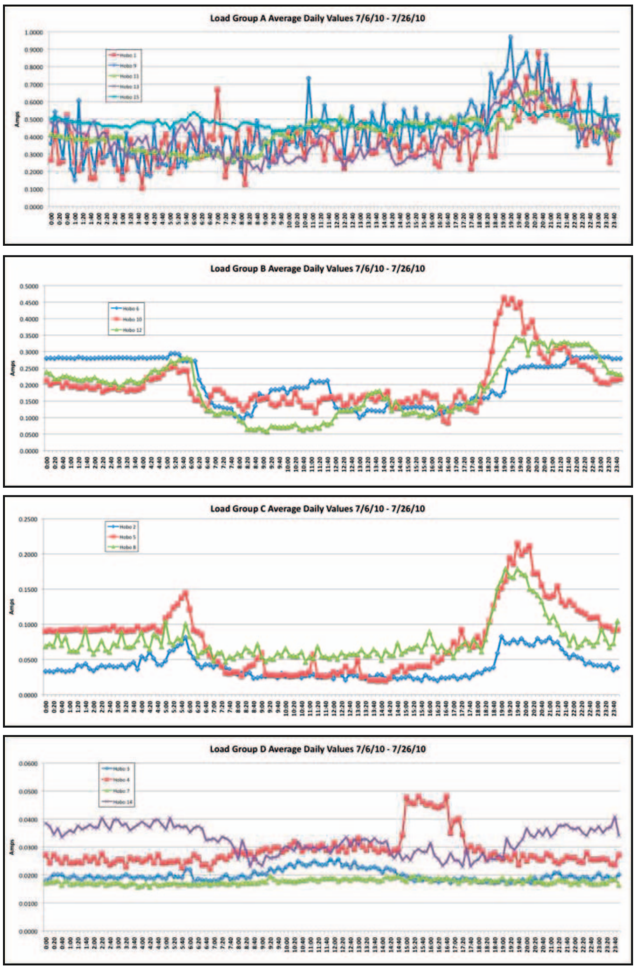


Figure 4: Average Daily Load Profiles for buildings in Load Groups A, B, C and D from July 2010.

The fluctuation noticed in load group A is due to the duty cycle which refrigerators follow. The information from all of these load groups is aggregated into one system-wide daily load profile as shown in Figure 5 below.

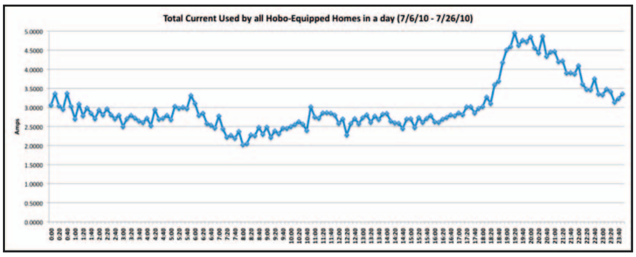


Figure 5: Aggregated Daily Load Profiles for Load Groups A, B, C and D from July 2010.

Discussion

In the time since this data was collected, Kg. Buayan has increased the amount of appliances and homes connected to the micro grid, thus putting more strain on an already fragile system. The data given above is somewhat out of date as at least seven of the 15 homes shown can now be categorized as load category A. In addition to these 15 homes, there are now a total of 23 loggers installed in every connected home as of 2012. More are required as there are now approximately 30 buildings connected to the microgrid, due to village expansion. More up to date data is being finalized, and will be made available in the near future.

Considering the large amount of outages present, and from qualitative knowledge of the system and its operation, it is clear that reliability is one of the major challenges faced by the Kg. Buayan microenergy system. This has been somewhat addressed in the time since this data was collected by the diversion of additional water resources which allow the microhydro to more fully realize its design capacity and provide a buffer during periods of drought. Connective infrastructure in the form of a road has reached Kg. Buayan making household diesel generators more feasible then they were previously.

It is clear from the data that during the beginning and middle of the day when consumption is low, encouraging the use of high-load items might seem like a potential solution. However, given that this is the time when most villagers are working in the fields, and most loads are time related, it seems unlikely that rescheduling these loads will enact the type of changes necessary to increase peak reliability significantly.

Instead, encouraging energy efficiency during peak hours may provide the community with some of the energy savings necessary to improve reliability. However, more up to date data, preferably at a shorter logging interval for increased resolution is necessary to make more accurate recommendations. As high-load appliances diffuse further into the community, the generation capacity of the microgrid will need to increase to meet this load.

References

Cross, N., & Gaunt, C. T. (2003). Application of rural residential hourly load curves in energy modelling. In Power Tech Conference Proceedings, 2003 IEEE Bologna (Vol. 3, p. 4–pp). IEEE. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1304492

Howells, M., Alfstad, T., Cross, N., Jeftha, L., & Goldstein, G. (2002). Rural energy modeling. Citeseer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.110.1532&rep=rep1&type=pdf

Takada, M., & Fracchia, S. (2007). A Review of Energy in National MDG Reports. UNDP. Retrieved from http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/a-review-of-energy-in-national-mdg-re-ports/A%20Review%20of%20Energy%20in%20National%20MDG%20Reports_2007.pdf

Scientific Papers

II. Demand Assessments

Financing Energy Efficiency and Climate Adaptation Measures on Household Level in Kyrgyzstan – Market Based Approaches in a Post-Soviet Country?

Anastasia Bakteeva (bakteeva.a@gmail.com)
Research Group Microenergy Systems, Technische Universität Berlin
Center for Technology and Society, Secr. HBS 1, Hardenbergstr. 16-18, 10623 Berlin, Germany

Jonas van der Straeten (straeten@ztg.tu-berlin.de)
Research Group Microenergy Systems, Technische Universität Berlin
Center for Technology and Society, Secr. HBS 1, Hardenbergstr. 16-18, 10623 Berlin, Germany

Abstract

This paper explores the potential of innovative financing tools to foster the implementation of energy efficiency measures such as thermal insulation, using the example of two regions in Kyrgyzstan. The country is challenged by cold winters, national energy crises and poorly insulated housing inherited from Soviet times. Based on a household survey the paper investigates the problem of climate vulnerability and high energy expenditures on household level, identifies financing gaps for investments into efficiency measures and discusses financing tools to address them, such as green microfinance.

Key words: Energy Efficiency; Kyrgyzstan; Green finance; Thermal insulation.

Problem Statement

The former Soviet states in Central Asia are profoundly challenged by climate change in two respects. Firstly, the region's diverse climatic zones are highly vulnerable to the ecological impacts of climate change, including droughts, heat waves, crop losses, decrease in precipitation and melting of mountain glaciers and snowfields (Cruz et al., 2007; Sorg et al., 2012). Secondly, the region has inherited an inefficient energy system shaped by the Soviet tradition of extensive, state-subsidized energy services (Wiedemann et al., 2012).The case of Kyrgyzstan shows how climate change impacts and power supply crises are interlinked: with its high dependency on hydropower (90% of the total electricity generation, GTZ 2009) water shortages dramatically reduce the total electricity generation capacity. In addition, subsidized electricity prices (in 2009 0.01 USD/kWh for residential sector, Gassmann, 2012), not only discourage modernization of obsolete equipment but also stimulate growth in energy demand that cannot be met in the future. This leads to the paradox situation, that Kyrgyzstan, rich in hydropower and currently a net-exporter of electricity, is expected to face winter power supply deficits from 2014 onwards, which could reach an annual 2,750 GwH by 2020 (World Bank, 2013).

With winter temperatures as low as -20 to -30 C°in some regions of the country, the aggravating problems in the energy sector affect many households on an existential level. As little emphasis was put on thermal insulation during Soviet times, the country was left with poor quality housing, with unsatisfactory quality outdoor insulation, high air permeability of windows and inadequate air exchange mechanisms (Energy Efficiency Protocol, 2011; Kraudzun et al., 2014). Recent studies show that households in mountainous areas of Kyrgyzstan spend up to 22% of their household budget on energy, mostly for coal, firewood and electricity for heating (Liu & Pistorius, 2012). In Kyrgyzstan the share of expenses for heating is up to twice as high for poor households than it is for wealthier households (Wu et al., 2004).

In total, the residential sector accounts for 63% of the country's total electricity consumption (Energy Efficiency Protocol, 2011), most of which is used on space heating (Wu et al., 2004). Therefore, increasing energy efficiency at the household level is not only advocated as one of the priority climate mitigation and adaptation measures (UNFCCC, 2007), but can also contribute to relieving the tense situation in the Kyrgyz energy sector and improving the livelihood of households, particularly in rural areas (Braubach et al., 2011; Sarkar & Singh, 2010). From an economic point of view, investments into energy efficiency measures such as retrofitting of houses to improve thermal insulation, often promises high returns by saving fuel expenses. Nonetheless, few households in Kyrgyzstan and other poor countries actually invest into thermal insulation. This fact suggests that there is a financing gap or at least an awareness gap for energy efficiency investments.

Effective means to fill this gap remain scarce. Multilateral financial agencies have had little success in financing energy efficiency projects in developing countries so far, as a review of recent literature shows. Approaches ranged from projects with utility companies and ESCOs (Energy Service Companies) to subsidies, grants or specific credit lines. These models proved to be effective in developed countries (Rezessy & Bertoldi, 2010) but they are often not adapted to countries with emerging economies. Building up ESCOs takes decades and credit lines credit lines often miss their target because of undeveloped financial sectors, legislative frameworks or high transaction costs(Sarkar & Singh, 2010). There is still a need for sustainable financing mechanisms, particularly on the level of households as well as micro, small and medium enterprises (MSMEs) (Painuly et al., 2003).

In recent years international development agencies and banks have increasingly paid attention to "green finance"; financial tools which are addressed at companies and projects that promote sustainable development, including resource efficiency, pollution reduction and mitigation of environmental damage (International Finance Corporation, 2011). An application of "green" financial instruments in microfinance offers a great potential to address energy and climate change adaptation needs of rural households using a market-based approach (Glemarec, 2012; Gujba et al. 2012). Kebir et al. also see it as important to provide access to green finance for MSMEs, as they are often crucial stakeholders in local value chains for energy efficiency measures (Kebir et al., 2013).

Research Objectives

Based on a household survey in Kyrgyzstan, this paper examines the problems of climate vulnerability and high energy expenses on household level and explores the potential of innovative financing mechanisms to mitigate them. The underlying research question of the study was: Can green finance foster the implementation of climate adaptation measures such as housing thermal insulation in Kyrgyzstan? The questions of the survey were aimed at identifying and quantifying the demand for housing retrofitting and thermal insulation. Based on this data, it was asked if there is a financing gap, which prevents this demand from being fulfilled. The household survey was accompanied by a comprehensive analysis of the country's microfinance sector and of supply chains and quality of products and services for thermal insulation.

Methods

The study is based on a quantitative survey of 384 households in the regions of Naryn and Issyk-kul. Households were randomly selected based on the official Kyrgyz census data (National Statistical Committee of Kyrgyz Republic, 2009).The survey was conducted on an individual basis and questions were addressed to the household head or the person responsible for housekeeping.

The results of the survey were complemented by qualitative interviews with ten households in the two regions that took place prior to the survey. Both the interviews and survey covered a range of aspects related to the demand for micro loans for thermal insulation: housing conditions, household energy consumption, satisfaction and awareness about energy efficiency and thermal insulation, experience with microfinance and household cash flows.

Results

The survey showed that 75% of the respondents' houses were built more than 20 years ago during Soviet times. Nearly half of these houses were built of *saman*, a locally available construction material made of haulm and clay with much higher heat conductivity then for example bricks. Households spend on average at least 20% of their monthly income on space heating. Despite the low prices for electricity, thermal fuels are also widely used for heating (coal by 93% of respondents, firewood by 74%, and manure cakes by 47%). In order to cut down the heating cost, families often live in just one or two rooms for the winter period and "seal off" the rest of the house. Still, 22% of respondents indicated that they suffer from a lack of heat in winter.

The capability and/or willingness to change that situation differed considerably between the two regions and between rural and urban respondents. While in the economic more advanced region of Issyk-Kul, two thirds of the rural and half of the urban population indicated that they were "planning to make any changes to make [their] house warmer within the next three years"[17], this was only the case for less than one third of rural and urban residents in the region of Naryn.

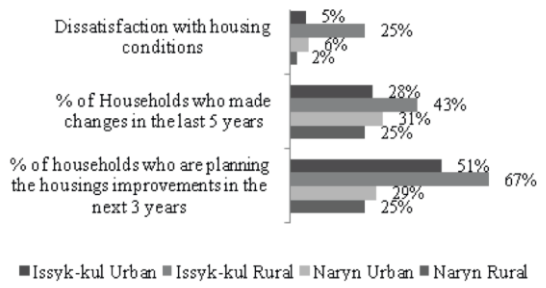


Figure 1: Comparison of demand patterns for thermal insulation measures across districts (n=384).

The replacement of heating systems, windows and doors were by far the most preferred retrofitting measures to make the house warmer.

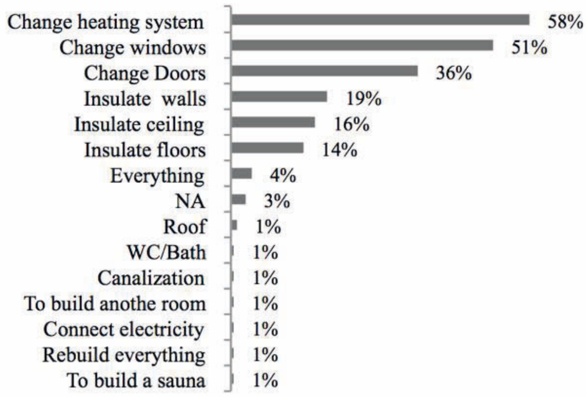


Figure 2: Types of planned improvements within the next three years in % (n=172, multiple answers possible).

However, an assessment of the underlying motivation for implementing retrofitting measures using a 5-point scale showed that comfort was ranked highest in both regions. However, opinions on other factors differ. In poorer and colder Naryn region "Saving money for heating fuel" was ranked as the second most important reason but only fourth in Issyk-Kul. This might be explained by

[17] The question were asked this way as the qualitative interviews had revealed that retrofitting measures were are not perceived as "thermal insulation" but as means to "make It warmer" (*"Uteplenie")*.

the lower total income and higher share of energy expenses in Naryn as well as the higher potential savings, due to the colder climate in this region.

Despite the general willingness to invest in housing insulation measures, the price of such retrofitting often exceeds household disposable income: the majority of respondents have a household income of less than 10,000 KGS (156 EUR) a month and 20 -30% have an income of less than 5,000 KGS (78 EUR). Thus, the purchase and installation of, for example, five PVC-windows which costs between 23,000 – 35,000 KGS (539 EUR) is way beyond the budget of typical household.

Respondents who already conducted housing retrofitting in the past resorted to different sources of financing, with savings (64%) as the most popular answer, followed by sales of livestock (12%) and loans from financial institutions (9%).

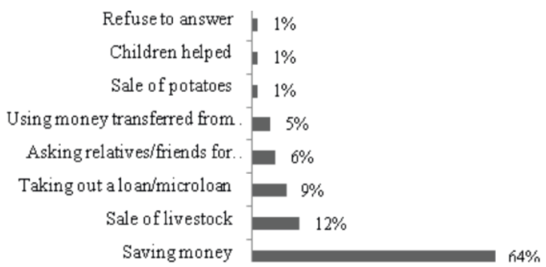


Figure 3: Financing sources for housing retrofitting (n=130, multiple answers).

Despite the low usage of loans for house retrofitting until now, the framework conditions for the disbursement of thermal insulation loans seem fairly favorable. The outreach of the financial sector in Kyrgyzstan is generally very high; in the survey sample 45% of the respondents have experience with taking a loan from a credit institution, 12% of which were dedicated to housing. There are however striking differences between the two regions. In Naryn, where respondents generally rely much more on informal sources of financing (e.g. relatives friends), the percentage of loans dedicated to housing was significantly lower as in Issyk-Kul (only 4% in rural Naryn). On the other hand, nearly half of the *total* number of respondents in rural Naryn (47, 9%) expressed a general willingness to apply for an insulation loan (urban Naryn 21.1%), compared to 25, 5% in rural and 9, 6% in urban Issyk-Kul.

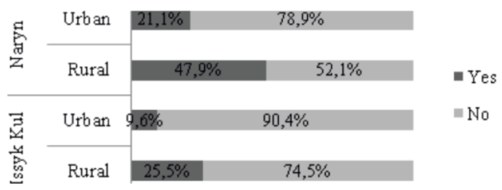


Figure 4: Willingness to apply for an insulation loan (N = 384, n=379).

Besides an aversion to owe money (74%), high interested rates were mentioned as prohibitive factor for not applying for a thermal insulation loan (30%).[18] For more than a fourth of existing loans, interest rates were higher than 25%, being as high as 35-40% in some cases. High interest rates of microfinance institutions have been subject to controversy debates and political exploitation in Kyrgyzstan lately.

Discussion

The results of the study show, that even in the challenging environment of Kyrgyzstan with its Soviet heritage of state-subsidized energy (especially electricity) services, there is a considerable potential for market-based approaches if they target a more efficient use of thermal energy in households, particularly for space heating. There is evidence of poor housing conditions, for example in regard to indoor winter temperatures, which leads to large heating fuel expenses among the population. It was shown in the study that this need does indeed translate into a demand for retrofitting measures: about one third of the population have already undertaken housing improvement measures and approximately 40 % are planning to do so in the next three years. This demand is however rather driven by the desire for more comfort, then by economic calculations of households, and it is more the wealthier urban households than those in poorer, rural areas, who have the financial means to fulfill this demand.

The study reveals the paradox situation, that the households in colder and more remote regions, with poorer housing conditions, a higher savings potential and a higher motivation to realize it, express the highest willingness to apply for thermal insulation loans but find it hardest to access these loans. If market-based approaches are supposed to address the energy and climate change adaptation needs of the most vulnerable households, they have bridge this financing gap with innovative and adapted financing tools, such as green microfinance.

The design of these loans has to take the following aspects into account: Interest rates need to reflect the long lifetime but relatively low yearly return on investment of energy efficiency measures. They furthermore should take into account the seasonality of income of many households. Loan programs rely on the local availability of products and services in the sufficient quality to ensure

[18] Choosing multiple answers was allowed in this question

efficiency gains. In the case of an existing program in Tajikistan, the "Warm comfort" program for example, this implied a high donor investment in building up and enforcing supply chains for high quality thermal insulation products, for example windows and doors. For Kyrgyzstan, however, the study showed that supply chains for some products are better developed. Finally, loan programs need to be accompanied by technical assistance and capacity building within financial institutions, to enable them to control and monitor the quality of energy efficiency products and services.

Research on the potentials and impacts of green finance instruments is still in its infancy. More evaluation of the few existing projects needs to be done e.g. on households factual energy savings. More attention should be paid to potential synergies with housing programs or to the role of utilities.

References

Braubach, M., Jacobs, D., Ormandy, D., World Health Organization, & Regional Office for Europe. (2011). *Environmental burden of disease associated with inadequate housing: a method guide to the quantification of health effects of selected housing risks in the WHO European region : summary report*. Copenhagen: World Health Organization, Regional Office for Europe.

Cruz, R. V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., … Li, C. (2007). *Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 469–506.). Cambridge,UK: Cambridge University Press.

Energy Charter Protocol on Energy Efficiency and Related Environmental Aspects. (2011). *Regular Review of Energy Efficiency Policies: Kyrgyzstan*.

Gassmann, F. (2012). Switching the lights off: The impact of energy tariff increase on households in the Kyrgyz Republic. UNU-MERIT.

Glemarec, Y. (2012). Financing off-grid sustainable energy access for the poor. *Energy Policy*, *47*, 87–93. doi:10.1016/j.enpol.2012.03.032

Gujba, H., Thorne, S., Mulugetta, Y., Rai, K., & Sokona, Y. (2012). Financing low carbon energy access in Africa. *Energy Policy*, *47, Supplement 1*, 71–78. doi:10.1016/j.enpol.2012.03.071

International Finance Corporation. (2011). *Climate Finance: Engaging the Private Sector*. Retrieved from http://www.ifc.org/wps/wcm/connect/5d659a804b28afee9978f908d0338960/ClimateFinance_G20Report.pdf?MOD=AJPERES

Kebir, N., Spiegel, N., Schrecker, T., Groh, S., Scott, C., & Aliaga Ferrufino, G. (2013). *Exploring Energy SME Financing in Emerging and Developing Countries*. Sustainable Business Institute.

Kraudzun, T., Vanselow, K. A., & Samimi, C. (2014). Realities and myths of the Teresken Syndrome – An evaluation of the exploitation of dwarf shrub resources in the Eastern Pamirs of Tajikistan. *Journal of Environmental Management*, *132*, 49–59. doi:10.1016/j.jenvman.2013.10.019

Liu, M. F. M., & Pistorius, T. (2012). Coping with the energy crisis: Impact assessment and potentials of non-traditional renewable energy in rural Kyrgyzstan. *Energy Policy*, *44*, 130–139. doi:10.1016/j.enpol.2012.01.025

Painuly, J. P., Park, H., Lee, M.-K., & Noh, J. (2003). Promoting energy efficiency financing and ESCOs in developing countries: mechanisms and barriers. *Journal of Cleaner Production*, *11*(6), 659–665. doi:10.1016/S0959-6526(02)00111-7

Rezessy, S., & Bertoldi, P. (2010). *Financing energy efficiency: forging the link between financing and project implementation*. Ispra: Joint Research Centre of the European Commission. Retrieved from http://ec.europa.eu/energy/efficiency/doc/financing_energy_efficiency.pdf

Sarkar, A., & Singh, J. (2010). Financing energy efficiency in developing countries—lessons learned and remaining challenges. *Energy Policy*, *38*(10), 5560–5571. doi:10.1016/j.enpol.2010.05.001

Sorg, A., Bolch, T., Stoffel, M., Solomina, O., & Beniston, M. (2012). Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). *Nature Climate Change*, *2*(10), 725–731. doi:10.1038/nclimate1592

UNFCCC. (2007). *Climate Change: Impacts, Vulnerability, and Adaptations in Developing Countries*.

Wiedemann, C., Salzmann, S., Mirshakarov, I., & Volkmer, H. (2012). Thermal Insulation in High Mountainous Regions: A Case Study of Ecological and Socioeconomic Impacts in the Eastern Pamirs, Tajikistan. *Mountain Research and Development*, *32*(3), 294–303. doi:10.1659/MRD-JOURNAL-D-11-00093.1

World Bank, 2013. *A More Efficient Kyrgyz Electricity Sector Could Reduce the Power Deficit by Half*. (2013, June 26). Retrieved January 28, 2014,from http://www.worldbank.org/en/news/press-release/2013/06/26/more-efficient-kyrgyz-electricity-sector-could-reduce-power-deficit-by-half

Wu, X., Lampietti, J., & Meyer, A. S. (2004). Coping with the cold: space heating and the urban poor in developing countries. *Energy Economics*, *26*(3), 345–357. doi:10.1016/j.eneco.2004.04.011

Demand Assessment of Solar Electrification in Off-Grid Rural Communities of Pakistan through Microfinancing of Solar Home Systems

Warda Ajaz (warda_ajaz@hotmail.com) and Hadley Taylor (hadleydltaylor@gmail.com)
Partners in Sustainable Development (PSD) and MicroEnergy International (MEI)
Islamabad, Pakistan and Berlin, Germany

Abstract

This paper documents the findings of a Demand Assessment study to facilitate a scale-up of the Pakistan Poverty Alleviation Fund's off-grid solar electrification program, through microfinancing solar home systems in Pakistan. The project was funded by Renewable Energy & Energy Efficiency Program of the GIZ Pakistan and was implemented by MicroEnergy International, Germany, with the support of Partners in Sustainable Development, Pakistan, as their local partner. A gender disaggregated, qualitative as well as quantitative demand assessment was conducted in three districts i.e. Chakwal, Khushab and Thatta, through household surveys and focus group discussions. The results depicted that introducing a microfinanced SHS program in rural off-grid communities is highly demanded by the rural, poor, off-grid residents.

Keywords: Microfinance; Solar Home System; Energy Access.

Introduction

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Renewable Energy & Energy Efficiency Program in Pakistan was initiated in 2005, with a focus to promote renewable energy (RE) technologies and industrial energy efficiency (EE).The program supports its partners, both from the public as well as the private sectors, in promoting solar energy, hydropower and biomass technologies in Pakistan. The program also provides advisory services to its partners for the development of national and provincial policies along with suitable market-based financial/economic instruments for large-scale and household level investment in RE and EE such as feed-in tariffs for RE technologies, EE financing mechanisms and microfinance for rural energy services.

The Pakistan Poverty Alleviation Fund (PPAF) is an autonomous organization that aims to serve the poor, marginalized and disadvantaged households across Pakistan by facilitating their access to resources and opportunities. In order to alleviate energy poverty in off-grid communities, PPAF is implementing a grant based village electrification program in off-grid rural communities. While several thousand of such systems are currently in operation, PPAF is exploring the feasibility of an exponential expansion of this program, using a microfinancing mechanism for solar home systems (SHS).The GIZ RE and EE program is supporting PPAF in the development and introduction of a suitable microfinancing mechanism.

For this purpose, the GIZ engaged MicroEnergy International (MEI) to conduct a detailed demand assessment to design SHS to be microfinanced through PPAF and its Partner Organizations (POs). In this respect, Partners in Sustainable Development (PSD) worked as MEI's national partner in Pakistan to conduct the presented demand assessment study in three districts to serve as an input for a comprehensive implementation plan.

Research Objectives

The objective of this assignment was to conduct a demand assessment for a rapid expansion of the on-going solar electrification program by introducing SHS using microfinance, in off-grid rural communities from three districts namely Chakwal, Khushab and Thatta, as selected by PPAF.Subsequently, an appropriately designed SHS and accompanying microloan were developed based on the energy needs, ability and willingness to pay of the target communities, as revealed by the demand assessment.

Methods

To fulfill the research objectives, the methodology of sample survey explained in *Figure 1* was used:

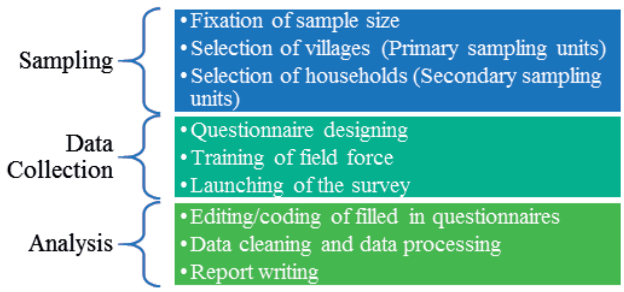


Figure 1: The survey methodology

Sample Size

The target Union Councils (UCs) in each district were selected after consultation with PPAF's POs working in the respective districts. In the Khushab and Chakwal districts, the sampling locations were narrowed down to four UCs located in these regions and then to ten villages where 200 questionnaires were conducted. In the Thatta region, the sample size of 211 households was proportionally distributed amongst the off-grid villages of target UCs.

Coverage with Respect to Gender

Female enumerators were included in the teams of enumerators particularly to address female respondents. Keeping in mind the difficulty in interviewing the female respondents which usually arises due to the local customs and religious aspects, initially it was decided to cover minimum of 20% female respondents in the target area. However, the competitiveness and hard work of the female staff made it possible to cover 38.92% female respondents in Chakwal, 42.65% in Khushab and 39.58% in the Thatta district.

Results

In order to appropriately design the SHS, and accompanying loan terms, it was critical to determine the market demand for SHS in off-grid regions. To assess the demand, MEI and PSD developed a household questionnaire and focus group discussion (FGD) guideline to determine respondents' energy needs, ability and willingness to pay for a SHS through a microfinancing scheme.

Energy Needs

Without a grid connection, households are forced to find alternative solutions to access energy. In many cases, households combine many sources to meet their basic energy needs. For example, a household may use kerosene for lighting, charge their mobile phone at a local shop, and listen to a radio run dry cell batteries. These traditional fuels are not only damaging to the environment (and in many cases the health of the users) but also are very expensive. It was found that almost all of the surveyed population's household energy needs could be replaced by a SHS with the exception of cooking. Therefore fuels and appliances used for cooking were out of scope of this study.

Lighting

The respondents of the survey stated that they mainly use lanterns (kerosene lamp), or Chinese made torches to light their homes. Kerosene/mustard oil and dry cell batteries are the prevalent energy sources for lanterns and torches respectively. The percentage of households with respect to the lighting source being used is given in *Figure 2* by district.

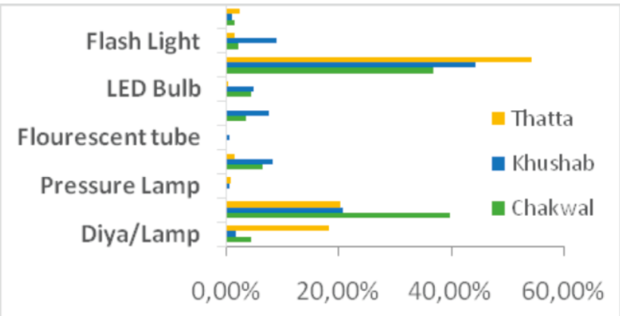


Figure 2: Percentage of households with respect to the source of lighting used, (multiple answers possible), (Chakwal=309, Khushab=263, Thatta=197)

Appliances

The results reflected that the mobile phone is the most popular appliance in the surveyed areas. Analysis showed that on average, 1.26 mobile phones, 0.14 fans, 0.07 TV and 0.13 radios per household are available. *Figure 3* shows the percentage of households owning radio, TV, fan and mobile phone.

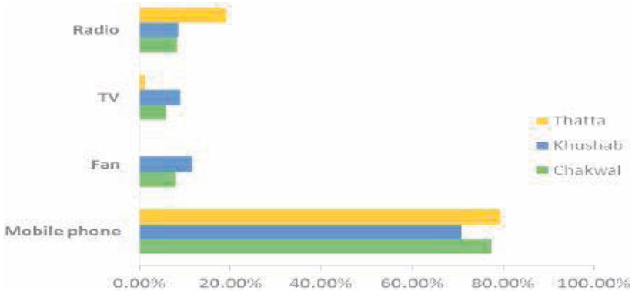


Figure 3: Percentage of households with respect to availability of appliances, (multiple answers possible), (Chakwal=201, Khushab=267, Thatta = 167)

Furthermore, the respondents were asked which appliances they plan to buy in the next 3 years, if given access to a reliable energy source. The responses, in order of preference, were fans, TV, bulb/tube lights and Radio.

Ability to Pay

The ability to pay for a SHS is determined by income characteristics, monthly savings, decision-making power in the household and the current energy expenditures and appliances that can be replaced by SHS.

Average Monthly Household Income

The results revealed that most of the surveyed households have a monthly income of less than PKR 10,000. The detailed income dispersion in each district is given in *Figure 4*.

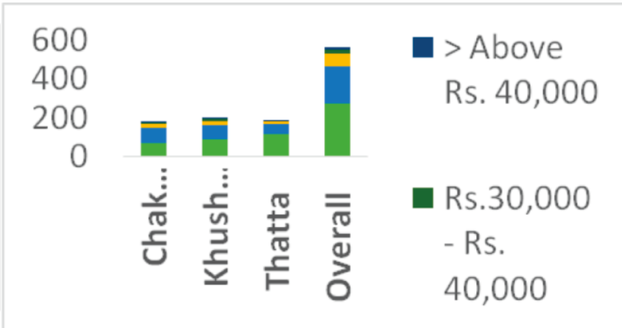


Figure 4: Number of households with respect to their average monthly income (N= 581, Chakwal=185, Khushab=204, Thatta=192)

Sources of Income

A clear majority of respondents in Chakwal and Khushab stated that the primary source of income in their household is agriculture. In Thatta however, labor was the dominant source of income. The percentage of households with respect to their primary source of income is given in Figure 5.

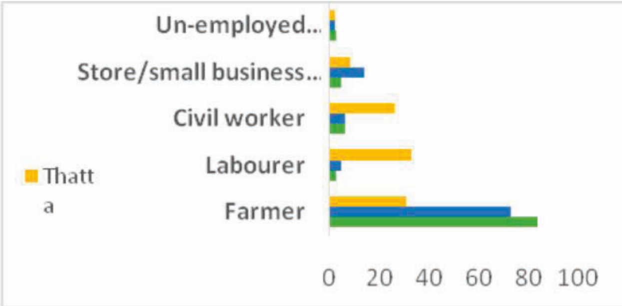


Figure 5: Percentage of households with respect to their primary source of income, (N=581)

Moreover, out of total 581 sampled households, 166 households reported that there are other persons in the households working to earn money in addition to the respondents/head of household. The source of this secondary income is described in *Figure 6*.

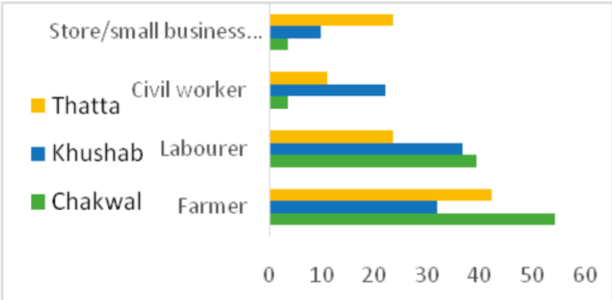


Figure 6: Percentage of households with respect to their secondary source of income, (N=166)

Due to the nature of income generation in the studied regions, the majority of respondents either receive their income monthly (24%), or seasonally (45%).

Average Monthly Savings

Out of total surveyed households in Thatta district, 57% reported that they are able to save less than PKR 1, 000/- per month. This is followed by 43% and 39% in Chakwal and Khushab respectively. Only 6% in Khushab, 4% in Thatta and 3% in Chakwal reported that their households are able to save above PKR 10,000 per month *(Table 1)*.

Table 1: Average household monthly savings (%)

Average Monthly Savings (PKR)	Chakwal	Khushab	Thatta	Total
< 1,000	43.24%	39.22%	57.29%	46.47%
1,000 - 4,000	20.00%	23.53%	15.10%	19.62%
4,000 - 8,000	7.03%	12.25%	4.17%	7.92%
8,000 - 10,000	2.70%	4.41%	1.56%	2.93%
> 10,000	3.24%	6.37%	3.65%	4.48%
Don't know	11.89%	9.31%	9.90%	10.33%
No response	11.89%	4.90%	8.33%	8.26%
Total	100.00%	100.00%	100.00%	100.00%

Current Energy Expenditures

Households spend significant proportions of their monthly income to meet their most basic of energy needs through traditional fuels, and paying neighbors and nearby shops to recharge their devices. The average household energy expenditure was found to be PKR 589/- per month. On an overall basis 46% of respondents are spending PKR 827 per month on kerosene/mustard oil and 14% are paying PKR 380 per month to recharge their appliances at a neighbor's house or local shop. For distribution of energy expenditures that can be replaced by a SHS, please see *Figure 7*.

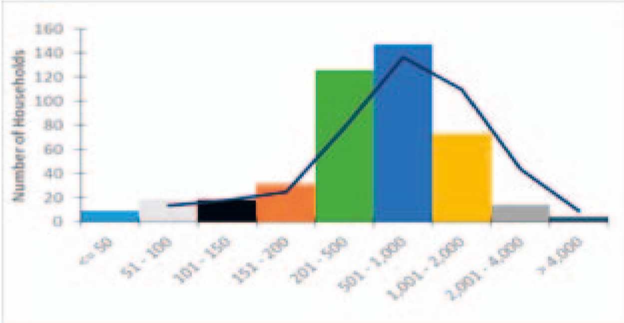


Figure 7: Average Monthly Energy Expenditures in PKR (Chakwal=162, Khushab=160, Thatta=118)

Decision making power in the household

Identification of the most appropriate target group is critical to develop marketing and consumer awareness campaigns to support the scale-up of a microfinanced SHS program. Respondents were asked who in the household decides on purchases larger than PKR 5,000. 94% of respondents in Khushab, 91% in Chakwal and 75% in Thatta all responded that the "male head of household" is the decision maker in this regard. As a general practice in Pakistan, authority on spending belongs on the income generator, however in many cases, as was revealed during the FGDs, the female head of household expresses her needs to the male head of household, and he is then responsible for fulfilling this need.

Willingness to Pay

The questionnaire included the questions on respondents' willingness to pay for a SHS. Willingness to pay was assessed by evaluating perceptions about SHS, expectations for national grid connection, as well as their desire to take out a microloan to finance a SHS, if the opportunity were available.

Relationship to the National Grid

78% households in Khushab, 73% in Chakwal and around 29% in Thatta reported that they are not expecting to get an on-grid electricity connection in the near future. Whereas 18% households in Thatta district, 3% in Khushab and only 1% in Chakwal district stated that they are expecting to get an electricity connection from the national grid in the coming year.

Perceptions of SHS

Overall, 71% respondents showed their willingness to buy a SHS. Results dissagregated by district reflected a figure of around 93% for Chakwal, 91% for Khushab and 76% for Thatta. Moreover, the gender dissagregated analysis shows that the percentage of men who were willing to purchase SHS is greater in all districts as compared to women *(Table 2).*

Table 2: % of respondents who would like to purchase a SHS, (%), (N=412).

	Men	Women	Total
Chakwal	59.15%	33.54%	92.68%
Khushab	53.76 %	37.10 %	90.86%
Thatta	47.50 %	28.33 %	75.83%

Of those who did not show their willingness to buy a SHS, around 42% of the respondents stated the reason that it is too expensive. See *Figure 8* for the variations in answers.

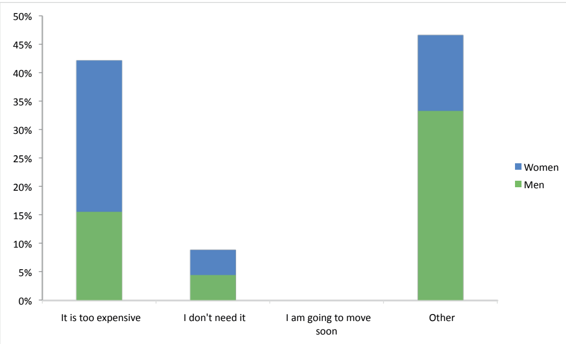


Figure 8: Percentage of respondents reporting different reasons for unwillingness to purchase a SHS, disaggregated by gender, (N=45)

Willingness to Microfinance a SHS

Furthermore, the respondents were asked if they would be willing to take a microloan to finance a SHS. The percentage of respondents who showed their willingness is shown in *Figure 9.*

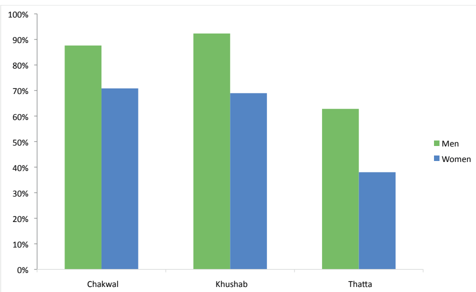


Figure 9: Percentage of respondents willing to take a microloan to finance a SHS, disaggregated by gender, (N=421)

As can be seen, the ratio of respondents willing to take loan in Khushab is higher than in the other two districts. The reason is that the PPAF PO responsible for the region is already implementing a microfinance program for the purchase of SHS and therefore the communities are fully sensitized. Chakwal, although slightly below Khushab, also shows a high percentage of respondents willing to take microloan for purchase a SHS as the local PO is working very closely with the communities. Although they are not providing microfinancing for SHS, the communities are fully aware of the potential of solar energy. In Thatta, the communities did not report any loan under any microfinance arrangement from their respective PO or any other source. This is because in Thatta, local PO provides community mini-grids for household clusters, and therefore the public perception about solar energy is understood as a communal asset rather than that of the individual household.

Overall, more than 72% responded ‘yes’ to this question. Of those who stated ‘no’, the reasons are detailed in *Figure 10.*

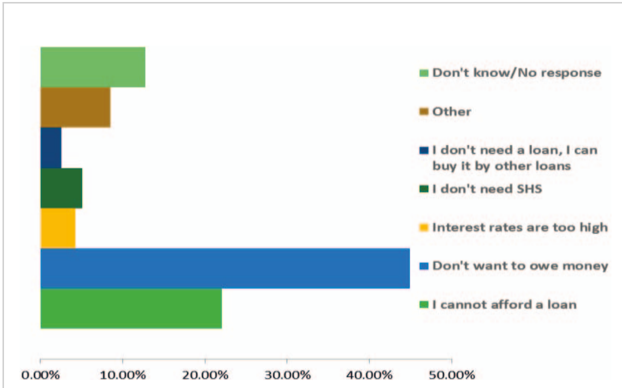


Figure 10: The reasons for unwillingness to take microloan for SHS

Analysis of gender disaggregated data depicts that out of total respondents in the Chakwal district, 54% men and 28% women are interested in buying a SHS through a microloan against 8% in each case of men and women who are not interested in this arrangement. A similar picture is observed in the Khushab district, while in the Thatta district, 40% men and 14% women are interested in buying a SHS through microloan against 19% men and 16% women who are not interested in taking microloan.

Discussion

Considering the results of the surveys and inputs from the communities during the FGDs, it can be concluded that in these regions, SHS is highly demanded by off-grid rural communities. However, due to low income levels in the region, the technology is largely unaffordable to the population without a microfinancing mechanism. In the following section, preliminary recommendations for implementation of a microfinanced SHS program in Pakistan are presented.

SHS Technical Design

The SHS should be designed for three distinctive categories of the clients to address the heterogeneity in ability to pay and energy needs, as well as solar radiation and housing conditions across rural Pakistan. Graduated system sizing will allow the program to incorporate more segments of the off-grid population. For example, of the respondents who already owned a SHS, limited generation capacity was the most frequently cited reason for dissatisfaction with their system. While at the same time, the majority of respondents had an income of less than PKR 10,000 per month. Therefore, designing a range of SHS tailored to the energy needs of the different income groups, from very small and affordable to the very poor market segments, to a larger system to satisfy the energy demands of the less vulnerable poor is recommended. By employing MEI's SHS technical sizing methodology, as well as a sensitivity analysis to price, and critical inputs from the household surveys, the following SHS packages are recommended to be integrated into a microfinanced SHS program in rural off-grid regions in Pakistan (See *Table 3).*

Table 3: SHS Sizing and Technical Specifications

Solar Panel (W)	40	65	100
Battery (Ah)	40	75	120
Functions	Lighting, mobile phone charging and basic cooling	Lighting, mobile phone charging and cooling	Lighting, mobile phone charging, cooling and entertainment
Loads	3x 3 W LED, 1x USB Charger, 1x 6W fan	4x 3 W LED, 1x USB Charger, 1x 15 W fan	5x 3 W LED, 1x USB Charger, 1x 15 W fan, 1x 24 W television
Total Price Estimate (PKR)	25,170	39,495	57,340

In addition, to ensure that the SHS technical design incorporates women's needs in rural Pakistan, one detachable light should be included in all system packages for two reasons:

- The majority of respondents did not have an attached bathroom on their home. As this can be a major safety concern for women after dark, a mobile light would help mitigate this danger.
- Most households surveyed had an outdoor kitchen, which keeps harmful smoke inhalation to a minimum. A detachable light will help ensure that families do not move their kitchens inside the home to make use of the light while cooking.

During the FGDs, the respondents expressed apprehensions with regard to the quality of the equipment. They were worried that if the equipment stopped working, they would be trapped into a repayment scheme for non-functioning hardware. Therefore, quality products, proper warranty for replacement of all components, adequate after-sales services and end-user training must be provided to maintain the integrity of the program, and a sustained demand in the region.

SHS Loan Design

The end-user microfinancing scheme to accompany the SHS packages was tailored to meet the needs of the respective income groups for which they were designed. Sensitivity analyses were conducted when designing loans in a reiterative process with SHS design, to achieve harmony between quality and affordability of SHS and accompanying loan installments. Loan terms were designed in accordance to the respondents' ability to pay for energy access, in addition to utilizing the loan framework currently employed by the PPAF and its POs, to allow an ease of incorporation of the SHS packages into the financial portfolio of the POs.

Loans for the SHS should be distributed to the entire household through family loans, as this is the loan type that the POs are most familiar with, utilizing social collateral as the main form of guarantee. Also, since a SHS is used by all members of the household, this formulation is most appropriate.

Loan period should be limited to 2 years, as it should not exceed the minimum life of the battery included in the SHS. It is recommended to set the interest rate at 28%, allowing the PO the maximum profit margin for financing the SHS. As incorporating a renewable energy technology into an otherwise financial portfolio can stress processes within the institution, and requires significant capacity building for the loan officers, the maximum margin allowed under the PPAF financing framework is recommended to incentivize the program at the PO level. Additionally, a down payment of 20% should be required upfront, to finance installation costs of the SHS.

It is recommended that repayment schedules should be somewhat flexible to incorporate the income characteristics of the many different income groups and regional economies to incorporate more segments of the population. Therefore, MEI designed repayment schemes with monthly, biannual and annual installments to be negotiated between the client and the loan officer based on their income source *(Table 4)*. Biannual and annual installments were designed particularly to incorporate the produce farmers and fisherman's income frequencies as stated during the demand assessment. A grace period is not needed for the SHS loan, as energy savings are incurred immediately, by the eradication of traditional fuel expenditures.

Table 4: Installments for SHS Microloan displayed by SHS package and repayment scheme

	40 W SHS Package	**65 W SHS Package**	**100 W SHS Package**
Monthly installments (PKR)	604	947	1,375
Biannual installments (PKR)	7,764	12,397	18,263
Annual installments (PKR)	16,334	26,081	38,421

Conclusions

The results of the demand assessment showed a significant awareness of the benefits of a SHS, and demand for the systems. However, the main barrier to acquiring such a system for the households was ability to pay upfront. Therefore, a microfinancing scheme for SHS would achieve PPAF's goal of a rapid scale-up of solar electrification in Pakistan, ultimately alleviating energy poverty in the country, and significantly improving the livelihoods of rural households.

All data was collected through household surveys in the districts of Chakwal, Khushab and Thatta in December 2013 and January 2014. The report and data collection was commissioned by the GIZ on behalf of the PPAF, who have approved the presentation of the data for academic purposes.

Case Study of Decentralized Energy Project- Smoke-free Village

Dipl. Ing. Deepak Gadhia (deepak.gadhia@greenashram.org)
Muni Seva Ashram
Goraj, Waghodia 391761, Vadodara, India.
www.greenashram.org

Abstract

While trying to promote solar cooking in India, it was found that villagers were not willing to spend money to buy solar cookers. Even offer of easy loan through micro-finance which could be repaid in small installments, failed. The villagers were using free firewood sourced from nearby forest for cooking and did not want to give this up though this meant daily walking long distances for collection of firewood and transporting it as head-loads. To circumvent this reluctance of villagers, solar cookers were introduced as a tool for income generation and not for daily cooking. **"Pay from your Profit and not from your Pocket"** concept found immediate acceptance. This paper shares the success story of this experiment in Indian villages.

Keywords: Distributed generation; Indoor pollution; Solar Cookers; Income Generation.

Introduction

In India, millions of women and children spend hours to collect fire-wood for cooking and carry it back as head-loads on daily basis. Use of wood as fuel for cooking leads to deforestation and releases GHG (Green House Gases) in atmosphere leading to global warming. Women and children who go to the forest for its collection are exposed to attack by wild animals and molestation by unsocial elements. During its use, they get exposed to smoke in the kitchen causing various lung diseases leading to huge medical costs and early death. It is reported that smoke and soot in the kitchen lead to death of about 6 million women and children every year across the world, mostly in developing countries. WHO (World Health Organization) study concluded that more than 1.6 million deaths and over 38.5 million disability–adjusted life years (DALYs) were attributable to indoor smoke from solid fuels in the year 2000. 50% of world population even today uses solid fuels (Dung, wood, agricultural residue and coal) for cooking (and heating) on open fire (WHO 2004).

After studying and working in Germany for many years, I along with my wife Dr Shirin Gadhia returned to India where we established ICNEER (International Center for Networking, Ecology, Education and Re-integration)[19]; an NGO (Non Governmental Organization) to promote domestic parabolic solar cookers in villages to mitigate health hazards to ladies using wood as fuel for cooking and to protect environment.

We also established GSES (Gadhia Solar Energy Systems)[20] a private limited company, offering large solar cooking solutions. GSES soon became the leaders in supply of large institutional solar cookers. World's largest community solar cooking system for 50.000 people daily was installed by GSES and many years later, it is still running successfully. The primary objective of this venture was to provide support to ICNEER so that it can achieve its objective without financial constraints.

While GSES became leaders in solar cooking systems for large communities and institutions, ICNEER tried to promote domestic cooking using parabolic dishes, providing financial help through micro-finance on very easy terms. Initially it believed that providing loan on easy terms will motivate villagers to shift from using biomass for cooking and all will adopt solar cooking; a much cleaner option. This effort failed miserably because people generally did not agree to spend any money for solar cooking which they could otherwise do for free by collecting wood from the forest. At the time, the cost[21] of SK14 was only $125. The villagers had to pay only $75 and the rest was subsidized by the government. Though they were felling trees in the adjoining forest for wood, there was no awareness about the harm being inflicted on the environment and ecology.

Even this paltry sum of $75 was seen as wasteful expense by villagers as *there was no tangible pay back or advantage*.

Figure 1: Use of SK14 in smoke free village

Many earlier attempts to promote solar cooking failed due to various reasons. For example the solar box cookers were very cost effective at $30, but did not find wide acceptance as they were slow and did not fry or make chapaties. Domestic parabolic solar cookers viz. SK 10/14 overcame these short-comings but were costly and people who needed them could not afford to buy these. Many other varieties of slow cookers were designed but failed to

[19] http://www.pciaonline.org/node/128
[20] http://www.pciaonline.org/node/674,

[21] $1 = INR 50

achieve its sustained use in cooking food; notable among them are HotPot[22], Cook-It[23] and more recently Celestino Funnel Cooker[24]. All these, like box cookers were portable and much cheaper.

Presented here in this brief paper is the case study of four villages in south India which were converted into smoke free villages by enlarging the scope of 'solar cooking' into '*solar cooking for income generation*'. The novel concept of *"Pay from your Profit and not from your Pocket"* was evolved to tell the villagers that the cost of SK14 could be easily offset from the cash generated by selling baked/ boiled food items in a very short time.

Experiences, lessons learned and a possibility of replication in other parts of the country is also discussed.

Research Objectives

The main objective was to assess the acceptance or otherwise of solar cookers for income generation in Indian villages where fuel wood was freely available from nearby forest.

Figure 2: Carrying firewood as head load

A secondary objective was to understand why solar cookers failed to penetrate the Indian village homes in large numbers for day to day cooking in smoke free environment even though its efficacy was amply proved and contributed to monetary savings in many cases.
The spin off from these objectives was supposed to make the villages smoke free and thus contribute towards the health of villagers particularly women and children reducing medical costs. The clean environment and pollution control was to be a bonus.

[22] http://www.she-inc.org/hotpot.php
[23] http://solarcooking.wikia.com/wiki/CooKit
[24] http://solarcooking.wikia.com/wiki/Celestino_Solar_Funnel_Cooker

Methods

- Questionnaire based survey to assess
  - Need for intervention
  - What energy sources would be suitable
  - What would be the scale of operation
- Ensuring community participation by
  - Holding village level meetings with project proponents
  - Involving SHGs (Self Help Groups)
  - Getting support from nearby Women's Home Science College
- Market survey for
  - Identifying products that can sell
  - Contacting potential customers
- Implementation by
  - Demonstration of actual practices
  - Demonstration of value addition

Results

The pilot was successful to the extent that village SHG started using SK-14 for supplying mid-day meal to the village school. The school was their first customer. Once it became a successful venture, the group started producing various items, packing them and selling them in the weekend local bazaar to enhance their financial status.

They also realized the value of time and started using the solar cookers to cook food as it saved them several hours they had to spend in collecting fire-wood. People came up with many innovative ways of using solar cookers such as ironing of cloths by heating on solar cookers, selling of boiled water, preparing herbal medicines etc.

Three more villages in the immediate vicinity followed the footsteps and became smoke free.

The success of this project led to more projects in other parts of India. With the help of ICNEER, Barli Development Institute for Rural Women (Barli), a tribal women's development group with InterSol, an Austrian NGO as fund provider, started similar project in villages near Indore, Madhya Pradesh in Central India. Barli runs training program for empowerment of tribal girls in the area.

Another project for smoke free village was taken up recently by Little Big World, a German NGO in collaboration with Muni Seva Ashram, Goraj, Gujarat (MSA)[25] to make certain villages smoke free. After the death of my wife; driving force behind ICNEER, I sold off GSES and have been serving MSA as one of its Trustees.

Discussion

For the success of any project of this kind, it is essential that it has to be demand driven. We got this opportunity when Mr. Jagadeeswara Reddy of NEDCAP (Non-conventional Energy Development Corporation of Andhra Pradesh)[26], a Government of Andhra Pradesh enterprise,

[25] www.greenashram.org
[26] http://nedcap.gov.in/

invited ICNEER for helping them to provide renewable energy sources in some villages for cooking food. The need for such an intervention arose because these villages were adjoining a forest which was getting denuded due to indiscriminate felling of trees for procuring firewood for cooking. However, the demand for such an intervention from the villagers was missing. They were not willing to pay for the cookers but we decided to go ahead with the pilot.

A preliminary survey was conducted for selection of the villages where a pilot project was to run. Finally, village

Bysanavaripally with 36 households was selected. There were 23 biogas plants in this village. The cost of 1m^3 KVIC (Khadi and Village Industries Commission) model biogas plant was INR8000. A government subsidy of INR6000 on each plant was available provided the villager agreed to contribute free labor and some local building material worth about INR2000. Villagers were well off with income from sericulture.

Figure 3: Villagers learning to cook food using SK14

It was very clear from the start that the villagers were not ready to invest in owning the solar cookers for day to day cooking. Based on the survey results and protracted discussions between various stakeholders, it was decided to use SK14 for income generation of the SHG already existing in the village. Students from the local Women's Home Science College were roped in as a confidence building measure and to overcome the language barrier. The students came and cooked various food items on SK14 in front of the villagers.

Learning from earlier experiences, the following essentials were included in the pilot:

a. Marketing
    i. Market survey for demand of particular food product
    ii. Identifying and tying up with the prospective buyer
    iii. Enlarging the base for both, products and buyers
b. Training
    i. Assembly of cooker
    ii. Cooking of food materials
    iii. Maintenance and repair
    iv. Sales training
c. Financing
    i. Micro financing through ICNEER

Luckily, the local school agreed to be the first customer and the SHG was asked to supply mid-day meals to the children. We decided to place a few Sk14 to start the operations. Within a few weeks the first payment arrived from the school and the confidence level went up and more people came forward to join the action. Within a very short time, tasting the success of solar cooking, non-perishable food items were being baked/ roasted, packaged and were sold in the week-end local bazar. The villagers saw an opportunity to own a solar cooker without any financial burden as the cooker became a tool for extra income which could offset the cost of cooker quickly.

The payback period for SK14 was less than three months at $1 a day which was the normal wage for a daily wage earner. Once this was found to be clearly feasible, many came forward for buying the cooker.

Initially it was decided to offer solar cookers to only those who did not possess biogas plants but finally 26 families were provided with SK14, many of whom possessed biogas plants also. The families owning the biogas plants wanted to save biogas during day time for which they even agreed to pay full price (without subsidies) of the cooker.

The existence of large number of biogas plants was no more a threat but an opportunity. It was showcased as available fuel for continued cooking on non-sunny days.

The ladies in the SHG became innovative and started aiming to get a profit of $1 per cooker per day. For this job rotation was introduced where some went to work in the fields to earn daily wage, while others cooked the food for the school. When the question of cleanliness and hygiene was raised by the school, two cookers were shifted and placed in the school itself. The food was cooked under the direct supervision of one of the teachers. The children got hot food and transportation of cooked food was avoided. Only one member of the SHG by rotation could handle the cooking thus increasing the income per person of the group. On the demand of members of SGH, students from the Home Science Collage were contacted again to train them in baking cakes, bread and biscuits. This further enhanced the earning of the SHG.

Innovations continued to come from the SHG members. They discovered that it was more profitable to move the cooker at the premises of the buyer of solar products. Raw materials were usually provided by the buyer for producing baked/ roasted /fried products, thus guarantying the quality. The cleanliness and hygiene was also ensured because the cooking was done in front of everyone with clean hands and clean utensils. This also saved the problem of investing in raw materials and storing them. The problem of getting stuck with unsold items was also avoided. The group charged for labor and rent for the cooker. This concept became very popular and orders started pouring in regularly.

Soon owning a SK14 also became a *status* symbol and the proud owner was seen as *an entrepreneur* in the community in place of a daily wage earner.

As the concept of *"Pay from your Profit and not from your Pocket"* took firm roots in village *Bysanavaripally*, it was decided to extend it to three other nearby villages around the forest. The details of other three villages are given below:

1 *Village Sigamanuburugu Thamballapalle Mandal* with 38 households and 26 biogas plants were provided with 13 SK14
2 *Village Gopalpuram, Chendragiri Mandal* with 45 households was provided with 13 SK14. The residents of this village were all indigenous people and were comparatively poor. They had no animal to provide dung for biogas and hence the village had no biogas plant.
3 *Village Majjigavaripalle, Kalikiri Mandal* had 55 households and the villagers were prosperous and comparatively better off financially. Every house had animals to provide cow dung and almost all had a biogas plant based on KVIC model. There were 49 of them all. The surplus gas was used to generate 2.2 kV power. Each house was connected and was supplied with one T5 tubelight. Ten solar street lights were also provided in the village. Even in this village where doubts were expressed about the success of the intervention and were thus taken up last, there were six takers for SK14.

Finally, the concept of *"Pay from your Profit and not from your Pocket"* was working, even for those who had alternate source of energy, other than fuel wood, for cooking.

The felling of trees in the forest was drastically reduced. This was indicated by the dwindling number of persons carrying head loads of biomass from the forest. The ladies slowly started realizing the value of time which was made available to them by the use of solar cooker which eliminated the need for going to the forest for collection of fire wood.

Though initially it seemed that this model could be replicated as was the case in Andhra Pradesh and Madhya Pradesh, it did not proliferated as was expected. All the three projects had limited success and were wound up soon after their project proponents left. In the case of our experiment in Andhra Pradesh, Mr. Jagadeeswara Reddy of NEDCAP was promoted and transferred while further work in Indore stopped after Mrs Dr Janak Palta McGilligan and Mr James (Jimmy) McGilligan OBE of Barli, who were the main driving force, retired. The program did not continue elsewhere due to the sad demise of Dr Shirin Gadhia of ICNEER due to cancer. She was the one who was spearheading the concept of smoke free villages.

Lessons learnt

1. Indian villagers are habituated to cook food on modified versions of three stone cook stoves using wood. For any alternatives to work, understanding of local issues and offering innovative solutions are critical.
2. Demand for solar cooker from the prospective users must exist or must be created before or during the project implementation stage
3. Providing financial support/ subsidies is not a must but it is a great help. People in villages are very price sensitive.

References

Smith, Kirk. R. (2004) Comparative Quantification of Health Risks, In Kirk R. Smith, Sumi Mehta and Mirjam Maeusezahl-Feuz. Indoor air pollution from household use of solid fuels. World Health Organization. (www.who.int/publications/cra//chapters/volume2/1435-1494.pdf)

Scientific Papers

III. Minigrids – Case Studies

Experience from First Solar Minigrid Service in Bangladesh

Hasna J. (hasnajkhan@gmail.com)
Asma J. Huque (psldhaka2@gmail.com)
Kaysar Ahmed Sagor, Tanvir Ahmed, Rashedul Alam, and M. Riazul Hamid[i]

Prokaushali Sangsad Limited
House 4, Road 6, Block C, Banani
Dhaka, Bangladesh

Abstract

A 100 kW solar minigrid service in the remote off-grid rural market of Sandwip island of Bangladesh has shown technical and commercial viability for the service provider. Financial planning of solar minigrid requires an optimum blend of consumer categories to ensure maximum socio-economic return on investment. Demand and supply side energy management is an important component of stable power supply from the solar minigrid. Policy-wise, subsidized financing with attractive incentives for the private service providers is essential at this early stage of solar minigrid deployment.

Keywords: Solar minigrid; Sandwip island; Bangladesh.

Introduction

Despite its large population, Bangladesh has achieved substantial economic growth over the last 15 years. Deficient infrastructure prevents the country from achieving its full growth potential. This situation is particularly evident in the economically disadvantaged remote and rural areas. Whereas access to energy is a priority in the development framework, much work needs to be done on basic infrastructure for rural electrification. Remote and dispersed areas are currently adopting off-grid electrification as a viable alternative to the national grid service. In a country where Solar Home Systems (SHS) was established as a complementary solution to grid electrification, national interest has proven it to be the most viable off-grid electrification today. Prokaushali Sangsad Limited (PSL) was engaged in providing the original concept leading up to the final SHS program design (World Bank, 2001). Currently Bangladesh deploys over 70,000 SHS per month, with over 2.6 million (www.idcol.org) in total, under the national solar home program executed by Infrastructure Development Company Limited (IDCOL). This is one of the most successful off-grid SHS programs, with the highest installation rate in the world today.

Similar to SHS, solar minigrids can also offer reliable service for rural off-grid areas in Bangladesh (Khan, & Huque, 2012). With the initiative and technical support of PSL, private utility company Purobi Green Energy Limited (PGEL) has invested in the nation's first commercial solar minigrid in a southern coastal island of Bangladesh with financing from IDCOL. Germany based Asantys Systems, with local partner Energy Systems, installed the world-class solar minigrid technology in un-electrified Enam Nahar market in Sandwip island. Various productive end-uses revealed the potential of economic benefits from clean solar power compared to the previous micro Diesel generators. Commercial enterprises switched from Diesel service to solar. Similar application of solar minigrids for the vast number rural markets in the off-grid locations can offer significant improvement of socio-economic condition of this underserved population. Although rural markets show the maximum potential for solar minigrid application, clustered households adjacent to the markets are also additional beneficiaries. The experience of PGEL shows that a suitable mix of consumers is important for the success of a sustainable business, while also ensuring social and environmental benefits. Additionally, policy-wise, subsidized financing with attractive incentives for the private service providers is essential at this early stage of minigrid deployment.

This paper outlines the technical and business viability for operating solar minigrid in the remote, off grid locations of Bangladesh. Having the first installation of its kind, currently PGEL is the only utility company in the country that operates as a solar minigrid service provider, receiving technical support from PSL. Hence, this pioneering experience has become a learning platform for other investors, financing and developing agencies, in addition to the policy makers. Some of the national clean energy policy decisions for off-grid rural electrification business models are being made using the experience gained from Enam Nahar Market.

System Design and Planning

Consumer Profile in Enam Nahar Market

A survey was performed by PSL in 2008 to collect information on power demand of about 200 small and large enterprises in the project area. Initial survey showed that Sandwip Island had a dynamic population with several Diesel electrification services providers supporting the general public. Several educational institutions, health service centers, hospitals, major markets, computer service centers were present in Enam Nahar market. Although major businesses operated with their captive power, general shops in the markets received electricity from private Diesel micro-grid service providers. Such services operated on an adhoc basis for about 5 hours a day. Households were found to be un-electrified in general, unless using individual solar home systems. A government owned and operated Diesel generator occasionally operates in Sandwip island for 3-4 hours a day for the local government offices, situated about 5 km from Enam Nahar Market. Power lines used by the private service providers were of poor quality since they were not implemented considering efficiency and line loss. The service providers also did not account for their own time spent; therefore the power production cost calculation was arbitrary.

Business Plan

The planning of the project envisioned that a solar minigrid could serve the basic needs of commercial enterprises within Enam Nahar Market and some adjacent households, in addition to local schools and health centers. PGEL was hence formed with the objective of serving this remote location with state of the art minigrid technology. The level of services to be offered was to be based upon the needs of its clients, and quality of service would follow the standards of the national distribution grid.

Total estimated cost of 100kW PV plant with 40kW Diesel backup would be $730,000 (2009 price), including hardware, site development, civil works for an office building, distribution line, and 5.4% soft cost for technical assistance etc. The financial plan and business forecast showed the service to be financially viable under the scheme offered by IDCOL with a tenor of 11 years with 2 years grace period. Hence, with equity of 20%, PGEL obtained a loan for 30% at an interest rate of 6%, and a grant of 50% (KfW grant for the pilot project) of the total project cost from IDCOL. Keeping an affordable tariff with service hours of 9 am to 11 pm year-round, while retaining adequate revenue was key to the financial viability.

Tariff for Electricity

People residing in remote locations of Bangladesh pay one of the highest rates for electricity from Diesel-powered microgrids, which are typically less than 20kW in size. Surveys showed that most of the commercial enterprises of Enam Nahar Market were using Diesel minigrid services. Depending upon the type of appliance being used, daily rates converted to tariff ranged from 0.56 $/kWh to 0.96 $/kWh as shown in Table 1. Such high rates from Diesel-generated power were endured due to the high demand of electricity for commercial activities in the market.

Table 1. Tariff prior to Solar in Enam Nahar Market

Appliance	Watts	kWh/day	$/kWh
CFL Lamp	24	0.132	0.96
Ceiling Fan	60	0.33	0.77
Florescent Tube	40	0.22	0.58
Television	40	0.22	0.58

Preliminary surveys suggested that the potential consumers of a solar minigrid in Enam Nahar Market were eager to pay an equivalent amount to cover their cost of service, considering its reliability and scope of modernization with alternative energy. Based upon tariff prior to solar electrification, financial analysis and project financing criteria of IDCOL, PGEL set the tariff at 32 Taka/kWh ($0.40/kWh) with a connection charge of about $67 for all new consumers.

Hardware and System Configuration

In September 2010, a 220V minigrid of 100 kW solar PV coupled to a 40kW Diesel backup system was commissioned to meet partial demand of electricity for the people of Enam Nahar Market of Sandwip island. The layout of the grid connected and bidirectional inverters, with solar modules and battery bank is shown in Figure 1.

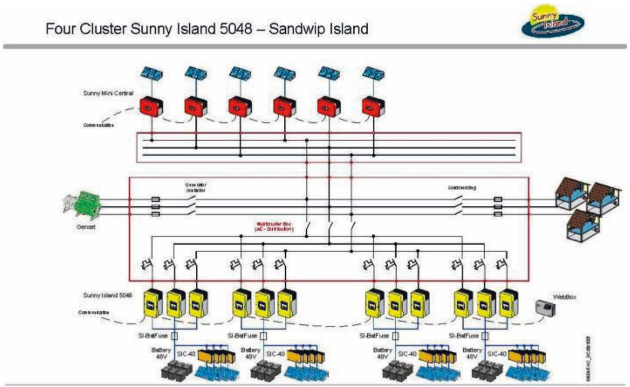


Figure 1. Configuration of Solar Power Plant

For nominal power of 64.8 kW, the PV modules are connected to 6 grid tied 11 kW inverters (Sunny Mini Central of SMA with MPPT), supplying directly to the 220V minigrid distribution line. A three phase AC distribution line is configured through the multi-cluster box, which is the interface for all connectors and controls. The unused portion of the generated power is stored in the batteries through 12 bidirectional inverters called Sunny Islands, distributed in 4 clusters. Additional 40 kW of PV are generated and stored directly into the same battery bank through DC battery chargers (SIC40 with MPPT). The power plant has a total 96 batteries in 4 battery banks with total 12000 Ah (@48V). The battery bank is sufficient to cover the evening load of the market with average isolation. During the worst season of solar irradiation and low state of charge of the batteries, backup power is provided by a 40kW Diesel generator, which also provides the equalization charge to the battery bank.

Total land used by PGEL for the solar power plant is 0.61 acres. Area requirement for 100 kW solar PV (Kyocera brand) was about 1500 square meters, which includes the ground mounted solar park along with the roof of the office building. Beyond solar plant design, site development, various licensing, civil and fieldwork supervision were done by PSL. Attempts were made to use the pre-existing power grid lines belonging to Bangladesh Power Development Board (BPDB). The BPDB lines were never energized in 20 years due un-economic production cost from Diesel fuel. Unfortunately the related bureaucracy became complex, and cable condition was not guaranteed. Moreover, since adoption of state-owned property would not be practical within a non-government project, PGEL procured its own 5 km distribution lines for the solar plant.

A three phase distribution line with 220V AC bus line is connected to the bi-directional inverter-battery assembly through a multi-cluster interface for minigrid. The power station being located in the central part of Enam Nahar Market, three separate phases extend in different directions, with a balanced load from the consumer end.

As shown in Figure 2, estimated load profile of the plant had a peak power exceeding 40 kW from 7 to 10 pm in the evening, where lighting contributes mostly to the load.

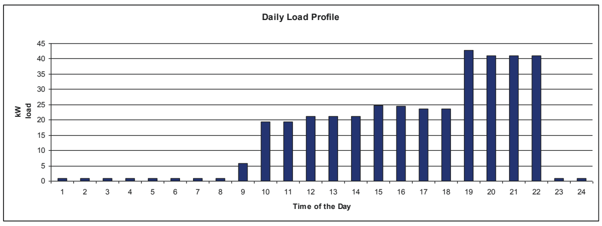


Figure 2. Planned Load Distribution for Service

Much attention was then given toward Demand Side Management (DSM) of the service. In order to minimize the evening load, consumers were encouraged to use only energy-saving compressed fluorescent lamps (CFL), and appliances with standard specifications. A major campaign is currently ongoing to introduce efficient LED lamps to replace all other types of lighting devices, in addition to promoting energy-efficient fans and motors. Distribution line, circuit breakers, service drop lines, and household meters follow the specification standards of the rural electrification cooperatives of the Rural Electrification Board (REB) of Bangladesh. Each consumer is billed on a monthly basis based upon individual electric meter readings.

Results and Discussion

Since October 2010, the solar minigrid of PGEL serves areas surrounding the Enam Nahar Market to provide electricity for basic lighting, fans, computers, printers and various appliances used on a daily basis. To date the plant has generated more than 320MWh from solar PV, with a specific yield of 80.52 kWh/kWp, displacing 222,230 kg of Co2. Generation from backup Diesel is below 10% of total supply of PGEL during last six months of 2013.

Up to December 2013 the service was being offered to a total of 230 consumers who had taken connection gradually over three years, as shown in Figure 3.

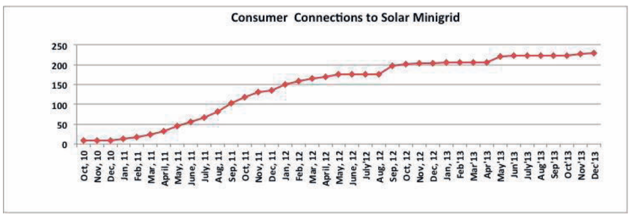


Figure 3. Consumers Growth of PGEL

The major focus was to serve enterprises that can benefit from profitable income generation through the use of reliable electricity. It took about one year for general consumers to build confidence in the services of PGEL before they collectively decided to disconnect from the earlier Diesel services.

Based upon the type of activities performed, all the consumers fall into diverse groups of four categories as shown in Table 2, where SMEs form the major 58% of consumers. Based upon average consumption patterns, the consumers are classified into three classes as shown in Table 3. It is noteworthy that each class nearly equally share the total energy produced by PGEL.

Table 2. Energy Used by Diverse Group of Consumers

Consumer Type	Total number	Total kWh
Small and medium enterprise	136	105,308
Institutions	54	82,876
Households	35	12,538
Small Industry	5	4,515

Table 3. Classification of Consumers of PGEL

Consumer Class	No	kWh/mo/Con
Large Consumers (>100 kWh)	16	173
Medium Consumers (41-100 kWh)	36	59
Small Consumers (1-40 kWh)	178	15

Monthly load pattern: Seasonal variations of load can be seen through the annual energy consumption shown in Figure 4. Overall trend in energy consumption is related to the increase in consumer base of PGEL (Figure 3). Between November and February fans are not used, therefore energy consumption is low during this period. With the onset of hot days in summer, electricity usage increases from April, followed by cooler temperature and less use of fan during the monsoon in July, and a peak demand for electricity appears in August of each year.

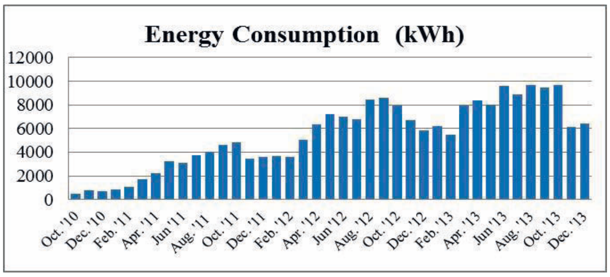


Figure 4. Monthly Load Pattern and Energy Consumption

Daily load pattern: Although the initial survey indicated apeak load in the evening (Figure 2), according to the actual daily load pattern of an average day shown in Figure 5, there are two peaks in total energy usage. One peak appears around 12PM when the offices, health centers and institutions are in full operation. Another peak appears between 7PM and 10PM, mainly for evening lighting and other commercial activities of the SMEs in the market. Since the nighttime use of electricity is mainly from battery storage, the load distribution restricts the use of power-intensive equipment for commercial activities during night. Specifically, the effort is to ensure complete charging and protection of the batteries from over discharge.

According to the daily charging pattern, the batteries are mostly charged between 6AM to 1PM, which leaves the afternoon power for various productive end uses. Hence water pumping and medical equipment of the health center are encouraged to operate at daytime. Such energy management is an important component to ensure a stable power supply by PGEL.

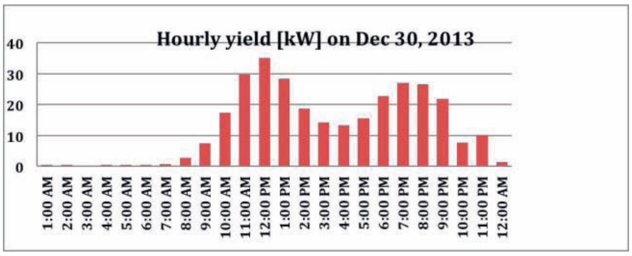


Figure 5. Daily Load Pattern of PGEL

Revenue from Solar Minigrid Service

A continued growth in revenue is shown in Figure 6 and Table 4 indicates sustained business of PGEL, where the operating costs are totally recovered following debt service coverage of IDCOL of about $74,000 up to September 2013. Total operating cost (not including debt service) of PGEL is about 25% of monthly revenue. With the growth of consumer size, the services of a local bank are being used for monthly bill collection.

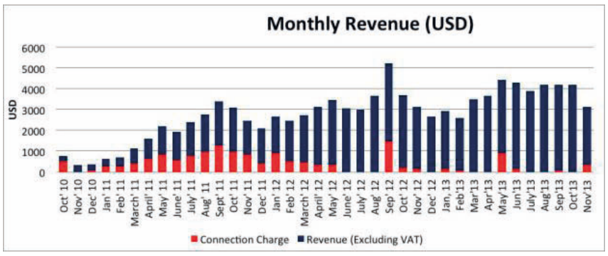


Figure 6. Monthly Revenue of PGEL

Table 4. Revenue Trend of Minigrid Service

	2011	2012	2013
Total Revenue ($)	24,446	39,138	44,319
Connection Charge	33%	11%	4%
Electricity Sale	67%	89%	96%
Total Operating Cost ($)	4,891	9,248	11,527
Diesel	1%	20%	25%
Others site expenses	43%	31%	15%
Salary	56%	49%	60%

Challenges Faced by Minigrid Service

Policy Uncertainties: Many potential risks remain with the first time investors and project implementers, and PGEL has experienced several such ordeals. Overcoming regulatory inertia, including undefined policies, has been a major drawback. Given that solar minigrid is a new technology, it is experiencing special scrutiny from development organizations, financing institutions, and BPDB, to gauge its true merit as a remote area power provider. Environmental clearance for renewable energy based power plants needs to be simplified and streamlined. Policies for allocating concessionary terms for the private sector need to be in place to avoid future threats from highly subsidized public services to enter in the same area. And finally, financing agreements between project implementer and investors need to be standardized. A recent document "Guideline for the Implementation of Solar Power Development Program" (MEMR, 2013) has looked into some of the issues.

Project Cost: The estimated budget for the project was$730,000, where 89% of the capital cost was for hardware. The high level of investment in hardware is typical for renewable energy projects, especially for solar, where the first cost is high and operating cost is minimal.

Due to the nature of load distribution, the peak evening load of PGEL is supported with batteries. The energy storage system through flooded lead acid batteries was 26% of total hardware cost. Replacement of the battery bank at the end of its useful life is a challenge to PGEL, which will also increase the life-cycle cost of the system. Recurring backup Diesel fuel cost must be managed over time by spreading the peak power load, especially the energy intensive loads in any market.

Subsidies and Incentives for RET: IDCOL plans to support 50 solar minigrids by 2016, with similar financing scheme as PGEL. It should be noted that 50% grant fund reducing the capital cost is an essential element for financial viability of such services. Moreover, there must be reasonable certainty that the public grid will not extend its services to the area in the near to medium term. Otherwise, sponsors would demand compensation for their assets in favorable terms, since their customers might opt for the drastically reduced subsidized tariff, even if reliability is low. PGEL's minigrid being a first of a kind power project, is used as a demonstration that feeds into subsidy policymaking, which, however, in this case, is a risk to the private investors.

Conclusion

The data presented in the study undertaken by PSL provides a reference for future solar minigrid configurations for remote rural markets in off-grid areas of Bangladesh. It provides an overview of commercial viability of solar minigrid services with special financing, keeping reliability of service as the priority. In the long run it may be worthwhile for the REB/PBSs to consider solar minigrid service in the remote un-electrified locations. Economic viability of such services is open for discussion on public-private partnership.

References

World Bank Report (2001). Bangladesh Rural Electrification-Solar Home Program Preparation. Prepared by Prokaushali Sangsad Limited (PSL) for The World Bank.

Khan, H. J., & Huque, A. J. (2012), Reliable Power Supply with Solar Mini Grid in Sandwip Island of Bangladesh, *Proceedings of 2nd International Conference on the Development in Renewable Energy Technology (ICDRET'12)*, January 5-7,2012, Dhaka, Bangladesh.

Ministry of Power, Energy & Mineral Resources (MEMR, 2013), Govt. of Bangladesh, *"Guideline for the Implementation of Solar Power Development Program",* published by the Power Division, October 2013.

---

[i] Associate Professor, Dept. of Electrical and Electronics Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh

Prospects for Electricity Access in Rural India using Solar Photovoltaic based Mini-Grid Systems

Leena Chandran-Wadia (leena.wadia@orfonline.org)
Observer Research Foundation (ORF) Mumbai
NKM International House, 178 Backbay Reclamation, Mumbai 400 020, India

Shruti Mahajan Deorah (shruti.deorah@berkeley.edu)
Visiting Scholar, Goldman School of Public Policy, University of California Berkeley (On leave from Observer Research Foundation Mumbai, India)

Sameer Nair (sameer@gramoorja.in) and Anshuman Lath (anshuman@gramoorja.in)
Gram Oorja Solutions Private Limited
NCL Innovation Park, Pashan, Pune 411 008, India

Abstract

Solar photovoltaic (PV) based mini-grid systems have the potential to be an environmentally friendly and sustainable long term solution for electricity access in India. However, the high upfront costs of these mini-grids present policy makers, entrepreneurs and consumers alike with difficulties in financing them. Other challenges to their implementation stem from socio-economic issues and from the lack of adequate support from government agencies. We assess the potential for deploying solar PV based mini-grids to provide on demand electricity access, beyond just lighting. We describe one very high-quality installation in detail, in operation for 20 months now, that exemplifies several of the challenges involved in providing end-to-end solutions in rural India, as well as some solutions. We review the policy measures of the Indian government in the context of scaling out such innovative solutions, and argue that government must work together with entrepreneurs to create an Energy revolution akin to the Green revolution in India in the 1970s.

Keywords: Energy Access; Solar Photovoltaic; Mini-grids; Rural India.

Introduction

India is blessed with tremendous solar potential, given its daily average solar reception[1] of 4 to 7 kWh/m [2]. Solar PV based mini-grid systems are relatively easy to install, can be scaled with increasing demand if necessary, and require minimal day-to-day intervention, which make them particularly suitable for use in rural India. Solar energy based lanterns and water pumps are already being widely used in villages. However, a compelling reason to deploy mini-grids[2] is the opportunity to provide *'on-demand electricity'*, beyond just lighting, to rural homes and businesses, so that livelihoods can be enhanced.

Of the 300 million or more Indians who do not have access to electricity today (Census of India, 2011), it is estimated that approximately 10 million[3] live in villages and hamlets that are much too remote for the grid to reach. Estimates of the count of such villages or hamlets vary from 11,000[4] to about 50,000. There is consensus that in these standalone villages and hamlets, renewable energy based electricity access can be a long term solution rather than a stop-gap one - 'till the grid arrives'. The goal here would be to provide electricity that is available 24x7, with the provision to accommodate growth in usage, for both household and commercial consumption. This can only be done with appropriately sized AC solar PV mini-grids, optionally hybridized with other renewable sources such as wind and biomass.

The surprise is that the bulk of Indians living without electricity reside in villages where the grid has already reached! There are several reasons for this including the lack of incentive to get connected due to poor supply from the grid, illegal tapping, etc. The Ministry of Power (MoP) of the Government of India (GoI), which holds the mandate for electrification, requires just 10% of the homes in a village to be connected to the grid for considering it electrified (Rural Electrification Policy, 2006). In such locations, grid-connected mini-grids could be set up provided the policy environment is made conducive.

Research Objectives

We attempt to understand the difficulties related to implementing solar PV mini-grids in rural India, and to discover innovative ways to mitigate them. Although there are some technological difficulties and many sociological barriers, the main challenge is financial - the high upfront costs for the panels, the balance-of-system, and the costs for installing, servicing and maintaining these in remote locations. The Ministry of New and Renewable Energy (MNRE) subsidizes 30% of the costs of such systems under the Jawaharlal Nehru National Solar Mission (JNNSM). Another program of the MoP called the Decentralized Distributed Generation (DDG) provides 90% subsidy, to be disbursed through the State governments[5]. Despite this generous subsidy very few private entrepreneurs have set up solar PV mini-grids so far, primarily due to benchmark costs being low[6] and policy being unclear on important issues. The objective of this paper, which is based on a detailed research report (Deorah & Chandran-Wadia, 2013), is to discover replicable end-to-end solutions that can be scaled out rapidly by entrepreneurs working together with Governments and with other stakeholders.

Methods

We have studied many mini-grid installations around the country - the technology and financial models used, and the challenges faced by them. Gram Oorja has also conducted detailed surveys in about 100 villages to assess the potential for deploying mini-grids. They interviewed villagers in a group (of 10-12 residents on average) at each location, to try and understand their willingness and their capacity to pay for electricity. The results clearly indicate a strong desire to be given electricity beyond lighting and little resistance to the idea of paying for electricity services. An average monthly billing of Rs 100 to 150[7] appears quite feasible, the number being even higher in some of the more prosperous villages.

We present a detailed case study of a 9.36 kWp mini-grid installed by Gram Oorja at Darewadi, a small break-away hamlet nestled in the Western Ghats in Maharashtra, not even recorded in the Census of India. It is inhabited by 39 families of Mahadev Koli tribals, totaling approximately 200 residents, who practice rain-fed farming (growing just one crop a year) and gather wild herbs for their livelihood. These villagers have been enjoying access to electricity, 24x7, for about 20 months now. Each home has been given basic lighting (2 to 3 bulbs totaling 10 W) and one plug point for use in mobile charging, TV, etc. Street lights and lighting for common areas have also been provided. The installation, which cost Rs 3,000,000, was funded by Bosch Solar as part of a techno-commercial pilot (MNRE subsidy not availed).

Costs and Tariff

The tariff at Darewadi has been designed to create a corpus that will cover the cost of maintenance and battery replacement every 4 to 5 years[8]. While the effective tariff being charged is Rs 20/kWh[9], it must be noted that the amount collected is retained within the village, in a trust account, so that villagers do not have to rely on further external/government funding for battery replacements. Including a fixed charge of Rs 90 to cover street lights and common usage, the monthly bill for a typical household in Darewadi is approximately Rs 120. For homes with televisions the cost goes up to Rs 150-200. There have been no payment defaults so far in the 20 months or more that the grid has been in operation.

Passing on equipment and installation costs to the user, even amortized over 25 years which is the lifetime of the panels, would have meant charging a minimum of Rs 36 per unit of electricity (Deorah & Chandran-Wadia, 2013)[10]. Clearly, the option of recovering system costs from revenues generated through sale of electricity is not a viable business model!

The State of Chhattisgarh has the largest number of AC mini-grids deployed in the country today. The State government, through the Chhattisgarh Renewable Energy Development Agency (CREDA) subsidizes the capital expenditure entirely, and levies only a nominal charge of Rs 5 per month per household to cover operational expenses. There is no metering of usage and every user pays the same fee. Over time this model has resulted in indiscriminate use by a section of the villagers making it difficult for the government to sustain the level of service originally envisaged. In several of the mini-grids electricity is provided for only a few hours each day because the present loads are much higher than the planned loads. In our view, this issue is best addressed by introducing a tariff system based on metering usage.

Tariff serves multiple purposes – It

1 Creates a sense of ownership of the asset;
2 Creates a demand for quality service;
3 Ensures a degree of self-regulation with respect to usage, as lack of usage discipline in off-grid systems will almost inevitably result in project failure;
4 Creates a corpus for battery replacement.

The last factor plays a crucial role in ensuring long term sustainability of an installation, especially since existing battery technology (lead-acid deployed in this case) needs replacement 5 to 6 times over the lifetime of the panels.

System Design, Maintenance and Management

The system cost at Darewadi is relatively high, partly due to its remote location but partly also due to local considerations. It receives three months of very heavy rainfall each year, during the monsoons, along with strong winds and continuous rain spells lasting for over a week sometimes. Gram Oorja therefore set the solar panels in concrete to withstand winds of up to 200 km/hr. They also created three separate feeder lines, one each for street lights, households and commercial loads. This ensures that commercial loads are used only during the day allowing for smaller battery size. A local caretaker, trained by them, manually prioritizes electricity to households during periods of low generation. The strategy has worked well and the villagers have had to go without electricity for as little as five days in 2013.

Sizing the system with a larger battery may have avoided the days without electricity but it would have driven the costs up substantially, both initial capital expenditure as well as replacement costs. Gram Oorja sized the battery system to provide backup for just one night, rather than the three nights that most designs provide for. The battery bank comprises a 600 Ah, 48 volt, system that can store 28.8 kWh of electricity at 100 % capacity. At a prescribed depth of discharge of 50 % this provides usable electricity of 14.4 kWh which is sufficient to meet the overnight needs of household consumption as well as street lights. With the street lights switched off it can last much longer. A battery of this size costs approximately Rs 250,000 and needs to be replaced every 4 to 5 years.

Each home has a metered connection and is fitted with a circuit breaker that cuts off unusually high loads. The distribution wiring at Darewadi has been done completely professionally, as per the regulations of Maharashtra's

State Electricity Regulatory Board. Notwithstanding the ease of installation that comes from simply stringing wires over trees (Ferris, 2014), it is best for the safety of the village and for long-term sustainability of the assets, that wiring to individual homes is done as per the standards prescribed for the grid. Doing this has increased the initial capital expenditure substantially, but it has also ensured that Darewadi is completely grid-ready. We believe that such a grid-ready installation must be adopted as a key requirement by the government and incorporated into its policy framework.

Darewadi is fortunate in that it is a hamlet with a high degree of coherence among its population. A village trust, consisting of 7 members, has been created to take charge of the assets and to oversee their care. Everyday maintenance for the panels and battery, and management of the feeder lines when necessary, is done by a young man from the village who is paid nominally from the village corpus.

The land for the panels and for the construction of the safe room for balance-of-system has been taken on a 25-year lease from a family, who are given free electricity in lieu of rent. It is critical that villagers are made stakeholders in this way, through initial ground-work aimed at building trust based relationships. Ownership by the community not only ensures safety of the installation, but also minimizes payment default as is evident in Darewadi.

The Darewadi system was designed to accommodate substantial growth in usage over time. The initial usage, during the first year, was just 30% of capacity. With the recent addition of a couple of water pumps, utilization has touched 50%. Since commercial loads are relegated to daytime use only, there is still plenty of room for growth for several years. The exact pattern of growth remains to be seen.

Livelihoods and long-term sustainability

On-demand electricity is critical for creating livelihood opportunities, as well as for the provision of healthcare, education, clean water supply and entertainment. While DC micro-grids (typically of size less than 1 kWp) are providing lighting and mobile charging to households in several villages in power starved states, the equivalent price/unit they charge does not scale with consumption (e.g. for a television). It has been observed time and again that once electricity is supplied, villagers discover latent needs and new applications, driving up the average consumption per household quickly. This is true of Darewadi, where a flour mill was installed soon after electrification. Several households now have a television, and youngsters are being trained to use computers donated by an NGO. Two water-pumps added recently by the villagers will enable several farmers to graduate from growing just a single-crop to two or even three crops a year. Another example is the village of Meerwada in Madhya Pradesh, where SunEdison has set up a 14 kWp solar PV mini-grid. This plant provides electricity to approximately 400 people in 70 households. Funded by SunEdison as a demonstration project, utilization of this plant climbed quickly from the initial 15% to about 70% within just a few months[11].

Although utilization of the mini-grid inevitably increases, first for entertainment purposes and later for livelihood options, many of the latter uses are knowledge intensive as also infrastructure intensive. Computer education, milk chilling plants, cold storage for fruits and vegetables, are some examples of livelihood enhancing options that have followed in the past. In fact it is these very opportunities that are more likely to generate revenues for the energy entrepreneurs, should they choose to stay engaged with the community.

Results

Gram Oorja has in effect moved out of Darewadi, handing over control of the mini-grid to the community, which was in fact their intention. They continue to remain available on call as needed. Their work illustrates that if the up-front costs of a high-quality installation can be covered through a one-time investment, it is possible to make the installation self-sufficient, even covering battery replacement costs. End users find the tariff acceptable since it is being levied for electricity that is available 'on-demand', 24x7. This is an important input to policy makers and government agencies, such as CREDA of Chhattisgarh that has put in considerable energy into scaling out mini-grids. In another DDG tender, Madhya Pradesh Urja Vikas Nigam (MPUVN) has imposed unrealistically low flat tariffs (Rs 15 a month for consumers who are below the poverty line and Rs 30 for those above) without any clarity on how future battery replacements are going to be funded.

Some of the key innovations made by Gram Oorja that ensure quality and long term viability of the standalone mini-grid installation in Darewadi must also be adopted as best practices and scaled out. These include:

- Feeder line separation;
- Minimal battery support;
- Local involvement and ownership of assets;
- Grid-ready installation.

As mentioned earlier, developers would have to charge an unacceptably high price/unit to the end user if they intended to recover capital costs, despite the existing subsidies. Maintenance costs alone contribute to a high price/unit (in conventional terms), especially if the losses in a standalone system are included. 'Electricity as a service' models that charge users a flat monthly fee for a package (of lights, mobile charging and/or fan) are difficult to scale and do not scale with increase in the consumption of households.

Employment of local youth can make a tremendous difference to the last mile implementation and servicing of mini-grids. However, given the lack of trained manpower, entrepreneurs installing small standalone mini-grids cannot leverage economies of scale while training a few youth at a time. A national program, perhaps as part of the National Skill Development Mission[12], will be required to train tens of thousands of technicians, and possibly thousands of local youth who can work alongside private entrepreneurs.

We argue that two levels of 'assisted entrepreneurship models' are essential in this space. The first is the assistance provided to local entrepreneurs by developers such as Husk Power Systems (HPS) and Gram Power. At another level, these developers such as HPS, Gram Oorja, Desi Power and many others can benefit immensely from the assistance of governments, both Central and State, so that they can take on the scale challenge of reaching electricity to the millions of Indians going without electricity today. The assistance required chiefly takes the form of capital subsidies to cover the high capital expenditure costs, which should rightly be considered as an infrastructure investment, rather than as a pure industry subsidy. Assistance from the State DisComs (Distribution Companies) and the Electricity Boards would be extremely useful in securing right-of-way for wiring to homes in grid-connected villages. Cooperation of State DisComs and MNRE is essential, especially with regards to potential grid integration. Unfortunately, these state actors are not involved in the renewable energy effort that is being driven largely by the Central government and state nodal agencies of MNRE such as CREDA.

The policy issues that come in the way of setting up mini-grids in grid-connected villages are much more complex, but the lack of clarity with respect to all aspects of grid integration, and coping with the gap in tariff for electricity from the grid vs. that of renewable systems are the most prominent.

Discussion

A recent report on microgrids[13] for rural electrification (Daniel Schnitzer et al, 2014) based on seven case studies, five of them in India, corroborates and extends several of the observations made in this paper. This comprehensive report which covers over 700 grids in India including solar PV installations in the States of West Bengal and Orissa, besides Chhattisgarh, and biomass based installations by two private entrepreneurs, Desi Power and HPS, throws up several additional points for discussion.

None of the developers surveyed intended to provide 24x7 electricity access! The State agencies see these micro-grids as a stopgap solution to be used largely only for lighting, and the private entrepreneurs are struggling to control costs. We believe that such an approach, particularly by the State agencies, is unfortunate. Not just in remote locations, but even in grid-connected villages, these micro-grids have a tremendous potential to enhance livelihoods, a potential that must be leveraged.

The report also illustrates that when State agencies get involved, as in the case of Chhattisgarh, it is possible to achieve scale quickly. However, they need to find a way to avoid pitfalls such as the flat fee charged by CREDA, and life of WBREDA mini-grids cut short by grid extension. The report also cites lack of 'community cooperation' and 'village cohesiveness' as one of the challenges facing Indian micro-grids, such as those operated by HPS & OREDA. As acknowledged earlier, Darewadi does not suffer from conflicts within that could compromise the operation of the mini-grid. Nevertheless, this emphasizes the importance of initial ground-work and fine tuning the model of community stake in the project.

In terms of the cost of subsidies in remote locations, installing 10 kWp systems at the benchmark cost of Rs 3.5 million per village would imply that the upfront capital outlay on 50,000 mini-grids would be a total of Rs 175 billion (i.e. Rs 17,500 crores). Staggered over a period of 5 years, the allocation would be just Rs 35 billion (Rs 3500 crores) per annum. Given that the Indian government spends several times this figure on annual kerosene and diesel subsidies (TERI, 2012) the number in itself is not a concern. However, the primary method of awarding subsidy - to the lowest cost bidder - compromises the quality of installation. Making funds available to entrepreneurs directly, on the basis of representative benchmark costs, will substantially lower barriers to entry.

The implementation of tens of thousands of solar PV mini-grids in India is an attractive option for enhancing livelihoods and catalyzing development in a sustainable manner. The innovations called out in this paper can go some way towards overcoming some of the challenges and making the installations successful. More importantly, this will require the same kind of will and leadership that went into bringing about the Green revolution in agriculture in India in the 1970s.

Endnotes

- http://www.mnre.gov.in/schemes/grid-connected/solar/
- The Government of India distinguishes between micro-grids (< 10kWp) and mini-grids (between 10kWp and 250kWp). For the purposes of this paper we refer to both as mini-grids.
- Assuming 50,000 remote villages, each consisting of 40-50 households and accommodating 200 residents on average. This leaves 290 million people living in grid-connected villages!
- Private conversation with officials from the Ministry of New and Renewable Energy, Government of India.
- http://powermin.nic.in/whats_new/pdf/Guidelines_for_Village_Electrification_DDG_under_RGGVY.pdf
- Current benchmark cost is Rs 350/Wp (including 5 year O&M) but actual costs have been much higher for Gram Oorja.
- The exchange rate is approximately Rs 62 to 1 US Dollar.
- A 10kWp system is expected to generate approximately 12,000 to 14,000 units (kWh) of billable electricity annually.
- Almost 4 times the cost paid by urban residential consumers.
- Many State governments set an upper limit on the tariff that is chargeable to consumers, depending on whether they are above or below the poverty line.
- Rahul Sankhe, MD SunEdison, at ORF Mumbai, July 2012.
- See http://www.nsdcindia.org/index.aspx
- The authors refer to grids sizes below 100kWp

References

Census of India. (2011). *Household Amenities and Assets: Source of Lighting.* Office of the Registrar General and Census Commissioner.

Rural Electrification Policy. (2006). Retrieved from http://powermin.nic.in/whats_new/pdf/RE%20Policy.pdf

Deorah, S. M., & Chandran-Wadia, L. (2013). *Solar Mini-grids for Rural Electrification: A Roadmap to 100% Energy Access for India@75.* http://zeeba.orfmumbai.org/file/view/7329/solar-minigrids-for-rural-electrification

Ferris, D. (2014, January 16). Indian Microgrids Aim to Bring Millions Out of Darkness. Retrieved January 25, 2014, from Yale Environment 360:

Schnitzer, D., Lounsbury, D. S., Pablo, C. J., Deshmukh, R., Apt, J., & Kammen, D. M. (2014). *Micro-grids for Rural Electrification: A critical review of best practices based on seven case studies.*

United Nations Foundation.

TERI. (2012). *A Citizens' guide to Energy Subsidies in India.* The International Institute for Sustainable Development.

Off-grid Rural Area Electrification by Solar-Diesel Hybrid Mini-grid in Bangladesh: Design Considerations

Shahriar Ahmed Chowdhury[1*], Shakila Aziz[2]
[1]Centre for Energy Research, United International University (UIU), Dhaka, Bangladesh
[2]School of Business and Economics, United International University (UIU), Dhaka, Bangladesh
*Email: shahriar.ac@gmail.com

Abstract

Bangladesh is experiencing the most successful solar home system based rural electrification program. So far the program has installed more than 3 million SHS in rural areas of Bangladesh. The SHS can provide electricity to rural areas for 4 to 5 hours to operate basic loads like lighting, mobile phone charging, B/W TV etc. The SHS can hardly contribute to productive commercial activities in rural off grid areas. In the rural areas loads are sparsely distributed and demand of energy is at a barely minimum. So, it is not economically viable to extend the national grid to the remote off grid areas. Also in the island areas the grid extension is not economically feasible. Electricity access in rural Bangladesh is less than 40%. It is the common tendency of the rural people to live in clustered households. These paved the options for electrification of off grid areas with small standalone solar PV mini-grids, considering that Bangladesh has moderate solar insolation. One of the challenges of developing mini-grids is the storage system management. Incorporation of a small diesel generator not only reduces the requirement of storage system but can also provide energy in low insolation days, thus reduces the requirement of autonomy days. This paper highlights the technical design consideration for developing solar-diesel hybrid mini-grids in off grid rural areas of Bangladesh.

Keywords: Solar PV; Hybrid mini-grid; load factor; Storage system.

Introduction

Bangladesh is a power deficient country with around 50% of the population having no access to grid electricity [1]. Extension of grid network to remote places for a country like Bangladesh is expensive due to high transmission cost in comparison to load demand. Effective use of electricity (load factor) in rural households is less than 40%. Commerce and industry are not yet developed in the rural areas and the share of electricity consumption from these sectors is not expected to be high. With increased awareness of the adverse effect of global warming due to greenhouse gas emission, efforts are made all over the world to curb the greenhouse gas emission by increasing energy generation from renewable energy (RE) resources. In line with the global effort, Bangladesh has taken a plan to generate 5% of the total power generation (~500MW) from renewable sources by 2015 and 10% (~2000MW) by 2020 [2]. As renewable energy conversion technologies are still expensive, it is not clear how much RE sources can be tapped within the next 2 years to meet the set target. Till now solar is considered as the only RE resource in Bangladesh that can be harnessed effectively and has wide spread application at this stage. However, even with the current downward trend of PV price in the world market, PV based grid power generation cost is significantly higher than the gas/coal fired grid energy price prevalent in the country. Thus, the grid expansion, based on RE resources, is expected to be slow for the next few years, unless there is government support. However, with the gradual increase in the price of fossil fuels and declining price of solar PV, the cost of generation of electricity from solar PV will be competitive with the cost of generation of electricity from fossil fuels. In rural areas there is demand for power for meeting the basic needs (like lighting and cooling) of the rural household. To have access to electricity, people in the off-grid areas are prepared to pay a much higher price than the price of grid electricity. This opens up the opportunity to install small sized mini-grids for localized populous areas in off-grid areas or villages. Such small scale projects will provide electricity to the rural people and can contribute significantly to improve their quality of life. At the same time, these projects, when designed properly, can be sustainable and economically viable. Even if the grid is extended in the future to the stand alone mini-grids area, the solar PV can be connected to grid by the grid tied inverters.

Project Functional Structure

The solar-diesel hybrid mini-grid system for rural electrification program in Bangladesh is supported by the Infrastructure Development Company Limited (IDCOL) of Bangladesh, which is a non-bank financial institution, established by the Government of Bangladesh. The program is financed by international donor agencies like KfW, WB, ADB and JICA, who provide soft loans and grants to IDCOL which in turn channels the soft loans and grants to the developers of solar mini-grid projects. Entrepreneurs or the project developers with experience of solar PV systems are encouraged to submit proposals for the financing of solar hybrid mini-grid projects to IDCOL.

Project developers choose a remote off-grid area which has potential for installation of a mini-grid. They also appoint consultants for developing the project profile for IDCOL financing. Based on the market survey conducted by the project developers, IDCOL, in consultation with the sponsor and the consultant, conducts load assessments. The technical consultant then designs the hybrid system and prepares a bill of materials for the project and also supports developers to select suppliers based on the bill of material for the project. After arriving at the project costs based on submitted price quotations, IDCOL approves the project & starts the documentation process for financing the project.

The financial scheme for the solar-diesel hybrid mini-grid project developed by IDCOL is 50% grant, 30% soft loan (interest rate 6%) and 20% equity from the project developer. The soft loan is given for tenure of 10 years with two years grace period. Under this financial scheme one project has successfully been installed in Sandwip Island in the estuary of the Bay of Bengal in 2010. Initially, the project aimed to provide electricity to a rural market and its adjacent households from 9am in the morning to 11pm at night. IDCOL further approved 3 more solar mini-grid projects which are under construction. Seven other projects have already been submitted to IDCOL for financing considering uninterrupted power supply for 24 hours. IDCOL has a target of installing 50 solar-diesel hybrid mini-grids all over Bangladesh by 2016 [4].

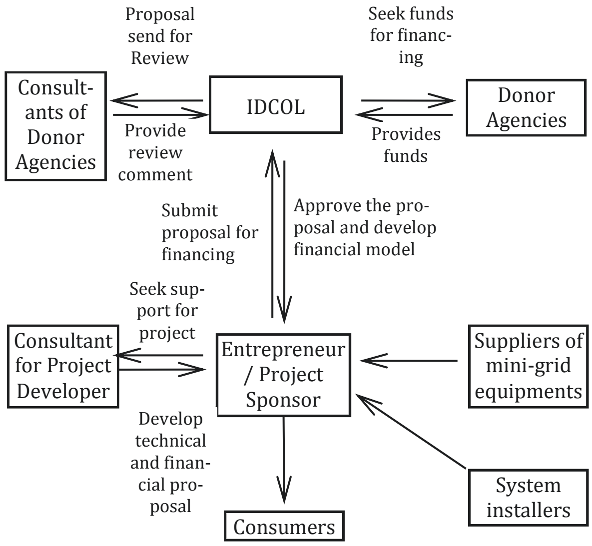


Figure 1: Functional structure of the solar-diesel hybrid mini-grid project of Bangladesh

Key Design Considerations

Mini-Grid design considerations are the key parameters for designing a mini-grid in a specific location. Some considerations can be made according to the actual scenario of the project location for minimizing the cost of energy and increasing sustainability. Design steps of the solar-diesel hybrid mini-grids are given below:

- Load estimation and development of load duration curve
- Estimation of day load and night load
- Calculation of battery size considering supply of night energy demand and battery DoD.
- Sizing of diesel generator considering peak load
- Length of distribution feeders considering 5% voltage drop at the end of distribution line.
- PV panel capacity of maximum 250 kWp [As per government regulation a mini-grid of less than 250 kWp of capacity does not need government approval].

Following criteria are given special attention while designing the mini-grids:

Selection of Technology: Different technologies of mini-grid power systems are available worldwide. Considering the availability of resources in Bangladesh, solar-diesel hybrid mini-grids are considered to be the most suitable solution.

Renewable energy fraction: Ahigher renewable energy fraction in the annual energy mix minimizes the running cost for the energy supply system. Transportation of diesel oil to remote places is cumbersome. For the hybrid projects in Bangladesh the RE fraction is considered to be more than 90%. A higher renewable energy fraction also keeps options for future demand growth [additional loads can be served by running the diesel generator for longer durations].

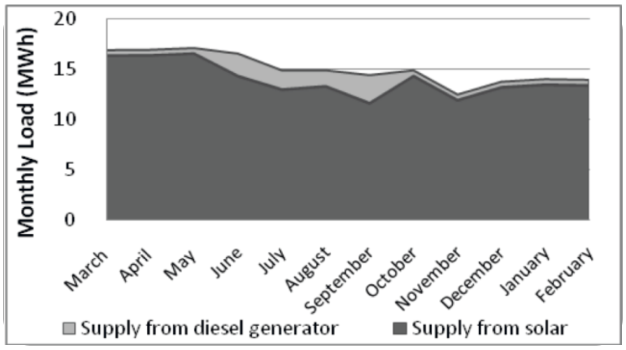


Figure 2: Typical energy mix for a solar diesel hybrid mini-grid in rural Bangladesh.

Productive use of solar power: during daytime, income generating activities like solar irrigation, cottage industries, husking mills, sawmills, grinding mills (for spice), welding machines, lathe machines, and ice factories in rural market places can be supported through the solar mini-grids. These day loads do not require storage facilities. Cost of energy for day loads are cheaper than the cost of energy for night loads. So, day loads are encouraged while designing mini-grids.

The addition of a generator reduces battery requirement: A diesel generator helps to reduce the size of the storage system for a mini-grid and no autonomy days need to be considered.

Cost reduction potential:
The increase of day loads reduces the levelized cost of energy.

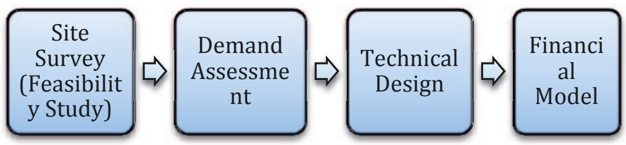


Figure 3: Design steps for solar-diesel hybrid mini-grids

Site Survey and Survey Items

Site survey is the initial requirement for planning a mini-grid for a specific location. Survey findings show the feasibility of a project in the present and future context. Parameters for survey vary from one location to another. Remote and isolated locations are ideal for mini-grid sites such as islands and habitations that are far away from the national grid network. The sites are selected in such a way that within the next 10 years the government has no plans to extend a grid line there. Secondly, interest and affordability of electricity by the local people of the site is to be considered. The levelized tariff of electricity considering IDCOL model stands at US$ 0.37 for a typical 150 kWp hybrid system is much higher than the energy tariff (US$

0.11) of grid electricity [3]. The average family income and profession of the adults of the location reflect the interest and affordability of electricity. Site surveys show that there are some areas where people cannot afford to buy electricity, on the other hand, some off-grid places are found to be economically developed and people are willing to pay a high price for electricity round the year. People use kerosene to meet their lighting demand in off grid areas while in some off grid areas diesel generators are used to provide electricity for some hours per day. In some cases, several shop owners or households share a diesel generator for their own consumption. The average tariff being charged to the customers by the diesel operators currently ranges between US$ 0.80 to US$ 0.90 per kWh. Finally, load assessment is the most indispensable tool to determine the size of the power plant. In the context of rural Bangladesh, lighting, cooling fans and mobile phone chargers are the main loads. Televisions, refrigerators and DVD players are also found to be potential loads. Rural sites for mini-grids are selected to cover one or two rural villages with a rural market place.

Demand assessment

Demand assessment in rural areas is quite challenging. Rural people are not familiar with electrical loads other than lighting and cooling. Their expectations are influenced by those who live in or frequently visit urban or city areas. They want to use luxury loads like TVs, DVD players and refrigerators without any idea about their energy consumption. Very careful assessment should be there to assess the rational load demand. It is wise to count the number of rooms in the households, the monthly income of the households, present expenditure for energy and the willingness to pay for better lighting should be taken into account.

Packages: To overcome actual load assessment barrier, different packages should be defined for different types of users according to their income level. The packages should be designed using energy efficient loads, for example LED lamps, higher efficiency cooling fans etc. Furthermore, to settle the load as a package, a relation between monthly energy price and present monthly cost for energy should be analyzed, so that the people can realize their expenses. Based on the survey findings in seven rural off grid areas the consumer packages developed are shown in table 1. It also shows the breakdown of each package according to the demand of rural households. The ratio of the packages varies with the variation of socio-economic condition of that locality.

Load factor: The rural economy of Bangladesh is mostly dependent on agriculture. People of the rural area work in their land all day long and go to sleep early. However, the scenario may not remain the same after electrification; therefore, the load factor needs to be decided considering the predicted scenario after electrification. Such as the demand of cooling fans during winter are negligible.

Table 1: Typical loads for different packages

Package	Gadget Type	Watt	Quantity
Package 1 (Small Household)	LED light	7	3
	Cooling fan	25	1
Package 2 (Medium income Household)	LED light	7	4
	Cooling fan	25	2
	TV	50	1
Package 3 (Well off Household)	LED light	7	6
	Cooling fan	25	2
	TV	50	1
Package 4 (Rich Household)	LED light	7	6
	Cooling fan	25	3
	TV	50	1
	Refrigerator	100	1
Package 5 (Shops)	LED light	7	2
	Cooling fan	25	1
Package 6 (Big Shops)	LED light	7	4
	Ceiling fans	25	2
	TV	50	1
	Refrigerator	100	1
Package-7 (Rural School & College)	LED light	7	10
	Cooling fan	25	20
Package-8 Industrial (Saw mills, Lathe m/c, others)	LED light	7	1
	Cooling fan	25	1
	Motor	5000	1
Package 9 (Irrigation pumps)	Motor	2000	1

Day Load: The cost of energy in a solar-diesel hybrid mini-grid system is high. Main reason behind this is the high price of the storage system and the cost of diesel. It is possible to reduce the energy cost to a tolerable limit by increasing the day load. Energy can be supplied directly to the day loads from the solar PV system except in rainy or foggy days. Thus, we can avoid the requirement of higher storage.

Night Load: The main challenge in running a mini-grid is when energy production declines in the early evening. To maintain the supply of power after the sunset, it is essential to continue the power supply either from a storage system or by running a diesel generator. On the other hand, the main load demand rises in the evening because maximum lamps and other electric gadgets turn on together. So, it is imperative to calculate the night load perfectly to determine the optimum size of the storage system and the run time of the generator.

Peak Load: In general, the peak loads are experienced in the evening. The size of off-grid inverters and generators are dependent on the night load.

Seasonal variation: During summer, the demand for electricity is at its highest as cooling load adds to the lighting load. Moreover, the run time of the cooling load is much higher than that of the lighting load. On the contrary, during winter, the cooling load goes off. The demand for electricity is lower in winter than in summer. Furthermore, in the context of Bangladesh winter lasts longer in rural than in urban areas. Considering these seasonal variations, the plant size varies. Taking into account all these seasonal load variations a source of power should be designed that can provide reliable power throughout the year. The graph below shows the estimated load profile in summer and winter of Bangladesh for a 200kWp solar-diesel hybrid power plant according to a survey data. During summer our irradiance is higher than in winter; on the contrary during summer our irrigation demand is highest. So, additional power generation from solar PV system can be used for irrigation.

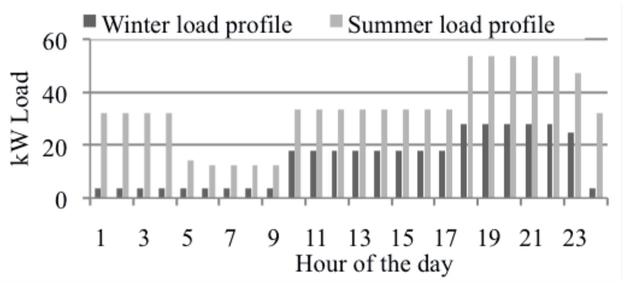


Figure 4: Typical load profile of a 150 kWp hybrid mini-grid.

System Design

Survey data shows that the demand reaches its peak after sunset and it generally lasts till 10 pm. solar power is the main source and the generator is kept as a backup or standby for such a mini-grid. The daily average generator run time depends upon the shortfall in solar energy and amount of storage in the battery bank. The solar-diesel hybrid mini-grids are predominantly powered by solar photovoltaic systems. Monthly generation from PV can be determined from the hourly averaged radiation data. Hourly average expected demand data is determined from the site survey. The day load is considered from 8 am in the morning to 5 pm in the evening. Generally the demand of the day load is lower than the generated PV power, so in the battery capacity calculation the day load is excluded. The night load is served by stored energy in the battery through the bi-directional off grid inverters. The generator will run only when the stored energy in the battery is not sufficient to serve the night load. As the system contains a diesel generator, no autonomy day is considered. Figure-6 shows the schematic diagram of a typical solar-diesel hybrid mini-grid. Main hardware of the solar hybrid PV plant consists of

1. Solar PV panels to convert solar energy into dc electricity.
2. Solar charge controllers to charge the battery directly from the solar PV panels,
3. Grid tied inverters to convert the solar energy to ac main power to serve the day loads,
4. Off grid bi-directional inverters to provide power to the loads during night from the battery and also to charge the battery from the grid power (when the generated power from the grid tied inverters during day are more than the demand of the grid).
5. Diesel generator for backup power and
6. Batteries to store energy.

Cooling fans are one of the major loads in rural areas of Bangladesh. It is found from the technical design that a significant portion of solar energy remains unused during the winter. To reduce the portion of unused energy some seasonal industrial loads are sought to use that energy. In some of the cases the mini-grids provide energy to the rural irrigation pumps only during the winter.

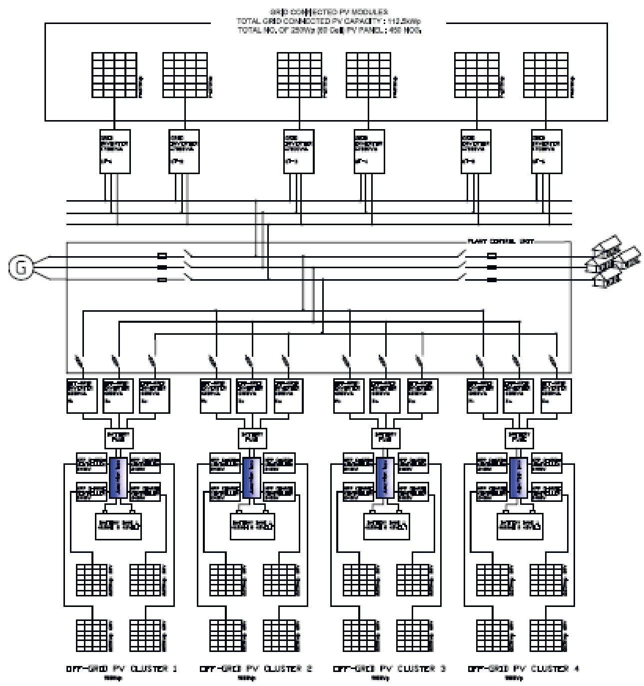


Figure 5: Single line diagram of a typical 150 kWp solar-diesel hybrid mini-grid system.

Conclusion

Solar diesel hybrid mini-grid systems, if designed properly, can serve off-grid areas with grid quality electricity. The proportionate increase of day load reduces the requirement of storage system, which in turn reduces the cost of electricity. The addition of a diesel generator further reduces the size of the storage system. It also helps to avoid the need for autonomy days. Demand assessment is one of the most important criteria for designing a mini-grid for rural areas. The demand or consumption pattern of a particular area is solely dependent on the socio-economic condition of that area. One model designed for a particular area cannot be directly used for another area. Each area should be individually surveyed for demand assessment. Installation of solar PV based mini-grids not only provides electricity to the rural off-grid areas but also reduces the GHG emission. The cost of electricity in a mini-grid can be kept within affordable limit by designing it properly. There should be a provision for future expansion to avoid system overload. The cost of electricity from isolated mini-grids is more than that from national grids, so the use of higher efficiency electrical gadgets can reduce the energy consumption.

References

Annual Report 2010-11, Bangladesh Power Development Board, Ministry of Power Energy and Mineral Resources, Government of Bangladesh.

Renewable Energy Policy of Bangladesh, Power Division, Ministry of Power Energy and Mineral Resources, Government of Bangladesh, December, 2008.

Retail Electricity tariff for all utilities, Bangladesh Energy Regulatory commission, Ministry of Power Energy and Mineral Resources. 29th March, 2012.

Infrastructure Development Company Limited (IDCOL), www.idcol.org

Scientific Papers

IV. Cooking

The influence of the end user's context on the dissemination of domestic biogas systems in developing countries

Willington Ortiz* (willington.ortiz@wupperinst.org)
Wuppertal Institute for Climate, Environment and Energy GmbH
P.O. Box 100480, 42004 Wuppertal, Germany

Julia Terrapon-Pfaff (julia.pfaff@wupperinst.org)
Wuppertal Institute for Climate, Environment and Energy GmbH

Carmen Dienst (carmen.dienst@wupperinst.org)
Wuppertal Institute for Climate, Environment and Energy GmbH

*corresponding author

Abstract

Long term mass dissemination programmes for domestic biogas have led to a significant increase in the volume of installations in some Asian countries. While these successes can offer insights for the targeted countries, the only moderate progress in some other countries, underline the need for understanding of favorable conditions and related sociotechnical context. By applying a quasi-evolutionary sociotechnical transition perspective, this study explores how contextual factors may influence the adoption and diffusion process. The analysis suggests that the adoption of domestic biogas requires adjustments to sociotechnical configurations that go beyond the cooking system; notably animal tenure and crop production. Due to the diversity of factors involved, greater emphasis on testing appears advisable, particularly at the outset of the dissemination process.

Keywords: Domestic biogas; sociotechnical transitions; renewable energy; developing regions.

Introduction

Domestic biogas systems are considered as clean cooking alternative for rural poor population. Accelerating the diffusion of biogas systems is expected to significantly contribute to reach the ambitious goal of ensuring universal access to modern energy services by 2030 (IEA, 2011). The striking success (in terms of quantity of installed systems) of mass dissemination programmes in some Asian countries seem to support that assumption; for example, more than 26 million biogas systems were installed in China by 2006 (Chen et al., 2010) and, since 1992, over 260,000 have been installed in Nepal (SNV, 2013). Those kinds of programs have been counting on continuous and long-term political support from central governments and have led to the emergence of national-wide institutional structures for reaching their targets. In contrast, installation rates of domestic biogas are rather marginal in countries where such (long-term) mass dissemination programs have not been established.

Criticism against the effectiveness of mass dissemination programs has been emerging, arguing that those striking installation rates are mainly driven by installation targets and correspondent subsidies, whereas commitment and motivation for the technology remain poor among users (Bath et al., 2001). This, in turn often leads to poor management practices of users, lack of follow-up services, malfunction or, in the worst case, abandonment of the systems (Huanyun et al., 2013; Cheng et al., 2014).

These controversial issues reflect particular complexities in the adoption and diffusion process of domestic biogas. This process may be better understood as taking place in a dynamic system with strong interactions between the user, the technologies and the broader context (Ruiz-Mercado et al., 2011). The enduring processes that led to those striking installation rates in some Asian countries are, undoubtedly, a valuable source of lessons that can help to develop and modify similar processes in other countries. However, the degree to which these lessons can be applied is certainly influenced by contextual differences, such as environmental, social, economic and political circumstances.

Research Objectives and Methods

This study aims to understand which contextual factors influence the adoption and diffusion process of domestic biogas systems and how these influences manifest themselves. To achieve this, a quasi-evolutionary sociotechnical transition perspective is applied to the problem. Within this analytical perspective the main objective of the analysis is to explore which components of the emerging sociotechnical system offer particular challenges in the end user's context; i.e. those aspects that require considerable adaptation efforts in order to ensure that end users benefit from the adoption of domestic biogas systems. This ability of adopters to effectively draw benefits from the technology is considered in this study as central indicator for successful dissemination.

After briefly describing the central concepts of the proposed analytical framework, the first stage of the analysis consists of conceptualizing the problem of promoting domestic biogas systems as a sociotechnical transition management process, i.e. a process that strives to steer change in incumbent sociotechnical systems in order that biogas technology can become 'mainstream' within the region. Relevant structural incompatibilities are analytically deducted.

A systematic review of scientific literature on the subject is proposed in order to code and map empirically observed factors that have been reported as influential to the dissemination of domestic biogas. A heuristic is built in order to guide the review process. The last stage of the analysis looks for patterns within those systematically mapped factors that may give indications of the validity of the challenges predicted, as well as about other challenging structural configurations specific to the dissemination of the technology.

The findings presented here are drawn from detailed analysis of empirical observations reported in 14 studies (See Table 1). All the studies appeared in publications vetted through a peer review process. The main criterion for selection was that the research addressed (at least partially) aspects of the dissemination of domestic biogas. Only studies published after 2000 were considered.

Table 1. Geographic distribution of analyzed studies

Country	Studies
Cambodia	Buysman et Mol, 2013
China	Qu et al., 2013; Chen et al., 2012; Chen et al., 2010; van Groenendaal et Gehua, 2010
India	Bhat et al., 2001
Nepal	Cheng et al., 2014; Katuwal et Bohara, 2009
Peru	Garfí et al., 2012
Rwanda	Landi et al., 2013
Tanzania	Laramee et Davis, 2013; Mwakaje, 2008
Uganda	Walekhwa et al., 2009
Vietnam	Thu et al., 2012

Analytical framework

Quasi-evolutionary perspective of sociotechnical change

The dynamics of sociotechnical change are conceptualized as a function of interactions between (and within) sociotechnical systems with different structuration levels. The central role is played by the incumbent sociotechnical systems, which are also called regimes. Regimes represent the dominant structures that, on the one hand, facilitate practices and behaviors related to the provision and use of mainstream solutions (Grin et al. 2010). On the other hand, innovation dynamics in sociotechnical regimes are usually 'locked-in' (i.e. they follow technological trajectories) and tend to be quite incremental.

Radical innovations to persistent problems are more likely to emerge from less structured sociotechnical systems (niches), which allow for experimentation with options that may conflict with mainstream patterns. Both types of sociotechnical systems (niches and regimes) are influenced by "external context that actors cannot influence in the short run" (Geels et Schot, 2007, p.403). This so-called sociotechnical landscape includes factors such as climate and long-term change in social, political or economic development, but also encompasses sudden shocks such as war or price fluctuation.

Interactions can reinforce the structuring functions of a sociotechnical system or act as disruptive factors. Disruptive or competitive interactions are also conceptualized as selection pressures (Smith et al. 2005). This wording emphasizes the underlying quasi-evolutionary perspective, which applies the three basic elements of evolutionary theory (variation, selection and retention) to understand innovation: technological variation as a creative process of "reordering the physical world in ways considered useful or desirable" (Hughes, 1987, p.53); a selection environment where the criteria for evaluating what is useful are defined; and the retention of successful outcomes by stabilizing their underlying sociotechnical configurations.

Promotion of domestic biogas from a quasi-evolutionary socio-technical perspective

Considering the promotion of domestic biogas from a quasi-evolutionary sociotechnical perspective accentuates two aspects of the problem definition:

i) The goal of the transition process comprises a stable sociotechnical system where domestic biogas systems have become mainstream options for providing specific services (e.g. energy for cooking and fertilisers). In this case a set of actors (users, firms, government, universities etc.) enable the production, commercialization, use, maintenance and further development of the technology by interacting according to a set of stable rules (norms, regulations, cognitive components).
ii) On the other hand, the quasi-evolutionary perspective foresees that to achieve that goal requires a process of co-evolution and stabilization of those components and their interactions. Additionally, and due to their innovative character, it can be expected that (during the transition process) the promoted domestic biogas technologies do not (completely) fit with the existing sociotechnical configurations.

Structural incompatibilities in the interaction between users and biogas systems are anticipated to be particularly disruptive. Firstly, users are intensively involved in many domains where the sociotechnical systems for domestic biogas technologies are expected to evolve and reproduce. As well as being consumers of the biogas systems, users are often also operators and owners. .

Secondly, domestic biogas systems are often promoted as technical solutions offering the user various benefits; most notably, to provide 'clean' energy for cooking, biological fertiliser and a solution for the adequate treatment of waste water and sanitation. If this is the case, the adoption of the new technology requires users to change not only one but a number of sociotechnical configurations that have been providing different kinds of services. There are, therefore, a range of potential structural incompatibilities at user level.

Heuristic of sociotechnical systems for domestic biogas

The interaction between the adopters and the technology can be seen as taking place in four domains:

- Making the investment decision: all activities leading to the actual decision to invest in the domestic biogas system.

- Investing in the system: all activities triggered by the investment decision that result in the actual installation of the system.
- Operating and maintaining the system: all activities required to ensure the correct functioning of the biogas system.
- Using the end-products: all activities related to the actual use of the products provided by the system, particularly the biogas and the slurry.

Influential factors observed in the course of these interactions can be interpreted as practical expressions of structural configurations that frame the agency of adopters. By mapping these empirical observed factors in the action domains of the adopters, the aim is to reach a better approximation of the challenging structural configurations specific to the adoption and diffusion of domestic biogas technologies.

Results

Table 2 summarizes the results of coding and mapping factors reported in the selected studies as being particularly influential in the dissemination of domestic biogas systems.

Table 2 Summary of factors influencing action domains of adopters.

Action domains	Factors
Decision Making	Promotional tasks Cooking fuel alternative Living standard Age of head of household
Investing	Subsidies Affordability Qualified suppliers
Operation and Maintenance	Quantity of animals Stabled animals User's recurrent tasks After-sale services
Use	Partial substitution of fuels Slurry as fertiliser

Two aspects emerge as being decisive in the potential adopter's decision making process: promotion and individual motivation. Organizations that coordinate programmes or initiatives are often responsible for promotional activities. Moreover, Qu et al. (2013) and Thu el al. (2012) find that adopters are more influenced by the promotional activities of official organizations than by other sources. The opportunity to replace or reduce conventional fuels is found to be central motivation for adopters in studies in Tanzania, Uganda and India. Qu et al. (2013) and van Groenendaal et Gehua (2010) find that the motivation of Chinese adopters is more likely to be related to improving living conditions, e.g. lower levels of indoor smoke and improvements to kitchens, toilets and pigpens.

Affordability is an often reported influential issue. Studies containing financial analysis find that most of the potential adopters do not have the capacity to invest in the technology. The existence of subsidy schemes is highlighted in the majority of the studies. Moreover Bhat et al. (2001) identify availability of diverse credit alternatives (beyond the subsidy) as one influential factor for the success of the analyzed case study; even though the targeted households are reported to be of "relatively high income" (p. 45).

The influence of supply infrastructures on adopter's interaction with the technology appears very significant. Thu et al., (2012) and Cheng et al. (2014) find recurrent failures related to improper design and insufficient skills for construction and installation. The majority of the studies emphasize the importance of follow up services to ensure sustained operation, and therefore long lasting adoption. Measures for training technicians and regulations regarding after sale services are in place in most of the national promotion programs covered by the studies. Though, the issue seems to be quite challenging. Chen et al. (2012) emphasize the urgency "to innovate on the institutional mechanisms to improve service abilities" (p. 62) in China, even though a large infrastructure of service outlets already exists.

Physical infrastructure and practices related to animal tenure are highlighted by the majority of the studies as crucial for adoption and diffusion process. Factors like the quantity and kind of animals, feeding practices (e.g. grazing/stabling strategies), maintenance tasks (e.g. cleaning, collection of urine), type and quality of stables frame adopters' interactions; more notable the daily operation tasks and the decision making process.

Adopter's tasks operating, maintaining and using the biogas system are manifold. They require considerable time resources and learning skills. Indications about the relevance of both factors can be found. E.g. Cheng et al. (2014) and Thu et al. (2012) attribute often observed failures to insufficient knowledge about the technology and maintenance requirements by the adopter. Walekhwa et al. (2009) find that larger households headed by younger persons are more likely to adopt biogas in Uganda and suggest that the availability of labour and the will to learn new skills might explain this result. Qu et al. (2013) make similar observations regarding the age of head of household in China. However, there the optimum age for success is 45, which is probably explained by the fact that younger people have greater opportunities to move to the city for work.

Discussion

The findings confirm that the adoption of domestic biogas does require significant adjustment to various sociotechnical configurations in addition to the sociotechnical system for the provision of cooking energy. More notable are the challenging structures related to animal tenure and crop production. The proper functioning of biogas technology depends on the adequate alignment with sociotechnical configurations related to animal tenure. Significant adjustment can be required in material (e.g. stables, pigpens), practical (e.g. feeding, cleaning) and regulatory components. The value of slurry as fertiliser is often mentioned in the literature, but its application is often neglected - even in countries with a long track record of the technology, such as Nepal and China (Cheng et al., 2014 and Chen et al., 2010 respectively). The alignment of practical and material components (such as options for pumping and transporting the slurry to the fields) can be particularly challenging (Thu et al., 2012), but also lack of knowledge about the real nutritional value and adequate application practices can hamper proper integration of domestic biogas into adopter's crop system (Garfí et al., 2012)

Studies that analyse financial aspects of the process find that domestic biogas is still a technology with low profit potential, as previously observed by Barnett et al. (1978). Consequently, the availability of subsidy schemes remains a critical factor for the diffusion of the technology .

Our findings suggest that it is relevant to broaden our perspective of domestic biogas. Conventionally, it has been understood as an alternative for energy provision (particularly cooking energy). However, it can be better viewed as a technology that enables (or even necessitates) the reshaping of several sociotechnical systems related to the living standards of rural populations. More prominently systems linked to animal tenure, crop production and eventually sanitation. Greater attention to these interactions seems to be needed even by those long-lasting programs with impressive installation records.

In the same vein, the extent at which adopters perceive benefits from domestic biogas depends on the adjustment between the (new) domestic biogas sociotechnical configuration and the above mentioned sociotechnical systems. Lessons (e.g. designs, methods, heuristics, institutions) from 'successful' programs might help to that process. Though, further research is needed in order to assess which lessons can be generalized and which not. In the meantime they should be treated as options to be (re)validated under new contexts and thus, greater emphasis on experimentation is highly recommendable, particularly at early stages of dissemination programs.

References

Bhat, P.R., Chanakya, H.N., Ravindranath, N.H. (2001). Biogas plant dissemination: success story of Sirsi, India. Energy for Sustainable Development, 5(1), 39-46

Barnett, A., Pyle, L., Subramanian, S.K.. (1978). Biogas technology in the Third World: a multidisciplinary review. International Development Research Centre, Ottawa, Canada.

Buysman, E., Mol, A.P.J. (2013). Market-based biogas sector development in least developed countries -The case of Cambodia. Energy Policy, 63, 44-51.

Chen, L., Zhao, L., Ren, C., Wang, F. (2012). The progress and prospects of rural biogas production in China. Energy Policy, 51, 58-63.

Chen, Y., Yang, G., Sweeney, S., Feng, Y. (2010). Household biogas use in rural China: A study of opportunities and constraints. Renewable and Sustainable Energy Reviews, 14, 545-549.

Cheng, S., Li, Z., Mang, H.P., Neupane, K., Wauthelet, M., Huba, E.M. (2014). Application of fault tree approach for technical assessmentof small-sized biogas systems in Nepal. Applied Energy, 113, 1372–1381.

Garfí M., Ferrer-Martí L., Velob, E., Ferrera, I. (2012). Evaluating benefits of low-cost household digesters for rural Andean communities Renewable and Sustainable Energy Reviews, 16, 575-581.

Geels, F.W. et Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy, 36, 399-417.

Grin, J., Rotmans, J, Schot, J. 2010. Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change. New York.

Huanyun, D., Rui, X., Jianchang, L., Yage, Y., Qiuxia, W., 2013. Analysis on sustainable development countermeasures and barriers of rural household biogas in China. Renewable Sustainable Energy, 5.

Hughes, T., 1987. The Evolution of Large Technological Systems. In: Bijker, Wiebe E; Hughes, Thomas P; Pinch, Trevor J (Eds.), The Social Construction of Technological Systems. New Directions in the Sociology and History of Technology. MIT Press. Cambridge, Mass.159–187.

International Energy Agency (IEA), 2011. Energy for All. Financing access for the poor. International Energy Agency. Paris, France.

Katuwal, H., Bohara, A.K. (2009). Biogas: A promising renewable technology and its impact on rural households in Nepal. Renewable and Sustainable Energy Reviews, 13, 2668-2674.

Landi, M., Sovacool, B.K., Eidsness, J. (2013). Cooking with gas: Policy lessons from Rwanda's National Domestic Biogas Program (NDBP). Energy for Sustainable Development, 17, 347-356.

Laramee, J., Davis, J. (2013). Economic and environmental impacts of domestic bio-digesters: Evidence from Arusha, Tanzania. Energy for Sustainable Development, 17, 296-304.

Mwakaje, A.G. (2008) Dairy farming and biogas use in Rungwe district, South-west Tanzania: A study of opportunities and constraints. Renewable and Sustainable Energy Reviews, 12 , 2240-2252.

Ruiz-Mercado, I.,Masera, O.,Zamora, H.,Smith, K.R., 2011. Adoption and sustained use of improved cookstoves. Energy Policy, 39, 7557-7566.

Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Research Policy 34, 1491-1510.

SNV, 2013. Africa witnesses 40% increase of biogas plants in 2012. Domestic biogas newsletter, 8.

Qu, W., Tu, Q., Bluemling, B. (2013) Which factors are effective for farmers' biogas use?-Evidence from a large-scale survey in China. Energy Policy, 63, 26-33.

Thu, C.T.T., Cuong, P.H., Hang, L.T., Chao, N.V., Anh, L.X., Trach, N.X., Sommer, S.G. (2012). Manure management practices on biogas and non-biogas pig farms in developing countries – using livestock farms in Vietnam as an example. Journal of Cleaner Production, 27, 64-71.

van Groenendaal, W., Gehua, W., 2010. Microanalysis of the benefits of China's family-size bio-digesters. Energy, 35, 4457-4466. Walekhwa, P.N., Mugisha, J., Drake, L. (2009). Biogas energy from family-sized digesters in Uganda: Critical factors and policy implications. Energy Policy, 37, 2754-2762

Scale vs. Substance? Lessons from a Context-responsive Approach to Market-based Stove Development in Western Kenya

Temilade Sesan (temi@gbengasesan.com)
Centre for Petroleum, Energy Economics and Law
University of Ibadan, Nigeria

Abstract

Improved stoves targeted at the 2.6 billion people worldwide that use solid biomass for cooking have not been taken up in the numbers expected by donors and practitioners. Following widespread critique of the subsidy-based dissemination models popular in the 1970s and 1980s, donors have begun to emphasise the potential of market-based models to increase stove adoption rates. In analysing the USEPA project implemented by Practical Action in western Kenya, this paper examines how a market-based approach has translated in the kind of informal economy operated by many biomass-reliant communities. The paper concludes that a context-responsive approach is likely to facilitate the dissemination of locally appropriate interventions, but it may not always be compatible with mainstream visions of large-scale stove deployment.

Keywords: Improved stoves; Market-based development.

Introduction and Objectives

In improved stove development practice, a distinction is usually made between the pilot and scaling up phases of a programme. While there is little debate over the importance of scaling up improved stove projects, there is a considerable degree of uncertainty in the field as to what would constitute an effective approach to scaling up those interventions. Subsidy-based stove dissemination models, popular in the 1970s and 1980s, were retrospectively denounced by experts as having hindered the potential of many stove projects of the period to continue unaided. Following the general critique of subsidy-based approaches, major funders of improved stove interventions have begun to emphasise market-based dissemination models (see for example Hoffman et al. 2005). Increasingly, stove development organisations are subscribing to the ideology that the only way improved cooking technologies can reach the millions of poor households that need reaching is to adopt the practices associated with a fully functioning market system of the kind found in rich countries. Indeed, very few voices of caution or dissent can be heard today amidst the growing enthusiasm to establish market routes to scaling up cooking interventions – voices, like Bailis et al. (2009) and O'Neal (2005), which crucially reflect an understanding of the context of poverty in which most stove interventions are implemented, rather than an unquestioning belief in the 'power' of the 'market' to provide appropriate solutions in all contexts.

The market movement in stove development was consolidated with the advent of the United Nations Foundation-led Global Alliance for Clean Cookstoves (GACC) in 2010 (Smith 2010). The GACC promotes the activities of institutionalised market actors on the national and international scenes, but it also acknowledges the role that local women in particular have to play in taking market-led solutions to the last-mile customer (Hart and Smith, n.d.). This latter function is especially important in the context of the mostly informal economies in which solid biomass is widely used. This paper discusses the potential of informal market models to deliver targeted outcomes through the work of Practical Action, a UK-based international non-governmental organisation that has implemented improved stove programmes in Kenya since the mid-1980s. Practical Action's stove programme, despite being specifically targeted at poor and marginalised populations, has historically favoured market-based dissemination approaches over the giving of subsidies and handouts. Practical Action's subscription to a market approach however seeks to take into account the realities of the socio-economic contexts into which improved stoves are introduced, in effect privileging the needs of the poor over the inflexibility of market operations. The organisation employs a participatory approach in working with local women's groups to establish small-scale supply chains for improved stoves in their communities. Using the case of the USEPA smoke alleviation project implemented by the organisation in Kadibo, western Kenya from 2009 to 2010, the paper describes some of the market development elements of the context-responsive approach taken by the organisation to establishing stove enterprise groups and discusses the outcomes for the poor households targeted by the programme. First though, the methods used in gathering the data presented will be briefly outlined.

Methods

Fieldwork for this study was carried out between November and December 2009 using qualitative methods, specifically semi-structured interviewing and non-participant observation. Of the eight 'locations' within Kadibo division that were involved in the USEPA project, I was only able to gain access to one – West Kochieng – due to time and resource constraints which Schatzman and Strauss (1973) identify as having the potential to restrict the researcher's access in the field. The sample size was restricted to twenty-one – not sufficiently large to elicit generalisable observations, but small enough to facilitate in-depth analysis of the interview data generated.

Interviews were conducted across three actor categories, as follows: Practical Action staff (4 interviews); project community authorities (2 interviews); and local energy users (15 interviews, four of which were with members of the only stove enterprise group in West Kochieng involved in the project at the time of fieldwork). In addition to membership (or otherwise) of the stove enterprise group, the local energy users in the sample were selected on the basis of their adoption (or otherwise) of the improved cooking interventions introduced by the USEPA project. As such, four different sub-categories of local energy user emerged: stove enterprise group members that had adopted at least one of the six interventions promoted on the project; group members that had not adopted any of the interventions; non-group members that had adopted at least one of the interventions; and non-group members that had not adopted any of the interventions. This multi-faceted sample structure afforded insight into both the demand and supply-side dynamics of the project in West Kochieng, though the lessons drawn out in this paper relate mostly to the latter. The Practical Action staff interviewed were selected on the basis of organisational hierarchy (for instance, the sample included a senior member of staff with a good overview of the organisation's stove programme in the region) and degree of involvement in field implementation of the USEPA project. The questions asked varied across the different respondent categories: the interviews with Practical Action staff focused on project implementation processes and outcomes relative to specified targets, while those with local energy users explored issues relating to adoption decisions, group membership and identity, project participation, and household priorities. The interviews with community authorities discussed their role in facilitating links between local stove enterprise groups and external organisations such as Practical Action.

Non-participant observation was carried out at all times in interview settings to complement interview data and capture naturally occurring clues that could shed further light on the investigation and provide context for data interpretation (Kvale 1996). The detailed field notes taken during and after each interview/observation session provided a starting point for coding the data gathered as well as an ongoing reference point during analysis of those data.

The USEPA Smoke Alleviation Project

In January 2009, Practical Action commissioned a two-year project to develop market systems for the dissemination of six improved cooking interventions – the Upesi stove, the fireless cooker, the solar cookit, the smoke hood, the LPG stove, and eaves spaces – in western Kenya (Interview Practical Action Staff 1). The project was christened the USEPA project after the donor organisation, the United States Environmental Protection Agency, which funded its implementation. Under the USEPA project, stove enterprise groups mostly acted as retailers and installers of the improved cooking interventions; production, mainly of fireless cookers out of locally available materials, was limited to a few women within the groups. This section goes on to describe the form that the project took in West Kochieng where fieldwork was conducted, but first outlines some of the peculiarities of the informal economy in the location to provide context for the discussion that follows.

A Different Kind of Marketplace

West Kochieng is situated in Nyanza province, which is one of 8 administrative provinces in Kenya and home to the Luo people, who constitute the third largest ethnic group in the country. The Luo are a close-knit people who live communally: the unit of spatial demarcation is not the household, but the 'homestead' which comprises several individual homes – occupied by extended family members – arranged around an open courtyard. The Luo, particularly those who reside in rural areas, attach great significance to the observance of tradition and custom, eschewal of which would cause an individual/household to be regarded by society as an outcast. The influence of culture is all-pervasive, touching on every area of individual and communal life, from living and cooking arrangements to hospitality codes to the attribution of gender roles.

In particular, women are culturally assigned a subordinate position to men in the region. This is a reality that is reflected even in the routine of everyday life: in the absence of her husband, for instance, a woman is expected to simply tell visitors who come knocking that 'no one' is at home, a response which tacitly discounts her own existence as an individual. In the absence of broader societal affirmation, women typically band together in groups of fifteen to twenty 'to uplift one another as members' (Interview West Kochieng Resident 1) both socially and economically, oftentimes via the platform of cooperative savings or 'merry-go-round' schemes. In adopting these women's groups as the focal point for its stove intervention in West Kochieng, Practical Action is in effect operating within the boundaries prescribed for women by culture while seeking to empower them socio-economically so they gain a measure of influence as providers and users of improved cooking technologies.

Similarly, the effect of tradition on market exchanges in West Kochieng is very significant. I observed in the course of fieldwork that some of the traditional and time-honoured practices valued by people in the community would be considered as violating the modern economic norms of commoditisation and profit maximisation. A good example is the way that land is appropriated for building and farming purposes. Empty structures belonging to dead people are retained as they are, rather than being sold off or turned over to more 'lucrative' purposes. In fertile areas, individual *shambas*, or farm plots, grow progressively smaller as land is divided and re-divided among however many sons are born into the household. Smaller farm plots definitely mean a decrease in individual farm yield, yet family land is divided as many times as is necessary because that is the way prescribed by tradition. As such, the widely proclaimed 'efficiencies' of a modern market system do not come into play in this context. For instance, according to the women who run stove enterprises in West Kochieng, conventional marketing and advertising tactics such as the use of 'memorable' radio jingles as suggested by Brewis (2005) are not very effective in reaching prospective customers. The women understand that their peers in the community respond better to more personalised forms of advertising such as one-on-one marketing and public demonstrations, and they respond accordingly:

> 'Advertising on the radio would help, but the more effective one is, bring it to the market and to public *barazas*…Because some people who have never heardabout it don't believe… So when they demonstrate, the people are actually ready to wait and see. And when they see that, then they actually buy and some will say, 'okay, I'll give you

> the deposit'… So the direct marketing has really helped.' (Interview West Kochieng Resident 2)

Besides the market and community *barazas*, other popular demonstration outlets for stoves include schools and churches – places where community members gather for social purposes not normally associated with buying and selling. Though sales and marketing of interventions are done individually, the burden of advertising is sometimes shared among members of a stove enterprise group.

Credit management is another aspect of this marketplace that has been modified to fit the requirements of local enterprise. According to the stove enterprise group members interviewed, the credit models which have been proven to work best are those that harness the power of the group. Such schemes rest on the principle that members who take out individual loans will hesitate to default on repayments because they are accountable to their fellow group members, which is often the case. However, the peculiar challenges of living on low incomes in rural areas can sometimes undermine that premise: according to Practical Action Staff 1, a woman may take a loan for the purpose of expanding her small business, but the moment an emergency shows up in the form of a sick or hungry child, she promptly diverts the funds to healthcare or food as the case may be. The relatively flexible credit provisions of this marketplace, though not conducive to a conventional profit-maximising enterprise model, are essential to the viability of market-based interventions seeking to improve aspects of residents' livelihoods.

Context-responsive Stove Market Development in West Kochieng

It is against this background that the USEPA project set out to provide local women with start-up support to enable the stove enterprises they initiated to eventually take off unaided. By November 2009 when fieldwork for this study was conducted, the project was only assisting stove retailers with making financial and logistical arrangements for bulk stove purchase. From the point of delivery of the stoves, each woman was expected to find her own buyers, sell the stoves without assistance from the project, take out her profit, and give the capital back to the project towards the purchase of another batch of stoves. The women were not required to pay at the point of collection of the stoves, but only after they had sold the stoves and realised a profit. This system was adopted to circumvent the women's inability to gain access to adequate start-up capital. At the time of fieldwork, the possibility of facilitating access to capital through the channel of village savings and loans schemes was already being explored:

> 'But now the locations that we have started working in, we have now created 6 groups, and these groups have currently started what is called... village savings and loans. And so when they raise money here, we are trying to talk to them, that when their loans get to the level that they can get 100 stoves by themselves, we will leave that. They get 100 stoves, and they come and sell. So it becomes like revolving for them.' (Interview Practical Action Staff 1)

Such community savings and loans schemes – succinctly referred to as 'COSALO' in the localities where they operate – are usually initiated by development agencies working to improve different aspects of livelihoods, and they appear to be gaining widespread acceptance in Kadibo division as a whole. The loan amounts that can be taken out by individuals are usually proportional to the value of their contribution to the fund. A small interest rate is usually applied which constitutes the main source of income for the group and goes towards building up the group capital. Practical Action expects that the COSALO scheme will contribute to resolving the challenge of limited access to capital present at all levels of the local stove distribution chain.

According to one scenario laid out by Practical Action staff, if 10 group members take loans of 2,000 Kenyan shillings (Kshs) each and pool their individual sums together, with the bulk sum they can arrange for purchase and delivery of a batch of 100 stoves. When the stoves are delivered, each woman collects her quota and, as usual, conducts the marketing and sales by herself. The potential challenge with this model, however, is that the COSALO platform is purely transactional and members are free to use their loans to pursue any commercial activity as long as they can repay. As such, there is no guarantee of getting up to 10 women who will be willing to invest their capital in stoves at any given time. The observations I made in the course of fieldwork, as well as conversations I had with women running stove enterprises, indicate that access to credit/capital is highly valued in West Kochieng. However, these facilities are often sought for the purpose of initiating or expanding a range of micro-businesses that may not be related to stove enterprise. Thus in attempting to persuade COSALO group members to invest their resources in stove enterprise, Practical Action seeks to influence priorities on the supply side. This may be particularly difficult to achieve as only a few group members, some of whom are seen by their peers as the stove 'experts', rely on stove enterprise as their main or only source of income. Although stove businesses offer higher profit margins than most local micro-businesses do, many women in West Kochieng stated that they found it difficult to establish the market links required to derive a steady income out of the enterprise. This indicates that, even where formal or informal credit platforms have been introduced, the entry barriers to stove enterprise need to be further lowered for many local women by offering them training in 'soft' skills such as networking and marketing. In addition, such women will likely require longer-term donor support – both financial and logistical – for their fledgling businesses than is normally allowed for in programme design, an argument made more generally by Bailis et al. (2009) in their critical assessment of the current market orthodoxy in stove development. The nextsection summarises the opportunities and limitations of the context-responsive approach to stove market development exemplified by Practical Action's intervention in West Kochieng.

Discussion

This paper has highlighted Practical Action's attempts to develop local improved stove supply chains in informal economies within western Kenya through its USEPA project. The merits of using local women as the main actors in stove enterprise are evident in this case: apart from empowering otherwise marginalised women socio-economically, the final costs of the improved technologies to users tend to be highly sensitive to local realities. The Upesi stove liners, for instance, produced, marketed and sold by members of various women's groups in western Kenya, are the least expensive of the technologies introduced by the USEPA project at 350 Kshs. The smoke hood on the other hand, which is manufactured and installed by city-based artisans and meant to be used in conjunction with the Upesi stove, comes at a final cost of 5,500 Kshs – fifteen times as expensive as the Upesi and the equivalent of two months' wages in West Kochieng.

The result is that the Upesi stove was the most widely adopted technology in the sample – taken up by 7 of 13 households – while the smoke hood, present in only one relatively affluent household, was one of the least accessible of the technologies promoted.

The lessons offered by this case are especially pertinent in the current phase of stove development when, as noted earlier, a near-consensus has been achieved on the desirability of adopting market strategies over dissemination approaches which incorporate subsidy elements, on the basis that the former route is more financially sustainable over the long term and is potentially more value-adding than the latter. As has been shown, Practical Action's context-responsive approach to market development required the organisation to operate within the provisions of the 'economy of affection' (Hyden 1980) in West Kochieng. The provisions within the community for certain 'market' functions such as advertising and credit arrangements were seen to deviate from the rational, profit-maximising norms of formal markets. Those informal provisions have, however, been critical to sustaining the local market for improved stoves. Where the approach needs further strengthening is in the provision of complementary skills and sustained donor support that will better equip local women to take advantage of the market platforms that have been adapted to fit their context.

Notwithstanding the potential for impact demonstrated by Practical Action's context-responsive approach to market dissemination, such approaches may not always be compatible with mainstream visions of 'scaling up' which emphasise universal reach and access of, sometimes, 'efficient' stove technologies which are developed out of context and which therefore may not be economically or culturally appropriate. Though Practical Action's context-responsive approach resulted in low-cost and culturally appropriate interventions such as the Upesi stove being directed toward local users on the lowest rungs of theenergy ladder, progress has been achieved slowly and incrementally (Sesan 2012). With respect to alleviating energy poverty among biomass-reliant households, therefore, the outcomes of the context-responsive approach to market-based stove dissemination taken by Practical Action suggest the possibility of a trade-off between scale and impact on stove programmes specifically directed at the poorest energy users: such an approach may yield small scale but is likely to have high impact, which means that it is better able to reach the neediest households with technologies they can afford, even if the benefits derived from those technologies are only incremental. Several examples are now emerging in the literature of market-led stove programmes that are on their way to achieving significant scale while leaving out the poorest households (q.v. Sesan et al. 2013, Shrimali et al. 2011). Perhaps the greatest challenge for stove development experts in this phase will be ensuring that the poorest are able to participate substantively in the burgeoning global stove market and do so on context-specific terms.

References

Bailis, R., Cowan, A., Berrueta, V., & Masera, O. (2009). Arresting the killer in the kitchen: The promises and pitfalls of commercialising improved cookstoves. *WorldDevelopment*, *37*, 1694-1705.

Brewis, A. (2005). Ten top tips for successful scaling up. *Boiling Point*, *50*, 5-6.

Hart, C., & Smith, G. (n.d.). *Scaling adoption of cleancooking solutions through women's empowerment: A resource guide*. Washington, DC: Global Alliance forClean Cookstoves.

Hoffman, K., West, C., Westley, K., & Jarvis, S. (2005). *Enterprise solutions to poverty: Opportunities and challenges for the international development community and big business*. London: Shell Foundation.

Hyden, G. (1980). *Beyond ujamaa in Tanzania:Underdevelopment and an uncaptured peasantry*.London: Heinemann.

Kvale, S. (1996). *InterViews: An introduction toqualitative research interviewing*. London: Sage.

O'Neal, D. (2005). Designing stoves for mass production. *Boiling Point*, *50*, 8-11.

Schatzman, L., & Strauss, A. (1973). *Field research:Strategies for a natural sociology*. Englewood Cliffs,NJ: Prentice-Hall.

Sesan, T. (2012). Navigating the limitations of energy poverty: Lessons from the promotion of improved cooking technologies in Kenya. *Energy Policy*, *47*, 202-210.

Sesan, T., Raman, S. Clifford, M., & Forbes, I. (2013). Corporate-led sustainable development and energy poverty alleviation at the bottom of the pyramid: The case of the CleanCook in Nigeria. *World Development*, *45*, 137-146.

Shrimali, G., Slaski, X., Thurber, M.C., & Zerriffi, H. (2011). Improved stoves in India: A study of sustainable business models. *Energy Policy*, *39*, 7543-7556.

Smith,K.(2010).What'scooking?Abriefupdate.*Energy for Sustainable Development*, *14*, 251-25

Feasibility study assessing the impact of biogas digesters on indoor air pollution in households in Uganda

Vianney Tumwesige (trustvianney@gmail.com)
School of Biological Sciences, University of Aberdeen 23 St. Machar Drive, Aberdeen, Scotland

Lauren Harroff (lharrof@g.clemson.edu)
Clemson University (USA)

Andrew Apsley* (andrew.apsley@iom-world.org)
Sean Semple (sean.semple@abdn.ac.uk)
Jo Smith (jo.smith@abdn.ac.uk)
University of Aberdeen (Scotland)
*University of Aberdeen and Institute of Occupational Medicine

Abstract

Inefficient cook stoves are commonly used in Sub-Saharan Africa to burn biomass such as wood and charcoal. The combination of poor kitchen ventilation and incomplete fuel combustion cause elevated exposure levels of fine particulate matter (PM), carbon monoxide (CO), and nitrous oxide (N_2O). Biogas produced from anaerobic digesters offer a cleaner alternative cooking fuel.

Biogas digesters were installed in nine households in Tiribogo, Uganda as part of a pilot study examining the effects of cooking with biogas on indoor air quality. Fine particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and CO were measured before and after digester installation to represent household air quality. Overall, 24-hour average $PM_{2.5}$ and CO concentrations decreased by 25 and 27 percent, respectively; however, households with digesters still experienced pollutant exposure exceeding recommended health limits.

Keywords: Biogas; Indoor air pollution.

Introduction

Over 600 million people in Sub-Saharan Africa (SSA) depend on biomass fuel to meet household cooking demands (Abraham et al, 2007), with firewood and charcoal accounting for 74% of the total energy consumption on the continent (Davidson, 1992). This study focused specifically on Uganda, where biomass contributes to over 91% of the total energy consumed in the country to meet basic energy needs for cooking and water heating. Biomass use for energy is 80% wood, 6% charcoal and 5% agricultural waste (Ministry of Energy and Mineral Development, Uganda, 2008).

Biomass is primarily burnt directly for cooking purposes in inefficient and poorly maintained cookstoves (Po et al, 2011; Bruce, 2004). The resulting incomplete combustion of fuel creates emissions of fine PM, CO, N_2O, polyaromatic hydrocarbons, benzene, and butadiene (WHO, 2006; Nolte et al., 2001). The combination of emissions and poor ventilation in kitchens results in poor health conditions for users (Semple et al., 2014; Po et al, 2011; Bruce, 2004) Emissions from biomass cooking fuel account for approximately two million premature deaths per year in addition to increased incidence of pulmonary diseases, increased risk of cancer, and degradation of eyesight (Bruce and Albalak, 2000).

In SSA, both women and children are disproportionately exposed to biomass pollutants due to their extended time spent preparing meals. Women carry the primary responsibility for cooking and often carry small children in the kitchen with them (Po et al., 2011). Children also begin to complete kitchen chores when they become teenagers, thereby exposing themselves to biomass pollutants for three to seven hours each day (Campbell, 1997). The increased health risk is evidenced by studies showing that women in developing countries have a higher risk of developing chronic obstructive pulmonary diseases than men and that acute respiratory infections are a major cause of death in children under five in Zimbabwe (Bruce et al., 2000; Collings et al., 1990). Studies have also linked early life exposure to biomass pollutants to reduced capacity of the lungs to function, reduced growth/development of children, and intensified danger of respiratory illness such as bronchitis and lung cancer in later life (Robin et al., 1996).

One approach to reducing exposure to air pollution from burning solid biomass fuels may be the use of biogas. Biogas digesters use organic wastes, such as cattle and pig manure and crop residues, to produce biogas through anaerobic digestion. Biogas is a mixture of methane and carbon dioxide that can provide an alternative to biomass fuel sources (Igoni, 2007; Angelidaki et al., 2008). Tumwesige et al. (2014) measured emission using the portable emissions measurement system and reported combustion efficiency and safety of biogas stoves used in Uganda. The paper also reviewed other biogas appliances being used in SSA.

In SSA, biogas technology has been promoted by the efforts of various international organizations and foreign aid agencies. The African Biogas Partnership Programme with support from SNV Netherlands Development Organization aimed to finance 70,000 digesters over a five-year program (2009 to 2013). By end of 2012; 25,015 small-scale digesters were installed in nine SSA countries (Heegde, 2012). However, the impacts of these digesters have not been studied. There is little evidence of the effect they have on air quality (and consequently on health). This study aimed to assess changes in air pollution concentrations before and after installation of biogas digesters in a typical Ugandan settlement.

Research Objectives

This study aimed to determine the health implications of adopting biogas digester technology, particularly related to indoor air quality. Levels of particulate matter with a diameter less than 2.5 µm ($PM_{2.5}$) and carbon monoxide (CO) were measured before and after installation of a biogas digester to represent changes in air quality. $PM_{2.5}$ - and CO levels in kitchens were expected to decrease after adoption of biogas digester technology.

Methods

A baseline questionnaire was administered to 54 households in Tiribogo, Uganda to determine the families most suited for uptake of biogas digester technology. Data on cooking fuel demand, ability to manage organic waste, availability of digester feedstock, and access to water were collected. Households were scored and ranked using a numerical weighting system and multi-criteria decision approach. The nine highest-scoring households were selected to receive flexible-balloon biogas digesters.

Household air quality was monitored in each home for one 24-hour period before digester installation and one 24-hour period post digester installation. Monitoring was performed between April 2012 and October 2012 for pre-installation and between November 2012 and February 2013 for post-installation. Household air quality was assessed by measuring the airborne concentration of $PM_{2.5}$ and CO. A TSI SidePak AM510 (TSI Inc, CA, USA) was used to measure mass concentration of $PM_{2.5}$ through laser light scattering techniques. A CO data logger (LASCAR EL-USB-CO) with a measurement range of 0-1000 ppm was used to measure household levels of CO. Both devices measured concentrations every 1 second and recorded the average value every minute. The instruments were placed in the room designated as the primary cooking space, within 1 meter of the cooking stove(s). Monitoring took place over 24 hours, except when interrupted by poor battery life of the TSI SidePak.

The collected data were downloaded using proprietary software (Tsi TrakPro Ver. 4.5.1.0), 24-hour averages calculated and peak concentrations identified. The $PM_{2.5}$ concentrations collected by the SidePak were corrected by a factor 0.295 (Kabir et al., 2009) to account for the difference in density of the aerosol used to calibrate the SidePak (Arizona road dust) and that created by the combustion process of organic matter. The percentage of time when $PM_{2.5}$ measurements exceeded two thresholds—the World Health Organization (WHO) 24-hour guidance limit of 25 µg/m^3 (WHO, 2010) and the US Environmental Protection Agency (US-EPA) 24-hour hazardous level (250 µg/m^3)—was also extracted for each sampling period. A similar process was carried out for CO concentrations exceeding the WHO 24-hour guidance value of 6 ppm.

Results

Tables 1-4 display the results for $PM_{2.5}$ and CO monitoring in individual homes before and after installation of biogas digesters in Tiribogo.

Table 1: Pre-installation $PM_{2.5}$ concentration in µgm^{-3}

Home ID	Mean Concentration (SD)	Peak Concentration	% Time > WHO Limit	% Time > EPA Limit
H1	83 (222)	2324	29	8.7
H2	211 (531)	5040	38	17
H3	21 (57)	1560	34	0.4
H4	187 (600)	5900*	59	14
H5	350 (504)	4600	69	38
H6	828 (1520)	5900*	60	37
H7	722 (1500)	5900*	83	31
H8	189 (428)	4460	32	17
H9	1160 (1920)	5900*	64	41
Mean	**416 (393)**	**3597**	**52**	**23**

*indicates that the maximum concentration of the SidePak was attained and likely exceeded, so this figure is an underestimate.

Table 2: Post-installation $PM_{2.5}$ concentration in µgm^{-3}

Home ID	Mean Concentation (SD)	Peak Concentation	% Time > WHO Limit	% Time > EPA limit
H1	57 (150)	2537	49	4.2
H2	110 (235)	2642	43	13
H3	687 (1404)	5900*	62	29
H4	234 (420)	3826	71	26
H5	261 (835)	5900*	41	17
H6	366 (887)	5900*	55	25
H7	562 (1224)	5900*	54	27
H8	602 (1291)	5900*	51	30
H9	423 (1067)	5900*	61	23
Mean	**367 (221)**	**3002**	**54**	**21**

*indicates that the maximum concentration of the SidePak was attained and likely exceeded.

Table 3: Pre-installation CO Concentration in ppm

Home ID	Mean Concentration (SD)	Peak Concentration	% Time > WHO Limit (6 ppm)
H1	1.5 (4.6)	52	8.1
H2	7.4 (16)	226	26
H3	3.4 (13)	340	14
H4	4.8 (13)	224	49
H5	5.6 (5.3)	26	44
H6	10 (17)	214	45
H7	10 (13)	106	42
H8	3.5 (7.3)	84	21
H9	31(4.6)	272	57
Mean	**8.6 (9)**	**172**	**34**

Table 4: Post-installation CO concentration in ppm

Home ID	Mean Concentration (SD)	Peak Concentration	% Time > WHO Limit (6 ppm)
H1	0.93 (4.8)	89	4.6
H2	2.3 (8.6)	157	24
H3	5.6 (13.2)	75	20
H4	4.9 (9.8)	79	25
H5	5.1 (14)	109	22
H6	5.4 (9.8)	71	24
H7	7.3 (11)	108	38
H8	18 (42)	308	40
H9	6 (12)	109	26
Mean	**6.2 (5)**	**123**	**25**

Table 5: Summary data using each household as a paired sample

	Median Percent Change of Paired Samples*	
Parameter	**$PM_{2.5}$**	**CO**
24-Hour Average Concentration	-25%	-27%
Peak Concentration	0%	-31%
% Time Above WHO Guidelines	13%	-44%
% Time Above EPA Guidelines	-26%	N/A

Discussion

The individual household results displayed in Tables 1 through 4 provide interesting case studies for the impact of biogas digesters. Six of the nine homes showed a decrease in average $PM_{2.5}$ and CO concentrations. From the three homes that experienced an increase in air pollutant concentrations, one (H3) saw a marked increase of $PM_{2.5}$ (3171%). This may be explained by changes in the household cooking habits. Prior to digester installation, the family primarily used charcoal for cooking and prepared food in a larger room. During the installation period, the family moved their kitchen to a smaller room and converted to firewood use for cooking, for reasons unrelated to digester installation. When the post-installation measurements were taken, the family had just begun to use biogas for cooking and had not yet tried cooking many foods so were using biogas mainly for making tea, with firewood used to cook all other foods.

Many of the other families experienced a similar transition period during which they slowly experimented with cooking different types of food using the biogas before more fully converting their cooking habits. This trend may partially explain the unhealthy $PM_{2.5}$ and CO levels observed after digester installation. Although average concentrations of both pollutants decreased overall after digester installation, the percent of time above WHO and EPA recommended values remained high. The EPA Air Quality Index classifies 250 μgm^{-3} $PM_{2.5}$ as hazardous, and WHO recommends a 24 hour mean to be 25 μgm^{-3} or less for $PM_{2.5}$ (WHO, 2010) . In Tiribogo, $PM_{2.5}$ levels remained above EPA recommendations for 54% of the 24-hour sampling period and above WHO recommendations for 21% of the sampling period. EPA does not offer an equivalent recommendation for CO, but WHO suggests CO concentrations less than 6 ppm. Homes in Tiribogo experienced CO concentrations above this limit for 25% of the sampling period.

The medians from Table 5 indicate a 25% and 27% decrease of 24- hour average concentrations of $PM_{2.5}$ and CO. respectively. Additionally, the percent of time above WHO guidelines decreased for both measurements, as well as peak concentration for CO. The peak concentration did not appear to decrease for $PM_{2.5}$; however, this value is influenced by the maximum measureable concentration by the SidePak, as indicated for Table 1.

A paired t-test did not indicate statistical significance for any of the measured parameters for this small pilot study; however, the observed trends in air quality improvements indicate the importance of future studies with larger sample sizes.

Limitations of this study

Due to delays in installation of digesters and time limitations for the project, this study was based on a limited number of homes. Air quality in each home was measured on a single occasion before and then after digester installation. Without repeated measurements for each home, the results are more susceptible to the influence of unusual circumstances, such as visiting relatives in the household, children being home from school (or away at school), and large celebrations that would influence the amount of cooking performed and therefore the levels of indoor air pollution. Variations in the types of trees used for firewood and moisture content in the wood would also affect cooking time and level of air pollutants. Also due to time limitations, the post-installation data was collected within one or two weeks of a family first being able to light their stove with biogas. In this short period of time many families had not yet experimented with cooking different types of food and were not using their biogas to its full capacity. After a few months of experience with the biogas, many families report using biogas more often and have replaced more traditional cooking with biogas than they had when the data for this study was collected.

Conclusions

Levels of CO and $PM_{2.5}$ in household kitchens decreased in six out of nine homes where biogas digesters were installed to provide fuel for cooking. While air pollutant concentrations typically reduced by about 25-30%, levels often remained above air quality guidelines. Future studies should follow up with families who have been using biogas for longer periods of time to determine if CO and $PM_{2.5}$ levels will decrease further. This feasibility study has led to further work investigating the impact of the implementation of biogas digesters on air quality in a SSA village, which is currently ongoing.

References

Abraham, E.R., Ramchandran, S., Ramalingam, V., (2007), *Biogas: can it be an important source of energy?* Env. Sci. Pollut. Res., 14(1), 67-71.

Angelidaki, I., Ellegaard, L. (2003). *Co-digestion of manure and organic wastes in centralized biogas plants; status and future trends*. Applied Biochemistry and Biotechnology, 109 (1-3), 95-106.

Annual report, (2008). Ministry of Energy and Mineral Development, Uganda.

Bruce N., McCracken J., Albalak R., Schei M.A., Smith, Lopez, West, (2004). *Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young Guatemalan children*. J Expo Anal Environ Epidemiol; 14: S26–S33.

Bruce N, Perez-Padilla R, Albalak R (2000). *Indoor air pollution in developing countries: a major environmental and public health challenge.* Bull World Health Organ 78(9):1078–1092.

Cambell H., (1997). *Indoor air pollution and acute lower respiratory infections in young Gambian children*. Health Bull (Edinb); 55: 20-31.

Collings D.A., Sithole S.D., Martin K.S., (1990). *Indoor wood smoke pollution causing lower respiratory disease in children*. Tropical Doctor; 20: 151–155.

Davidson, O.R. (1992). *Energy issues in Sub-Sahara Africa. Future directions.* Annual review of Environment and Resources 17:359-403.

Felix ter Heegde, SNV East African regional advisor (2012). https://sites.google.com/site/biogas4all/overview/biogas-africa-overview.

Igoni A.H., Abowei M.F.N., Ayotamuno M.J., Eze C.L., (2008). *Effects of municipal solid waste on the biogas produced in an anaerobic continuous digester.* http://www.cigrjournal.org/index.php/Ejounral/article/viewFile/1288/1144; accessed, 02/01/2013.

Kabir Z, Manning P J Holohan J, Keogan S, Goodman P G and Clancy L (2009). *Second-hand smoke exposure in cars and respiratory health effects in children*. European Respiratory Journal, 34, pp.629-633.

Nolte C.G., Schauer J.J., Cass G.R., Simoneit B.R., (2001). *Highly polar organic compounds present in wood smoke and in the ambient atmosphere*. Environ Sci Technol; 35: 1912–1919.

Po J.Y.T., FitzGerald M.J., Carlsten C., (2011). *Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis*. Thorax; 66: 232-239

Robin L.F., Less P.S., Winget M., Steinhoff M., Moulton L.H., Santosham M., (1996). *Wood burning stoves and lower respiratory illnesses in Navajo children*. Pediatr Infect Dis J; 15: 859-65.

Semple S., Apsley A., Wushishi A., and Smith J., (2014). *Commentary: Switching to biogas – what effect could it have on indoor air quality and human health?* Biomass Bioenergy 2014 (accepted for publication).

Tumwesige V., Fulford D., Grant C.D., (2014). *Biogas appliances in Sub-Saharan Africa*. Biomass Bioenergy 2014 (accepted for publication).

WHO, (2006). Fuel for life: *Household Energy and Health.* World Health Organization press.

WHO, (2010). *WHO guidelines for indoor air quality: selected pollutants.* http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf; accessed March 2014.

Scientific Papers

V. Minigrids – Participatory Energy Ecosystems

Swarm Electrification - Suggesting a Paradigm Change through Building Microgrids Bottom-up

Sebastian Groh[#1*], Daniel Philipp[#2], Brian Edlefsen Lasch[#3], Hannes Kirchhoff[#4]

 # Research Focus Microenery Systems, TechnischeUniversität Berlin
Center for Technology and Society ·Secr. HBS, Hardenbergstr. 16-18, 10623 Berlin, Germany
**author for correspondence*
[1]groh@ztg.tu-berlin.de
[2]philipp@ztg.tu-berlin.de
[3]mini-grid@microenergy-systems.de
[4]hannes.kirchhoff@microenergy-systems.de

Abstract

This paper outlines a bottom-up concept for microgrids. A case study for Bangladesh illustrates the potential for building on the existing infrastructure of solar home systems and underlines the strength of the approach: it aims at economic and infrastructure development created from the communities themselves. Individual stand-alone energy systems are linked together to form a microgrid that can expand towards and eventually interconnect with national or regional grids. This approach can be likened to the concept of swarm intelligence, where each individual node brings independent input to create a conglomerate of value even greater than the sum of its parts.

Keywords: Bottom-up electrification; microgrid; Bangladesh; development; microfinance.

Introduction

Discussions on economic development are often centered on two key players of development: the government and the private sector. This approach however, fails to take into account “the crucial third agent, in whose name development is carried out: people organi[z]ed 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 basic needs and to govern from below” [Kothari and Shrivastava, 2013]. This paper suggests a new conceptual approach on rural electrification where a microgrid is built through the people´s own resources from the bottom-up aiming to empower a large share of today´s 1.3 billion people lacking access to electricity. In light of the multiple global initiatives driving rural electrification and sustainable development today, especially the growing importance placed on sustainable energy supply by the United Nations as an important catalyst in the effort towards achieving their Millennium Development Goals, rural energy programs and practitioners around the world have a new opportunity to address the issue of sustainable energy access for all [UN Foundation, 2012]. The authors advocate a bottom-up user-centered concept in the pursuit of sustainable and effective models. For rural electrification strategies, small-scale energy systems can provide rapidly deployable, affordable, and flexible solutions, which can address end-user needs on a highly adaptable basis [Groh, 2013]. Grid-based solutions, on the other hand, can offer great potential to provide stable and sufficient electricity supply for productive uses, which play a key role in bolstering economic development [Kaygusuz, 2011]. Here the authors suggest a concept coined as swarm electrification, where individual stand-alone energy systems are linked together to form a microgrid. This approach can be likened to the concept of swarm intelligence, where each individual node brings independent input to create a conglomerate of value even greater than the sum of its parts [Kampwirth, 2009]. The rest of the paper is organized as follows. Section 2 gives a brief literature review on the motivation of microgrids as well as their status of achievement today. Section 3 suggests an alternative model of building microgrid and discusses its viability from a theoretical perspective. Section 4 concludes.

Short Literature Review

Clarify your research questions and objectives. The UN General Assembly has declared the years 2014-2024 to be the “Decade of Sustainable Energy for All”[UN, 2013], underlining the importance of supporting the roughly 1.3 billion people living without access to electricity. Groh (2013) introduces the concept of an energy poverty penalty arguing that poor energy services rooted in infrastructural handicaps inhibit or at least delay people’s economic development. He states that “poor energy service quality can refer to insufficiencies, unreliability, dangers in usage, low durability, unfitness, lack of after-sales service and even non-affordability, in the sense of poor financial services” [Groh, 2013]. As a consequence, better energy service quality could well serve as an essential tool to fight the energy poverty penalty and ultimately help achieve the Millennium Development Goals (MDGs) [UNDP, 2005].The “Energy for All Case” expects that only 30% of rural areas can be electrified via connection to centralized grids, whereas 70% of rural areas can be connected either with microgrids or with small stand-alone off-grid solutions [OECD/IEA, 2011]. Yadoo and Cruickshank (2013) estimate that about half of the 1.3 billion people living off-grid today could be best supplied with decentralized microgrids.

Although microgrids have been employed for village electrification already for over 30 years, there are only very few examples that can claim to be based on a long term viable model based on financial, managerial and technical criteria [Frearson and Tuckwell, 2013]. They describe the main barriers as

1. securing a standardized and streamlined procurement system establishment and governance process,
2. ready access to suitable finance,
3. appropriate consumer consultation, hardware selection and integration, and
4. developing effective O&M structures.

Especially the large initial capital investment and the related question of refinancing and ownership put a brake on many efforts to implement larger microgrids [Ulsrud et al. 2011]. National utilities, that might have the capacity to maintain them, usually lack incentives to do so being aware that it is often less profitable than the centralized grid considering the disproportionate amount of challenges of maintenance and operation [Goldemberg and Lucon, 2010]. As an alternative, community managed microgrids have emerged. Literature on these models remains scarce as it is considered a new field [Peterschmidt and Neumann, 2013]. Still, grey literature, in terms of project reports, indicates that these schemes often do not last very long but fail much earlier than expected. Often microgrids are designed with the goal of an equitable socio-economic development. As a by-product there is evidence found for theft, non-payment and overuse leading to overall system failure. This process can be described as a form of the 'tragedy of the commons' [Hardin, 1968]. In contrast, if the ownership is left to energy small and medium enterprises a severe financing gap is limiting their capacity to scale to a degree to run such a scheme [Kebir et al. 2013].

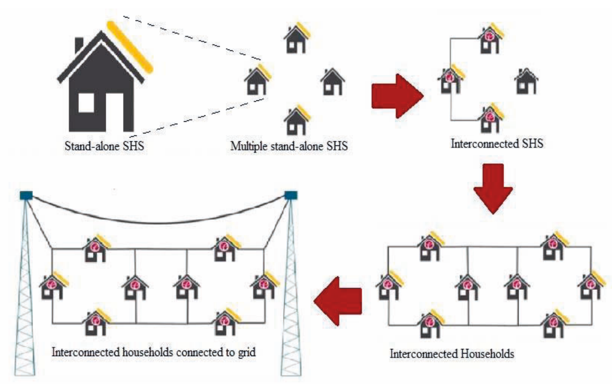
Nonetheless, the International Energy Agency (IEA) argues that "smart grids could enable a transition from simple, one-off approaches to electrification (e.g. battery- or solar PV-based household electrification) to community grids that can then connect to national and regional grids" [IEA, 2011]. This paper picks up on these ideas while aiming to address the barriers and challenges described above. A paradigm change for rural electrification is suggested and introduced below.

Analyzing an alternative model: Case Study Bangladesh

The so-called swarm electrification model, where individual stand-alone energy systems are linked together to form a microgrid, derives its name from the concept of swarm intelligence, where each individual node brings independent input to create a conglomerate of value even greater than the sum of its parts. Under the concept of swarm electrification, end-users act as simultaneous consumers and producers of electricity, so-called prosumers, forming the core nodes of a microgrid that can expand towards and eventually interconnect with national or regional grids. This paper applies the concept in a case study for Bangladesh. The approach builds on network effects generated through the inclusion of localized economies with strong producer-consumer linkages embedded within larger systems of trade and exchange.

In Bangladesh 40% of the population has no access to the national grid representing 65 million people [Wold Bank, 2013].

Solar Home Systems (SHS), currently consisting of a 20 to 85Wp solar panel, battery, and charge controller, have begun to electrify Bangladeshi rural communities [IDCOL, 2013]. 2.7 million SHS are already installed through microfinance schemes implemented by so-called Partner Organizations (POs), who are expanding their customer base at a rate of 65,000 systems per month, making Bangladesh the fastest growing SHS market in the world. Further, the rural area consists of various clustered areas where household tend to stick together in a densely pattern. So, it is very common to see the clustered households in rural Bangladesh However, many households do not fully utilize the electricity stored in their battery, resulting in a full battery by midday, limiting the generation potential of their systems [Boldt, 2012]. At the same time, some households require electricity beyond what their systems can supply and others cannot afford a complete SHS, remaining trapped in energy poverty. Mondal and Klein [2011] further point to the limits of SHS in terms of its potential to directly affect an individual household's ability to improve its income generation. There is a need for more cost effective, reliable and flexible electricity supply. Swarm electrification suggests interlinking multiple households with SHS and households without systems. The approach is based on the principle that energy sharing between individual standalone systems can mitigate the present limitations of decentralized rural electrification and contribute to a significant alleviation of energy poverty in Bangladesh. By forming a reliable village-scale microgrid through the connection of a network of electricity-sharing homes, end-users can make use of their differentiated energy generation capacities and consumption patterns to allow for a more efficient and consistent source of energy supply for all involved: both for SHS-equipped as well as non-equipped households and businesses. It thus represents a democratization of electricity generation. Below the stepwise approach of swarm electrification is shown. Step one shows individual households equipped with SHS as well houses without solar or grid electricity supply. Step 2 shows the interconnection of households with solar panels, whereas in Step 3 the remaining houses are included in the growing microgrid. As a final step, the microgrid can be connected to a national or regional grid.



Source: MicroEnergy International, 2013

Figure 1: Stepwise approach for swarm electrification

The resulting network is based on a high voltage DC grid and can facilitate trade and increase usage flexibility and reliability. The trade of electricity allows SHS owners to generate additional income through the sale of (excess) electricity and consumption smoothing. The electrification of additional households and businesses has the potential to improve the broader community's social and economic quality of life. With recent advances in information and communications technologies and smart grid technologies, this bottom-up interconnected electrification approach becomes feasible [Unger, 2012].The authors show that a commercially feasible business model (from step 2 onwards) can be implemented where the end-users, the partner organizations, hardware providers and the international donor community are able to profit. Current trading costs in the field haven been used as baseline scenario and rigorous sensitivity analysis has been performed. The figures below show the viability of the approach in a simulation from an economic perspective.

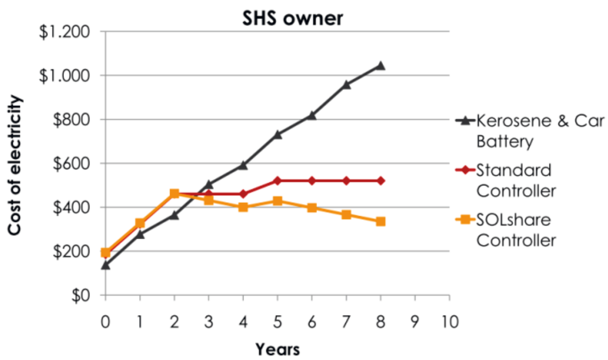


Figure 2: Cost of electricity for an electricity prosumer in a swarm scheme

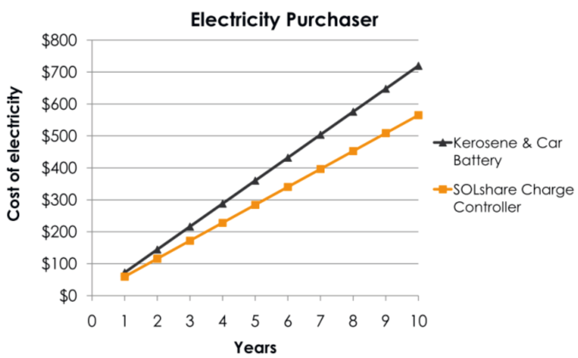


Figure 3: Cost of electricity an electricity consumer in a swarm scheme

Figure 2 indicates the electricity cost for a prosumer over a lifetime of ten years, where 30% of the generated electricity of a 40Wp SHS is traded/ fed-into the microgrid. Refer to Figure 4 and 5 in the appendix for details on cost and system sizing used for the simulation. The swarm concept requires an advanced charge controller to enable interconnection of SHS, and sale and purchase of electricity between the systems. This scenario with such a controller is indicated with the name "SOLshare Controller" in the figures above. Assuming the electricity seller is purchasing a new SHS, three scenarios are compared: 1) the costs of continuing to meet electricity requirements through kerosene and car battery, purchasing a 'standard' SHS, and purchasing an SHS with the SOLshare Controller. The data show that while there is initially a slightly higher cost for the system with SOLshare (see Figures 4 and 5), the long-term value exceeds the present options. It is particularly striking that the SOLshare option starts out being equally competitive with the standard SHS scenario. The use case of kerosene and/or car batteries reveals a cost advantage over the period of up to 2.5 years, after which the SHS starts to play out better cost performance once the microcredit on the system has been paid off due to only minor running cots. This scheme has already played out 2.7 million times with the standard SHS replacing kerosene and/or car battery expenditures [IDCOL, 2013]. The swarm concept based business case, however, further outweighs the advantages of the traditional SHS scheme. Figure 3 further shows that additional electrification effort can be realized, especially for households who could not afford a full system before and/or simply are located in a disadvantage position for a solar-based system (e.g. in a shaded area). In that case these people can buy electricity at a lower cost compared with business as usual.

Discussion and Conclusions

Despite the current trend toward traditional top-down mini-grids, the authors are convinced that in certain rural areas the concept of swarm electrification is a better fit to meet the combined goals of universal energy access for all and fostering rural development. The approach does not require a large initial capital investment, or top-down system sizing. The key barriers addressed in chapter 2 do not apply in this case, as it builds on an existing and proven financing and O&M platform. Moreover, a tragedy of the commons problem is unlikely to occur in this case as the majority of individuals have their own system or supply, with the ability to choose to utilize their energy generation and storage equipment as income generating assets, monitored on an individual metering system without a centralized maximum storage capacity. In the mechanism presented, the microgrid is based on organic growth, empowering the people themselves to build a critical mass to swarm toward the national grid and to thereby gain greater negotiation power with energy utilities in future interconnection and growth scenarios. At the same time, supply of DC voltage instead of AC at the household level avoids the relatively high cost of inverters eliminating inverter and high transmission losses The theoretical case study based on Bangladesh shows that the swarm concept is able to create win-win situations. Calculations suggest that the process can be designed in a financially mutually beneficial way for end-users who are able to afford a complete SHS, end-users who are unable to afford a complete SHS but still pay high prices for energy, hardware providers, and partner organizations providing last mile services.

However, as the model is based on network effects, initial sales need to gain momentum, as well as critical social acceptance issues may occur. These questions need further research. Also, the potential for replication in different settings needs further research as it is unlikely that comparable levels of population density or a similar local infrastructure for SHS can be found elsewhere.

In conclusion, the authors advocate changing the mindset of prohibitive last mile cost (centralized perspective) to an end-user perspective and the people´s development capabilities. As such, a paradigm change is suggested from top-down planned decentralized microgrids toward a bottom-up microgrid approach where the decision and managing power is up to the people and their existing resources themselves without creating a common pool resource. The authors are convinced that in the future microgrids based on these concepts will play an important role for decentralized energy supply in order to foster rural development.

References

AKRSP (2012a): Micro-Mini Hydropower (MHP - Technical Assessment Report Skardu Region. Aga Khan Rural Support Programme (AKRSP). Islamabad.

AKRSP (2012b): Micro-Mini Hydropower (MHP) - Chitral Region, Technical Assessment Report Prepared. With assistance of Asif Farid, Aftab Ahmad Shah. Aga Khan Rural Support Programme (AKRSP). Islamabad.

Boldt F. (2012): MESUS-Concept- An innovative solution for the electrification of regions with poor energy infrastructure. Promotionskolleg Mikroenergie-Systeme. Berlin.

Frearson L. and Tuckwell M. (2013): The future of mini-grids: from low cost to high value. Using demand driven design to maximise revenue and impact. Asian Development Bank. Manila.

GIZ (2008): Micro Hydro Power (MHP) Survey in Badakhshan. With assistance of Ulrich Frings.Editedby GmbH (GIZ) Deutsche Gesellschaft für Internationale Zusmmenarbeit, Kabul.

GIZ (2010a): Small Hydro Power Promotion Project Nepal. Knowledge Management Mission. With assistance of Bart Jan van Beuzekom, Mirka Bodenbender, Jana Landschulze, GIZ Eschborn.

GIZ (2010b): Survey Report on Micro Hydro Power Plants Survey Report on Micro Hydro Power Plants, Takhar Province, Afghanistan. With assistance of Anita Richter. GIZ, Kabul.

Goldemberg, José; Lucon, Oswaldo (2010): Energy, environment and development. 2nd ed. London, Sterling, VA: Earthscan.

Groh S. (2014) "The role of energy in development processes - The Energy Poverty Penalty: Case study of Arequipa (Peru)".Energy for Sustainable Development. Volume 18, February 2014, Pages 83–99.

Hardin, G.J. (1968): The Tragedy of the Commons. Washington, D.C.

IDCOL (2013): http://www.idcol.org/. Last accessed August 28th 2013.

IEA (2011): Technology Roadmap Smart Grids. Paris: OECD/IEA.

Kampwirth R. (2009) SchwarmStrom- Die Energie Der Zukunft". Hamburg: LichtBlick.

Kaygusuz K. (2011): Energy services and energy poverty for sustainable rural development. Renewable and Sustainable Energy Reviews. Vol. 15, Issue 2, February 2011, pp. 936–947.

Kebir N., Spiegel N., Schrecker T., Groh S., Scott C. and Aliaga G. (2013): Exploring Energy SME Financing in Emerging and Developing Countries. Sustainable Business Institute. Oestrich-Winkel.

Kothari A. and Shrivastava A. (2013): Economists on the Wrong Foot. Economic and Political Weekly. Vol. - XLVIII No. 33, August 17, 2013.

Mondal, A. and Klein, D. (2011) Impacts of solar home systems on social development in rural Bangladesh, Energy for Sustainable Development, 15 (1), pp. 17-20.

OECD/IEA (2011): Energy for All. Financing Access for the Poor. Special early excerpt of the World Energy Outlook 2011, Paris.

Peterschmidt N. and Neumann C. (2013): Scaling up Successful Micro-Utilities for Rural Electrification. Sustainable Business Institute. Oestrich-Winkel.

Ulsrud, K., Winther, T., Palit, D., Rohracher, H. and Sandgren, H. (2011) The Solar Transitions research on solar mini-grids in India, Energy for Sustainabe Development, 15 (3).

Unger K. (2012): Organically Grown Microgrids: The Development and Simulation of a Solar Home System-based Microgrid. Universtity of Waterloo, 2012.

UNDP. 2005. Energizing the Millennium Development Goals. New York: United Nations Development Programme.

United Nations Foundation (2012): Energy Access Practitioner Network-Towards Achieving Universal Energy Access by 2030. June. New York.

World Bank Indicators (2013): http://data.worldbank.org/country/bangladesh. Last accessed on November 30th 2013.

Yadoo, A. and Cruickshank, H. (2012): The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya. Energy Policy 42, pp. 591–602.

Appendix

Figure 4: Cost scheme 'Prosumer'

SHS Owner	
System Size (W)	40
PV System Derate	0.80
System PVWatts Production /day (Wh)	144
System Voltage (V)	12
Battery Size (Ah)	55
Max. discharge	50%
Average Wh Available to Sell/day (Wh)	40
% Generated Electricity Sold (Wh/day)	28%
Wh Available to Sell/month (Wh)	1200
Electricity Price $/kWh	$3.00
Monthly Revenue from Electricity Sales($)	$3.60
Existing Charge Controller Cost	$10
Swarm Controller Cost	$80
System Sharing Wiring Cost	$3
Additional Cost of Swarm Controller + Wiring	$73
Additional Cost of Swarm Controller ($/mont	$3.34
Swarm Controller Simple Payback	2.20
SHS SOLshare NPV	**$118.08**

Figure 5: Cost Scheme 'Consumer'

Electricity Purchaser	Sale	Leasing
Swarm Controller	$80	
Battery (10 Ah)	$15	
System Sharing Wiring	$3	
Swarm Controller + Battery + Wiring	$98	
Hardware Cost ($/Month)	$2.93	$2.23
Electricity Price $/kWh	$3.00	
Usage/day (Wh)	20	
Cost ($/Month)	$1.80	$1.80
Total Cost ($/Month)	$4.79	$4.03
NPV Savings	**$214.78**	

A Simulation Gaming Approach to Micro-Grid Design and Planning: Participatory Design and Capacity Building

Maizakiah Ayu Abdullah (mabdullah@masdar-alumni.ac.ae)
Independent Researcher
Abu Dhabi, UAE

Scott Kennedy (skennedy@thecenter.mit.edu)
The Dalai Lama Center for Ethics and Transformative Values at MIT
77 Massachusetts Ave., Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Abstract

Existing micro-grid design and planning approaches tend to emphasize techno-economic assessments and lack community engagement, necessary for effective planning and implementation. New approaches must be employed to not only include significant social impacts of micro-grids beyond technical components, but prioritize human development objectives, participation and capacity building.

A simulation gaming approach to micro-grid design provides an innovative, participatory tool and process that incorporates social, organizational, technical and financial factors for improved design and planning. Additionally, the approach represents an experiential learning and capacity building exercise that teaches shared resource management and collaborative decision-making.

Keywords: Energy design; Micro-grid planning; Participatory design; Simulation game; Capacity building.

Introduction

Recent advances in distributed generation technologies have intensified interest in decentralized electricity delivery models, particularly in its potential to meet rural users' energy and development needs through greater flexibility in technology options and organizational structures. However the design and planning of a micro-grid system for comprehensive development purposes requires careful and further consideration. With a wide range of possible technologies and delivery models, micro-grid design and planning is highly dependent on available resources, local social context, markets, institutional structures and users' energy requirements.

Planning a community-level, micro-grid system generally consists of a needs assessment, a resource assessment, technical design, and economic and financial analyses. Energy needs assessments for rural electrification are commonly conducted using participatory methods such as surveys, questionnaires and focused group discussions (FGDs) in order to assess electricity demand and ability to pay (Howells, Alfstad, Cross, Jeftha, & Goldstein, 2002). Data from these methods are then used as a baseline for techno-economic assessments, employing energy design tools such as HOMER, LEAP, and RETScreen (Connolly, Lund, Mathiesen, & Leahy, 2010). These consist of energy modeling tools used specifically for designing the technical system against costs. Tariffs are designed around cost recovery and end users' financial abilities.

The majority of energy design and planning approaches are largely focused on the technical system, or on techno-economic assessments that do not enable sufficient or effective community participation. Techno-economic assessment tools are typically operated by non-community members, who may not have a thorough understanding of local energy needs and the system's impacts on the community. Additionally, rural community members with limited technical skills and understanding of micro-grid operations (or rural electrification in general) are unable to use these tools to fully participate in the design process, which restricts community engagement and does not leverage nor build on their capacities.

Techno-economic assessment tools also tend to exclude critical, social micro-grid success factors such as organizational or institutional considerations, demand side management options and community participation, all of which affect uptake and operational sustainability. A narrow system boundary also inadvertently limits the micro-grid's scope for human development impact, as systems are installed to mainly deliver electricity rather than support energy use for facilitating development. Furthermore, systems that do not account for social dynamics and local complexities may cause unanticipated and unintended outcomes (e.g. electricity or equipment theft) that consequently limit and hinder energy access for development. In order for rural electrification to enable development, system design and planning must reprioritize human development objectives over electricity delivery, and encompass an expanded system boundary to account for broader social and financial considerations targeted at development-related outcomes.

Meanwhile, participatory methods used to collect data for energy planning are challenging to conduct and may provide limited useful information. Inaccurate demand forecasts directly affect system size and capacity, which in turn produces higher installation costs for an oversized system, and inadequate electricity supply if undersized.

Surveys and questionnaires on household energy use elicit information through a mainly one-way transfer, and do not induce learning or capacity building. Obtaining useful responses depends on participants' understanding of the questions (which also means the interviewer has to ask participants meaningful questions) (Cross & Gaunt, 2003; Howells et al., 2002), and the power dynamic between interviewer and respondent, which may further affect accuracy of responses. Additionally, communities with limited exposure to electrification may have difficulty in predicting their own electricity consumption and behavior. To account for this, surveys and questionnaires are used to forecast electricity demand based on the community's existing energy use (including traditional energy use). This creates uncertainty and inaccuracies as past energy use does not necessarily translate directly into electricity use, and moreover cannot predict new uses with electrification.

We propose a novel participatory design approach that merges the technical aspects of a techno-economic assessment tool with the emphasis on the social system from participatory processes. We utilize a simulation game to address the aforementioned shortcomings by building capacities in decision-making and resource management. This process expands the system boundary beyond a techno-economic assessment by including organizational considerations, participation and social interaction. It provides a simulation gaming environment in which community members have equal opportunity for participation (Chua, 2005) and induces dynamic learning so they can contribute informed decisions and input into the design process (Brandt, 2006).

This new approach can be used to both enhance the design process (i.e. build a sustainable micro-grid that delivers adequate, reliant and affordable electricity supply for enhancing human capabilities) and serve the more fundamental objective of building technical and governance capacity of the community.

Research Objectives

The main objective of this work is to create a useful participatory tool and process that can be used to elicit a rural community's energy needs and system design parameters, in order to facilitate design and planning. Meanwhile, the participatory process is also aimed at empowering and building community members' capacities by enabling a greater understanding of household and system load profiles, technical limitations of a micro-grid, the importance of system cost recovery and managing the micro-grid as a shared resource.

Methods

The Simulation Game as a Tool and Artifact

The participatory game is a simplified representation of an operating micro-grid, with individual players representing households (or other load center forms) and a facilitator acting as a system operator. The game may be used to explore both planning and operational decisions. The facilitator prompts the players to choose their end-use loads (e.g., appliances), as well as to play out their periods of operation. Players are networked so individual and aggregate behavior can be visualized real-time.

In the current version, the simulation has been implemented using the multi-method simulation software, AnyLogic. A game-round is initialized with system capacity, number of households and levelized cost of energy (LCOE), which may be calculated using HOMERor similar tools. The example shown here has reference data from a Malaysian case study (Abdullah, 2013). The game shows two windows that represent individual household consumption and system-wide consumption. The game has a graphical user interface where players can choose household appliances, then change their loads by turning them on and off by clicking on them. The choice of appliances and power ratings are also based on the Malaysian case study. Currently, household energy costs are based on a minimum tariff set by the LCOE.

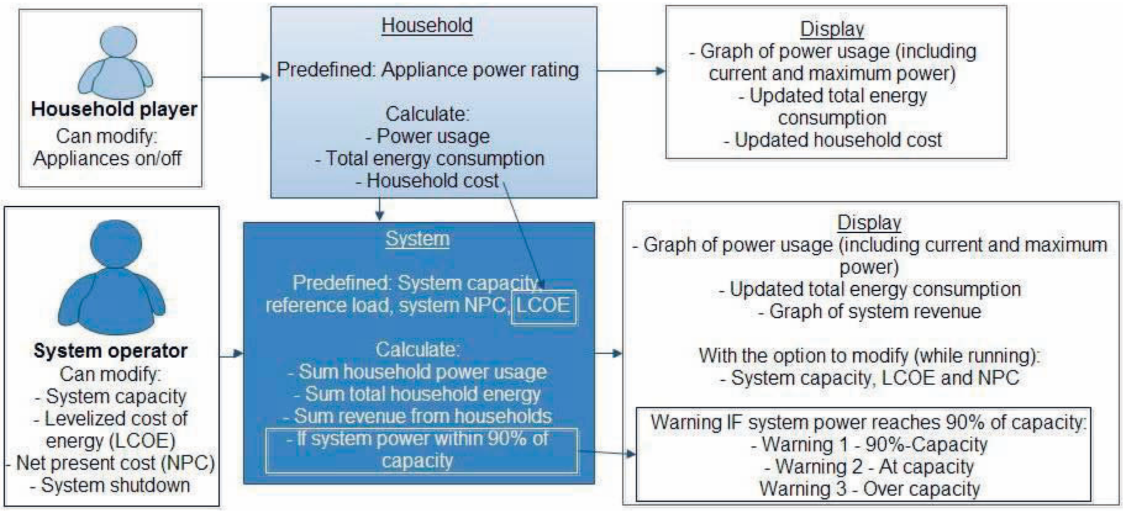


Figure 1: Diagram explaining the simulation game methodology (Abdullah, 2013)

The main system window shows real-time total load, and revenue collected (assuming all payments are made).

The current version allows the facilitator to set a varying generation output, but does not explicitly model the power generation process or include distribution losses or other network features. Warnings appear when total load is near capacity (90-100%), at peak capacity, and over capacity (the system shuts down within a given duration).

The Simulation Gaming Process for Participatory Design

This participatory design process elicits system design parameters by alternating between simulation game playing and facilitated discussions. During discussion rounds, facilitators pose a set of questions aimed at obtaining the following system design parameters:

- System capacity
- Demand side management options
- Organizational model
- Tariffs
- System policies and regulations

The questions that lead to the above parameters are meant to represent an improved participatory design process over traditional planning methods such as surveys, questionnaires and techno-economic assessment tools. A representative set of questions is as follows:

- Identifying a reference load profile.
  - Based on observed system behavior in previous rounds, should the generationcapacity be increased or decreased? → Installation costs and technology options will depend largely on system size.
  - What demand side management options are effective and acceptable? → Necessary especially when demand nears system capacity.
- Deciding organizational and management structures.
  - How will the community enforce demand side management strategies, system policies and regulations?→ It iscomplex to enforce policies in rural communities. Design of such mechanisms must come from the community.
  - What type of organizational structure would work best for the micro-grid? Who will own and manage the micro-grid? → The community understands their requirements and social structuresbest.
- Deciding tariff structures.
  - Should the tariff be raised in order to generate revenue? → Ability to pay for micro-grid services is important to recover costs. However, rural users may have limited ability to pay and should decide on their own tariff structure.
  - What will revenue be used for? Only cost recovery? What about an optional community savings fund?
- What will future load profiles look like? → Players can test potential future scenarios and load profilesto forecast future demand.

The Simulation Gaming Process for Capacity Building

A summary of intended learning outcomes is given in Table 1 below.

Results: Simulation game screenshots

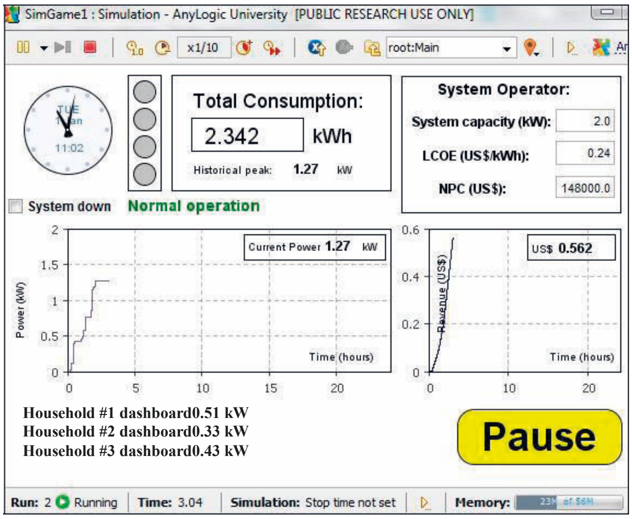


Figure 2: System window showing micro-grid load profile

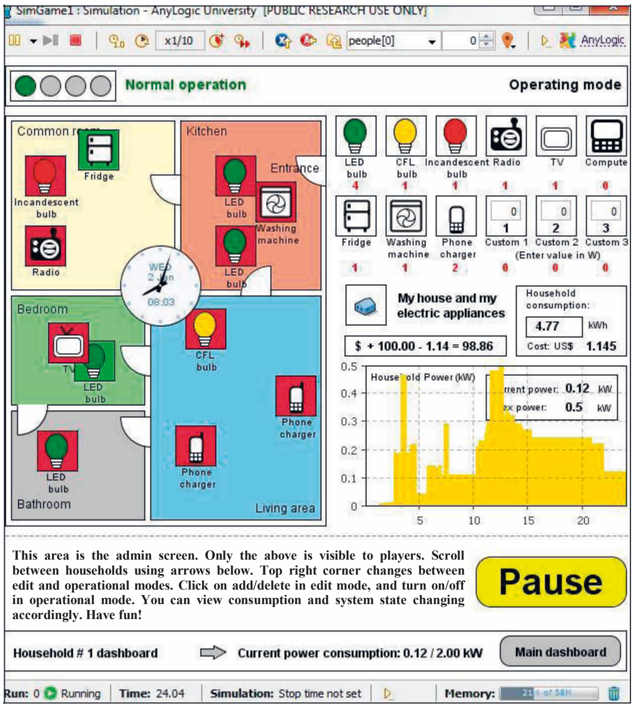


Figure 3: Individual household player window

Table 1: Intended learning outcomes for capacity building using the simulation gaming process.

Game feature	Action	Learning outcome
Household consumption playing	• Adding/removing appliances as if buying and discarding • Turning on/off appliances as if using in real-time	• Players will better understand their own household load profile and electricity use and can identify peak loads • Players will have a grasp of how different load profiles affect expenditure and be able to roughly estimate monthly charges and decide whether to lower consumption if costs are too high
System-wide load profile and warnings	• Viewing system load profile in real-time against capacity	• Players will appreciate that capacity is limited and understand the need for both individual and collective load management • Players will learn about system load profiles, community peak loads and total electricity usage and behavior.
Discussion rounds	• Collectively discuss findings, experiences and observations from the game • Discuss best way to manage consumption and micro-grid	• Players/community members will come together and work out issues with managing a shared resource • Community will apply existing governing structures to support decision-making process and strengthen local institutions • Community will apply existing (if any) resource sharing management to electricity use. E.g. agricultural communities that share water resources
Tariffs, revenue generation	• Viewing energy use against tariff, costs and revenue	• Players will understand the importance of cost recovery and how best to afford and use electricity for productive end use
	• Changing tariff in order to generate more revenue for the community micro-grid • Testing of future scenarios	• Players will learn how different tariffs and corresponding consumption can contribute to greater revenue for a community savings fund. This could open up the opportunity to articulate desired services and capabilities for community development

Discussion: Case Study Observations

Development of the game is currently ongoing and has yet to be tested in a rural community setting. However, a beta version was trialed in August 2013 among university students and young professionals participating in an energy access workshop, and was used as a teaching tool for community participation and micro-grid planning. The participants were from various countries and originated from both rural and urban areas. They were divided into teams of 3-4 per group, each group representing households. The game was played on networked laptop computers, although the next version of the game will be played on devices (i.e. tablet) for easier deployment.

Most of the case study participants have mainly experienced grid electrification, and thus were new to the unique challenges in using and managing a micro-grid. The first few game-rounds (after initial familiarization) saw participants prioritizing their individual households, which in turn overloaded the system causing blackouts. As facilitators attempted to guide the discussion towards increasing system capacity or implementing demand side measures, some interesting and unanticipated social interactions took place. Namely, households began to blame one another and demand for the prohibition of high-resistance appliances. Within a gaming environment, participants felt freer to behave as they wanted. This is not an undesirable outcome. On the contrary, the simulation game provides participants with the freedom to experiment with different behaviors in order to observe system impact. For example, a future version of the game may include the option to 'steal' electricity, a prevalent problem with micro-grids in some countries. The game by itself is not meant to be biased in that it favors a desirable (or undesirable) behavior. It has been developed to remain as flexible as possible to enable participants to choose what normative actions and decisions work best for them.

It was observed that although the household teams could easily participate equally in discussions, the collective decision-making process still depended on group power dynamics or how comfortable participants felt voicing their opinions. However, the total system load profile displayed contributions of every household (an optional feature) and hence non-participating players could still be drawn out to discuss their contributing loads.

Like other participatory methods, the facilitator role is critical and requires an objective, unbiased (towards a particular solution) individual, knowledgeable about micro-grid delivery. However compared to conventional surveys and questionnaires, the simulation gaming design process has greater flexibility and can be applied in different local and social contexts without much customization. It is also dynamic in nature, providing immediate feedback and learning to players. In the trial, after three game-rounds, participants were collaborating well, had decided on a system capacity that suited their energy needs, and were no longer overloading the system.

The simulation game as a design tool was also useful in testing effectiveness of demand side management options. In the trial, participants were able to choose and test between limiting individual household capacity and voluntarily decreasing consumption when the game's warning signals displayed that the system was nearing capacity. During one game round, households were given the option of reducing their consumption within a specified time period when the system reached a critical state. Three out of the four households immediately reduced consumption when the warning appeared, while the remaining household waited until the others had reduced consumption. This provides interesting insight into human behavior and the game could help devise new demand side management strategies.

Ultimately, participants recognized that cooperation was necessary in order for everyone to have access to reliable electricity. The beta version trial was considered successful in providing an interesting and enjoyable learning experience for resource management and cooperative, participatory design. The process does have limitations, the most important one being that the simulation gaming process does require a certain level of community organization in order to successfully make design decisions. A hands-on, physical version of the game that works without devices is also being considered. The physical version will be for communities that have very little experience with technology and operating devices. Although the game would not be as dynamic nor will it provide immediate household load profiles, a physical version of the game will still be able to impart concepts such as cooperation in using a limited micro-grid capacity and making decisions as a community.

Acknowledgement: To Dénes Csala (Masdar Institute) forcoding the beta version, developing its multi-user networking functionality, and providing technical support during the trial.

References

Abdullah, M. A. (2013, June). *A Participatory Approach to Rural Energy Systems: Design, Planning and Implementation* (Master of Science Thesis).

Masdar Institute, Abu Dhabi, UAE. Brandt,E.(2006). Designing exploratory design games: a framework for participation in Participatory Design? In *Proceedings of the ninth conference on Participatory design: Expanding boundaries in design Volume 1* (pp. 57–66)

Chua, A. Y. K. (2005). The design and implementation of a simulation game for teaching knowledge management. *Journal of the American Society for Information Science and Technology*, *56*(11), 1207–1216. doi:10.1002/asi.20224

Connolly, D., Lund, H., Mathiesen, B. V., & Leahy, M. (2010). A review of computer tools for analysing the integration of renewable energy into various energy systems.*Applied Energy* , *87*(4), 1059–1082. doi:10.1016/j.apenergy.2009.09. 026

Cross, N., & Gaunt, C. T. (2003). Application of rural residential hourly load curves in energy modelling. In *Power TechConference Proceedings, 2003 IEEE Bologna* (Vol. 3, p. 4 pp.Vol.3–). doi:10.1109/ PTC.2003.1304492

Howells, M., Alfstad, T., Cross, N., Jeftha, L., & Goldstein, G. (2002). *Rural Energy Modeling*.

DC Nanogrids: A Low Cost PV Based Solution for Livelihood Enhancement for Rural Bangladesh

M. Rezwan Khan
United International University
Dhaka, Bangladesh
Email: rezwanm@uiu.ac.bd

Edward D. Brown
Loughborough University
Loughborough, UK
Email: E.D.Brown@lboro.ac.uk

Abstract

A concept paper, along with cost estimations, is presented proposing the development of very small sized solar PV grids, which we have termed nano-grids. These grids allow the incorporation of developmental activities such as irrigation, along with household usage of electricity. It is argued that the developmental activity should be chosen in such a way that it matches with the seasonal variation in insolation and load demand to keep the energy cost to a minimum.

Keywords Nano-grid; DC-grid; livelihood enhancement; irrigation; household load in Bangladesh.

Introduction

Falling PV prices in the world market have opened up wide opportunities for accelerated deployment of solar energy technologies in developing countries like Bangladesh. Although, the energy cost of a PV based system is still higher than that of grid power, there is ample scope for PV based energy generation for offgrid regions where the potential for grid extension is likely to remain low. Studies of off grid rural areas in Bangladesh (Khan, et.al, 2012) indicate that the main fuel for lighting in the off-grid areas are kerosene based lamps (Kupi or Harricane) and a family on average spend Tk. 200 per month on the cost of the kerosene. Besides the high cost of this imported oil to families on low incomes, these lamps produce significant fumes posing health threats and are prone to fire hazards. The significant growth of the Solar Home System (SHS) in Bangladesh (www.idcol.org) started to take place at a time when the cost of solar PV panels was about two times higher than its present price. Although the energy cost of the SHS was very high at that time in comparison to grid electricity, the actual cost for lighting a house with efficient fluorescent lamps via the SHS were comparable to the expenditure that families had been making on kerosene purchases, with the advantage that the health hazards from the fumes and the fire hazard from the open flames had effectively been eliminated. Additionally, people had the opportunity to charge mobile phones and watch TV in the case of the installation of systems with panel sizes of higher than 50Wp (www.idcol.org) which constituted another very important incentive for families to opt for a SHS. As the price of the PV started to fall, the rate of penetration of SHS in the market soared accordingly. Today, more than 50,000 SHS are being installed every month in Bangladesh (www.idcol.org) and it is considered as one of the fastest growing and most successful solar programs in the world.

Nevertheless, for all of the successes of the Bangladesh SHS programme, it is clear that for a sizeable proportion of the rural population the costs of such systems remain beyond them. In this context, the kinds of solar lighting products which have been promoted via the Lighting Africa initiative (www.lightingafrica.org) have been proposed as a very low cost solution for these types of households. Typically, these types of solutions have involved the use of very small PV panels, sometimes termed Pico-PV. The typical size of the PV panels vary from 5-10W, with a small storage battery and 2/3 LED lights. As these systems are very small, the typical cost is low and the system is well within the affordable range of the population remaining at the bottom of the pyramid (BOP) in Bangladesh. There are currently several propositions from a variety of international organizations and funders to implement similar systems in rural Bangladesh to promote these types of solutions to the lighting needs of the poorest Bangladeshi communities However, before taking a hasty decision to roll out similar programmes in Bangladesh based on the success story of Lighting Africa, it is important to analyze socio-economic conditions in rural Bangladesh. One of the most striking dissimilarities between communities in rural Bangladesh and most parts of rural Africa is the much higher population density in the former which leads to people living closely in houses clustered in a small area. This may offer possibilities for pursuing an alternative solution in Bangladesh. A simple observation will show that the electricity generated by smaller PV panels is more expensive than that generated by larger panels (as, for example, a 100Wp panel is less than 10 times more expensive than a 10Wp panel) as there are some fixed overhead costs like framing and the connectors at the back of the panel. Very small systems also require small sized batteries and small sized lead-acid batteries are usually not very good quality meaning that the practical options left are Nickel or Lithium based batteries. These Nickel or Lithium based batteries are 4-5 times more expensive than an equivalent lead-acid battery which also adds to the relative cost of small systems. It is estimated (Khan *et.al.,* 2012) that the energy cost of a small system with this type of more expensive battery is almost two times that for a conventional lead-acid battery based energy storage system.

So there are significant questions over whether small-scale pico-PV solutions are likely to be the most appropriate for the Bangladesh context, particularly when one considers the growing identification of the limitations of the SHS even amongst those households where it is more or less affordable. Despite all the positive features of the SHS, it has a very serious limitation in terms of its potential to directly affect an individual household's ability to improve its income generation and overall quality of life (Blunck, M., 2007; Mondal, and Klein, 2011, p.17).The energy output of a SHS is so small that it can only support the meeting of basic lighting necessities and perhaps the charging of mobile phones and the running of a TV as a basic entertainment for rural people. Studies (Khan *et.al.,* 2012) made on energy needs in rural Bangladesh, however, indicate that there is demand for further very important facilities. One of these is a fan for comfort during the hot summer months and the others include income generating activities like irrigation, saw mill, flourmill for rice or wheat crushing, rice husking machine etc. Irrigation in particular seems to be a very good prospect as 2/3rd of the total number of irrigation pumps driven by diesel in the country are located in off-grid areas. Demand of refrigerator is still very limited due to economic limitations of the households.

In this paper we propose a community based small sized centralized solar PV system, termed 'nano-grid' for its small size (in contrast to the larger networks envisaged under terms such as mini-grids), that can provide energy to 15-20 households and can support small scale developmental activities like irrigation. The energy cost is quite competitive and the capital cost is low as the system is quite small.

Solar PV based Irrigation in Bangladesh

Irrigation is one of the major energy-demanding activities carried out in rural Bangladesh as Bangladesh is predominantly an agricultural country. Bangladesh has a monsoon climate where there is plenty of rainfall during the months from June to September. Indeed, sometimes there is too much rainfall and flooding takes place. The main cropping seasons are 'Aman' harvested during the month of November and 'Robi' harvested during the month of May. The 'Robi' season is predictably dry with plenty of sunshine and with proper irrigation this is the most important crop producing season for Bangladesh. However more than 60% of the rural area is not connected to the national electricity grid and irrigation mainly depends on diesel-based engines in these areas. The cost of diesel in the city areas is about Tk. 61 per litre and it is at least 20% higher in the rural areas due to the incidence of transportation and storage costs. Bangladesh imports USD 1bn worth of diesel for use in the agricultural sector alone
(http://www.nationmaster.com/).

The cost of diesel-based irrigation at the field level is Tk. 21 per kW-hr equivalent of electricity. The irrigation pump owners charge about 25% of the value of the crop produced for irrigating the land for a season.

With this background scenario, our studies presented here, indicate that with the present price of PV panels and prevailing patterns of solar radiance, solar PV based irrigation can be cheaper than diesel based irrigation in Bangladesh. However, it is important to understand that irrigation requirements in any particular season varies with the rain fall, the crops grown etc. and any dedicated irrigation scheme will not be cost effective as the PV energy will be wasted during the non irrigating months (from June to September). So, for any PV-based alternative to diesel-based irrigation to be viable, it will be very important to integrate the irrigation scheme along with a rural grid so that PV energy will have alternative usage. Another very important aspect is the monthly sunshine availability. During the main irrigating months (February to May) the temperature is relatively low and household demand for electricity is therefore also lower as, for example, cooling fans are likely to be one of the main sources of energy demand. So, we would expect that the higher sunshine during the irrigating months can very effectively be utilized for irrigation without causing shortages for household energy consumption. On the other hand, during the months of June to September, there is plenty of rainfall and the sunshine is relatively low resulting in less production of PV energy. This, however, is the season when irrigation needs are minimal and the PV output can be very effectively used for household purposes. So, our assumption is that if we consider the distribution of sunshine and the seasonal variation of demand including for irrigation, net electricity requirement would appear to match the availability of PV output. This has the added benefit of suggesting very effective usage of the PV output, leaving the likely amount of unutilized energy at a minimum.

Although the proposed nano-grid uses battery backup for supply of energy during the night hours, irrigation can be done during the day time without battery backup that reduces the cost of electricity for irrigation can make the scheme commercially viable. It is worth mentioning that the requirement of battery backup increases the cost of PV energy by more than 70%.

The Concept of DC nanogrid: Its Feasibility in the Context of Bangladesh

Drawing together the discussion in the previous sections, it can be seen that the nano-grid idea is based on the fundamental concept of the Solar Home System, where the basic necessities of households are met, but at the same time some small scale applications like irrigation can also be incorporated. This concept takes advantage of the fact that houses in Bangladesh are usually clustered together in rural areas in a group of 15-20 houses (within a diameter of less than 150m). A schematic diagram depicting the concept is shown in Fig. 1. In the proposed nano-grid system, something like a 1.5 to 2kWp PV system is installed in a small cluster of households within a radius of 60-70m and power is distributed to 10-15 households from this system. The PV panels and the battery used in the proposed nanogrid will be connected in series in such a way that the grid voltage is 220V DC (nominal) and the households are supplied with this voltage. There are already strong voices being raised regarding the advantages of DC grids (Khan, 2012).

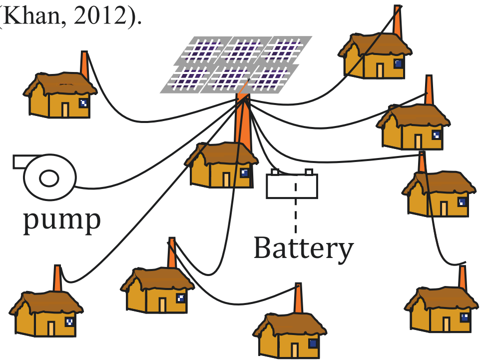


Figure 1: Schematic diagram for the nano-grid. Roof top locations of one or two houses will be chosen for PV installation and the storage battery will be placed in a convenient location close to it.

As described in the later part of this section, the main household loads for this system are likely to be lighting, TV, fan and mobile phone. The LED or CFL lamps and TV have their own built in controller circuits that make them insensitive to DC or AC supply. These days, brushless DC fans are widely available in the market. Although the brushless DC fans are more expensive, they are much more efficient (~80%) than the usual induction motor based AC fans (efficiency ~60%). The higher cost of the brushless DC fans is likely to be compensated within three years considering the lower power consumption of the fans. However, in case of irrigation pumps or some other income generating activities a separate inverter is likely to be needed. The advantage of the DC grid is its low cost, as no inverter is needed and at the same time this avoids inverter energy losses. Our preliminary estimates indicate that there can be more than a 25% cost saving by avoiding inverters in the grid.

Considering the typical load in a household, the expected summer time (May to September) load is around 3 times the expected winter (November to March) household loads. This, as explained above, is due to the fact that there is expected to be high usage of fans in summer due to hot weather condition. The average typical household load in rural Bangladesh given below in Table I and Table II. The demand for refrigerator is not considered at this stage as it goes beyond the affordability of the average households.

From Table I and Table II it can be clearly seen that fans constitute a significant part of the household load in summer whilst the zero fan load in the winter months reduces the total load to less than half. Although the mobile charger is an important component, its actual energy consumption is very small and has not been included in the tables. The surplus generated from the significant fall in the household demand is proposed to be used for developmental activities like irrigation during the dry months.

Fig.2 shows the average daily solar radiation on a horizontal flat surface in Bangladesh. The main irrigation season is from February to 1st week of May and the weather remains reasonably dry and cool until the end of April.

Table 1:House hold consumption (summer months)

	Light	Fan	TV
%House hold (HH)	100	100	25
No./HH	3	2	1
Watt/unit	5	20	30
Hrs of usage, hr	4.5	8	8
Diversity	0.8	0.8	0.8
Energy/day, W-hr	54	256	48
Total/day, W-hr			358
Avg.load/HH, Watt			62.5

Table 2: House hold consumption (winter months)

	Light	Fan	TV
%House hold (HH)	100	100	25
No./HH	3	2	1
Watt/unit	5	20	30
Hrs of usage	6.0	0	10
Diversity	0.8	0.8	0.8
Energy/day, W-hr	72	0	60
Total/day, W-hr			132
Avg.load/HH, Watt			22.5

It is interesting to note that sunshine is higher during these months, which together with relatively low demand for fan-use in the house holds during this period generates sufficient surplus energy to divert it for irrigation. Our preliminary calculations show that a small pump of 1.1kW (1.5HP) can be easily run to irrigate the fields. During the months after June, the rainy season starts and demand for irrigation is reduced to around 5-10%.

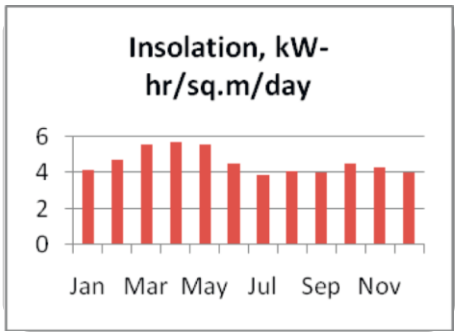


Figure 2: Month wise average daily insolationin Bangladesh.

Although the sunshine is lower during the rainy season (June-September), absence of irrigation makes the overall energy demand lower and a well-designed system should be able to cope quite satisfactorily with household demand. For a very small system, we estimate that a 1.1kW pump and 10 households can be supplied with the necessary primary energy needs using a 1.9kWp PV system with a 500AH, 12V battery as storage. During the daytime it is recommended that the pump will run from 10.00am to 2.30pm. The rest of the time will be dedicated to battery charging. At the same time, the panel size is such that it can generate enough energy even in rainy, cloudy or foggy days to keep the battery size small compared to those used in SHS. Fig.3 below gives a month wise energy demand and production scenario for such a system.

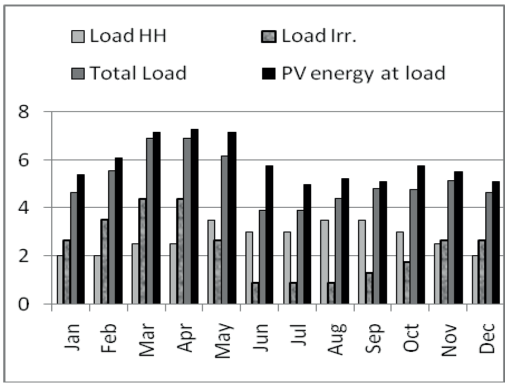


Figure 3: Month wise average daily energy (kW-hr) budget for a 1.9kWp PV nano-grid supplying power to 10 households and an irrigation pump of 1.1kW

A Calculation for water Delivery for a Small Irrigation Pump

A 1.1kW (~1.5HP) irrigation pump can run quite satisfactorily if the input power is within 1000-800W. A 1.1kW electric pump driven by an inverter, having an overall efficiency of 50%, can pump around 90,000 litres of water per day (4 hours of run time) from an average head of 7m. In the case of a submersible deep tube well the figure will be significantly lower due to the higher water head. Most of the irrigation pumps in Bangladesh use shallow tube wells not exceeding a depth of 6-7m.Rice is the most important crop in Bangladesh that needs irrigation during the dry months, 90,000 litres per day can irrigate about 6-7 acres of rice field for a whole season (3 months). In the case of other crops like vegetables, wheat or maize the area of irrigated land will bemuch larger as they require much less water than rice cultivation.

The Cost Calculation for the Proposed nano-grid

Cost of the system and electricity

The description of a model system is given below
Size of the PV – 1.9kWp
Size of the battery bank – 480 AH at 12V
One irrigation pump (AC) – 1.1kW (1.5HP)
No. of households – 10
Summer load per house hold – 360W-hr per day
Winter load per house hold – 135 W-hr per day

Estimated total cost of the system including installation and accessories is USD 4652. Based on IDCOL model of financing (50% grant, 30% loan at 6% interest rate for 8 years and 20% equity) energy cost for household electricity is USD 0.35/kW-hr and energy cost for irrigation is USD 0.20/kW-hr.

Considering a monthly connection charge of USD 1.25 electricity bill for an average household for summer months is USD 5.0 and that for winter months is USD 2.7.Corresponding irrigation energy cost per season is 10.7% of the crop produced for rice fields. As mentioned earlier, the usual charge for diesel based irrigation is 20-25% of the crop produced in the irrigated fields. It is worth mentioning here that the average energy cost in a SHS under a similar financing model is close to Tk. 40. As SHS has only fixed load of light, mobile charger and/or TV, it cannot accommodate the seasonal variation of sunshine resulting in underutilization of the available PV energy. The nanogrid provides energy at a lower cost with more options for household gadgets. Apart from household use, it can incorporate a small sized irrigation pump that can have significant impact on agriculture.

Conclusions

The paper has proposed the concept of DC nano-grid highlighting its technical advantages and some of the economic and social considerations involved in their development. These are not capital intensive solutions as their size is quite small and can be easily implemented in a small community overcoming the financing difficulties; unlike, for example, the case of large scale mini-grids (Ulsrud et.al, 2011). At the same time, supply of DC voltage instead of AC at the household level avoids the relatively high cost of inverters eliminating inverter losses, particularly when the load demand is less than 10% of the peak during late night hours. Considering the sunshine and climatic conditions of Bangladesh, irrigation is incorporated with the system to run directly from the PV (without battery) during the dry seasons when the sunshine is high but house hold load demand is low, taking the advantage of energy surplus in the nanogrid. The solar PV irrigation energy cost, as presented in section 4, is lower than diesel based irrigation costs in Bangladesh.

References

Blunck, M. (2007) ‘Electricity and sustainable development: Impacts of Solar Home Systems in Rural Bangladesh’, Diploma Thesis, Department of Geography of Johannes Gutenberg, University ofMainz, Germany, May 2007.

Khan,M. Rezwan, ‘A Stand Alone DC Micro-grid for Electricity Supply in Rural Bangladesh’*, Proceedings of International Conference on the Developments in Renewable Energy Technology*, Dhaka, Bangladesh, January 2012.

Khan, M. Rezwan, Khan, M. Fayyaz, Chowdhury, Shahriar Ahmed, *24kW solar-Diesel hybrid power system for off grid Shonatala Island of Nasir Nagar upazilla of Brahminbaria districs,*GIZ –UIU study report,2012.

Mondal, A. And Klein, D. (2011) Impacts of solar home systems on social development in rural Bangladesh, Energy for Sustainable Development, 15 (1), pp. 17-20.

Ulsrud, K., Winther, T., Palit, D., Rohracher, H. and Sandgren, H. (2011) The Solar Transitions research on solar minigrids in India, Energy for Sustainabe Development, 15 (3). (minigrid)

Gas Diesel oil consumption in agriculture statistics, http://www.nationmaster.com/graph/ene_gas_oil_con_in_agr-gas-diesel-oils-consumption-agriculture

IDCOL website: www.idcol.org

Lighting Africa website : www.lightingafrica.org

.

Scientific Papers

VI. Planning and Governance

The role of gender concerns in the planning of small-scale energy projects in developing countries

Julia Terrapon-Pfaff* (julia.pfaff@wupperinst.org)
Wuppertal Institute for Climate, Environment and Energy GmbH
P.O. Box 100480, 42004 Wuppertal, Germany

Carmen Dienst (carmen.dienst@wupperinst.org)
Wuppertal Institute for Climate, Environment and Energy GmbH

Willington Ortiz (willington.ortiz@wupperinst.org)
Wuppertal Institute for Climate, Environment and Energy GmbH

*Corresponding author

Abstract

Energy poverty affects women in developing countries more severely than it affects men; at the same time, women have less control over household resources and are often not involved in decision-making processes on energy matters. In order for transition processes of energy systems to be sustainable, these gender-related concerns need to be addressed. Although this link is widely recognized, gender aspects are still not well perceived in the planning of energy projects.

To better understand the role of gender concerns in project planning, the research presented in this paper evaluates concepts of small-scale sustainable energy projects with regard to their gender sensitivity. The data originates from an expert evaluation process and was analyzed with focus on gender-related aspects. The results show that even in sustainable energy projects the issue is still not high on the agenda.

Keywords: gender; sustainable energy transitions; project concepts; developing countries.

Introduction

More than 2.6 billion people worldwide still lack access to an affordable and dependable energy supply to meet their fundamental energy needs (IEA & OECD 2012). Without access to energy, it is unlikely to reduce the poverty of these people and to further development. Although both men and women are affected by energy poverty, the negative implications associated with the lack of available, affordable and reliable energy supply disproportionally affects women and girls due to their traditional socio-cultural roles. In these traditional roles women are usually responsible for household tasks such as cooking, food processing, heating, water supply and washing. Providing and managing the energy sources necessary to fulfill these household tasks is also generally the woman's responsibility. Accordingly, it is mostly women who shoulder the burden of domestic energy supply in developing countries. This fact is validated in numerous studies that provide empirical evidence to support the assertion that women spend more time and travel longer distances than men to collect biomass fuels to meet domestic energy needs (e. g. Pachauri & Rao 2013, Practical Action 2012, Oparaocha & Dutta 2011, Parikh 2011, Wickramasinghe 2003). Due to their traditional tasks in the home, women and girls are also more severely affected by the high levels of indoor smoke pollution arising from the direct combustion of biomass. Consequently, since the UN Conference on Women in Beijing in 1995, the international development community has emphasized the potential welfare improvements that access to energy services can bring to the lives of women in developing countries (Clancy 2009).

As well the fact that women have more to gain than men in terms of health and welfare, the implementation of sustainable energy technologies is also associated with the potential empowerment of women. Freeing women's time by providing reliable energy services potentially allows women to engage in income-generating activities and education (Clancy et al. 2012, Misana & Karlsson 2001). However, although this would appear to be a realistic and reasonable outcome of improved access to energy for women, the empirical evidence to support these assumptions is sparse (Dienst et al. 2013, UNDP 2011, World Bank 2008).

Despite the anticipated gender differentiated effects that sustainable energy access can have, the gender dimension itself influences energy projects in multiple ways. Gender can have substantial effects on technology preferences and on how these technologies and the generated energy are used (Pachauri & Rao 2013). Due to their gender roles, poor women and men also have different attitudes to paying for certain energy services (Skutsch 2005). In addition, gender can also play a significant role for the efficiency and long-term sustainability of energy projects (Oparaocha & Dutta 2011, Cecelski 2000).

All of these realities substantiate the need to integrate the gender dimension into project planning to ensure that local energy transitions in developing countries can be sustainable. However, despite theoretical knowledge and the growing number of publications on the relationship between sustainable energy and gender, little progress has been made in terms of gender equality and there is still much to learn about better integrating gender aspects into transition processes for more sustainable energy systems (Figure 1). This gap, between gender mainstreaming rhetoric in concepts, guidelines, management tools etc. and the practice, where gender-sensitive energy policies, programs and projectsare still the exception, has been described by numerous authors (e.g. Alston 2013, Cecelski 2004, Skutsch 1998); however, little information exists on why this discrepancy persists.

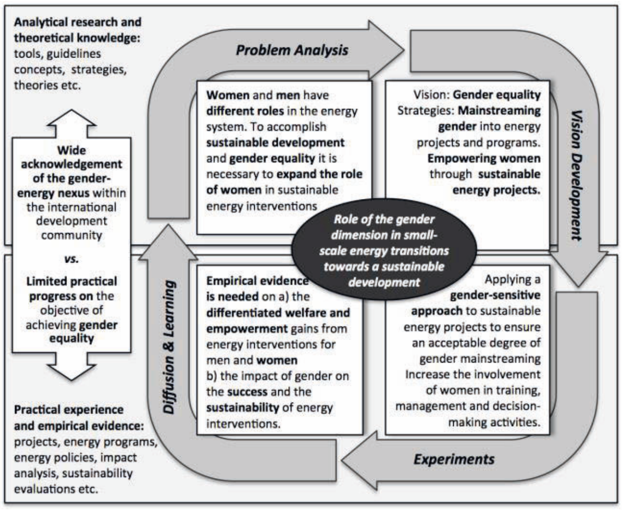


Figure1: The gender dimension within the energy transition cycle

Research Objectives

In view of these observations, by analyzing the role of gender in sustainable energy projects, this paper aims to address the question of why gender implications have been widely conceived in theory but have not been transferred into practice. The study concentrates on small-scale and local projects that are designed to meet the needs of energy-poor households and communities and should, therefore, be sensitive to gender concerns.

Within the transition cycle these projects can be seen as experiments (Figure 1), where the theoretical and analytical knowledge is converted into practice in the form of subsidized technology innovations, demonstration projects or market development activities. These experiments are central to a sustainable transition process because they provide insights into the underlying developments and are often the basis for systemic change (Geels 2011). Analyzing the concepts of these project-level experiments can help to better understand and accompany this stage of the transition process.

The objective is to provide empirical evidence on (a) how gender concerns are perceived in the design of small-scale sustainable energy projects in developing countries and (b) if technology choices or geographical factors play a role in the extent to which gender is integrated into these experiments. These analyses are the first step in more comprehensive research effort that aims to analyze the role of gender and of women's empowerment in local sustainable energy projects. The overall objective of this research is to increase the understanding about how to better transfer theoretical and analytical knowledge into practical results in order to unlock the potential for sustainable energy transitions to empower women.

Methods

The data for these analyses was collected from the SEPS (Sustainable Energy Project Support) scheme, which is part of the WISIONS initiative. WISION has been actively promoting the introduction of sustainable energy solutions and resource efficiency since 2004. SEPS supports projects in developing countries with innovative approaches that respond to energy need at local level.

To better understand the role gender concerns play in these small-scale projects, this study starts at the beginning of the project cycle by examining and evaluating the gender-sensitivity of the project concepts. In total, 192 project proposals submitted between 2007 and 2012 (of which only a small share were realized through SEPS funding) were evaluated.

The proposals that were taken into account passed the pre-validation process and were then evaluated by at least two experts against a set of well-established sustainability criteria. For the detailed examination of the proposals against these criteria, the experts provide marks on a four-point scale (0 = the proposal fails to address the issue or cannot be judged against the criterion due to missing or incomplete information; 1= poor; 2= fair; 3= good; 4= very good). For this study, the data collected was revisited and analyzed according to whether the project contributed to gender equity or addressed gender-related issues.

Results

The first analysis provides empirical evidence about the extent to which gender concerns were incorporated into the design of small-scale sustainable energy projects in developing countries.

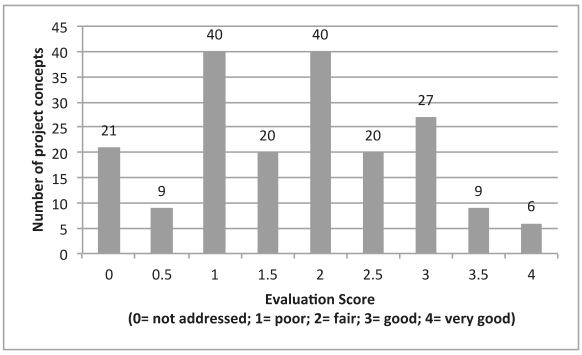


Figure 2: Distribution of scores corresponding to the question of whether the project concepts contributed to gender equity or addressed gender-related issues

Looking at the distribution across the entire sample of the 192 evaluated proposals, about 16% of the project proposals scored less than 1, meaning that gender issues were not addressed at all, 21% of the proposals only reached 1 point, indicating that gender issues were only poorly addressed and a further 10% attained an average score of 1.5, positioning these project concepts between 'poor' and 'fair' in terms of their gender-sensitivity. Overall, 47% of the projects were considered to address gender issues less than fairly (Figure 3). Project concepts that were rated as 'good' with regards to their contribution to gender-related issues on the other hand represented only 18% of the sample. Only 3% of the evaluated sample achieved the maximum score of 4, meaning that these project concepts fully addressed gender-related issues or contributed strongly to gender equality. These results provide empirical confirmation of the observation that despite the wide uptake of gender mainstreaming rhetoric in research literature and the availability of numerous guides on how to integrate gender into project concepts in the development cooperation literature, gender still does not play a prominent role in energy project planning.

However, when examining the data in relation to the development over time of gender awareness in project design, it can be observed that over the last six years the average score increased by over 0.6 points (Figure 3). This trend in the data allows for the assumption that in recent years gender issues have been better incorporated into small-scale energy project planning. This might indicate that the theoretical knowledge about the importance of gender in sustainable energy transitions and lessons learned from previous project-level experiments is slowly becoming more widely adopted by practitioners and project planners.

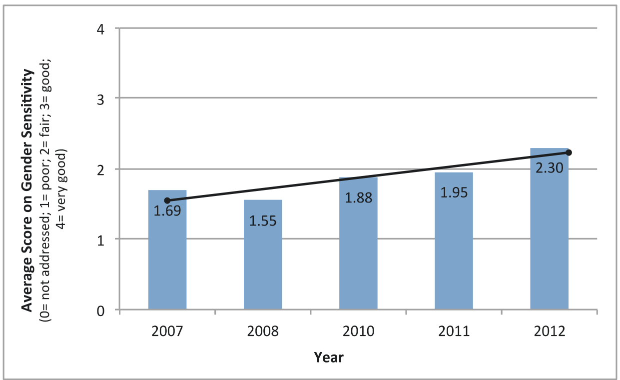


Figure 3: Average score per project concept for the project cycles 2007-2012

With regards to renewable energy technologies many publications point out that gender issues are most widely addressed in the context of biomass fuels (Skutsch 2001, Dutta 2003). The stronger focus on gender in projects that use biomass as renewable energy source is explained by the fact that the burden of providing and using biomass fuels is strongly differentiated by gender. However, the fact that it is generally women who are responsible for managing traditional biomass energy sources at household level does not guarantee that women will also be the ones who are trained, who make the decisions, or are responsible for the management and/or ownership of modern biomass technologies. Consequently, projects focusing on biomass as renewable energy source may benefit women but do not automatically contribute to gender equality. This fact is also reflected in the results of the evaluation characterized by the technologies that were proposed in the project concepts (Figure 5). Project designs that utilize biomass only have an average score of 1.84, similar to solar (1.82) and hydro technologies (1.86). Only project concepts that focus on wind power score higher with an average of 2.14, meaning that these, at least, fairly address gender-related issues. However, wind projects represent only about 4% of the evaluation sample, meaning that the number may not be considered as statistically significant. Taken as a whole, Figure 4 shows that, based on the analyzed sample, the choice of technology has no significant influence on how far gender-related concerns are considered as part of the project idea. Project concepts that focus on energy efficiency measures contribute even less to gender equality, scoring on average 1.29. This low rating can be explained by the fact that energy efficiency measures in the evaluated concepts mainly addressed the optimization of energy appliances in public buildings. Often, the benefits of these types of improvements cannot be differentiated by gender, which explains the low scores for the contribution to gender equality.

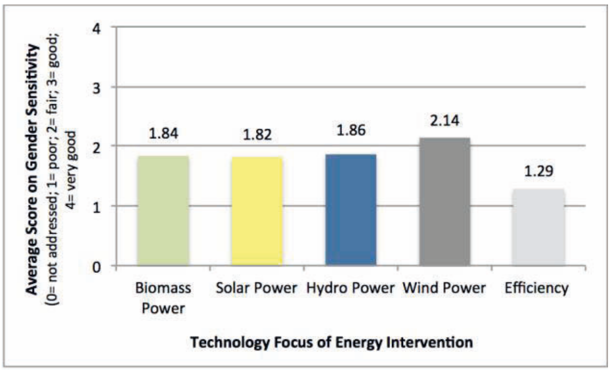


Figure 4: Average score according to technology focus

As well as differentiation in terms of technology, the project designs were analyzed in terms of the effect of geographical location on gender concerns. The 192 reviewed project concepts were supposed to be implemented in over 40 different countries; nearly half (47%) were located across Asia, 32% were located in Africa and 14% in Latin America, while only 5 project concepts were supposed to be implemented in the Middle East. The average gender-sensitivity scores of the project ideas in different regions are presented in Figure 5. The low results for projects concepts in the Middle East are particularly noticeable. However, as the number of submitted project concepts for the Middle East is very small, these low scores cannot be considered as representative. On the other hand, the better perception of gender issues in project concepts located in Latin America can be considered to be statistically significant. Additionally, the low gender-sensitivity rating of projects concepts located in Asia (1.72) is of particular interest because a lot of research and many empirical studies addressing the subject of gender and energy have been focused on Southern and South East Asia (e.g. Reddy & Nathan 2013, Parikh 2011, Malhotra et al. 2004, Shailaja, 2000). Therefore, the expectation was that gender concerns would have been better integrated into concepts for sustainable energy interventions in this region. Yet, this was not the case in the evaluation sample as the average gender score of concepts for Asia (1.72) and Africa (1.77) did not even score 2, which is the level designated for 'fairly' addressing gender concerns.

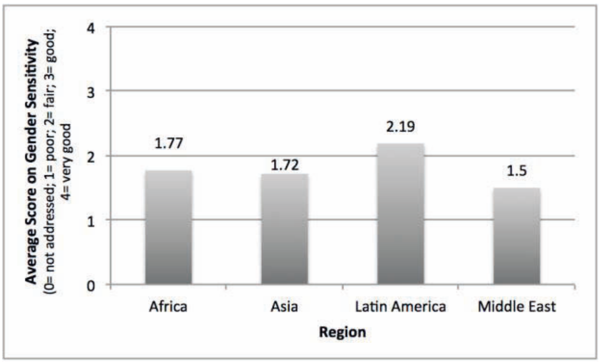


Figure 5: Average score according to geographic region

Discussion

The presented study is based on expert judgments and limited to analyzing project concepts, which restricts the ability to predict in what way projects would actually contribute to gender equality in practice. Notwithstanding these limitations, the results suggest that nearly a decade after Cecelski (2004) and Skutsch (2005) criticized the lack of perception of gender concerns in the planning processes of energy projects and programs, surprisingly little progress has been made. In the evaluation sample gender-related concerns are still only incorporated to a limited extent into project concepts across technologies and regions. However, there are indications that this situation is gradually changing. To push this development further, enhanced information and knowledge exchange between science, donor and implementing organizations and practitioners is needed. Furthermore, knowledge about the limitations of the gender approach must be further explored as, for example, the potential influence of small projects on gender roles may be restricted. As different authors point out (e.g. Pachauri & Rao 2013; Skutsch 1998), one of the main reasons for the limited uptake of gender perspectives is that energy project managers often see gender equality as a cultural matter that cannot be influenced by individual energy projects. To really understand the type of long-term effects that small projects can have, further research is needed. Empirical evidence is required to demonstrate how, or even if, local project-level experiments affect women and men differently, and whether the role of women can really be changed in the long term or if, eventually, men reassert their privileges. Therefore, in order for gender to become a positive driving force, instead of a barrier, in the transition process towards sustainable local energy systems, it is necessary to generate more transformation knowledge by closer analyzing the impacts and learning from the conducted experiments.

References

Alston, M. (2013). Gender mainstreaming and climate change. Women's Studies International Forum (2013), in print.

Cecelski, E. (2004). Re-thinking gender and energy: Old and new directions. ENERGIA/EASE Discussion Paper.

Cecelski, E. (2000). The Role of Women in Sustainable Energy Development. National Renewable Energy Laboratory Golden, Colorado.

Clancy J, Winther T, Matinga M, Oparaocha S (2012).Gender equity in access to and benefits from modern energy and improved energy technologies. In World Development Report: Gender Equality and Development. World Bank.

Clancy, J. (2009). Late Developers: Gender Mainstreaming in the Energy Sector. http://www.devstud.org.uk/aqadmin /media/uploads/4ab8efeb3f827_SA3-clancy-dsa09.pdf. Accessed 10 January 2014.

Dienst, C.; König, J.; Ortiz, W.; Terrapon-Pfaff, J. (2013). Small is beautiful!? Evaluating the sustainability of small-scale renewable energy projects in developing countries. In: Schäfer, M.; Kebir N.; Philipp, D. (2013). Micro Perspectives for decentralized energy supply. Proceedings of the International Conference 27 Feb.- 1 Mar. 2013, Berlin.

Dutta, S. (2003). Mainstreaming Gender in Energy Planning and Policies. UNESCAP Project On Capacity Building on Integration of Energy and Rural Development Planning. Background Paper For Expert Group Meeting, New York.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions 1, 24–40.

International energy agency (IEA)/ Organization for Economic Co-operation and Development (OECD) (2012). WorldEnergy Outlook 2012: WEO2012 Measuring progress towards Energy for All. International Energy Agency, Paris.

Misana, S. & Karlsson, G. (2001). Generating opportunities: Case studies on energy and women. United Nations Development Programme. New York.

Oparaocha, S. & Dutta, S. (2011). Gender and energy for sustainable development. Current Opinion in Environmental Sustainability 2011(3), 265–271.

Pachauri, S. & Rao, N. D. (2013). Gender impacts and determinants of energy poverty: are we asking the right questions? Current Opinion in Environmental Sustainability 2013, (5), 205–215.

Parikh, J. (2011). Hardships and health impacts on women due to traditional cooking fuels: A case study of Himachal Pradesh, India. Energy Policy 39 (2011), 7587–7594.

Practical Action (2012). Poor People's Energy Outlook 2012. Warwickshire, UK.

Reddy, B. & H. Nathan (2013). Energy in the development strategy of Indian households—the missing half. Renewable and Sustainable Energy Reviews, 18 (2013), 203–210.

Shailaja, R. (2000). Women, energy and sustainable development. Energy for Sustainable Development, Energy for Sustainable Development, 4 (1), 45-64.

Skutsch, M. M. (2005). Gender analysis for energy projects and programmes. Energy for Sustainable Development, 9 (1), 37-52.

Skutsch, M. M. (2001). Why Special Attention to Gender in Electrification Programmes? www.energia.org/pubs/papers/ skutsch_electrification.pdf. Accessed 10 January 2014.

Skutsch, M. M. (1998). The gender issue in energy project planning. Welfare, empowerment or efficiency? Energy Policy, (26) 12, 945-955.

United Nations Development Programme (UNDP) (2011). Towards an "energy plus" approach for the poor. A review of good practices and lessons learned from Asia and the Pacific. UNDP, Bangkok.

Wickramasinghe, A. (2003). Gender and health issues in the biomass energy cycle: impediments to sustainable development. for Sustainable Development 7 (3), 51-61.

World Bank (2008). The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits. An IEG Impact Evaluation. The World Bank, Washington D.C.

Fuel Oil Volatility – Complications for Evaluating A Proposed Power Purchase Agreement for Renewable Energy in Nome, AK

Antony G Scott (agscott@alaska.edu)
Alaska Center for Energy and Power, University of Alaska Fairbanks
Fairbanks, AK, USA

Abstract

Private development of a geothermal project to bring electric power to Nome, AK, will require a power purchase agreement between the developer and local utility. Small loads and difficult logistics increase fuel costs for the existing diesel based system, suggesting potential economic benefit from geothermal power. But tools for evaluating future diesel prices in remote, rural markets are sparse – in large part because only 1-3 deliveries determine diesel prices for the year. This paper leverages standard tools to help clarify consequences for Nome citizens of replacing a portion of their stochasticly diesel-based power with stable-priced geothermal energy. It finds that accounting for the unusual nature of episodic fuel deliveries significantly adds to normal annual fuel-oil volatility.

Keywords: Renewable energy; power purchase contracts; economic evaluation; diesel prices; risk; microgrids.

Introduction

While government or donor resources are often stretched, private capital resources for investment in renewable energy systems are vast and their deployment increasing. But many factors inhibit commercial diffusion of renewable technologies to remote rural communities. High counterparty risk, and inadequate commercial prizes given transaction costs can be disincentives to would-be suppliers of wholesale renewable electricity. In remote roadless regions that currently rely on diesel fuel, another factor may be important for would-be power purchasers: the complexity of evaluating the comparative economics associated with a proposed renewable energy “deal”.

Electricity costs in remote Alaskan communities are driven by poor economies of scale and difficult logistics. Community grids are islanded and serve small loads. Lack of roads significantly increases costs of diesel fuel delivery, upon which baseload electricity generally depends. Barged fuel delivery may occur only a few times during the summer ice-free season, increasing price volatility. In Nome, AK, the fuel portion of electricity costs last year exceeded $0.22/kWh, with total costs of $0.55/kWh. Such conditions would appear to enable renewable energy to cost effectively displace diesel fuel.

The Pilgrim Hot Springs geothermal resource lies 60 miles from Nome. Down-hold resource assessment began in 1979; sporadic but substantial efforts since that have reduced geological uncertainty (Holdmann et al, 2013). Commercial development would require new-build construction of single-purpose transmission to from the site to Nome, making up roughly three-fourths of the project’s $40 million in capital costs. While the costs create scale potentially sufficient to render the investment attractive to an investor, it also shifts project economics from slam-dunk to close thing.

The Nome Joint Utility System (NJUS) and a private investor have been engaged for the last year in negotiating a long-term take-or-pay power purchase agreement. The contract might enable development of Pilgrim Hot Springs. The range for discussions appears to be $.22-$.25/kWh, subject to annual escalation (Doogan, 2013).

For the private developer, aside from residual geologic uncertainty, a contract substantially shields it from business risks outside its control. As well, the developer enjoys risk mitigation associated with having a portfolio of other current and future renewable energy investments.

For Nome the value proposition is more uncertain and more material. The stochastic path of future diesel prices determines whether purchased power “pays off”, yet sporadic fuel deliveries add to uncertainty inherent in long-term diesel fuel price forecasts. As well, the size of the geothermal resource is large relative to Nome’s annual average (4 MW) and baseload (2.5 MW) demand (Vander Meer and Mueller-Stoffels, 2014). Accordingly, so too might be the “hedging” benefit of replacing volatile diesel with flat-priced geothermal power. In short, a contractual commitment could have potentially broad, rather than marginal, welfare impacts. The relatively high proportion of cash income allocated to energy expenditures compounds the stakes.

Research Objectives

This paper seeks to leverage standard tools to help clarify economic consequences for Nome citizens of entering into a power purchase agreement for geothermal power. Specifically, we:

- Present a simple method to correlate Nome diesel prices to benchmark crude oil prices that would facilitate assessing future Nome equilibrium prices given availability of public third party crude oil price projections;
- Describe and simulate the unusual form of price uncertainty engendered by irregular and episodic fuel purchases;
- Assess representative household welfare impacts of displacing modelled volatile diesel fuel with stable-priced geothermal power.

Methods

Nome’s excess generating capacity and slow load growth suggests that contract price should be compared to the existing system’s short-run marginal costs. Although roughly 2.7 MW of installed wind capacity complicates assessment, it turns out that geothermal penetration reduces diesel fuel consumption essentially linearly Vander

Meer and Mueller-Stoffels, 2014). Accordingly, the existing system's marginal costs are reasonably captured by the cost of diesel.[27]

Thinness of market complicates assessment of future diesel prices. The NJUS receives 1-3 barge deliveries of diesel fuel during the ice-free season. This inventory sets diesel costs for the year. Negotiated during the winter, delivered prices typically reflect a 3-day average published indexed product price at the time of refinery lift, plus some negotiated margin to cover expected distributer costs and profit (Bristol Bay Native Association, 2013). At most three distributers compete to supply Nome's need. (Wilson et al, 2008)

The remainder of this section describes methods used to model future Nome diesel price paths given the data.

Price Levels

We use OLS to regress Alaska North Slope West Coast (ANS WC) crude oil spot prices on Nome product prices:

$$Pdiesel_t = \alpha + \beta(Poil)_{\hat{t}} \qquad (1)$$

Here $Pdiesel_t$ is the product price per gallon at delivery date t, as recorded by invoices on file with the Regulatory Commission of Alaska; there are 16 observations between 2003 and 2013. $Poil_{\hat{t}}$ is the 3-day moving average ANS WC price per barrel on dates 25 or 35 days prior to t, reflecting respectively average time of transport between refinery lift and delivery to Nome for early and late-summer deliveries (A. Morris, personal communication, 12/17/2013). $Poil_{\hat{t}}$ are calculated from data available from the Alaska Department of Revenue's Tax Division web site (http://tax.alaska.gov/programs/oil/index.aspx). Crude and product prices are adjusted to 2013 dollars using CPI-U. US DOE projections of annual oil prices are then run through the OLS parameter estimates to obtain equilibrium Nome product price projections. Effective prices paid by consumers reflect 2% uplift for the cost of financing bulk fuel purchases with commercial paper.

Price Volatility

Annual volatility of electricity prices is modelled as a function of diesel fuel volatility. Diesel price volatility is simulated as a linear function of crude prices, conditional on the OLS parameter estimates linking diesel and crude oil prices. Two price volatility components are modelled.

First, we address year-to-year volatility by assuming a mean-reverting Brownian motion process for crude oil prices. ANS WC crude prices are modelled as:

$$d\ln(P_{t+1}) = \eta(\mu - \ln(P_t) - \frac{\sigma^2}{2\eta})dt + \sigma dW_t \qquad (2)$$

where P_t and P_{t+1} are prices for time t and time t+1, η is the mean-reversion rate, σ is a measure of volatility, μ is the logarithm of mean price to which the process converges, and W_t is a Brownian motion. Following Dixit-Pindyck (1994), we obtain parameter estimates for (2) by using simple regression to estimate its discrete form:

$$\ln(P_{t+1}) - \ln(P_t) = (1 - e^{-\eta\Delta t})\mu - (e^{-\eta\Delta t} - 1)\ln(P_t) + \varepsilon_t \qquad (3)$$

That is, we estimate

$$\ln(P_{t+1}) - \ln(P_t) = \alpha + \beta\ln(P_t) + \varepsilon_t \qquad (4)$$

To recover

$$\mu = -\frac{\alpha}{\beta} \qquad (5)$$

$$\eta = -\ln(1+\beta) \qquad (6)$$

$$\sigma = \sigma_\varepsilon\sqrt{\frac{2\ln(1+\beta)}{(1+\beta)^2 - 1}} \qquad (7)$$

Parameter estimates are based on annual ANS WC price data for 2003 through 2013. This coincides with the public availability of NJUS invoice data, and broadly captures a period when real oil price levels and movement have substantially departed from prior dynamics.

Second, we address the product price volatility caused by Nome's small number of erratic deliveries within a year. That is, limited sampling from the daily price process – 1-3 realizations per year, taken during the summer – creates additional annual price volatility that is worn by consumers for the entire year. We non-parametrically model this variability as follows.

The 3-day moving average ANS WC crude price path generates an "implied" Nome diesel price path. For each day in a given summer season – May 15 through September 20 (the chronological end-points for product lifts associated with invoiced deliveries) – we calculate the percentage price difference from that year's implied mean diesel price. Aggregating these percentage differences across all years generates a dimensionless distribution of daily differences from annual mean prices.

Household Welfare Effects

Given knowledge of future equilibrium crude oil prices, and of power purchase terms, Nome households' expected present value of displacing diesel with geothermal power could readily be calculated. Lacking knowledge of either, we focus on the degree to which stochastic diesel prices create variability in household electricity expenditures.[28] Risk-averse consumers should value reduced variability that geothermal power could bring. We rely on the foregoing characterization of diesel price volatility to develop measures of associated power cost volatility.

Diesel price movements are translated to household expenditures given data on NJUS fuel consumption and assuming perfectly inelastic electricity demand. (While extreme, estimates of rural Alaska demand lend support towards the assumption of perfect inelasticity. (Villalobos Melendez, 2012) This may be due to extant conservation efforts encouraged by high costs and comparatively low income.) Household expenditures on the diesel portion of

[27] While reduced diesel run-time could also reduce generator overhaul and maintenance, interviews with utility management

[28] Experience with making and applying them erodes confidence in the accuracy of any long-term oil price projection. Price volatility however seems an inescapable fact of life (even if its magnitude may not be stationary).

NJUS electricity costs are the residential sector share of total sales. Data for Nome sector power sales, as well as its annual total diesel fuel consumption, were taken from annual Power Cost Equalization program reports (e.g. Alaska Energy Authority, 2013).Household diesel expenditure changes are modelled using Monte Carlo simulations of 10,000 trials. Price paths generated by (2) are augmented by multiplicative shocks drawn from the seasonal and refinery lift non-parametric distribution. Central tendencies of household expenditure risk is measured by the coefficients of variation of the present value of expenditures over the course of Nome's contractual obligation (e.g., 20 years), and of expenditures within a single (year 3) year. The first measure incorporates information on the full expenditure time path; the second better indicates the magnitude of the shocks that a household must manage in any given year.

Results

The model, (1), linking Nome diesel prices to crude oil prices yields statistically significant parameter estimates but leaves unexplained much of the diesel price variation.

Table 1: Diesel Price Model

Parameter	Coeff	T statistic
Intercept	1.30	2.33
Poil	.0206	3.39
		R square = .47

The parameter estimates enable translation of US Energy Information Administration's (EIA) projections of crude oil prices into Nome's equilibrium diesel prices and, given generator efficiency, costs per kWh. (Figure 1) EIA brackets their "reference" projection with high and low price scenarios. (EIA, 2013)

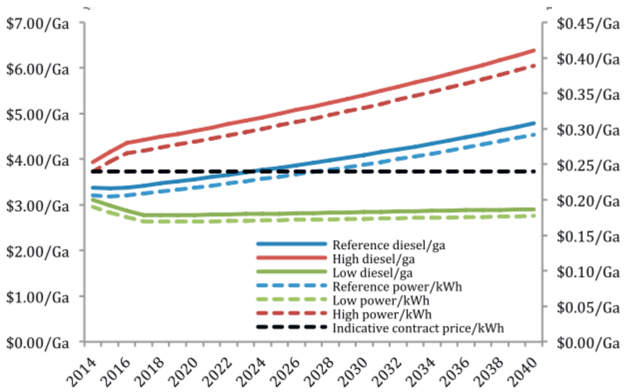


Figure 1: Implied real equilibrium Nome diesel prices and kWh costs given EIA oil price projections, with indicative power purchase price/kWh as reference. price paths that broadly capture price dynamics that reasonably resemble the recent past.

The distribution of percentage "shocks" associated with seasonal variation and episodic refinery lift dates is both fat-tailed and skewed. (Figure 2)

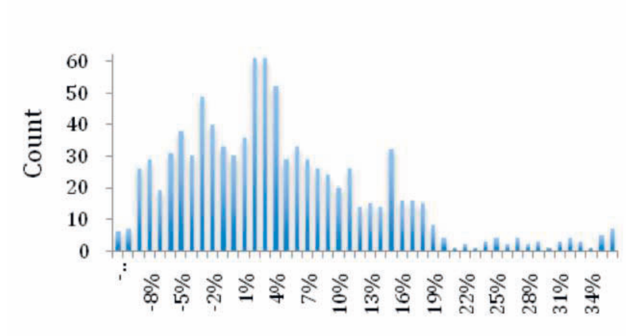


Figure 2: Truncated histogram (2%, 98%); Summer 3-day moving average ANS WC percentage price differences from yearly means, 2003-2013.

Incorporating such shocks into the annual stochastic price paths generated by (2) increases apparent volatility of modelled diesel prices. (Figure 3)

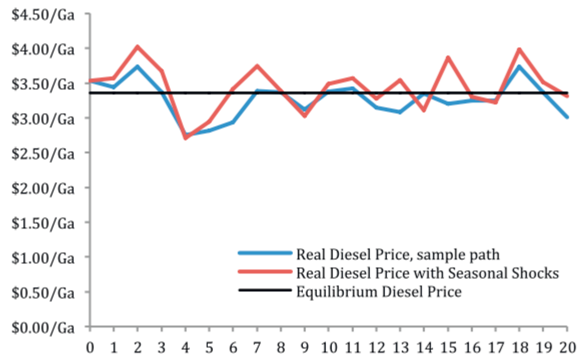


Figure 3: Sample Monte Carlo paths showing annual mean-reversion Brownian motion, and effect of seasonal and lift-date shocks, on modelled diesel prices.

The seasonal, episodic lift-date shocks affect household expenditure uncertainty. If 2 MWe of geothermal power were connected into the Nome grid, the average household would have to pay for roughly half of the approximately 367 gallons of diesel now annually consumed. At a 4% discount rate the expected present worth of displaced fuel rises from $10,730 to $11,013 if seasonal-lift shocks are considered; the coefficient of variation (CV) of expenditure present worth rises from 4.56% to 4.84% – a 6% relative increase.[29]

The CV of household expenditures in a given year is significantly greater than for the present worth of 20 years of expenditures. This is owing to the non-linear telescoping effect of discounting on future-year expenditure differences. The price process (2) generates a CV of 11.77% – more than double the full-path figure. Adding seasonal and lift date variability further increases the CV to 13.47% – an increase of 14%. The standard deviation of yearly household expenditures in this latter case exceeds $86, and the difference between P98 and median

[29] The CV was essentially unchanged when calculated at discount rates of 2% and 6%.

expenditure levels exceeds $217. (Figure 4)

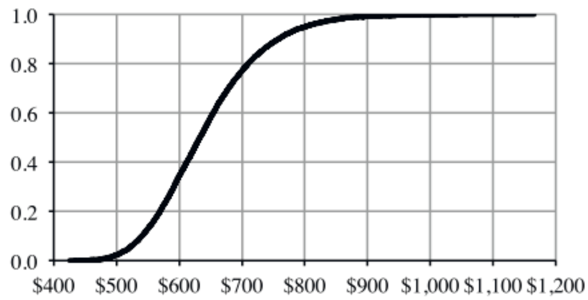


Figure 4: Cumulative probability function of single-year representative household expenditures for diesel fuel

The cost of diesel volatility is linear in the quantity of fuel displaced. It is therefore worth noting that the reported measure of household responsibility for displaced diesel fuel – 184 gallons – is a lower bound, conditional on 2 MWe of geothermal power. If local residents are ultimately responsible for the cost of electricity used in community or local government facilities, then average household cost responsibility might be as much as 310 gallons.

Discussion

A linch-pin of this work's precision rests in the correlation of limited Nome diesel-price data with ANS WC crude oil prices. Unfortunately, the regression explains a substantially smaller portion of diesel price variation than when more and better data are available. The simple specification in (1) typically explains about 95% – almost twice what we find here – of the variation in product prices when correlating several years of daily NY Harbor #2 and marker crude prices (Wilson et al, 2008). This might be due to errors in variables. Fuel invoices to not indicate the precise period between a given delivery and its date of lift, which if known would allow selecting the contractually-correct daily crude prices. Alternatively, a relatively large portion of Nome's diesel prices may reflect negotiated outcomes in imperfectly competitive markets, rather than the distributer's cost.

Even so, the value in this work lies less in prediction than in providing a framework to inform decision makers as to a logically-consistent set of possible stylized outcomes. Since 2003 NJUS managers have experienced only 16 diesel price transactions. The resultant ambiguity makes evaluation of alternatives difficult.

If commodity prices evolved smoothly, Figure 1 might capture the relevant information for Nome decision makers. But one of the more compelling aspects of the potential addition of geothermal power lies in the opportunity to reduce volatility in Nome electricity prices. Characterizing that volatility directly is difficult, but diesel price volatility (Figure 3) has bearing on purchase power contract value. Indeed, reducing diesel expenditure volatility (Figure 4) may be particularly relevant in smaller communities where households have fewer economic opportunities to absorb price shocks. To our knowledge this is the first attempt to quantify diesel price risk in remote places that receive only a few, highly episodic deliveries per year.

More work remains. An obvious extension would be to graft the risk framework developed here to EIA or other structural model projections of oil prices. This would result, in essence, in a model with a "mean"-reversion term that drifts towards the equilibrium projection path.

Even more, research is needed on measuring the value that remote rural residents place on the volatility of diesel price expenditures to which they are exposed. Comparing measures of central tendencies of volatility, especially against median or average incomes, generates results that are underwhelming. A standard deviation in expenditures of $86 seems small, even against the P20 Nome household income of $35,000. But it is one thing to describe the distribution of potential diesel price outcomes in a given year (Figure 4); it is another to understand how residents value that uncertainty.

Acknowledgements

This work was supported in part by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, under Award # *DE-SC0004903.*

References

Alaska Energy Authority. (2013). Statistical Report of the Power Cost Equalization Program, Fiscal Year 2012. Anchorage, AK: Alaska Energy Authority.

Bristol Bay Native Association (2013). Bristol Bay Bulk Fuel: Purchasing Potential and Interest in a Cooperative Buying Program. Fairbanks, AK: Information Insights.

Dixit, A. & R. Pindyck (1994). *Investment Under Uncertainty*. Princeton, NJ: Princeton University Press.

Doogan, Sean. 2013. Geothermal could be key to figuring out Nome's costly power problem. *Alaska Dispatch*. September 23, 2013. Retrieved from http://www.alaskadispatch.com/article/20130923/geothermal-could-be-key-figuring-out-nomes-costly-power-problem

Holdmann, G., D. Benoit, R. Daanan, A. Prakash & C. Haselwimmer (2013). Summary: Pilgrim Geothermal System Conceptual Model. Fairbanks, AK: The University of Alaska Fairbanks.

Vander Meer, J.B. & M. Mueller-Stoffels (2014). Wind-Geothermal-Diesel Hybrid Microgrid Development: A Technical Assessment for Nome, AK. *In review*

Villalobos Melendez, A. (2012). Aligning Electricity Energy Policies in Alaska: Analysis of the Power Cost Equalization and Renewable Energy Fund Programs (Master's thesis). Fairbanks, Alaska: University of Alaska Fairbanks.

Wilson, M., B. Saylor, N. Szymoniak, S. Colt & G. Fay (2008). Components of Delivered Fuel Prices in Alaska. Prepared for the Alaska Energy Authority, Anchorage: University of Alaska Anchorage Institute of Social and Economic Research

Barriers and solutions to the development of renewable energy technologies in the Caribbean

Philipp Blechinger (philipp.blec hinger@rl-institut.de)
Reiner-Lemoine Institut, Ostendstrasse 25, 12459 Berlin, Germany

Katharina Richter (katharina.richter@rl-institut.de)

Abstract

Despite large amounts of readily available renewable energy (RE), island states in the Caribbean are still heavily dependent on mostly imported fossil fuels for their energy production. Making use of empirical analyses, this paper explores the barriers to the development of RE for power generation in the Caribbean, an d outlines a strategy of how to overcome these barriers. Semi structured interviews with three "super-experts" serve to supplement the findings of a preceding literature review. Approximately 30 experts are consulted to confirm and rank the identified barriers to RE according to their importance. The end-product of this study is a ranking matrix that will serve as a strategy instrument for decision-maker, who are then able to prioritize barriers and initiate their removal.

Introduction

Despite large amounts of readily available renew able energy (RE) in the form of wind and solar, hydro power, geo-thermal or biomass, 97% of the Caribbean's energy production is based on largely imported fossil fuels (ECLAC & GTZ, 2004; ECLAC, 2009; CREDP, 2 010; IDB, 2011). As a result, high electricity prices, energy poverty and grid connectivity issues are coupled to both the challenge of the region's projected increase in population and thus energy demand (Insulza, 2008), as well as to the challenge of mitigating the potentially severe effects of climate change of the Caribbean island states. Despite recent RE promotion efforts throughout the region, more drastic measures are required to re move existing barriers and achieve CARICOM's set goal of a 20% renewable electricity capacity share by 2017 (CARICOM, 2013). This paper sets out to explore the diverse barriers and their solutions to the use of RE for electricity production in the Caribbean today, thereby focusing on islands only, and excluding Cuba.

Research Objectives

The aim of this paper is to elicit the barriers to the development of RE for the electricity sector on Caribbean islands, and to rank them according to their importance. While different geographical and political circumstances affect overarching regional analyses, this paper uses empirical analysis to identify and categorize barriers to RE into a framework that can be applied by decision makers within Caribbean islands. Where as much work has been done on the barriers to RE in general (Painuly, 2 001, Verbruggen et al., 2010), only one academic study (Ince, 2013) has focused on this specific region. The identified four main categories of barriers are technical, economic, political and social constraints (Blechinger, 2013; Negro, Alkemade & Hekkert, 2012). The contribution of the present paper consists of an elaboration on these barriers, and the development of rating matrix that includes a strategy on how to prioritize and initiate their removal.

Thus the central questions pursued are the following:

- What are the barriers to the development of RE in the Caribbean?
- Which are the most important barriers?
- What measures can be implemented to overcome these barriers?

Methods

In order to answer these questions, a three- fold analysis is performed. Firstly, a literature review of peer-reviewed papers and reports leads to the existing expertise on barriers to RE and the challenges to sustainable electricity production in the Caribbean.

Secondly, a qualitative survey serves to more closely elicient current difficulties in the implementation of RE. To this end semi-structures interviews were conducted with 3 "super experts" who have diverse and extensive professional experience within the Caribbean energy sector.

The interviewees approached are associated with the Caribbean Electric Utility Services Corporation (CARILEC), the Caribbean Community Secretariat (CARICOM) and the DeutscheGesellschaftfür Zusammenarbeit (GIZ). The latter organization looks back on more than ten years of project experience in the Caribbean, and was heavily involved in the Caribbean Renewable Energy Development Programme (CREDP). While the results from the preceding literature review serve as an interview guide, the open character of the qualitative research process ensures balancing the insights for the interviews with the outcomes of the literature review. A mere confirmation of the latter is thus avoided. Consequently, the interviews are followed by an alteration of the list of barriers. The aggregation of the results of these two steps culminates in a list of 31 detailed barriers.

They are subsequently weighted empirically through another round of questioning. Via email an /or telephone, 30 experts from the private and public sector, utilities, international organizations (IOs) and academia were presented with a questionnaire containing the list of barriers, and were asked to rank them on a Likert scale from 5 to 0 (cf. Figure 1).

5	4	3	2	1	0	Z
Highest importance	High importance	Moderate importance	Low importance	Very low importance	Absolutely no import.	Don't know

Figure 1: Likert scale

To allow for more in-depth interpretation, the questionnaire contains a comment section for the participants to further elaborate. The low number of samples is balanced with a careful selection of experts, thus ultimately ensuring empirical validity.The summation of the weightings finally permits a detailed clustering of the barriers, whereby the mean of the responses is evaluated for both the separate stakeholder groups, as well as for the overall sample size. The end-product of this paper is a rating matrix of the identified and categorized barriers and sub - barriers. Since the ranking follows the importance and impact of the barriers, this matrix serves as a strategy instrument to allow for their removal by political and economic decision makers. In this regard, this paper will advance the implementation of RE in the Caribbean and thus contribute to the region's energy security, access and sovereignty, as well as the diversification and decarbonisation of its energy production.

Results

The first step of the research produced a list of 32 barriers to renewable energies in the Caribbean, grouped into the aforementioned four broad categories. While the bulk of the analysed literature pointed in the general direction of the single barriers and aided in the formulation of the key and supporting questions of the interviews, it was the crucial information extracted from the responses of Mr Williams (CARICOM), Mr Homscheid (GIZ/CREDP) and Mrs Jean (CARILEC) that allowed for the creation of a thorough list of Caribbean-relevant barriers to RE. Literature on barriers to renewables on small island states, for example, frequently mentioned natural barriers such as limited availability of natural resources or land as restriction to the implementation of RE (IRENA 2012, Ince 2013, del Río 2011). Since the former found no mention in the interviews, it was dropped out the list, while the latter was modified as barrier to be included as "Land use competition on islands". Homscheid (2014) illustrates this by saying "[l]and is available but it comes with certain problems. You can't put up a wind farm in the midst of a hotel development area." As Williams highlighted both the risk averseness of commercial banks, as well as the lack of evidence-based assessments of RE potentials as barriers to their funding and implementation, these two aspects were included in the list. According to Homscheid (2014), there is no "study that was looking at the complex economics comparing one vs. the other [RE], looking at the scaling effect."

In the literature, efficiency constraints of RE technologies were given high priority as a barrier to their development (Ince 2013; Timilsina, Kurdgelashvili, & Narbel 2012; Painuly 2001), yet could not be confirmed in the interviews, leading to their exclusion from the list. A significant social barrier frequently pointed to in the literature was the consumer resistance to RE, and their preference for the status quo (Reddy & Painuly 2004 Painuly 2001, Verbruggen et al 2010, Sovacool, 2009, Ince 2013). However, the interviews indicated that consumers were mostly concerned with high electricity prices (Jean, Williams 2014), and possibly in favour of RE if they lead to their reduction. The second step of the analysis thus altered the list, e.g. by incorporating ′"short terms of procurement contracts" (ECLAC/GTZ, 2004) into other financial barriers, while adding "strong fossil fuel lobby" as social barrier.

Table 1 represents the barriers as listed in the questionnaire. The questionnaire is available for download from the Reiner-Lemoine Insitute's website (2014), and contains a detailed description of the individual barriers.

Table 1: Unranked barriers to RE in the Caribbean

i)	**Technical Barriers**
1.1.	Natural Conditions
Land use competition on islands	
1.1.2.	RE impact on landscapes and ecosystems
1.1.3.	Natural disasters
1.1.4.	Lack of evidence-based assessment of RE potentials
1.2.	Technical Constraints
1.2.1.	Lack of technical expertise and experience
1.2.2.	Low availability of RE technologies
1.3.	Infrastructure
1.3.1.	Inappropriate transport & installation facilities
1.3.2.	Unsuitable transmission system and grid stability issues with decentralised RE
2.	**Economic Barriers**
2.1.	Price/cost
2.1.1.	High initial investments
2.1.2.	High transaction costs
2.1.3.	Diseconomy of scale
2.2.	Financial Aspects
2.2.1.	Lack of access to low cost capital or credit
2.2.2.	Lack of understanding of project cash flows from financial institutions
2.2.3.	Lack of private capital
2.3.	Market Failure/distortion
2.3.1.	Utility monopoly of production, transmission and distribution of electricity
2.3.2.	Small market sizes
2.3.3.	Lock-in dilemma (conventional energy supply structures block REs)
2.3.4.	Fossil fuel subsidies and fuel surcharge
3.	**Political Barriers**
3.1.	Policy
3.1.1.	Gap between policy targets and implementation
3.1.2.	Lack of incentives or subsidies for RE
3.2.	Institutional Capacity 3.2.1. Lack of formal institutions
3.2.2.	Lack of RE experts on governmental level
3.3.	Regulatory
3.3.1.	Lack of legal framework for IPPs and PPAs
3.3.2.	Lack of regulatory framework and legislation for private investors
4.	**Social Barriers**
4.1.	Consumer Behaviour/awareness
4.1.1.	Lack of social norms and awareness
4.1.2.	Lack of educational institutions
4.2.	Interaction Networks
4.2.1.	Lack of RE initiatives
4.2.2.	Lack of local/national champions/ entrepreneurs
4.2.3.	Strong fossil fuel lobby
4.3.	Cultural
4.3.1.	Dominance of cost over environmental issues 4.4. Psychological/Moral
4.4.1.	Preference for status quo

ECLAC (2009), Arenas (2013), Weisser (2004a,b),Beck & Martinot (2004), ESMAP (2009), Boyle (1994), Unruh (2000), CREDP (2010), Union of Concerned Scientists (2002), Owen (2006), Timilsina, Kurdgelashvili & Narbel (2012), Quadir et al (1995), IEA (2011), LCCC (2012)

Within the timeframe of this research, 17 participants responded, none of which were from the governmental sector. The results presented are thus comprised of the answers of six private sector, four utility, three international organization and four academic representatives. Figure 2 shows the overall ranking of all barriers by the four stakeholder groups who participated, in which a to p four under the barriers can be identified.

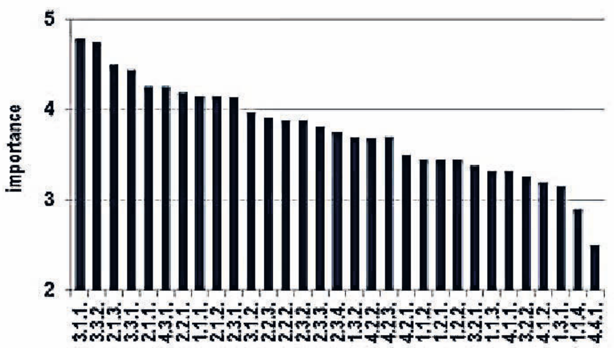


Figure 2: Importance of barriers for all stakeholder groups

The four most important barriers to a l four groups are “gaps between policy targets and implementation”, “lack of regulatory framework and legislation for private investors”, “diseconomy of scale” and “ lack of regulatory framework for independent power producers (IPPs) and power purchase agreements”, respectively.
The four barriers considered least important of all the groups were, beginning with the last one, “preference for status quo”, “lack of evidence-based assessments for RE potentials”, “inappropriate transport and installation facilities” and “lack of educational institutions”.

Analyzing the results for the four stakeholder groups, it becomes evident that representatives of organizations rank 20 barriers with 4 or higher, thus considering these to be of high or highest importance. The participating researchers ranked a total of eleven barriers with 4 or higher. In contrast, representatives of the Caribbean utilities and private sector only consider five barriers to be of high importance or slightly above that.

Another striking aspect when comparing results o f the different groups is that the overall top four barriers have been ranked into the top five barriers of all single stakeholders, except t e organizations. Yet, the organization’s single most important barrier, unanimously ranked with 5 for highest importance is the “lack of access to low cost capital or credit”. Interestingly, this barrier has been ranked tenth with an average importance of 3.25 by the utilities, fourth with an average importance of 4 by the private sector and 23rd with an average importance of 3 (of moderate importance) by the researchers. Noticeable when looking at the latter’s top five ranked barriers however, is the fact that researchers have given an average importance of 4.2 and 4 to two barriers that have not been rated relatively important by the others.

“Unsuitable transmission system and grid stability issues with decentralised RE”have been given an average importance of 3.5 by organizations and utilities, and a mere 2.17 by the private sector, showing second last in their ranking. “Low availability of RE technologies” is of low importance to utilities and private sector with an average ranking of 2 and 2.33 in both groups respectively.

Discussion

Three of the four most important constraints for al l stakeholder groups were political barriers, pointing to the leading role governments must play if they are to achieve CA RICOM’s 20 % renewable electricity capacity share b y 2017. Linking the non-participation of the governmental representatives approached for the study with its outcome is purely speculative, yet a possible indicator of prioritization issues for RE within Caribbean governments, despite their urgency with regards to consumer prices and climate change. The responsibility of overcoming these three barriers lies with the governments, who must provide clear incentives such as feed-in tariffs that guarantee grid access, long-term contracts, cost-based purchase prices etc. Similarly, the “diseconomy of scale” barrier can be overcome by governments making their market sizes attractive to investors, or alternatively enabling the creation of a single Caribbean- wide market.

Organizations are much more skeptical about the success of RE and rate about four times as many barriers of high importance than he private sector and utilities have done.

The results expose a clear discrepancy in the perception of the barriers to RE within the different stakeholder groups.

Consequently, single problems cannot be isolated , inevitably further impeding concrete action to remove these difficulties. Furthermore, the results reflect the distance of most IOs to actual RE project implementation.

Crucially it is IOs who have a mandate to enable or even to fund these projects. The negative feedback from their lack of understanding of issues on the ground with regard tothe lack of external support for both public and private sector RE initiatives results in delaying a higher RE share in electricity production in the Caribbean even more. The study thus highlights the clear need for engagement of public (funding) organisations with the private sector, IPPs and utilities, who ultimately implement RE projects. This study moreover reveals the huge need for improving the dialogue and interplay between research and industry, as well as the communication between utilities, private sector and researchers in the Caribbean. Like their counterparts from the IOs, the representatives of academia have demonstrated a similar trend in rating many barriers as very important. Moreover, they have prioritised barriers that were not perceived to be important by the other groups at all, which points to severe communication probems between those who areimplementing RE projects on the round and academia. Again, a lack of mutual understanding impedes the developm ent of RE.

Despite low actual RE shares, utilities have expressed confidence in developing RE by rating relatively few barriers of importance, which on the one hand, might be a reflection of their monopolistic position in the market. On the other hand, the private sector seems t o confirm this issue by including the utilities’ monopoly market distortion in their top five barriers. However, both groups clearly call for a stronger legal regulatory framework in order to enable a higher RE share. By rating transaction costs and diseconomy of scale among their top five barriers, utilities furthermore indicate the need for an external actor to step in and mitigate the effect. In doing so, governments need work with the utilities and to provide incentives for private sector development.

Apart from identifying the key barriers to the development of RE in the Caribbean, the seminal contribution of this paper lies in pointing out the systemic, overarching lack of communication and mutual understanding between the RE key players. Its removal lies at the heart of a high RE share, and with that cheaper electricity prices and an environmentally sustainable and independent energy supply.

References

Arenas, D. (2013). *Transition to Renewable Energy in theSmall Island Developing States of the Caribbean.* Master Thesis, Faculty of Technology, Policy and Management, DELFT University of Technology, Netherlands.

Beck, F. & Martinot, E. (2004). Renewable Energy Policies and Barriers. *Encyclopedia of Energy*, 1–22.

Blechinger, P. (2013). Regional and structural differences of barriers to implement renewable energies: Implications for less or least developed countries. *Proceedings of the International Conference Micro Perspectives for Decentralised Energy Supply* (pp.56-59). Berlin, Germany: Technische Universität Berlin, Zentrum Technik und Gesellschaft, Promotionskolleg Mikroenergie-Systeme.

Boyle, S. (1994). Making a renewable energy future a reality: Case studies in successful renewable energy development. *Renewable Energy*, 5(2), 1322-1333.

Del Rio, P. (2011). Analysing future trends of renewable electricity in the EU in a low-carbon context. *Renewableand Sustainable Energy Reviews,* 15, 2520-2033.

CARICOM (2013). *Caribbean Sustainable EnergyRoadmap (C-SERMS), Phase 1: Summary and Recommendation for Policymakers,* http://www.caricom.org/.

CARILEC. http://www.carilec.com/.

CREDP (2010). *Analysis of the Potential Solar EnergyMarket in the Caribbean,* http://credp.org/.

ECLAC and GTZ (2004). *Renewable Energy Sources inLatin America and the Caribbean: Situation and Policy Proposals,* http://www.cepal.org/default.asp?idioma=IN.

ECLAC (2009). *A Study on Energy Issues in theCaribbean: Potential for Mitigating Climate Change,* http://www.cepal.org/default.asp?idioma=IN.

ESMAP (2009). *Latin America and the Caribbean RegionEnergy Sector: Retrospective Review and Challenges.* Technical Paper 123/09, www.esmap.org.

Homscheid, S. (2014). Personal communication, February 3rd, 2014.

IDB (2011). *Renewable Energy Best Practices inPromotion and Use for Latin America and the Caribbean.* Capital Markets and Financial InstitutionsDivision, Discussion Paper No. IDB-DP-190, www.iadb.org.

IEA, (2011). *Renewable Energy: Policy Considerationsfor Deploying Renewables.* November 2011,www.iea.org.

Ince, P.D.M. (2013). *Drivers and Barriers to theDevelopment of Renewable Energy Industries in the Caribbean.* Doctoral Dissertation, Department ofGraduate Studies, University of Calgary, Canada.

Insulza, J.M. (2008). Energy and Development in South America. in C.J. Arnson, C. Fuentes and F.R. Aravena (Eds.), *Energy and Development in South America:Conflict and Cooperation.* Washington, D.C.: WoodrowWilson International Centre for Scholars.

IRENA (2012). *Renewable Energy Profiles Caribbean.* September 2012, www.irena.org.

Jean, A.A. (2014). Personal communication February 17th, 2014.

LCCC (2012). *Energy Policy and Sector Analysis in theCaribbean 2010-2011.* Available athttp://www.ecpamericas.org/data/files/Initiatives/lccc_c aribbean/LCCC_Report_Final_May2012.

Negro, S. O., Alkemade, F., & Hekkert, M. P. (2012). Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable andSustainable Energy Reviews*, 16(6), 3836–3846.

Owen, A. D. (2006). Renewable energy: Externality costs as market barriers. *Energy Policy*, 34(5), 632–642.

Painuly, J. P. (2001). Barriers to renewable energy penetration; a framework for analysis. *RenewableEnergy*, 24(1), 73–89.

Quadir, S.A., Mathur, S.S. & Kandpal, T.C. (1995). Barriers to dissemination of renewable energy technologies for cooking. *Energy ConservationManagement,* 36(12), 1129-1132.

Reddy, S. & Painuly, J. (2004). Diffusion of renewable energy technologies: barriers and stakeholders' perspectives. *Renewable Energy*, 29(9), 1431–1447.

Reiner-Lemoine Institute (2014). *Publications,* February. http://reiner-lemoine-institut.de/sites/default/files/140218_re_caribbean_quest ionnaire_blechinger_richter.pdf

Timilsina, G.R., Kurdgelashvili, L. & Narbel, P.A. (2012). Solar Energy: Markets, economics and policies. *Renewable and Sustainable Energy Reviews,* 16, 449-465.

UNDP/GEF (2011). *Final Evaluation CREDP.*http://web.undp.org/gef/.

Union of Concerned Scientists. (2002). *Barriers toRenewable Energy Technologies* (pp. 1–11). Cambridge,MA. Retrieved from http://www.ucsusa.org/clean_energy/smart-energy-solutions/increase-renewables/barriers-to-renewable-energy.html?print=t.

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy* 28, (March), 817–830.

Verbruggen, A., Fischedick, M., Moomaw, W., Weir, T., Nadaï, A., Nilsson, L. J., Nyboer, J., et al. (2010). Renewable energy costs, potentials, barriers: Conceptual issues. *Energy Policy*, 38(2), 850–861.

Weisser, D. (2004a). On the economics of electricity consumption in small island developing states: A role for renewable energy technologies? *Energy Policy,* 32(1), 127-140.

Weisser, D. (2004b). Costing electricity supply scenarios: A case study of promoting renewable energy technologies on Rodriguez, Mauritius. *RenewableEnergy,* 8, 1319-1347.

Williams, J. (2014). Personal communication January27th, 2014

Scientific Papers

VII. Microfinance

How to Scale Up Green Microfinance? A Comparative Study of Energy Lending in Peru

Natalia Realpe Carrillo (natalia.realpe@microenergy-consulting.com)
MicroEnergy International
Potsdamer Str. 143, 10783 Berlin, Germany

Abstract

Among the green microfinance initiatives, energy lending still appears to lack long-term sustainability, and therefore remain difficult to up-scale. In the rollout of these programs, implementing a two-hand model approach – where microfinance institutions (MFIs) partner with energy suppliers – becomes a challenge for both parties. Obstacles entail the access to technical assistance, and the development of efficient supply chains and profitable business models. In this paper, a comparison of the energy diversification process – from a pilot phase towards a large commercialization – of the Peruvian MFIs *Fondesurco* and *CMAC Huancayo* is presented, highlighting their experiences, challenges and discusses opportunities to build from their lessons learned in order to innovate green microfinance.

Keywords: Energy lending; two-hand model; up-scaling.

Introduction

Green microfinance, microfinance services addressing the triple bottom line – impacting at the economic, social and environmental level, entails a variety of internal or external actions that MFIs undertake with the common denominator of environmental preservation. In particular, *energy lending* aims at enhancing access to clean energy by offering credit for modern energy technologies. The portfolio diversification into energy represents an opportunity to extend the market and to reach vulnerable communities in need of accesses to finance and/or energy. However, profitable business models have not yet been validated on a large scale.

Energy lending programs worldwide vary in engagement strategies, product offerings and service delivery models. Parkerson (2005) differentiates three credit sale forms: the lease purchase model, the dealer credit model '*one-hand model*' and the end-user credit model '*two-hand model*'. While in the first two models one organization assumes the delivery, financing and maintenance of the systems, in the two-hand model, through strategic partnerships, the responsibilities between the MFIs and the energy suppliers are clearly divided. For the initiation of such energy lending programs, MFIs are rather attracted to develop strategic partnerships with energy companies, instead of incurring heavy organizational changes or assuming the entire supply chain of the technologies by themselves (MicroEnergy International and PlaNet Finance, 2010).

In such partnerships, MFIs require the motivation and the abilities to channel capital into loans for energy, as well as a high capacity to assume the largest risk, as green loans are built upon the linkage between the microfinance and energy sectors (Rao et al. 2009). Therefore, engaging in these initiatives requires strategic decisions from the MFIs' management and operational capacities, as well as full support from the energy companies (Morris et al. 2007). Indeed, given the right stakeholder constellation, capital, interests, and favorable external conditions, this approach has potential to succeed.

A comparative analysis of two energy-lending programs implementing a two-hand model approach is presented in this paper, displaying the variety of challenges both institutions face in reaching scale. Since 2011, the Peruvian NGO *Fondo de Desarrollo Regiona*l (Fondesurco) and the *CMAC Municipal de Ahorro y Crédito*, (CMAC Huancayo) have diversified their portfolio by incorporating energy-lending among their financial services. Both green microfinance programs have been supported with financial and specialized technical assistance. Through partnerships with local energy companies, both MFIs are offering tailored "green loans" in the south and center of Peru. Driven by their social commitment and their aim to differentiate themselves from their competitors, after the conclusion of the pilot projects, *Fondesurco* and *CMAC Huancayo* are scaling up at varying paces.

Objectives

Why is it difficult to scale-up? The ability of the MFIs to foresee and tackle market obstacles is required in order to overcome the challenges of disbursing green loans. Financially sustainable returns, and institutional and operational capacity to manage energy programs, both at the head office and branch levels are needed in order to achieve viable business models (Levaï et al., 2011). Moreover, one of the most constraining factors for MFIs engaging in green initiatives is the access to technical expertise and knowledge in order to establish new management and operational procedures (Allet, 2011).

On the other hand, local energy companies have limited access to funding and technical assistance (Kebir et al. 2013). In particular, challenges entail the set-up of the distribution networks and the adaptation to a long-lasting relationship with the client. In order to guarantee a reliable supply of products, the local expansion of energy services into the working areas of the MFIs requires well-built distribution capabilities (Levaï et al., 2011). Given the differences between their infrastructures and business models, achieving balanced partnerships is crucial to success of this two-hand model.

The comparative analysis of *Fondesurco's* and *CMAC Huancayo's* energy programs aims at understanding, from a practitioners point of view, how to address these obstacles – e.g. acquiring technical assistance, developing right supply chains and developing profitable business models for both parties, identify the challenges involved, and highlight opportunities moving forward to scale-up the two-hand approach.

Background

In 2010, the Luxembourgish NGO *Appui au Développement Autonome* (ADA) and the German consulting company MicroEnergy International (MEI), agreed to jointly develop and implement a green microfinance pilot, supporting MFIs to integrate energy services or products into their portfolio. As a first step, a *Microenergy Atlas*[30]was developed, in which Peru was identified as one of the countries with the greatest potential. An increasingly competitive micro-finance market and a well developed market for clean energy technologies made Peru an ideal environment to initiate an energy and financial inclusion program. Among the shortlisted MFIs, *Fondesurco* and *CMAC Huancayo* were finally selected in October 2010. Moreover, the local support of the project Energy, Development and Life (*Energía, Desarrollo y Vida*) from the GIZ (EnDev/GIZ Peru) was identified as local technical partner in order to support implementation and evaluation of the programs. The MFIs' size, culture, experiences and structures largely differ from each other, utlimately influencing the energy program development.

Fondesurco, operating in southern Peru, was recognized as one of the most innovative and customer-oriented MFIs in the sector and was ranked in first position due to its high motivation to launch a structured large-scale pilot project. By 2010, besides serving a rural client base with high-energy needs, *Fondesurco* had experience in financing a solar home system for a household and a solar thermal system for an eco-tourism hostel, assuming high risks with informal agreements with suppliers.

The portfolio diversification became an opportunity to attract new and potentially cheap sources of funding (Casal, 2012)[31]. Despite the fact that donor pressure to achieve financial sustainability might limit MFIs' ability to innovate and experiment with new products (Hall et al., 2008), *Fondesurco,* following its intrinsic social mission, conducted the energy lending program, and perceived it as a way to offer a differentiated service in an increasingly competitive market (von Wolff & Phalpher, 2014).

CMAC Huancayo, covering almost a fourth of the country, demonstrated substantial experience with product loans for hardware products such as housing appliances and cars valued up to 20,000 USD. Its commercial operations consisted of contracting a network of suppliers and facilitating purchases from its clients through product loans. The analysis highlighted the remarkable enthusiasm of the management, the systematic approach for the introduction of new products and the sound experience with suppliers. *CMAC Huancayo* recognized the first-mover advantage in adopting a triple bottom line approach, while the microfinance sector tended to prioritize profit-oriented types of portfolio diversification (Lentz, 2011)[32]. Yet, the political embeddings of the MFI at the management level was recognized as a potential factor that could negatively affect its performance[33].

Greening the MFI

A field study conducted in order to assess the energy needs, expenses and habits of the MFIs' current and potential clients, identified a potential market for solar thermal systems (STS) replacing electric heaters, improved cooking ovens (ICO) reducing in 50% firewood consumption than traditional ovens, and solar crop dryers (SCD) substituting traditional methods for coffee drying[34].

Technologies were selected based on their potential productive use, aiming to meet the micro-entrepreneurs' needs, enabling them to either increase their income or reduce energy expenses (electricity or firewood, with the solar thermal system and improved cooking oven respectively) in the long run. Specifically, the solar thermal systems targeted hostels and rural eco-tourism households; the improved cooking ovens were promoted for restaurants, and the solar crop dryers were selected for both independent coffee farmers and cooperatives.

Both MFIs enabled access to the technologies through the creation of a specific green loan with preferential interest rates: *Fondenergía (Fondesurco)* and *Credieco-lógico* (*CMAC Huancayo*), first offered in few selected pilot branches. *Fondesurco* acknowledged its program as a re-launch of the previous pilot, while *CMAC Huancayo* offered its first green credit product.

Model and Set-up

The energy programs were implemented as *two-hand models*, fostering energy-microfinance partnerships, with the guidance and support of the technical assistance that identified, evaluated and selected the energy service suppliers for each MFI. Initially, after having validated the technologies with specific product testing[35], one supplier per technology was considered, establishing a list of prices and procedures for the piloting regions.

ADA together with MEI supported the MFIs in the elaboration of internal procedures of the two-hand model. High investment costs in the learning process were delegated to both MFIs during the set up of the pilot projects. In order to properly transfer and integrate the methodologies and tools provided by the technical assistance, the MFIs were advised to create a new position of *Energy Technical Advisor* (ETA) in addition to the assigned responsible person of each Department in charge, aimed at

[30] A tool to assess the potential of microfinanced modern energy services based on renewable energy and energy efficiency evaluating the microfinance and energy sectors.

[31] Through a partnership between ADA and the ULB (*Université Libre de Bruxelles*), internships for students of the Master European Microfinance Program at the local MFIs were sponsored. Pierre Casal was awarded a scholarship from May to July in 2012, supporting *Fondesurco* in its initiation of the small commercialization phase.

[32] Ibid. Caroline Lentz assisted *CMAC Huancayo* in the implementation of the pilot project from May to July 2011.

[33] As a public institution, stability of the management positions largely depends on the municipal elections and political agreements, which influence personnel rotations.

[34] Only for *CMAC Huancayo*

[35] Laboratory tests, contracted by EnDev/GIZ, were conducted at the *National University of Engineering of Lima* and the *University of San Agustín* to validate the ICOs and STS, while a technical study conducted by the *National Institute of Agricultural Innovation* compared the performance of the SCD with traditional drying methods.

enabling the MFI to manage the supply chains. *Fondesurco* hired an ETA after two months, at *CMAC Huancayo*'s an ETA was enrolled after more than a year, close to the end of the pilot phase.

The ETA coordinated the credit disbursement process as well as the aftersales services provided such as customer satisfaction follow-up, programmed visits and complaints handling, as well as the planning, project monitoring and knowledge transfer from the technical assistance. The ETA reduced the amount of tasks traditionally allocated to the suppliers, including the technical assessment of potential clients, the organization of order placements and the logistics coordination with the supplier for the delivery/installation of the technology (Lentz 2011; Casal 2012). The extended role of the MFIs in the supply chain management surpassed the expected responsibilities in a two-hand model approach. The engagement of the MFIs to assume a larger role in the supply chain was crucial to the functionality of the programs.

The pilot phase began in June 2011 and concluded in April 2012 for *Fondesurco* and September 2012 for *CMAC Huancayo,* turning into a small-scale commercialization phase. The scaling-up phases aim at including additional branches and new technologies. In this second stage, technical assistance focused particularly on the supply chain reinforcement and on the selection, evaluation and validation of new technologies.

Challenges

The Peruvian energy market and the willingness to participate among players have catalyzed innovation in green microfinance, despite the relatively high costs and limited revenues for the MFIs. However, both MFIs faced a series of challenges in the scaling-up process, related to their structure and their capabilities to innovate and adapt their processes to client needs.

Green Loan Disbursement

Fondesurco. The disbursement of the green loans involves a significant amount of work for low credit amounts (Casal, 2012). Compared to the average loan size of 1.811 USD, the *Fondenergía* ranges from 300 to 1000 USD, with limited portfolio profitability. The lack of a proper incentive structure hinders the motivation of loan officers to promote the *Fondenergía*[36]. Nevertheless, the value of differentiation in a competitive market has prevailed and promotional activities have been widely undertaken.

CMAC Huancayo. Cash sales at the exhibitions affected the motivation of loan officers to promote the green loans, which focused on the sole add-ons of the credit, such as the level of after-sales service, the validation process of the technologies and guarantees offered (Lentz, 2011).

Institutional Commitment

Fondesurco. The integration of energy lending represented a high-risk diversification. Given the correlation between the technology and the MFI reputation risk, the quality of the technologies and of the supply chain play a major role. This institutional awareness motivates the organization to adapt the green loan disbursement in a learning-by-doing process. However, more efficient and systematic processes are needed in order to scale-up.

CMAC Huancayo. Despite the incentive structure designed for the loan officers – initially planned only for senior officers, and offered for the first time for a specific product at the institution – the awareness raising campaign for loan officers required as much effort as the one directed for clients. Following the recommendations of the pilot evaluation[37], the complexity of the loan disbursement has been reduced, and a systematic calendar of trainings and exhibitions has been established in half of the agencies selected for the expansion of the program. Nonetheless, the MFI requires larger commitment at the operational level and better coordination skills from the energy suppliers.

Supply Chain Design

Fondesurco. Each pilot branch was organizing its own supply chains, conducing technical assessments of interested clients. However, the considerable involvement of *Fondesurco* might not be sustainable on a larger scale. A close collaboration with suppliers is needed in order to manage the complexity of the value chain and to establish sustainable partnerships (Casal, 2012). The functioning of the supply chain has been stabilized through measures such as *Fondesurco*'s financing of improved cooking ovens manufacturers[38] and EnDev/GIZ's technical support to maintain a minimum stock.

CMAC Huancayo. The main challenge regarding solar water heaters has been the need for local installers to support the selling process. Concerning the ICOs, a relatively new technology in the market, the manufacturers faced serious challenges in the expected quality of the systems. Moreover, due to the absence of ETA during the pilot phase, despite the rigid structure and restricted flexibility of *CMAC Huancayo*, loan officers had to coordinate the delivery and installation of the devices. Finally, external risk factors, such as the coffee disease "*roya*", affected the business of the SCD and the overall portfolio of this market segment.

Client Response

Fondesurco. Despite the great customer acceptance and satisfaction, and the excellent performance of the portfolio (zero default rate), energy lending was uncommon for both the clients and the partner energy enterprises. Hence, major efforts have been required from the MFI side in order to raise awareness of the benefits of the technologies.

CMAC Huancayo. Due to a less mature market for STS, larger efforts were needed for promotional campaigns. Moreover, a change of suppliers of the ICOs was needed

[36] A project evaluation – contracted by ADA – was conducted in 2012 by *COPEME*, a Peruvian microfinance network and consultancy company.

[37] COPEME Evaluation (2012).

[38] Kebir et al. (2013) explain how MFIs tend to be the only formalized institutions able to lend to the customers of energy SMEs or small informal local distributors. In this case, being *Fondesurco* the financer of the supplier, the risks of its energy portfolio is intensified.

due to quality issues, and the higher price set by the new supplier did not match the willingness to pay of the customers, requiring further promotional activities.

Empowering Green MFIs

Characterized by sourcing equipment and maintenance services from local suppliers, two-hand model projects have a strong focus on local market development and capacity-building measures, prioritizing productive energy uses to promote local business activity. Through the systematic implementation of their green microfinance programs, *Fondesurco* and *CMAC Huancayo* continue to adapt their businesses and operational models to their required conditions and capabilities. This case study is limited to the specificities of the support provided by the financial and technical assistance to both MFIs. Further research on two-hand models underlying the role of energy partners shall be conducted to counterbalance these results.

The outcome of this study identifies the following ways forward towards a successful scale-up for policy makers and practitioners in the field of green microfinance.

External support for MFIs and Energy Partners

Considering the costs and the risks entailed in the experimentation of new business models, the necessity of external support to launch green microfinance programs is apparent, at least in the start-up phase. The financial assistance from ADA since 2010 and REEEP in 2013, as well as the technical assistance from ADA, MEI and EnDev/GIZ, has been essential for the MFIs, from the pilot until the small-commercialization phase, and in the implementation of the scale-up structures, particularly in the reinforcement of the supply chain, the validation of new suppliers for the existing products and the inclusion of new technologies in their portfolios. Furthermore, a special follow-up of the energy partner on its growing business solidifies not only the emerging energy market, but also paves the way for the success of the green microfinance businesses.

Consolidation of green programs within MFI internal structure and governance

Formalized internal structures facilitate decision-making processes, a strict execution and monitoring of project plans. This allows, on the one hand, the internalization of the know-how transferred from the technical assistance and the building of internal capabilities, and on the other hand, the ownership to react with strategic decisions in the business development. The ETAs enrolled at *Fondesurco* have been promoted within the institution, strengthening the role of the R&D department in the green activities. This shows how *Fondesurco* has been able to capitalize on the established structure of the green program. At *CMAC Huancayo*, the only ETA enrolled since 2012, despite several changes of champions, has gradually assumed further responsibilities for the coordination of the energy program. Within its internal structures, *CMAC Huancayo* adapted its financial product to ‘credit destination’, allowing loan flexibility to access energy technologies, as well as getting a lower interest rate depending on the chosen and fit loan category.

Capacity building and empowerment process

In the transition towards large-scale commercialization, the technical assistance shall focus on capacity building and the ‘autonomy’ process for both MFIs. This entails support in introducing new technologies and providing the necessary technical tools to develop the respective business plans, assess energy needs and market size, and design efficient supply chains.

References

Allet, M. (2011). *Measuring the environmental perfor-mance of microfinance.* CEB Working paper N. 11/045.

Casal Ribeiro, P. (2012). *Can micro-financing green energy be sustainable? A case study of Fondesurco, Peru*. Master thesis ULB (European Microfinance Programme).

Hall, J.C., Collins, L., Israel, E. and Wenner, M.D. (2008). *The Missing Bottom Line: Microfinance and the Environment. Green Microfinance*. SEEP Network Social Performance Working Group. Social Performance MAP

Hart, S. L. (2011). *Taking the Green Leap to the Base of the Pyramid. Next generation business strategies for the base of the pyramid: New approached for building mutual value*. New Jersey: FT Press. Pages 79-102

Kebir, N., Spiegel, N., Schrecker, T., Groh, S., Scott, C. and Aliaga, G. (2013).*Exploring Energy SME Financing in Emerging and Developing Countries.* Sustainable Business Institute. Oestrich-Winckel.

Lentz, C (2011). *Case Study on the Integration of Micro-Energy Credits into the MFI’s loan portfolio.* Master thesis ULB (European Microfinance Programme).

Levaï D., Rippey, P., Rhyne E. and Allderdice A. (2011). *Microfinance and Energy Poverty: Findings from the Energy Links Project.* Final Report to AFD (now FHI 360) and USAID under the FIELD Project. Center for Financial Inclusion. Publication No. 13.

Morris, E., J. Winiecki, S. Chowdhard and D. Cortiglia (2007). *Using Microfinance to Expand Access to Energy Services: Summary of Findings.* SEEP Network.

Parkerson, D.J. (2005). Assessing the Potential for Microfinance Institutions to Finance Solar Photovolatic Systems in the Dominican Republic. Working Paper (14). SEEP Network.

MicroEnergy International and PlaNet Finance (2010) Fact Sheet “The Potential of Linking Microfinance & Energy Supply”. 4th Microfinance-Breakfast. UMM, Up Micro Loans. March 4th 2010, Berlin.

Microfinancing decentralized solar energy systems in India: Innovative products through group approach

Satish Pillarisetti
National Bank for Agriculture and Rural Development (NABARD)
C-24, Bandra-Kurla Complex, Mumbai-400051, India
www.nabard.org
satishp99@usa.net

Abstract

The apex development bank in India-NABARD (National Bank for Agriculture and Rural Development) first facilitated the microfinancing scheme for solar home lighting system by rural banks. This turned out to be a success and the government introduced a subsidy linked bank credit programme to upscale and mainstream the programme. Initially the programme met with only a limited success as it had too many loose ends. Later, with a number of modifications, the programme gradually took off and is now making steady progress. However, NABARD realized that there are many areas and communities which may not be able to benefit by this scheme and may need a different financial product. NABARD developed group based products for such communities. These products are based on a partnership with NGOs, and at times involving retail banks. The successful take off of two such products is discussed here.

Keywords: microfinancing; solar home lighting; joint liability groups; self-help groups.

Introduction and background

To address the problems of access to energy in India, one of the missions started by the government of India was the Jawaharlal Nehru National Solar Mission (JNNSM). The mission envisages deploying 20,000 MW of solar power by 2022 of which 2000 MW would be through off-grid applications. A major part of the off-grid applications would be through solar lighting and heating systems supported by bank finance. Modeled on the initiative taken by a regional rural bank in northern India and facilitated by the apex bank for agriculture and rural development-the National Bank for agriculture and Rural Development (NABARD), the government launched a capital subsidy-cum-refinance scheme for installation of solar off-grid (photo-voltaic and thermal) and decentralized applications. The scheme had undergone several changes to improve its implementation which included changes in the pattern of subsidy, financing modalities etc. Later the central bank of the country- Reserve Bank of India was persuaded to include financing of solar home lightning systems also as a part of priority sector advances. Further on the suggestion of NABARD, the government has accepted the proposal to include cooperative banks also in the scheme. The main product in focus has been on the solar home lighting system. Though further action is needed in terms of training and sensitizing the bankers as well as users to upscale it, the programme is now set to take off on an even keel, with nearly 200,000 units financed by banks so far, and a large number in the pipeline.

While the solar home lighting scheme was picking up steady progress, NABARD was receiving constant feedback from NGOs and other field based organizations and its own district level officials that there are a large number of communities and groups which would not be in a position to make of use of this scheme and would require a special dispensation. NABARD utilized two funding arrangements available with it to innovate products for group based financing.

The Rural Innovations Fund (RIF) was a fund created in NABARD with the support of the Swiss Agency for Development and Cooperation (SDC) and was being used to support innovations in rural areas through grant, loan or soft loan. The Umbrella Programme on Natural Resource Management (UPNRM) is a programme of NABARD launched with the funding support of KfW, the German development bank. This programme supports any type of activity which contributes to the conservation of natural resources. Innovative schemes for financing solar lighting systems were launched through Joint Liability Groups (JLGs) in the inaccessible estuarine islands of Sundarbans in West Bengal state and through Self Help Groups (SHGs) in the remote tribal communities of Jharkhand and Bihar states, utilizing the funds available under RIF and UPNRM.

Discussion and results

West Bengal Regional Office of NABARD has covered new ground by financing Joint Liability Groups (JLGs) for solar electrification of school hostels in the remote Patharpratima block which falls in the off grid region of Sunderbans area in the South 24 Paraganas district in the year 2012-13. The villages did not have electricity connection and the girl students /hostellers of the schools, majority of them belonging to backward strata of the community, pursued their studies using kerosene lamps.The families of the hostellers made a contribution of Rs. 2 per day for use of kerosene lamps. A local NGO working in the region in the area of clean environment-Mlinda Foundation motivated the school hostel committee to replace the kerosene lamps with solar LED lights. However the Foundation realized that none of the existing schemes could finance such an activity. This predicament of the NGO came to the notice of NABARD's district level official. After several rounds of exchange of views and discussions between the NGO, parents and NABARD officials at various levels, the conclusion was that a group approach could work and the financing could be done through Joint Liability Groups (JLGs).

A Joint Liability Group (JLG) is an informal group comprising preferably of 4 to 10 individuals coming together for the purpose of availing bank loan either singly or through the group mechanism against mutual guarantee. JLGs can be formed by small and marginal farmers, sharecroppers, microentrepreneurs, small businessmen etc. The members should normally be residing in the same village /area and should know and trust each other. JLG is primarily intended to be a credit group, but group savings may be an optional activity. The quantum of credit need not be linked to savings and no collaterals need be insisted upon by banks against their loans to JLGs. JLGs are formed by facilitators like NGOs or other individual rural volunteers.

The Mlinda Foundation organized the committee members involved in running the school hostels into JLGs. These JLGs then approached NABARD for support for providing solar lights in the school hostels under the RIF. This innovative project was sanctioned to three JLGs of parents and school teachers. The three JLGs covered a total of 172 hostel children and a total of 157 solar powered LED lamps were installed. The total financial cost of the installation in the three hostels was Rs 581,128 of which 50 percent was loan and 30 percent was grant under RIF from NABARD and 10 percent each was the contribution of Mlinda Foundation and the JLGs themselves. With the help of this financial assistance the kerosene lamps being used by school children for studies during evening hours were replaced with solar lights. The lights have been installed with the condition of repayment of loan through contribution from the school children.The responsibility of maintenance of solar lightning system as well as collection and repayment of loan assistance lies with the respective JLGs.

The project is being implemented successfully at ground level in association with the NGO and the loan repayment has already started coming in from the JLGs. For the timely repayment of loan assistance, the JLGs opened their bank account in a nearby bank branch. They used this account to deposit the monthly collection from the school students.The per monthly collection from students was decided on the basis of the number of students and the capacity of solar panel installed for electrification.The total number of students covered under these project in the 3 JLGs was 172 and the per LED unit collection per day from the students was Rs 2.00 in two JLGs and Rs 3.00 in another JLG. This was the amount the students were paying to the school hostel authorities for provision of kerosene lamps. Per student per month collection for repayment was related to the number of units installed in each of the hostels. It was Rs. 62 in one hostel, Rs. 129 in the second and Rs. 106 in the last one. The loan repayment fixed was 2 years for two JLGs and 5 years for one JLG. The project is expected to improve the health of the girls residing in the hostels, reduce absenteeism and provide better environment for students and also save the environment from carbon dioxide generated from the kerosene lit lanterns.

In the same region of Sunderbans another project focused on household solar micro grids through cluster mode of JLGs.As this region is in the estuarine area of the Ganges River, many island areas are cut off from the grid. To address this problem of non-availability of electricity, solar micro grids were financed through community participation in association with the NGO, Mlinda Foundation. The project aimed at replacement of the use of kerosene for lighting purpose by solar energy. The repayment of loan was to be made from savings accrued from non-usage of kerosene for domestic lighting. The business model involved adoption of solar system by community in a financially sustainable manner with huge potential for replication across the rural geographies. Adoption of JLG model in the project aims to incorporate the element of both individual and collective ownership and accountability and also reduction of risk of non-repayment of default.The loan cum grant assistance of Rs. 71,500 was sanctioned to 13 JLGs for installation of solar panels in 13 micro cluster units comprising 7-10 households to provide 3 LED lights points and one mobile charging point to each household of the cluster. The loan component was Rs. 36,000 and grant component was Rs. 35,500. Both the loan and grant support for the project was sourced from the RIF of NABARD. The total loan component for 13 JLGs was Rs. 468,000 and grant component was Rs. 461,500. Mlinda Foundation spent Rs. 8,000 per JLG for formation and nurturing.

The repayment of loan was to be through monthly collection of savings from the non-usage of kerosene by JLG members for lighting purposes. The repayment period was fixed for 4 years.The JLG members proposed to save an additional amount for replacement of battery and maintenance of solar panel. The maintenance of the panels would be the responsibility of each of the JLGs. The project is based on the concept of innovative business model in which end users are enabled for payment of energy services through utilization of amount presently spent on the purchase of kerosene for home lighting purpose. The element of both individual and collective ownership and accountability is inherent in the JLG model and the risk of non-repayment and default is greatly reduced.

NABARD is currently implementing the Umbrella Programme on Natural Resource Management (URNRM) supported by the German development bank KfW. The programme finances a wide range of activities which encourage the sustainable use of natural resources. Financing of a variety of renewable energy projects was taken up under this programme. One such project taken up by NABARD in 2010-11 is situated in Jamui, Chakai and Khaira blocks of Jamui district of Bihar state and Deoghar district of Jharkhand state. The project area is rich in natural resources, but inhabited by poor and marginalized tribal communities. Livelihoods are based on subsistence farming and forest produce. Energy consumption is based on firewood from forest. For the lighting of the homes communities are solely dependent on kerosene lamps. In these communities the solar lanterns alternative was proposed as these communities are extremely backward and would not be able to maintain even if the lower end of solar home lighting systems are financed and supplied. The project was taken up for implementation by a well-known NGO-Association of Sarva Sewa Farms (ASSEFA) through the model propagated under Lighting a Billion Lives (LaBL) programme of The Energy Resources Institute (TERI), New Delhi. TERI, based on its wide expertise and rich on-field experience in energy sector, has initiated the (LaBL) scheme with the mission of enabling a billion lives to access light from solar technologies. The major players in the LaBL scheme are TERI, who has the technology; LaBL Associate who is interested in promoting clean lighting (in the present case, ASSEFA) and LaBL Franchisee (the identified SHGs who will run the units) who will be authorized to set up and manage the solar lantern charging stations.

LaBL model operates on fee-for-service or rental model where centralized Solar Lantern Charging Stations (SLCS) are set-up in villages for charging the solar lanterns and providing the lanterns daily on rent to households and enterprises.A typical SLCS consists of 50 solar lanterns with 5 solar panels and junction boxes.The solar lantern will provide light for 5-6 hours daily using LED lamps on full charge of the battery providing light equivalent of a 40 W incandescent bulb.If operated on dimming option, it will work for 8 hours. The SLCS will be operated and managed by entrepreneurs and are provided hand holding support by LaBL Associate (in this case, ASSEFA).Rent collected by the LaBL franchisee will be used for operation and management of the charging station and a part of the rent will be kept apart for replacement of battery after 18-24 months of operation. TERI provides the requisite training support to both the LaBL Associate and entrepreneurs.

Under this project, 40 charging stations were to be set up across these districts and per charging station 50 solar lamps can be charged. Thus a total of 2000 families are covered through this project. The cost per charging station was estimated at Rs. 175,000 and the total cost for 40 stations was at Rs. 7 millions. Additionally a grant component of Rs. 0.86 million was envisaged for accompanying measures of training and skill building. The contribution by participants was Rs. 0.48 millions. The loan and grant were both advanced by NABARD under the UPNRM programme**.** In each block one project coordinator was appointed to oversee the project activities. The project activities were to be implemented and monitored through women Self Help Groups which have been promoted by ASSEFA in the identified villages. Each charging station would be under the supervision of SHGs and the loans for all members are overseen by the SHG which also maintains a regular record of repayment of loan by members as well as the servicing and maintenance of the charging station. From each SHG, 1-2 women are identified for implementing the project and made responsible for the implementation.

The outcome of the project was to install sufficient lightning in evening and night hours, empowering the women in handling innovative technology, reduce health hazards by preventing in-house pollution, lessen the cost of consumption on kerosene and to provide congenial environment for students and workers to pursue their studies and occupations during the night.Last but not the least, the solar lamps are portable and ensure safety from fire hazards.

However the project did not proceed as planned. ASSEFA has indicated certain issues faced by them during implementation of the project, viz. the project did not gain popularity among the beneficiaries due to low illumination of the lamps and need for regular visits to charging stations.Community was not managing the asset properly – there was no belongingness and ownership and the maintenance was poor. Each charging station was to be looked after by 3 SHGs covering 50 members. This led to diffusion of belongingness and ownership. The villagers were preferring CFL solar lantern with individual charging panel In view of this, ASSEFA has proposed to introduce CFL solar lantern with individual charging panel model in place of LED type solar charging model (LaBL model).ASSEFA has also indicated that the change of activity is possible within the budgeted unit cost approved in the sanctioned UPNRM project.ASSEFA has already covered 250 beneficiaries with LED type solar charging station and CFL lamps will be distributed to the remaining 1750 participants.Thus, the initially envisaged 2000 number of participants will be covered.

The per unit cost of CFL lantern with panel is Rs 2550 compared to LED type (Rs 3500).So the total loan requirement would be Rs 4.46 million as against the balance available at Rs 5.78 million. ASSEFA proposed to utilise the entire grant assistance sanctioned for training the remaining 1750 participants. The physical units covered will be – 250 participants under LED charging station mode and the remaining 1750 participants to be assisted for CFL lanterns with individual solar panels. The total UPRNM loan was revised to Rs 5.34 million. Considering that the coverage of participants has remained the same, the total grant assistance for accompanying measures sanctioned to ASSEFA remains at Rs 0.86 million. In the modified project also the loan administration, monitoring and recovery is to be through Self Help Groups. The maintenance work is also to be overseen by the SHGs.

This project of solar home lightning through CFL lantern with individual charging panel has found a wider acceptance than LED lantern with a link to charging station in the remote areas of these backward states, as these are direct replicas of the kerosene lanterns hitherto being used.

Conclusions

The lessons from these projects can be evaluated only on the basis of MIS being received for both these programme, as there is no other data source. The data received indicates that 93 percent of the units financed are in working condition- though there was a mid-project change in the product in case of Bihar-Jharkhand project. Further all the loans advanced are being serviced regularly in terms both principal and interest, and there are no defaults. These two parameters are sufficient to underscore the fact of the success of these innovative group based finance products. To achieve success in financing this scheme a multi-pronged involvement is required from the side of all stakeholders. The scheme can be grounded only with a public-private partnership where a partner organization takes a major share of motivating and convincing people to ensure their participation.

The mid-course correction in the Bihar-Jharkhand project indicates a poor pre-project community mobilization as well as neglect of peoples' participation aspect by the NGO.

The two JLG based projects in West Bengal demonstrate effective community participation for seeking clean environment and also opened avenues for banks for providing loan to JLGs for non-agricultural purposes. These projects proved helpful in the development of sustainable business models for solar lightning system and showcasing the same to mainstream banks for providing bank finance. Looking at the success of these projects, the lead bank of the area, United Bank of India has adopted the same model for financing solar lighting systems in the off-grid areas through JLGs.

The Bihar-Jharkhand project provided the targeted community an alternate source of energy for lighting purposes on a sustainable basis.The benefits out of the project implementation were better living conditions on account of sanitation, hygiene and health. Kerosene, a non-renewable source of energy is becoming costlier and is going out of the access of the poor and marginalized community. Further, the use of kerosene also has adverse health effects due to the smoke emissions. Solar lighting is providing an environment/ health friendly and cost effective lighting to the poor villagers and uninterrupted study hours for school/ college going children. The project has also increased livelihood opportunities-increase in working hours for the household wage earners – the poor are mainly engaged in *bidi* (country cigarette) rolling, handicraft works, *tassar* (a type of silk) reeling, etc. In Deogarh district, it is reported that an additional earning of Rs 15,000 was made by an SHG of weavers (12 members) within a span of 9 months through increased working hours of weaving activity. In Jamui district, the income of the women who are engaged in livelihood activities such as *bidi* rolling, handicraft works etc. has increased by 30 per cent. Drudgery reduction and health benefits were also reported.

The group based projects affirm to the reality that for large sections of the population at the lower end of economic strata installation and maintenance of solar home lighting systems is not a convenient option due to the time and efforts required for that. In group based projects that responsibility is pooled and handled by a trained and active member of the community. These projects also disprove the conventional theories that the poor require subsidized loans and subsidized interest rates. In all the projects though a possibility of subsidy availability from the government was there the beneficiaries went ahead with the projects without waiting for the subsidies from the government. In the West Bengal project the interest rates on the loan was at 12 percent and in Bihar-Jharkhand project the rate charged was 13 percent. Both these interest rates were market rates and were well above the average base rates charged by commercial banks. This implies that it is a potential bankable activity for bank credit on commercial terms and market related rates. If banks are not able to look at this opportunity and expand their business with rural clientele one has to doubt their business sense. Based upon these successful projects NABARD should bring on board all banking institutions, especially regional rural banks and cooperative banks to introduce such group based financing schemes in their institutions to mainstream and upscale the financing of such variants of solar lighting systems. There is a vast untapped potential in rural India for these projects irrespective of grid connectivity as even in areas connected with grid, the power supply is highly erratic with regular shutdowns and outages.

Further research demands

This paper studies the manner in which the projects were conceived, the innovative features of the projects and the early results of their implementation, based on available MIS. As such it not a rigorous analysis based on comprehensive data sets. Therefore the outcome of these projects has to be studied in a more comprehensive manner after a reasonable time frame of 2-3 years. The mid-project product change in one of the projects could be an interesting issue for research on the intricacies of community mobilization. The objective reasons for success could be documented in detail.The benefits of the scheme, with a wide-ranging sample, could also be studied at a later date. It would be worthwhile for the technical aspects of the installed systems to be studied for their performance and utility after a period of, say, 3-5 years.[39]

[39] Notes

The currency used in the paper is Indian Rupee with the notation Rs. The exchange rate in the period 2010-11 to 2012-13 ranged from Rs 52 to Rs 60 per 1 US $.

The data and information used in the paper are based on the project proposals submitted by the NGOs, sanction letters issued to NGOs by NABARD, MIS from the NGOs, Annual reports of NGOs- Mlinda Foundation and ASSEFA and Annual Reports of the National Bank for Agriculture and Rural Development for the years 2010-11, 2011-12 and 2012-13.

Innovative Energy Access for Remote Areas: "The LUAV-Light Up a Village" project

Izael P. Da Silva[1](idasilva@strathmore.edu), Eliza Hogan[2](eliza@barefootpower.com), Benard Kalyango[2](benardk@barefootpower.com), Anne Kayiwa[2](annek@barefootpower.com), Geoffrey Ronoh[1](gronoh@strathmore.edu), Clint A. Ouma[1] (arthurclint@gmail.com)
Affiliation: 1. Strathmore Energy Research Centre
2. Barefoot Power Pty Ltd

Abstract

The Light-up a village (LUAV) program is a rural development initiative designed to improve access to modern energy solutions in remote areas of developing countries. The initiative addresses the challenge of Pico PV market penetration by empowering rural communities to actively participate in lighting up their own villages using micro-solar systems.

The LUAV business model was designed by an energy company, Barefoot Power (BFP), which began the LUAV field in 2012 in Uganda. The program incorporates local SACCOs and Community Based Organizations (CBO) as well as local governmental bodies in the identification and recruitment of participants. A LUAV program is designed to involve at least 100 households per community by providing each home with its own power generation solar system to run lighting and mobile device charging services. The participating households are given the option to either pay for the micro solar power system upfront or to pay for it in 3 to 12 monthly installments.

For this pilot program, BFP sourced for funding from private investors to operate a revolving fund which is managed the SACCOs and CBOs who have the mandate to manage debt recovery and keep the revolving fund active.

Through this business model, 18 LUAV projects were implemented in Uganda during the 18 month trial period providing lighting and mobile charging services to 3,000 plus households. The program's success has a growing interest and plans are underway to replicate it in South Sudan, Rwanda and Kenya in 2014.

Keywords: Micro-Solar Systems; Rural Village Electrification; Revolving Fund.

Introduction

In East Africa, the majority of the rural population (80% to 90%) (Asamoah, 2013) has no access to electricity. People light their homes with kerosene or candles, which produce inefficient light quality with poor illumination levels of about 1% to 10% the recommended levels; in addition, these light sources pose several health risks to the user such as burns, respiratory ailments and blurry vision among others (Mills, 2012).

Furthermore, it was found that the fuel based lighting systems are an expensive source of light (Miller et. al 2013) with some studies reporting savings of up to 400% in households that completely replace their kerosene lamps with solar lanterns (GIZ, 2010). Finally, in most rural communities, the people have no means to charge their mobile phones other than through central charging stations, which charge high prices and are often located far from their homes. Introduction of the solar lighting systems with phone charging options not only reduces the user's costs but provides an income generation avenue by charging the neighbors to use the service which was the case with about 70% of the users in a study carried out in Uganda (GIZ, 2010).

Solutions for these energy related problems have emerged in recent years. Solar powered LED home lighting and phone charging equipment is available throughout East Africa although rural penetration is about 4% (Lighting Africa 2012). These products provide a safer, more cost effective alternative for rural communities over the typical energy sources mentioned above. However, there are three main challenges limiting the accessibility and uptake of these energy solutions by rural off-grid communities;

- Affordability: The modern energy products have high upfront costs
- Consumer Awareness: Lack of trust and knowledge about the benefits of good quality solar products.
- Technical Expertise: Good quality installation and continued product service is not available

Research Objectives

The LUAV program has been designed as response to three main challenges experienced when supplying lighting solutions to rural off grid populations as mentioned in the introduction of this document.

The main research question in this study would be **to** find out whether installing community micro-solar lighting/ charging systems is a viable way to increase electricity penetration in rural villages. Specifically the study aims at:

ii) Evaluating the willingness and ability to pay for solar lighting systems when presented as a community project as well as preferred payment period/method
iii) Evaluate viability and scalability of the revolving fund in providing upfront capital for system installations.
iv) Evaluating the receptiveness of the people to the technology and ease of awareness dissemination in the community setting
v) To evaluate whether technical support is easier to deliver through community members or by technicians from BFP.

Additional Research

The Strathmore Energy Research Centre, SERC, is currently working with development partners to carry out additional research into the sustainability and scalability of the LUAV business model. In this, the long termsocio-economic impact of each LUAV as well as the opportunities and potential for replication in other developing countries is the main focus. As a result of the positive uptake of the LUAV in Uganda, SERC is working closely with BFP, the energy company, in its venture to replicate the program in South Sudan, Rwanda and Kenya in 2014. The main questions for research in addition to the current existing questions are listed below.

1.2. To evaluate the socioeconomic and lifestyle changes of residents within the successful LUAVs by comparing those who took up the system and those who did not participate in the program.
1.3. To evaluate the replication and scalability of the LUAV model by comparing the experience in Uganda with Kenya, Rwanda and South Sudan.

Figure 1: Installation of LUAV micro-solar systems in a village by Barefoot Power Uganda

Method

One of the main challenges of Pico PV market penetration in rural Africa is the lack of consumer awareness (Asamoah 2013). The first step in awareness creation for the LUAV program involves the identification of local NGOs, CBOs, SACCOs, community members, community associations and local government bodies or officials who will be willing and able to partner with the energy company in the implementation of the LUAV program. BFP evaluates each group and negotiates mutually beneficial partnerships towards the implementation of LUAV programs.

These partnerships are developed with the aim of raising support to recruit a minimum of 100 households per community who are ready to reduce or stop kerosene usage for lighting within the community by purchasing a micro solar system. It has been reported that local authenticity is one of the main success factors for new businesses in Africa (Accenture 2009). Local authenticity is developed by investing in local expertise and training the local people to run the activities on the ground. The partnerships with local CBOs and SACCOs increases local acceptance and makes the people more receptive to the product and LUAV program.

Once a community has been educated and is ready to take up a LUAV project, the energy company revaluates the participating CBOs or SACCOs within the community to determine which one is most suitable to carry out the project implementation tasks and trains the members in the project procedures. Next, the energy company makes arrangements to finance the LUAV; in the early stages, BFP financed the venture by putting together a revolving fund from private investors, who initially believed in the concept. Today this process involves multiple stakeholders such as the SACCO member's deposits, NGOs donations, crowdfunding, and savings groups.

The identification of a credible and reliable CBO/SACCO is crucial to the success of the project. This is because the CBO or SACCO plays the important roles such as managing community promotional campaigns, registering participating households, identifying community entrepreneurs, planning installations, and coordinating product repayment. This is done so that the energy company can focus on its main role of provision of reliable and relevant products, development of awareness campaigns and marketing strategies, continual evaluation of the CBO competence and training of users and local technicians to participate in product installation and maintenance.

The question of product affordability is addressed by the development of financial models that will allow the program participants to pay for the micro solar systems in installments. Although the financial models vary from case to case; the basic structure is that the systems are to be paid for upfront by the SACCO/CBO who thereafter collects the payment from LUAV participants.

In the case where a revolving fund is raised by an outside source, the community has to return it within an agreed time period (normally 12 months). Though, in some cases the source of the funding may allow for it to be utilized as a revolving fund to continue the initiative. The CBO is controlled by a clear MOU that ensures the funds are exclusively used for the LUAV. The CBO will manage the collections of the monthly installments of the households. After 12 months, all collections of installments will have regenerated the revolving fund at the CBO level, ready to finance the next LUAV. The products will also be priced to with 10% to 20% margins required for sustainability.

To ensure that the CBO is successful in the initiative, they share in the profit margin to pay for the management of the initiative. This money can be shared among group members or utilized to buy assets for the group.

In May 2013, BFP was able to partner with, a crowdfunding organization to be a financing partner for the revolving fund. This loan is interest free and the borrower has 14 months to pay back. These funds will enable BFP to scale up the LUAV program to three countries.

Once the financial aspects and payment collection processes have been set in place for the LUAV implementation, the CBO will register the participating households, upon which BFP values the systems and deploys technicians to install the micro-solar systems on the houses of each participant. The installation is carried out parallel to a technician training program to make technical assistance available to the LUAV participants. The local technicians will handle basic questions and trouble shooting of system challenges and the BFP technicians would visit the LUAV only to deal with major faults.

The product of choice in the LUAV program, shown in Figure 2, is known as the Connect 600 from BFP. It consists of a 6Wp polycrystalline panel with a 4 Ah AGM sealed battery and 4 LED lights which give light for a minimum 6 hours once fully charged. Additionally two USB output allows for charging mobile devices such as phones and tablets. A 12 Volt output provides for radio or fan powering. Every unit comes with a standard two year warranty. The systems currently retail for about 130 USD.

Figure 2: BFP Connect600 which is the micro system utilized in the LUAV project.

Results

The LUAV program relies heavily on partnership building within the local eco-system as well as national and global partnerships. In the beginning, partners were difficult to engage without a proven model. On the other hand, the communities were willing and enthusiastic to engage with Barefoot Power to take on the eradication of kerosene and supporting renewable energy as the main source of energy in their community. Over the last two years new partners have committed once seeing the preliminary positive results. Currently LUAV is actively engaged with partners such as WWF, CARITAS and GIZ and national governments to expand to new countries such as Rwanda, Kenya and Ghana.

At the end of 2012/2013 trial period, BFP had completed 18 LUAV projects. These projects resulted in 3000 plus households purchasing solar home systems.

These 18 completed projects counted on the support of partnerships with 11 NGO's, 3 SACCO's and one faith based organization. Furthermore, the initiative was supported by the Ugandan Rural Electrification Authority (REA) and the local governments in each village.

It was found that only one out of the 18 projects had not completed repayment of their micro solar systems within the stipulated 12 months and the default were due to the unreliable services of the CBO involved in that particular LUAV.

Although the projects were designed to cater for at least 100 households per community some projects had as low as 28 households while others exceeded the expectations and had up to 500 households signing up and successfully paying for the systems. Table 1 shows a summary of the results obtained from the first 14 LUAVs installed in Uganda, all payments were collected in duration of 12 months.

Table 1 Summary of the results for the first 14 LUAVs installed in Uganda.

	Name of Project	**Partner and/or CBO**	**No of HHs**	**Month Started**
1	Kiprotich Village – Kapchorwa	BFPU/ MESICS	100	Jul-12
2	Buswiriri LUAV – Bugiri	CARITAS-JINJA/ MESICS	120	Jul-12
6	Kasese (LUAV) – Kasese	Karambi Sacco/ WWF/MESICS	70	Dec-12
8	Kyabarungira Sacco – Kasese	Kyabarungira SACCO	90	Dec-12
13	Kalalu – Iganga	Mivule/ Solar Link s	162	Dec-12
14	Friends of Nature – Kasese	Friends of Nature/ WWF	28	Dec-12
10	Okabi – Arua	GIZ/ Barefoot/ Community	130	Feb-13
11	Fofo – Nyo	GIZ/ Barefoot/ Community	132	Feb-13
4	Tororo LUAV1 – Mbale	CARITAS-Tororo/ MESICS	500	Jun-13
5	Tororo LUAV2 – Mbale	CARITAS-Tororo/ MESICS	500	Jun-13
12	Kiwani – Iganga	Mivule/ Solar Link s	140	Aug-13
3	Maddo LUAV- Masaka	CARITAS-Masaka/ MESIC S	300	Sep-13
7	Kiyinda LUAV – Mityana	Kiyinda-Mityana Diocese	200	Sep-13
9	SOS Children's Village – Fort Portal	SOS Children's Villages	100	Nov-13
	Total		**2,572**	

Findings

The LUAV program has proven its success in Uganda due to the low delinquency rate and number of successful LUAVs. The findings of the research are currently being used to evaluate the expansion options into the neighboring countries of Kenya, South Sudan and Rwanda. Through the LUAV program, the research team reported the following findings;

1. A 12 month payment period for micro solar systems is considered affordable in rural Uganda. The payments were between 10 and 20 USD per month and the delinquency rate was less than 10%.
2. Community Based Organizations (CBO's) play an important role in facilitating the projects. The sustainability of such a project has been found to depend heavily on the CBO's ability to manage the local aspects of the project including addressing the

community concerns and managing the finances involved at the community level (Da Silva et al., 2011).

- Offering installation services in addition to the technology reduces failure rate of systems and provides an opportunity to build local technical capacity
- Local partnerships build brand trust and loyalty in African markets. The element of local authenticity helps to overcome the adverse effects of market spoilage and other challenges such as cultural relevance, product education and peer influence (Savannah Fund, 2013).
- Financing partners, institutions were more willing to fund the project once it was clear that they would be dealing with groups of users, SACCOs and CBOs rather than individuals. This makes it easier for accountability, to follow up payments and provides better control mechanisms such as the tracking and documentation of the project's success rate.
- The project yielded low default rates as the members of the group encourage each other to complete payments through peer influence consequently reducing the risk of delinquency due to the individual human factors. As a result, only one out of the 18 LUAV projects launched had cases of delinquency.
- Strict criteria are necessary when selecting the CBO that will partner with the energy company to carry out the project implementation. Criteria of competence must be established by the energy company for each case. This is necessary because each community is different in terms of socioeconomic activities, cultural tendencies and social make-up.
- In the LUAV trial period the collection of payments by the CBO proved to be a major bottle neck in the project development. There is need to consider the implementation of a Pay As You Go technology which would support, manage and track the revolving funds without incurring extra man power expenditure especially with the rapid increase in number of CBOs, SACCOs and villages that stand to take up the LUAV program.
- The efficiency of the solar technicians trained under the LUAV program will not be fully measurable until the two year product warranty period expires. It is worth noting that there are currently no accreditation criteria or institutions for solar technicians in East Africa. However, once the criteria have been established, the energy regulatory bodies and certifying authorities will be able to extend training services in remote areas through the existing LUAVs.

Scaling Up

The LUAV builds on the BFP Reverse Rural Electrification Model described by Da Silva & Sloet (2012) and promotes the notion of decentralized energy generation and distribution. This will have major long-term implications on the considerations of energy policy makers.

To ensure scalability of the LUAV program, BFP developed strategic partnerships with local governments which in turn led to the rapid adoption of the LUAVs in Uganda. These partnerships were set up to gain the authorization, endorsement and support of community leaders who would assist in the mobilization of the community to participate in the program. Led by enthusiastic government officials and popular community leaders, the recruitment of new members went beyond the initial expectations resulting in the recruitment of up to 500 participant households in some LUAVs such as Tororo LUAV 1 and LUAV 2.

The next initiative currently in its initial stages is to partner with local telecommunication companies in the marketing and promotion of the LUAVs as well as financial support. The telecommunication companies have an interest in the penetration of mobile phone charging technologies for rural areas in Africa as these technologies would increase the use and penetration of mobile phones. Leveraging the interest of telecommunication companies and mobile phone service providers is expected to improve the LUAV uptake rate further in remote areas.

References

Accenture (2009). *Expansion into Africa: Challenges andSuccess Factors Revealed.* [Online] Available from: http://www.accenture.com/SiteCollectionDocuments/PDF/Accenture_Strategy_Expansion_into_Africa_POV.pdf.[Accessed: 10/03/2014]

Asamoah, N. (2013). *Catalyzing Markets for ModernLighting*. *GVEP ESME GRANTS*. Lighting Africa: www.lightingafrica.com

Mills, E. (2012). Health Impacts of Fuel-based Lighting. *3rd International Off-Grid Lighting Conference.* Dakar, Senegal

Miller, C. et al. (2013). *Trust, Demand and Last MileDistribution: The Role of Head teachers in Building Africa's Market for Portable Solar Lights.* [Online]Available from: http://www.solar-aid.org/assets/Uploads/Publications/Small-PV-Conference-Paper.pdf.[Accessed: 04/12/13]

Lighting Africa. (2012). Lighting Africa Market Trends Report 2012. Overview of the Off-Grid Lighting Market in Africa.

GIZ. (2010). *Solar Lamps Field Test Uganda FinalReport*. [Online] Available from: https://energypedia.info/images/7/72/GIZ_Solar_Lamps_field_Report_Uganda_Webversion.pdf.[Accessed: 27/01/2014]

Savannah Fund (2013). *The Challenges and Opportunitiesof Start Up Marketing in Africa.* [Online] Availablefrom: http://www.savannah.vc/blog/2013/03/16/the- challenges-and-opportunities-of-startup-marketing-in-africa/.[Accessed: 10/03/2014]

Da Silva, I. P. & Sloet, B. (2012). *Barefoot power lightsup rural Africa.* [Online] Available from: http://www.mercatornet.com/articles/view/barefoot_p ower_lights_up_rural_africa.[Accessed: 17/01/2014]

Da Silva, I. P., Njuguna, P., & Njogu, M. (2011). *RuralElectrification using off-grid Solar PV powered Energy Kiosks.* Nairobi, Kenya

Scientific Papers

VIII. Lighting

How big is small? Enough to not breathe oil!
The Peruvian case of diesel-fuelled wick lamps for lighting

Angel Verástegui Gubler (angel.verastegui@giz.de)
Deutsche Gesellschaft für Internationale Zusammenarbeit – GIZ Energising Development Peru
Pje. Bernardo Alcedo 150
San Isidro – Lima 27
Perú

Verónica Pilco Mamani (veronica.pilco@giz.de)
Deutsche Gesellschaft für Internationale Zusammenarbeit – GIZ Energising Development Peru
Pje. Bernardo Alcedo 150
San Isidro – Lima 27
Perú

Abstract

Health risks due to indoor air pollution (IAP) from inefficient domestic burning processes for cooking or lighting are not breaking news. The presence of high levels of sulfur dioxide in burnt wood emissions from traditional cookstoves; its remaining high levels in the air after two hours from turning off the source; and the fact that this gets even worse with an oil-fuelled wick lamp that pollutes almost the same as a second traditional cookstove in the same room for at least one hour each day for 20% of the world´s population, maybe are. This paper shows first evidence from Peru´s rural context in the simultaneous lack of modern energy devices for lighting and cooking.

Keywords: sulfur dioxide; indoor air pollution; dieselwick lamp.

Introduction

Worldwide there are about 1,400 million people without access to electricity (OECD 2010). Of these, it is estimated that 500 million people still use fossil fuels, among them mainly kerosene, to produce light (Lam et al. 2012). In Peru, about three million people lack access to electricity (MEM 2013), so they need to use traditional wick lamps, candles, and/or batteries mainly for lighting.

Unlike in other countries, in Peru no one is using kerosene-fuelled wick lamps because kerosene has been prohibited by law since 2010, since it is used in the production of illegal drugs (narcotics). However, there are many families in rural areas of the rainforest which have replaced kerosene with diesel, using it as fuel for wick lamps.

In addition, almost all families using wick lamps cook in open fires (traditional stoves). The negative impact of traditional stoves in open fires has long been researched; however, there is only thin evidence about the exposure to both indoor air pollutants at the same time.

Research Objectives

This paper aims to study health risks created through exposure to the gaseous emissions produced by diesel-fuelled wick lamps (DFWL), as well as the risk of their simultaneous use with wood burning traditional cooking stoves. The first research question was to discover if the use of DFWL results in high concentration levels of the same dangerous gases that traditional cookstoves produce, mainly particular matter 2.5 ($PM_{2.5}$) and carbon monoxide (CO). In addition, it was tested if the concentration's levels of sulfur dioxide (SO_2) are higher than those recommended by the World Health Organization (WHO) as the highest exposure limits.[40] The focus on sulfur dioxide responds to the concerning about the high level of sulfur that Peruvian diesel has, one of the highest in Latin America as Figure 1 shows.

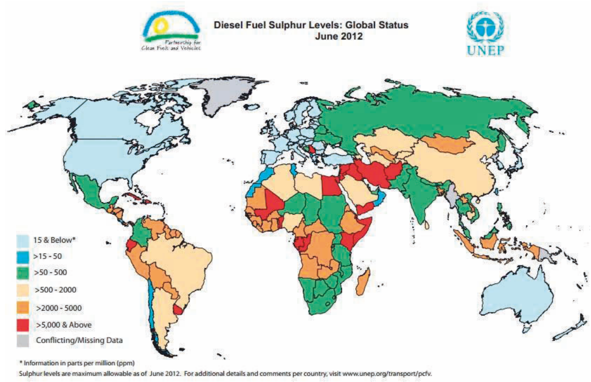


Figure 1: Diesel Fuel Sulfur Levels: Global Status (UNEP, 2012)

According to the Peruvian Environment Ministry (MINAM, 2013), the high content of sulfur in diesel is responsible for an increase in the last three years of SO_2 levels in the air by nearly 500% in the Peruvian capital Lima. The last occurred by stable levels of nitrogen dioxide NO_2 and ozone O_3 in the same time period.

The last research question was to measure the emission's levels of these three gases from DFWL in simultaneous use with a traditional cookstove (3-stone-fire), and to evaluate its remaining levels over time after turning off the sources. The measure of carbon dioxide (CO_2) was only for discovering if there are any health implications regarding its emissions levels in the discussion around IAP, since it wasn't recorded in Peruvian traditional stove test.

[40] SO_2 is one of the most common air pollutants according to the WHO beneath $PM_{2.5}$ nitrogen dioxide (NO_2) and ozone (O_3).

Methods

Two DFWL with different types of wick (Type A: cotton and Type B: old cloth) were collected from households in two different towns in the Amazon area (the provinces San Martín and Amazonas, respectively) and used as polluting sources.

Tests were conducted on indoor air pollutant concentration (CO, $PM_{2.5}$, SO_2 and carbon dioxide CO_2), resulting from the use of two types of DFWL with diesel fuel. These tests were conducted in SENCICO's improved cookstove certification laboratory in Lima.

The environment chosen had a ventilation rate of 4.29 h-1, which was determined with the window and door closed, as recommended by the new protocol for IWA (International Workshop Agreement, GACC 2012) on improved stoves.

During the trials for each type of test, it was intended to homogenize some variables such as:

- initial background measure of all tested gases (30 min.) for setting a baseline of concentrations in the room;
- length of the DFWL test; both types of DFWL A and B were evaluated for 3.5 hours each day on 3 consecutive days during similar hours respectively (D1-D6 for days 1 until 6);
- Similarly, during days D7-D9, the emissions of the traditional stove were evaluated in the mornings alone, and, in the afternoons, simultaneous with the most polluting DFWL according to the results of tests on D1-D6 (type A). The testing time with the operation of both polluting sources was 1 hour;
- after turning off the sources, measure equipment remained on for two hours to evaluate the dispersion speed of the gases;
- infrastructure conditions; the laboratory of SENCICO for IAP imitates a rural house of the Andes, made of mud bricks and typical digasesmensions and for walls and roof;
- fuel; same characteristics of diesel and firewood for all tests; SENCICO´s firewood is standardized for stove tests regarding humidity, wood type and origin;
- technical evaluator; same person for all tests with prior experience in stove evaluations, and
- the approximate level of light emitted by the DFWL; the lighting level should remain constant Durant the tests, so the evaluator pulled the wick during the tests for keeping its light constant)
-

To control the environmental variables that could influence the results of the tests, the Davis Vantage Pro Weather Station was used. This equipment took values for inner temperature of the room (°C), relative humidity (%), wind speed (m/s) and solar radiation (W/m^2). Average values of these units during the evaluation days can be seen on Table 1:

Table 1: Average values of environmental variables during evaluation days.

Average values	D1-D3	D4-D6	D7-D9
Inner temperature (°C)	32.9± 0.4	32.5 ± 1	41.9± 1.8
Relative humidity (%)	56 ± 0.6	54.7± 2.1	42.7± 2.0
Wind speed (m/s)	1.2 ± 0.3	1.3 ± 0.1	1.2 ± 0.2
Solar radiation ($W/m^{2)}$	578.9± 53.9	593.3± 56.5	476.4± 49.5

To measure the concentration of pollutants generated by DFWL, the following equipment was used:

vi) Indoor Air Pollution Meter (IAP, second generation 2012) for measuring $PM_{2.5}$ and carbon monoxide CO.

vii) Aeroqual (NDI sensor and GSE) for the measurement of carbon dioxide CO_2 and sulfur dioxide SO2.

Results

The results on concentrations levels of these gases should be compared to the recommended highest exposure levels made by WHO ($PM_{2.5}$, SO_2 and CO) and by the Occupational Safety and Health Administration (OSHA, CO_2) respectively. These levels can be seen on Table 2.

Table 2: Recommended exposure levels

Air pollutant	Exposure Time	Recommended level (ppm)	Institution
SO_2	10 minutes 24 hours	0.17 ppm 0.007 ppm	WHO WHO
$PM_{2.5}$	24 hours 365 days	25 µg/m3 10 µg/m3	WHO WHO
CO	30 minutes 1 hour	50 ppm 25 ppm	WHO WHO
CO_2	15 minutes 8 hours	30,000 ppm 1,000 ppm	OSHA OSHA

The DFWL type A showed in all test the highest concentration of gases. This DFWL showed the highest fuel consumption with an average of 101 g of diesel versus 55 g for 3.5 hours burning with DFWL type B respectively. All the results listed below are taken from the tests conducted with DFWL type A.

The average PM2.5 levels of the most polluting DFWL was around 10,499 µg/m^3. Figure 2 shows PM2.5 and CO concentration levels on D1 as a characteristic curve for the three days of measurement.

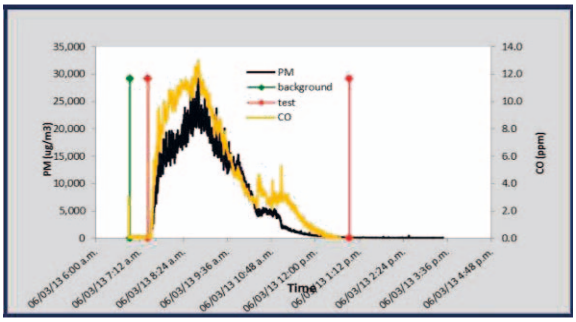


Figure 2: Characteristic curve of PM2.5 and CO for DFWL type A on D1

This concentration of $PM_{2.5}$ particles reaches approximately 60% of the emission levels of a traditional cookstove as the only pollution source, which showed average levels of 15,165 µg/m^3 in this research. The levels of $PM_{2.5}$ for a traditional cookstove as the only pollutant on D7 can be seen in figure 3.

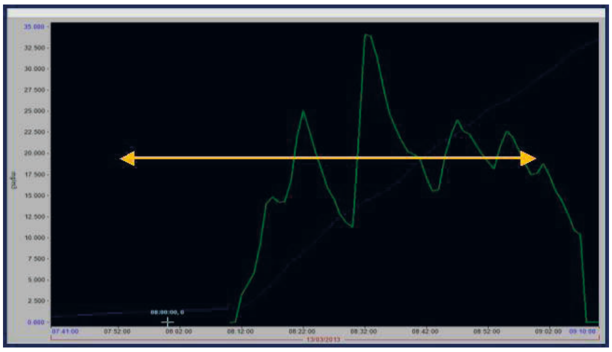


Figure 3: Characteristic curve of $PM_{2.5}$ for DFWL type A on D7

The tests with the same DFWL showed that the average concentration of SO_2 emitted after the first 10 minutes of burning was 1.14 ppm, exceeding almost up to seven times the limit allowed by the WHO for 10 minutes exposure of 0.17 ppm. There were peaks of 1.83 ppm. Figure 4 shows the characteristic curve seen on D3 for SO_2.

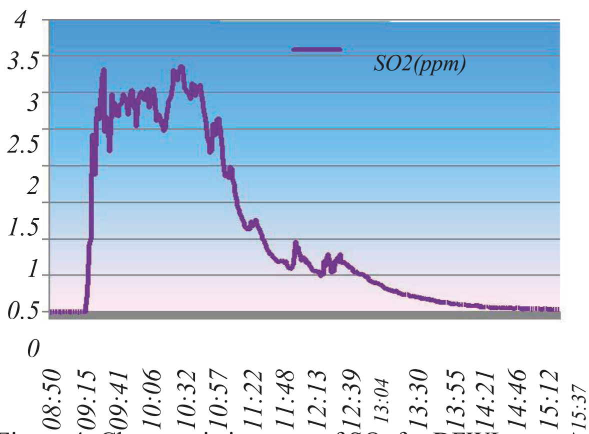


Figure 4: Characteristic curve of SO_2 for DFWL type A on D3

The concentrations of CO and CO_2 from both DFWL didn't show risky levels, neither in tests with only DFWL as with those with the traditional cookstove as well, which can be seen on the characteristic curves in figure 5 and from figure 2 as well.

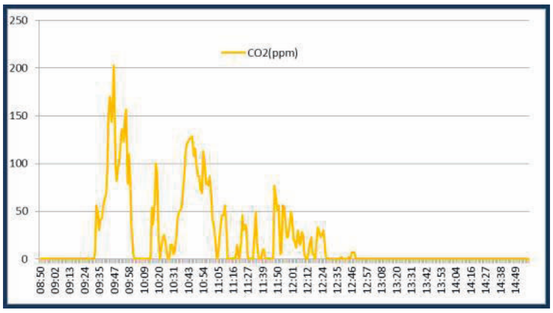


Figure 5: Characteristic curve of CO_2 for DFWL type A on D2

The use of a DFWL simultaneously with a traditional stove regarding $PM_{2.5}$ showed an average level of 19,723 µg/m^3 (with peaks over 43,000 µg/m^3) having an average increase of nearly 30% from the values with a traditional cookstove as the only pollutant. The characteristic curve of the concentration level on D7 with both burning sources can be seen in figure 6.

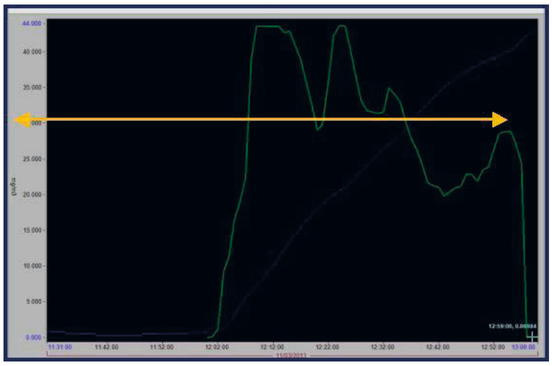


Figure 6: Characteristic curve of $PM_{2.5}$ for DFWL type A and a traditional cookstove on D7

An unexpected result was observed in that a traditional cookstove, as the only source of pollution, reaches levels of sulfur dioxide SO_2 far exceeding the permissible exposure values from various organizations, such as the WHO. SO_2 is not a typical gas taken into account in typical cookstove emission tests.

The intensity of this emissions are so high that they even exceed the maximum possible measurement levels of the instruments (> 15 ppm), hence the concentration levels during the full test couldn't be monitored for both cases (DFWL alone and in addition with a traditional cookstove). The disrupted evolution on D9 can be seen in figure 7.

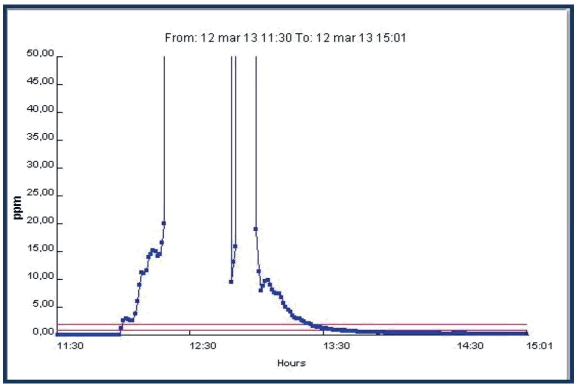


Figure 7: Characteristic curve of SO2 for DFWL type A and a traditional cookstove on D9

However, SO2 emission speeds of 0.5 ppm/min and 1.5 ppm/min with a DFWL alone and with both polluting sources respectively could be seen.

High levels of SO2 still remain in the room after two hours of ventilation without further emissions of both pollutants after one hour of both sources burning. After this time, there were levels of 1.31 ppm and 500 µg/m3 of SO2 and PM2.5 respectively.

Conclusions

The evaluated DFWL are less pollutant than traditional cookstoves regarding the typical gases known from stove tests PM2.5 and CO. Carbon monoxide emissions seem to not denote any risk for health, however the values for particulate matter represent around 60% of those for traditional cookstoves. This could be a serious problem, since both traditional devices exceed by far the exposure limits recommended by WHO and are commonly used simultaneously in rural households. This finding could set an additional challenge to improved cooking stove (ICS) programs, since the usage of ICS alone wouldn't be enough for those households using DFWL.

In addition both tested DFWLs seem to exceed while the whole burning process the recommended exposure levels of SO2 by the WHO for 10 minutes. There isn't a value for one hour exposure time, but it would be much lower than the 10 minutes one, making clearer the scope of health impacts by the normal usage of DFWL.

Unexpected results were SO2 emissions from the traditional cookstove above the recommended exposure levels (while burning alone and simultaneous with a DFWL). These values were higher than the equipment measure capacity and representing at least ten times the values from the DFWL alone. Traditional ICS tests could open the research for SO2, since it could be an invisible pollutant in the actual efforts for reducing IAP.

The CO2 emission levels remained by far under the exposure limits recommended by OSHA.

Discussion

This study invites further research on indoor air pollution, taking into consideration sulfur dioxide SO2 and its health implications, either through DFWL or traditional cooking stoves. It is recommended to test other typical diesel burning gases like nitrogen dioxide and evaluate its implications on health comparing results with WHO air quality guidelines. In relation to the DFWL, it is suggested to carry out evaluations with the same type of DFWL and with different types of carburant agents (wicks) since it has been observed that different varieties of wicks emit larger or smaller amounts of fine particles.

In the absence of complete simultaneous measurement of pollutants during the tests on DFWL and traditional stoves, it is suggested to perform this test with equipment that allows for a wider range of measurement and records other pollutants, such as nitrogen oxides and sulfur . It is also advisable to measure on different days, following similar time schedules, in order to control environmental variables.

The tests performed have also shown the existence of high levels of SO2, emitted only by wood burning stoves. For this reason, it is suggested to consider the levels of SO2 emitted during combustion when validating improved stoves.

It is understood that the high pollutant concentration levels recorded (especially PM2.5 and SO2) pose a risk to people who use these traditional devices for lighting and cooking in their homes. So, being the most likely means of exposure to sulfur dioxide and toxic particles by breathing contaminated air from the burners or traditional stoves, people should be warned about the risk of carrying out activities within a closed environment due to the presence of these polluting sources.

References

Apple,Vicente,Yarberry,Lohse,E.Mills.(2010). "Characterization of particulate matter size distributions and indoor concentrations from kerosene and diesel lamps". Wiley Online Library

Chalnick, A., & Billman, D. (1988). Unsupervised learning of correlational structure. Proceedings of the Tenth Annual Conference of the Cognitive Science Society (pp. 510-516). Hillsdale, NJ: Lawrence Erlbaum Associates.

GACC (2012), International Workshop Agreement, Global Alliance for Clean Cookstoves, an Initiative Led by the United Nations Foundation. Washington, USA.

Lam, N.L.; K.R. Smith; A. Gauthier; M.N. Bates (2012b) "Kerosene: A Review of Household Uses and Their Hazards in Low- and Middle-Income Countries,". Journal of Toxicology and Environmental Health, Part B: Critical Reviews, 15(6), 396-432.

MEM. (2013). Plan nacional de electrificación Rural 2013-2022. Ministerio de Energía y Minas, Perú.

MINAM (2013), Servicio Nacional de Meteorología e Hidrología del Perú – SENAMHI: http://elcomercio.pe/lima/sucesos/contaminacion-lima-aumento-veces-anos_1-noticia-1674872

NTP 243: Ambientes cerrados: calidad del aire. http://www.insht.es/InshtWeb/Contenidos/Documentacion/FichasTecnicas/NTP/Ficheros/201a300/ntp_243.pdf. España.

NTP 549: El dióxido de carbono en la evaluación de la calidad del aire interior. España.

OECD (2010) - World Energy Outlook 2010. International Energy Agency 2010OMS (2005). Guías de calidad del aire relativas al material particulado, el ozono, el dióxido de nitrógeno y el dióxido de azufre. Actualización mundial 2005. http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_spa.pdf.

Rosell, M. G., Guardino, X. y Berenguer, M. J (1994). NTP 345: El control de la ventilación mediante gases trazadores. Instituto Nacional de Seguridad e Higiene en el Trabajo.

UCLALaborOccupationalSafety&HealthProgram (LOSH).California-Arizona: Marianne Parker Brown.

UNEP (2012), Map World Sulphur. http://www.unep.org/transport/pcfv/PDF/Maps_Matrices/world/sulphur/MapWorldSulphur_June2012.pdf

US EPA. (2013). Major Environmental Laws. Laws and Regulations. http://www.epa.gov/epahome/laws.htm.

OSHA (2012). Occupational Safety & Health Administration, US Departmen of Labour. Washington DC, US.

Characterizing Kerosene Demand for Light in India and Evaluating the Impact of Measures Affecting Access and Dependence

Nicholas L. Lam (nllam@berkeley.edu)
University of California, Berkeley
Berkeley, USA

Shonali Pachauri (pachauri@iiasa.ac.at), Yu Nagai (nagai-yu@criepi.denken.or.jp), Colin Cameron (cameron@iiasa.ac.at), Pallav Purohit (purohit@iiasa.ac.at)
International Institute of Applied Systems Analysis
Laxenburg, Austria

Abstract

A national expenditure survey of India was analyzed to characterize demand for kerosene used for residential lighting. Results were use to model demand within MESSAGE-Access. Five scenarios were developed to explore the impact of policies that could alter fuel access (e.g. fuel subsidies) and dependence (e.g. electricity reliability), and the associated impacts on fuel demand, pollutant emissions, air quality, and health estimated.

Approximately 65-70% of kerosene consumed in the residential sector in 2005-6 was used for lighting (4700Gg). Over half (65%) was used by homes with an electricity connection, but unreliable supply. Estimated kerosene demand curves are highly elastic across population groups, and thus highly sensitive to fuel price (e.g. subsidy phase-out). Even under optimistic electrification scenarios, dependence on fuel-based lighting will likely continue without efforts to improve supply reliability. Considering both primary and backup kerosene users increases current BC emission estimates from the residential sector in India by 30-40%, but has only modest impacts on outdoor $PM_{2.5}$ concentrations. Estimates of health impacts from outdoor air quality and household-level exposures are forthcoming.

Results thus far emphasize the importance of electricity reliability in driving fuel demand for light and, likely, associated burdens. With efforts to reduce fossil fuel subsidies, mechanisms for providing affordable lighting, not dependent on centralized grid expansion, will be needed.

Keywords: Household energy; kerosene, lighting; air pollution; emissions, subsidies; electricity; reliability.

Introduction

Interventions to reduce emissions from household fuel combustion in developing countries have been proposed as important actions for decreasing short-lived climate forcers and global disease burden. Lighting is one such end-use, however, few efforts have attempted to quantify the current scale of demand, impacts and the potential benefits of cleaner replacement technologies.

Approximately 250 million households (1.3 billion people) lack access to reliable electricity to meet basic lighting needs (*1*). These households often rely on fuel-based lighting, with the majority relying on kerosene fuel burned in wick-type lamps. The quantity of light generated by these lamps is poor, and increasing illumination comes at the cost of emitting larger quantities of particulate matter (PM) into indoor environments, which subsequently vent to the outdoors. Kerosene cooking or lighting have been associated with increased risk of injury and disease (*2*), including pulmonary tuberculosis (*3*), asthma (*4*),and burns. Emitted aerosols are rich in black carbon (BC) and source emissions are definitively climate warming (*5*). Household welfare benefits beyond health and climate may also result from improved lighting (*6, 7*).

Over the last several decades, continued use of kerosene fuel in the residential sector has only been sustained through costly national subsidies on fossil fuels. Kerosene subsidies in India, for example, resulted in estimated under recoveries of 4.2 billion USD in 2008-9 (*8*). While the subsidy programs are intended as redistribution mechanisms to improve access and quality of life of poor households, programs in practice are often inefficient and thus highly criticized. In addition to their immediate burden on national budgets, several studies in India have revealed that as much as 30-40% of subsidized kerosene is diverted to non-residential uses (*8, 9*), and provide small, and possibly negative, economic benefit to target populations (*9*). Furthermore, these subsidies can distort consumption patterns and hinder the progression towards more efficient technology, leading to long-term dependence and welfare impacts (*10, 11*). Economic burdens resulting from household energy subsidies, especially kerosene, have prompted efforts to limit, re-design, or entirely remove their use (*8, 12*). Current assessments have given little attention to social costs, such as health and environmental impacts, of kerosene or its replacements.

Research Objectives

This study has several objectives: (1) Characterize national demand of kerosene for lighting in India across population groups. (2) Explore how national policies impacting kerosene access (e.g. subsidies) or dependence (e.g. electricity reliability) impact demand. (3) Quantify pollutant emissions, air quality, and human health impacts of kerosene lighting in India and under selected policy scenarios.

Methods

A schematic of the study design is presented in Figure 1. The “GAINS” and “MESSAGE” boxes refer to the integrated assessment models maintained by the International Institute of Applied Systems Analysis (IIASA, Laxenburg, Austria) and used here for evaluating air quality and emissions, and global fuel prices, respectively.

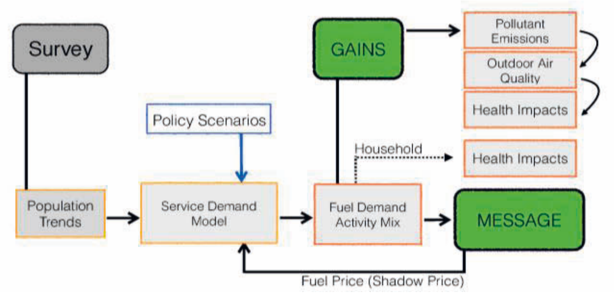


Figure 1: Study schematic

Survey and Population Groupings

Household energy and kerosene demand characteristics were obtained from an analysis of the India Human Development Survey (IHDS) 2005-6 (*13*). IHDS is a nationally representative, multi-topic survey of 41,554 household covering 1,503 villages and 971 urban neighborhoods across India.The survey collects detailed information on monthly kerosene expenditure, consumption, price, and information to help identify end-use activity. Kerosene can be used for lighting, cooking, heating, or a combination (primarily cooking and lighting). If a single activity is reported, all kerosene is allocated to that activity. If combination use is reported, we estimate the fraction used for lighting from a relationship between kerosene consumption, expenditure, and hours of electricity access per day.

To facilitate analysis, the population was separated into three hierarchical levels. Urban and rural area groupings were disaggregated into five per-capita expenditure groups (income proxy), 2 urban (<2.00, ≥2.00 Int$/day) and 3 rural (<1.25, 1.25-2.00, ≥2.00). For each expenditure group, a further distinction was made between households that have no access to electricity, less reliable (<16 hrs/day), and more reliable (≥16 hrs/day) electricity access ("access groups").

Policy Scenarios

Five scenarios were tested to explore the impact of policies influencing kerosene price and electricity access on kerosene demand for lighting. Three scenarios represent electricity transitions, in which household access and reliability to electricity increase over time. Two scenarios alter the kerosene subsidy price. Scenarios were evaluated for 2010, 2020 and 2030.

1. ***Baseline:*** Assumes that no measures are taken to increase electricity access or improve supply beyond the changes associated with growing household income over time.
2. ***Universal Access to Electricity by 2030 (UA)****:* All households receive connection to the power grid by 2030, but no additional efforts are made to improve supply reliability.
3. ***Universal Access to Electricity and Improved Supply by 2030 (UAS)*****:** Universal access to electricity scenario (UA) is coupled with improvements in supply reliability, such that all houses have at least 16 hours of electricity per day.
4. ***Full Subsidy Scenario (SF):*** Subsidized kerosene in India is administered through the Public Distribution System (PDS). All households are given access to kerosene at subsidized prices under Baseline conditions.
5. ***Subsidy Phase-out (Market) Scenario (SPO)*****:**The kerosene subsidy is phased out; all households experience market kerosene prices in 2030 under the Baseline conditions.

Scenarios account for changes in population and income growth over time, following methods used in the Global Energy Assessment (*14, 15*). Associated impacts on air quality, emissions and population health are evaluated for each scenario, although only partial preliminary results are presented here.

Kerosene Demand

Population demand curves for electricity access-groups were constructed from reported lighting expenditure to model how changes to the service cost of kerosene lighting would influence service demand. Service demand is then converted to consumption metrics (e.g. *Liters*) using lighting device efficiency. Changes to the service cost can arise from shifts to the global fuel price or kerosene subsidy. Upfront cost of lighting devices were annualized using discount rates specific to India (*16*). Changes to the fuel demand in the residential sector can have macro level effects on global market prices. The macro-level impacts, and subsequent feedback, on the global market price of kerosene are estimated using the energy systems model MESSAGE (IIASA, Laxenburg, Austria). Future demand is adjusted for changes in consumption resulting from changes in household income.

The service cost of lighting describes the monetary cost of operation per unit of utility. The *lumen-hour* for example is common metric used in developed countries and captures both the lighting duration and light intensity, thereby accounting for lumen efficiency. This metric is commonly used to compare performance between competing technologies (*17*). Early concerns arose over the appropriateness of the *lumen-hr* in describing lighting at the bottom of the energy access pyramid. As a result, analysis will also be performed using the somewhat unorthodox metric of *lighting-hour*: the hours of light provided by all lighting sources across the household with no adjustment for light quality. Future analyses will consider both metrics.

Emissions and Air Quality

Emissions of $PM_{2.5}$, PM_{10}, PM_1, black carbon (BC), organic carbon (OC), carbon monoxide (CO), SO_2, and volatile organic compounds (VOCs) from lighting devices were estimated at the state and national level for each scenario, however only results for BCare presented here. Associated changes to outdoor pollutant concentrations and impacts are estimated using the IIASA GAINS model (IIASA, Laxenburg, Austria).

Results

Population Consumption

In 2005-6, total residential kerosene consumption for lighting was estimated at 4700 Gg (5500 Gigaliters), constituting approximately 70% of total consumption in the sector. Lighting is the dominant end-use in rural areas (80%), while a more even split between cooking (51%) and lighting (43%) exists in urban areas. Heating constitutes less than 2% of total consumption.

Table1 presents lighting kerosene consumption by sector and electricity access group. Results indicate that approximately 65% of lighting kerosene, or 45% of total residential kerosene, was consumed by homes with an electricity connection but experience frequent supply interruptions. In urban areas, where prevalence of electricity connection exceeded 90%, nearly all lighting kerosene is used by electrified houses.

Figure 2 illustrates trends in reported consumption across household per-capita expenditure in three electricity access groups. As might be expected, demand for lighting fuel increases with income as well as electricity access reliability. Demand does appear to plateau, which is a trend observed in analyses of household cooking energy (*18*).

Table 1: Residential kerosene consumption for lighting (Gg/year) by area and electricity access group (2005-6). Column percentages are presented in parentheses.

	Rural	Urban	$\text{Total}_{\text{Access}}$
No Electricity	1580	100	1680
	(41%)	*(12%)*	*(36%)*
< 16hrs/day	1230	270	1500
	(32%)	*(32%)*	*(32%)*
> 16hrs/day	1030	470	1500
	(27%)	*(56%)*	*(32%)*
$\text{Total}_{\text{Area}}$	3840	840	4680

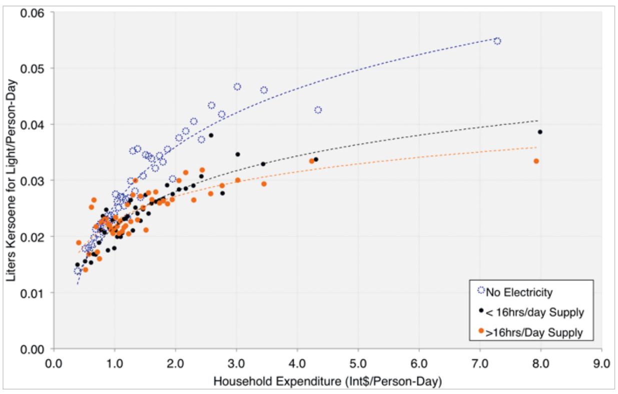


Figure 2. Kerosene consumption versus household expenditure by electricity access group.

Alternative Energy Sources

Constructed demand curves for all analysis groups were highly elastic (average ε = -8). High demand elasticity has also been observed in an analysis of cooking fuels (*18*). The high sensitivity to kerosene price on demand in the residential sector is consistent with findings from a small pilot study in Agwal, India, which showed an 85% reduction in kerosene demand three months following the removal of the subsidy (*19*).

Annualized cost of kerosene lighting was, on average, approximately 0.02 Int$/light-hour, and similar to the annualized service cost of an entry-level pico-solar lighting device, based on first approximations.

Policy Scenarios

Baseline scenario (Baseline) results indicate a gradual reduction in kerosene demand, over time, but at BAU rates, demand continues beyond 2030, indicating a continued reliance on non-grid lighting energy. Improvements in electricity access (UA) alone provide only a small reduction in total kerosene demand over 2010-2030 relative to baseline (-10%). While larger reductions occur under the improved reliability (UAS) scenario (-20%), considerable demand persists at the selected target of 16-hrs per day of supply. Under the subsidy phase-out scenario (SPO), total kerosene demand is reduced by 80% from baseline by 2030.

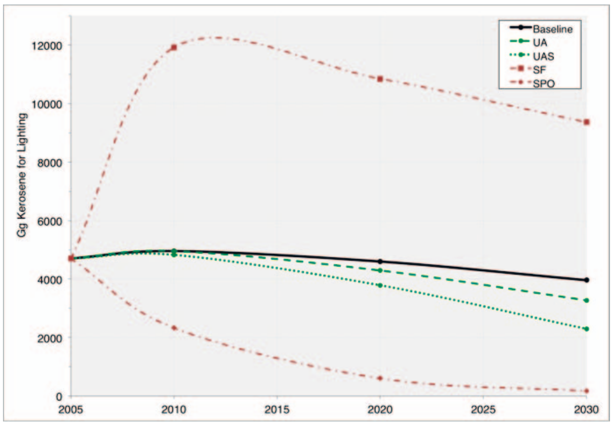


Figure 3. Projected kerosene demand for lighting under all policy scenarios.

Emissions, Air Quality and Health

Black carbon emissions from lighting, including both electrified and non-electrified households, was approximately 270 Gg in 2005-6. Preliminary estimates of direct health impact from outdoor air quality are small, with the most optimistic scenarios (UAS, SPO) reducing total years of lost life in India 1-2%.A more detailed reporting of impacts from outdoor and household level exposures is forthcoming.

Discussion

Survey analysis indicates that the consumption for lighting kerosene by houses with unreliable electricity access was approximately equal to that of non-electrified households. Kerosene use for backup light is well recognized, however, few efforts have apportioned the consumption, or related burdens, resulting from unreliable electricity. Most impact estimates on kerosene lighting consider only non-electrified populations, and therefore may be underestimates. Results illustrate the general importance of considering electricity reliability in evaluations of lighting and electrification. From a research perspective, measures of reliability should be considered in household energy assessments and studies of associated impacts.

As much as 7-9% of kerosene consumed in kerosene lamps is converted to carbonaceous particulate matter that is almost entirely black carbon (BC) (*5*). New lighting consumption estimates, including kerosene as a backup light source, increase total residential BC emissions by as much as 30-40% (*20*). Not surprisingly, preliminary estimates on direct outdoor air quality health impacts are very modest. However, the majority of impacts associated with household combustion in developing countries occur at the household level – where fuels are burned (e.g. cooking). Formal estimates of household-level impacts are in preparation.

Deadweight loss (DWL) is a measure of economic inefficiency and has been used to estimate the economic cost of global gasoline and fossil fuel subsidies (*11*). The high elasticity of demand for kerosene estimated here is suggestive of a large degree of DWL, even before considering any social costs associated with environmental and air quality externalities (formal estimates forthcoming). It is important to note, however, that while removal of subsidies would reduce DWL, with few “cheaper” alternatives to kerosene for light, and in the absence of clean alternatives, households may turn to other inefficient and polluting sources (e.g. paraffin candles) or be left in the dark. Reductions in lighting fuel access should therefore be accompanied by mechanisms to provide, at minimum, equal access to lighting. With current barriers to electricity access and supply improvements, pico-solar lighting may be one temporary solution based on reported household expenditure on lighting.

Acknowledgments

This research was funded by the National Science Foundation as part of the Young Scientists Summer Program (2013) at the International Institute of Applied Systems Analysis (IIASA). This work greatly has benefitted from the helpful comments and suggestions of Narasihma Rao, Lucas Davis, Kirk Smith, Michael Bates, Pedro Rochedo Arne Jacobson and Peter Alstone.

References

Bates, M. N., Chandyo, R. K., Valentiner-Branth, P., Pokhrel, A. K., Mathisen, M., Basnet, S., Shrestha, B. R., Strand, T. A., Smith, K. R. (2013). Acute lower respiratory infection in childhood and household fuel use in Bhaktapur, Nepal. *Environ Health Perspect*, 637-642.

Budya, H. & Arofat, M. Y. (2011). Providing cleaner energy access in Indonesia through the megaproject of kerosene conversion to LPG. *Energy Policy*, 7575-7586.

Commander, S. (2012). A guide to the political economy of reforming energy subsidies. *Policy Paper Series*(IZA, Bonn, Germany).

Davis, L. W. (2014). in *Working Paper,* B. University of California, Ed. . Berkeley, CA.

Desai, S., (2009). NCAER R. V. (Inter-university Consortium for Political and Social Research Ann Arbor).

Ekholm, T., Krey, V., Pachauri, S., Riahi, K. (2010). Determinants of household energy consumption in India. *Energy Policy*, 5696-5707.

Environmental Science & Technology (2012). 13531-13538; published online Epub2012/12/18.

Gustavsson, M. (2007). Educational benefits from solar technology: Access to solar electric services and changes in children's study routines, experiences from eastern province Zambia. *Energy Policy*, 1292-1299.

IEA (2011). "Energy for all: Financing access for the poor " *Energy Outlook 2011*. International Energy Agency. Osolo.

Jacobson, A., Lam, N. L., Bond, T. C., Hultman, N. (2013). "Black carbon and kerosene lighting: an opportunity for rapid action on climate change and clean energy for development," *Global Views: Global Economy and Development*(The Brookings Institution Washington DC).

Lam, N. L., Chen, Y., Weyant, C., Venkataraman, C., Sadavarte, P., Johnson, M. A., Smith, K. R., Brem, B. T., Arineitwe, J., Ellis, J. E., Bond, T. C., Household Light Makes Global Heat: High Black Carbon Emissions From Kerosene Wick Lamps.

Lam, N. L., Smith, K. R. , Gauthier, A., Bates, M. N. (2012). Kerosene: a review of household uses and their hazards in low- and middle-income countries. *Journal of Toxicology and Environmental Health, Parth B: Critical Reviews*, 396-432.

Nagai, Y. (2014). Technical University of Vienna, Vienna.

Nordhaus, W. (1998). in *Cowles Foundation for Research in Economics at Yale University*.

Pachauri, S., Brew-Hammond, A., Barnes, D. F., Bouille, D. H., Gitonga, S., Modi, V., Prasad, G., Rath, A., Zerriffi, H. (2012). In *Global Energy Assessment - Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria. pp. 1401-1458.

Pachauri, S., Ruijven, J. B., Nagai, Y., Riahi, K., Vuuren, D., Brew-Hammond, A., Nakicenovic, N. (2013) Pathways to achiev universal household access to modern energy by 2030. *Environmental Research Letters*.

Pokhrel, A. K., Bates, M. N., Verma, S. C., Joshi, H. S., Sreeramareddy, C. T., Smith, K. R. (2010). Tuberculosis and Indoor Biomass and Kerosene Use in Nepal:A Case-Control Study. *Environ Health Perspect*,.

Rao, D. N. (2012). Kerosene subsidies in India: When energy policy fails as social policy. *Energy for Sustatinable Development*, 35-43.

Shenoy, B. V. (2010) Lessons learned from attempts to reform India's kerosene subsidy. International Institute for Sustainable Development (IIST). Geneva, Switzerland.

Sloss, L. (2012). Black carbon emissions in India. IEA Clean Coal Centre.

TERI (2012). Fossil-fuel subsidy reform in India: Cash transfers for PDS kerosene and domestic LPG. The International Institution of Sustainable Development. Geneva.

Night fishing with solar powered LED lights on Lake Tanganyika

Robert Aitken (Robert@restio.co.za)
Restio Energy
Cape Town, South Africa

Axel Scholle (Axel@powersolutions.co.za)
Sustainable Power Solutions
Cape Town, South Africa

Abstract

Kigoma is located in the western extent of Tanzania, on the eastern shores of Lake Tanganyika. Kigoma Town and its rural surrounds are not linked to the national electricity grid, having instead to rely on small diesel-based mini-grid systems reticulated through the urban village centres. Fishing is an important economic activity in the Kigoma region, focused on Lake Tanganyika. The fishermen fish at night using pressurized kerosene lanterns to attract fish to the surface and their nets. This has important environmental as well as financial consequences for the lake, fishermen, local community and wider region. As part of a solar photovoltaic market development project funded by the Millennium Challenge Corporation, solar-powered LED lighting systems were designed and supplied to the fishermen on financed terms. This paper looks at how this was done, including technical design aspects, financial feasibility and commercial sustainability; as well as the eventual outcomes and the greater opportunity presented by this intervention.

Keywords: Night-fishing; Kerosene; LEDs; Solar; Productive Use.

Introduction

The Millennium Challenge Corporation (MCC) has a compact with the Government of Tanzania, managed through the Millennium Challenge Account-Tanzania (MCA-T). There are three basic areas of investment within the compact framework: Transport, Energy and Water. Under the Energy sector activities, a solar PV programme was proposed which would provide investment in energy access for the Kigoma region. A $5 million project was designed by MCA-T and appointed consultants.

Figure 1: Kigoma region

The programme design utilised the Sustainable Solar Marketing Package (SSMP) framework, with a baseload of public sector solar PV installations, including secondary schools, dispensaries, health centres and village markets, with additional components designed to support the overall sustainability of the solar installations.For the desired effect of stimulating a regional PV economy, opportunities within the private and household sector needed to be identified and leveraged. Important amongst these opportunities were the night fishing activities on Lake Tanganyika: boating pairs, consisting of two boats with three to four people per boat, fish at night using kerosene lanterns to attract the fish to their nets. Each boating pair consumes around 20 to 30 litres of kerosene per night. The Kigoma Solar PV programme presented an opportunity to pilot the introduction of solar powered, battery-operated LED lights as a replacement for these inefficient, dangerous and polluting kerosene lanterns.

Figure 2: Fishing boats on the Lake Tanganyika shore

As part of the Kigoma Solar PV Programme, the contactor was therefore required to pilot 30 double systems of solar powered LED lighting rigs with 30 boating pairs on Lake Tanganyika. The night fishing sector represents an important private sector market which has the potential to contribute significantly to a longer-term sustainable, commercial solar PV industry in the region. The principal objective was to successfully pilot the solar powered LED lighting systems to showcase an effective and sustainable alternative energy source for night fishing. There are an estimated 8,000 night fishing boats operating on the Lake Tanganyika and over 17,000 across the full extent of Tanzania's lakes and oceans (Gengnagel, T. et al: 2013). This represents a significant long-term market.

Counting the costs of kerosene

The current practice of using kerosene lamps is extremely costly to the fishing boat owners. Kerosene is a hydrocarbon, the price of which is directly linked to the global oil price. In addition, the cost of transporting the fuel from Dar es Salaam some 1200 km inland to Kigoma exerts additional upward pressure on fuel prices. The introduction of solar powered LED lighting rigs was aimed at reducing the overhead costs associated with night fishing. According to a recent report, the costs of kerosene represent 35%-50% of the fishermen's earnings (Gengnagel, T. et al: 2013). A significant reduction or elimination of kerosene use for lighting would significantly lower the overheads faced by the fishers, in turn increasing their profits. The night fishing industry is a key regional economic activity.

Developing an appropriate lighting rig design

The lighting setup currently utilized by the fishermen is based on eight kerosene lamps, positioned around the boat. Light is ineffectively directed downwards with a reflective collar.

The solar system designed for the night fishing application has the following features:

- Dedicated solar array (270Wp) with central battery (120Ah/12V, sealed) and five water proof LED spotlights (6W), switched individually;
- State of charge controller with LCD bar graph or % display in IP65 housing;
- DC connector between solar array and change controller, suitable for multiple reconnection while maintaining good contact (Anderson connector);
- The solar array is land-based;
- The charge controller and battery is housed in a plastic crate, with a cut out for the LCD display, while the Anderson connectors for the solar input and the light output are located on the side of the crate. The crate can be carried to and from the boat by either one or two persons;
- The five LED spot lights come with a 5m rubberized cable lead each that is connected to a single junction box with switches.

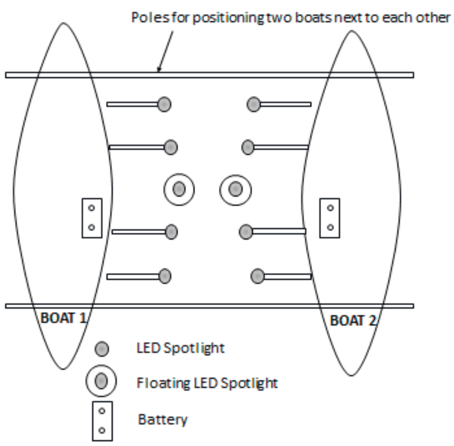


Figure 3: Diagrammatic presentation of lighting setup

The system was sized with the objective to recharge the batteries even under inclement weather conditions. Although the typical draw down during a night on the lake is approximately 25Ah (or 20% daily depth of discharge) the solar array is capable of charging approximately 2.5 times as much on a clear day. The overdesign is essential as to avoid the fishermen having to switch back to kerosene lamps in the rainy season.

Figure 4: The LED lights on the boats

Improving health and safety aspects

The widespread use of a flammable fuel such as kerosene will always be accompanied by some level of hazard. These night fishing activities are no exception. Anecdotal evidence pointed out that boat-fires caused by falling lanterns was a relatively common occurrence[1], while other researchers have noted that fishermen had sometimes complained of vertigo caused by the vapour of kerosene lanterns (Gengnagel, T. et al:2013).

Promoting environmental benefits

The key environmental concern linked to the use of kerosene is the carbon dioxide (CO_2) emissions associated with its burning. One litre of kerosene emits approximately 2.69 kgs of CO_2 (US EPA, 2011). Considering the extent to which night fishing practices rely on kerosene (20-30 litres/boating pair/night) the associated CO_2 emissions are considerable and have a very clear and negative environmental impact in terms of climate change. In addition, the Black Carbon[2] associated with burning kerosene lanterns is a further environmental concern (Jacobson, A. et al: 2013).

Piloting systems

While the costs of the systems were covered by the MCA-T investment, the approach agreed upon by contractor and monitoring consultants was that 30 double systems could be made available at a discounted rate to facilitate access to this unfamiliar technology, while at the same time un-

[1] Personal correspondence with a number of fishing boat owners and boat captains in and around Kigoma.

[2] A particle rather than a gas, Black Carbon is a powerful absorber of sunlight. Black Carbon comes from incomplete combustion and is closely associated with, amongst other sources, rudimentary, wick-based, kerosene lanterns.

derscoring the long-term commercial nature of this opportunity. The systems were distributed on the following basis:

- The first 10 double systems were made available to local boat owners who had expressed an interest in the technology through participating in the design tests, workshops and meetings. These were made available at $600 a system, which amounts to $1,200 for the required double system. Participants were allowed a two-month trial period, after which they either had to return the system or purchase at the agreed rate.
- The remaining 20 double systems were made available after the 2 month trial involving the 10 systems. These remaining systems were made available at $800 a system or $1,600 for the double system required. No trial period was applied as the 2 month pilot had provided enough time to understand the benefits (or otherwise) of the systems.
- The contactor provided a level of finance, allowing fishing boat owners to pay off the system in three monthly installments.

Research Objectives

This paper's objective is to assess the feasibility, outcomes and potential impacts of the night fishing component of the Kigoma Solar PV programme.

Methods

Research methods employed include surveys, focus groups and interviews. Results were triangulated using different research methods.

We undertook a two-month baseline study involving five boating pairs. Boat owners were requested to record every expense associated with the kerosene lamps, including the lamps themselves, wicks, mantles, chimneys, matches and the kerosene fuel. We also monitored the fishing catches associated with both the LED using fishing boats and non-LED using fishing boats. This was a very limited study (over four days, involving five boating pairs) but was supplemented by additional feedback gained through monthly meetings with boat owners' unions as well as a workshop held towards the end of the project where all boat owners and captains were invited.

Results

The results from the baseline survey are presented in the table below. With the exception of Boating pair_2, the monthly costs of kerosene were fairly similar, with a range of $485 - $655 spent in a month. The relatively low costs associated with Boating pair_2 ($223) is due the lower number of fishing trips[3] undertaken. The average monthly cost of utilizing kerosene lanterns for night fishing was determined at $515 a month.

Table 1: Monthly cost of kerosene

	Boat pair_1	Boat pair_2	Boat pair_3	Boat pair_4	Boat pair_5
Total TZS*	TZS 1 509 550	TZS 691 550	TZS 1 737 520	TZS 2 029 800	TZS 2 029 800
Total $	$973.90	$446.16	$1 120.98	$1 309.55	$1 309.55
Total $/month	$486.95	$223.08	$560.49	$654.77	$654.77
Average monthly expenditure:			**$516.01**		

* TZS is the Tanzanian Shilling. The exchange rate with the US$ was 1600/1

Once the two month trial period for the first 10 double systems was concluded, all boat owners elected to buy their systems and paid a 1/3 deposit ($400). Five months after the introduction of the first system and three months after the conclusion of the initial pilot, all 30 double systems were sold, installed and operational on the lake.

In terms of the fishing catch associated with the use of LED lights as opposed to kerosene lanterns, we were able to monitor the catch of 5 fishing boat pairs (two with LED lighting systems and three with kerosene) over a four day period. The results are included in the table below.

Table 2: Catch rates for LED & kerosene boats

	Catch (crates)			
	Day 1	Day 2	Day 3	Day 4
LED boating pair 1	1.5	0.25	0.5	1.75
LED boating pair 2	-	-	1.75	1.75
Kerosene boating pair 1	5	0	0	0
Kerosene boating pair 2	1	0	0	0
Kerosene boating pair 3	0.5	0	0	0

The catch is recorded in crates, which hold in the region of 80kgs of fish. Each of the three kerosene boats only caught once out of the four days, while the first LED boating pair caught every day. The second LED boating pair caught on day three and four but did not launch on the first two days. While the kerosene boating pair 1 caught the most over the four day period, it was the LED boats that were the most consistent catchers. Although the monitoring opportunity was limited, the results suggest that solar powered LED lights offer an effective alternative to the kerosene lanterns.

In addition to this limited monitoring of the five selected boating pairs, a number of meetings were held with the fishing boat owners and the boat owners'/captain's unions. The overall impression was that solar powered LED lighting rigs were as effective (if not more so) than kerosene lanterns and would prove to be significantly cheaper in the long-run.

At a workshop held for boat owners and captains towards the end of the MCA-T Compact in 2013, slightly more than 20 of the 30 boat owners that had bought the pilot systems were in attendance, as were many of the boat captains. While some issues were raised around security on the Lake[4] and moisture within the lamps, all participants pointed out how costs have been significantly reduced, while catches had remained constant, if not increasing; as one representative from the local Department of Fisheries pointed out: "for the first time in many years, there are fishermen on the lake making a profit"[5]. Comparing the lifecycle or integrated costs of kerosene and solar powered LEDs over a 5 year period, it is clear from

[3] Boat owners may decide not to send out their boats due to poor weather, crew availability, cashflow, engine problems, etc.

[4] Pirates have been known to harass the night fishing boats.

[5] Recorded as part of the minutes from workshop proceedings.

the tables below that the potential savings are considerable.

Table 3: Costs over 5 years for solar LED lighting rigs

System costs	Battery costs*	Cabling**	Lights***	Unforeseen****	Total
$3 240	$800	$800	$1 000	$584	$5 840
* Battery replacement every 2 years @ $200/battery					
** Replace cables every year @ $200/year (system costs cover 1st year)					
*** Lights - estimated $250/year (system costs cover 1st year)					
**** May include post-warranty technical issues. Calculated at 10% of total					

The estimated commercial cost of a 270Wp solar PV system in Kigoma would be in the region of $6/Wp fully installed. The market related cost of a double system is therefore $3240. By looking at costs over a longer period, the on-going or ancillary costs such as battery replacements, new cabling, replacement lamps, etc. offer a more integrated cost profile, allowing for a comparable cost analysis with kerosene.

Table 4: Costs over 5 years for kerosene lighting

Monthly costs*	Active months/yr**	# of yrs	Total cost
$500	9	5	$22 500
* Rounded down outcome of baseline survey			
** Assuming boats are inactive for 3 months a year			

The costs of using kerosene lanterns over a similar period were considerably higher at $22,500. The shift to solar powered LED lights therefore offers a saving in the first 5 years of over $275 a month, or 55%.

Table 5: Cost savings using solar powered LED lights

Estimated savings over 5 years	$16 660
Average annual saving	$3 332
Average monthly saving	$277.67

If we extrapolate these findings to the wider Kigoma region, as well as the rest of Tanzania, we get the following potential financial savings:

Table 6: Potential Financial Impact

Annual savings/boat	$ 1 666.00
Night fishing boats: Kigoma	8 000
Annual savings: Kigoma	$ 13 328 000.00
Night fishing boats: Tanzania	17 000
Annual savings: Tanzania	$ 28 322 000.00

In terms environmental impacts, the following CO_2 emissions savings are estimated based on current results:

Table 7: Potential Environmental Impact

CO2 emissions per litre kerosene (kg)	2.69
Litres of kerosene used per lantern/night	1.25
Lanterns per boat	7
Fishing nights per month	20
Monthly CO2 emissions/boat (kg)	470.75
Annual CO2 emissions/boat (kg)	5 649
Annual CO2 emissions: Kigoma	45 192 000
Annual CO2 emissions: Tanzania	96 033 000

Discussion

This study faces a number of limitations, primarily the small study/pilot population and the short time-frames used to measure impacts. Where possible, these have been addressed through triangulating results. Still, there is aneed for ongoing monitoring and robust evaluation of the results and impacts related to this initiative.

Nevertheless, the pilot of 30 solar powered LED lighting systems for night fishing has demonstrated the feasibility and effectiveness of alternative lighting technologies. The 'test pilots' have reduced the perceived risks associated with investing in new technologies for the other boat owners. There is little doubt that solar PV lighting will play an increasingly important role in night fishing activities on Lake Tanganyika.

The program showed that overall the components held upwell. Challenges included batteries not being fully recharged (not connected to the solar array in time, or technical problems), poor seals in the LED spotlights (IP65 was not maintained), cable breakage (daily reinstallation on boats) and wear and tear on waterproof light switches.

Perhaps the most important feature of this initiative is its potential contribution in terms of creating a sustainable solar PV market in the region. The long-term objective behind solar PV initiatives in developing countries is to establish a sustainable commercial market for the technology, leveraging further investment in the sector.

The commercial approach implied resonates closely with other global energy technology initiatives within developing countries, including the Global Alliance for Clean Cookstoves and Lighting Africa[6]. With this overall objective in mind, the development of the Solar PV LED lighting solutions amongst fishing communities is crucial for the long-term commercial underpinning of the Kigoma Solar PV Programme.

To this end, further efforts are required to develop and shape this commercial opportunity. These include:

- Developing finance solutions and products that facilitate access to this technology. While solar powered LED lights make financial sense over time, the 'first cost' constraints will need to be addressed to improve access. There are a number of traditional savings associations (SACCOs) and micro finance institutions (MFIs) which could develop appropriate solutions for this purpose[7].
- Technical standards should be developed, agreed on and enforced by the Department of Energy, Tanzanian Bureau of Standards as well as the Solar Industry to guide the design of these solar PV units and accompanying lighting rigs,.
- The Department of Fisheries and other relevant government entities need to promote the use of solar PV lighting solutions on Lake Tanganyika as well as other lakes and coastlines across Tanzania.

[6] www.cleancookstoves.org and www.lightingafrica.org

[7] The Kigoma representative of Pride (MFI) agreed to explore partnering opportunities with the local fishing boat owners union (Kiribizi) in the coming months.

References

Gengnagel, T., Wollburg, P & Mills, E. (2013). Alternatives to fuel-based lighting for night fishing: Field tests of Lake and Ocean Applications in East Africa. The Lumina Project, Technical Report 11.

Jacobson, A. Lam, N. Bond, T. & Hultman, N. (2013). Black carbon and Kerosene Lighting: an opportunity por rapid action on climate change and clean energy for development. *Global Views* Policy Paper 2013-03.

US EPA (2011). Emissions Factors for Greenhouse Gas Inventories.

Scientific Papers

IX. Community Energy Supply

Identifying Hidden Resources in Solar Home Systems as the Basis for Bottom-Up Grids

Hannes Kirchhoff (hannes.kirchhoff@microenergy-systems.de)
Microenergy Reserach Group, TU Berlin
Hardenbergstraße 16-18, 10623 Berlin, Germany

Abstract

In the context of the modern energy access challenge, one new pathway towards electrification is to make use of hidden resources already in the field through small microgrids. In particular, this paper analyses the amount of energy that is dumped in a medium sized (65 Wp) solar home system (SHS) located in Bangladesh. The SHS is modeled using synthetic load curves and a sophisticated battery model that accounts for battery ageing. The simulation shows that more than 30 % of the energy generated by the SHS remains unused.

Keywords: SHS; Hidden Resources; Microgrid; Bottom-Up.

Introduction

The energy access challenge presents itself on several fronts at the same time. While there are still more than 2.3 billion people without reliable access to electricity (United Nations Foundation, 2012), a carbon lock-in is on the horizon if the power sector does not turn green quickly (IEA, 2011, p. 3). For individuals who currently do not have access to modern energy services that are "affordable, clean, reliable, and safe" (Legros et al., 2009, p. 3) this translates into high prices and uncertain timelines for access.

As pointed out by (Tenenbaum et al., 2014),it is time for the "second", decentralized track in electrification. A track that does not rely on central entities but can grow from the bottom-up. The "swarm electrification" approach (Groh et al, 2013), shows a pathway for how this can be done, building on the existing infrastructure, such as the 2.6 million solar home systems (SHS) already installed in Bangladesh (IDCOL, 2013). SHS are linked to form small microgrid clusters that can gradually be extended by going through different stages, c.f. Figure 1.

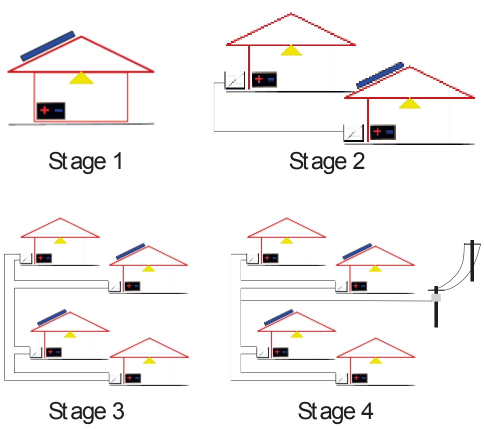


Figure 1: Step by step bottom-up electrification

The process is a step by step bottom-up approach that eventually leads to coverage of a whole village. The formed microgrid can, if desired, even be connected to the main grid.

There is limited literature available on interconnected SHS, however, one simulation showed a 15 % saving in generation capacity required when eight large SHS located in Tanzania were connected (Unger & Kazerani, 2012).

Research Objectives

This paper addresses the perspective for a single SHS in the initial process of swam electrification, showing the potential for energy sharing. Hence, the hidden resources that are dumped in normal SHS operation is investigated on.

Methods

The 65 W_p SHS package under the IDCOL solar programis simulated for the course of one year using Matlab Simulink with five minute intervals. The SHS package consists of a 65 W_p solar panel and a 100 Ah battery. Details of the respective component modeling are as follows.

Solar Module Simulation

For the model in this paper, each SHS is equipped with a 65 W_p multicrystal PV module, fitted to data sheets from Kyocera KC65T panel (Kyocera, 2007), which is modeled using a mathematical model developed by (Villalva, Gazoli, & Filho, 2009). This model is an improvement of the single diode equivalent circuit and can be easily adapted to different panels. The work presented in the paper includes an algorithm to determine the best fitting parameters for the shunt resistance R_S and the parallel resistance R_P requiring only datasets at open and short circuit as well as at the maximum power point (MPP). These parameters are then used to model the characteristic current behavior as in (1) where V_t is the thermal voltage and a the ideality factor of the diode. The parameters used are listed in Table 1.

$$I_{PV} = I_0 \cdot \left[\exp\left(\frac{V + R_S \cdot I}{V_t \cdot a}\right) - 1\right] \tag{1}$$

The temperature influence on the panel are reflected on through the temperature coefficient for voltage $K_V$and the temperature coefficient for current K_I.

The model is verified with the electrical performance at nominal operating cell temperature which is given in the datasheet (Kyocera, 2007), producing an error of less than 0.4 %.[48]

Table 1:Parameters used in the PV module model

Parameter at standard test conditions from (Kyocera, 2007)	Value
V_{MPP}	17.4 V
I_{MPP}	3.75 A
V_{OC}	21.7 V
I_{SC}	3.99 A
K_v	-0.0821 V/K
K_i	0.00159 A/K
Parameters obtained using (Villalva et al., 2009)	**Value**
a	1.3 [-]
N_s	36 [-]
R_p	266,565 Ω
R_s	0.2454 Ω

The ambient temperature is assumed constant at 30° C, while the temperature of the cells is modeled as being directly proportional to the irradiation *G*, as in (2). This approach is proposed by (Hansen et al., 2000, p. 14).

$$T_c = T_A + 0.03\frac{\mathrm{C}\cdot\mathrm{m}^2}{\mathrm{W}}\cdot \mathrm{G} \tag{2}$$

Real solar data for Dhaka of the year 2001 is used, specifically global horizontal solar insulation data from (NREL, 2005). The panel's orientation is assumed as perfect south and 24° tilt to allow for maximum generation. Correction factors for this tilt are based on data from (Boxwell, 2013).

Battery Model

The battery modeling has to cover a wide range of parameters and constants, but there are essentially only two variable inputs into the model during the simulation: temperature and current. Corresponding to the ambient temperature, the battery temperature is assumed constant at 30° C. Problems with overheating due to internal temperature build up are neglected due to the small size of the battery. Thus, the only remaining input variable is the current. The output parameters are the terminal voltage of the battery the state of charge (SOC) and, as a lifetime monitoring variable, the remaining capacity of the battery. Degradation and corrosion lead to reduction in capacity, which is reflected in the state of health (SOH).

[48] Input values are G=800 W/m², T_{cell}= 47° C and V_{PV}=15.3 V. The datasheet states 46 W output and the model calculates 46.15 W.

Respective parameters are taken from (Boldt, 2012). The terminal voltage U_{bat} is obtained by multiplying the cell voltage U_{cell} by the number of cells (six). The cell voltage is derived by using a set of two Shepherd Equations, one for discharging and one for charging, where the *SOC* and *DOD* are the state of charge and depth of discharge respectively:

for I > 0:

$$U_{cell}(t,I) = U_0 - g\cdot DO^{D} + \rho_c(t)\cdot\frac{I(t)}{C_N} + \rho_c(t)\cdot M_c\cdot\frac{I(t)}{C_N}\cdot\frac{SO^{C}(t)}{C_c - SO^{C}(t)}$$

for I ≤ 0:

$$U_{cell}(t,I) = U_0 - g\cdot DO^{D} + \rho_d(t)\cdot\frac{I(t)}{C_N} + \rho_d(t)\cdot M_d\cdot\frac{I(t)}{C_N}\cdot\frac{DO^{D}(t)}{C_d(t) - DO^{D}(t)}$$

The above equations can be both be rearranged so that each constitutes of one portion independent of the battery current and the other part dependent on the battery current. These are the values used for a simple equivalent circuit of the battery in the SHS model with a controlled voltage source(U_0) and an internal resistance (R_i) in series. Ageing effects are reflected in the model that are related to the following stress factors:

- *Time between full charges*, in particular modeling the build- up of irreversible sulphation,
- *Partial cycling* by taking into account the end of charge voltage when crossing over a SOC value of 90 % but not reaching 100 % which is critical for corrosion,
- *Ah-throughput* by evaluating the total discharge current in a weighted number of cycles which is an indication for the loss of active material as well as increased stratification,
- *Low discharge rates* which enhance stratification,
- *High temperature* is reflected in all relevant factors, in particular the build-up of the corrosion layer and the effect of gassing .

Charge Controller

The charge controller was modeled with an overcharge and a deep discharge protection. The threshold values for these operations were taken from the IDCOL SHS program specifications and translated from voltage cut-off values to SOC-values. As shown in Figure 2, the deep-discharge protection is activated after crossing 30 % SOC and the load is reconnected at 50 % SOC. Once the battery is fully charged, the charge controller changes the charging mode from boost to float, limiting the charging voltage to 13.5 V.

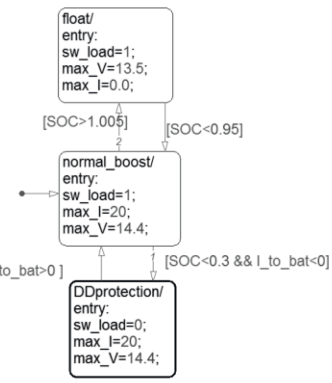


Figure 2: Model for the charge controller

Load Profile

As no real data on the usage pattern was available, literature values are used and combined to form a synthetic load curve. According to (UNFCCC, 2012, p. 6), 65 W_p SHS in Bangladesh are typically equipped with loads given in Table 2.

Table 2: Loads for 65 W_p SHS, from (UNFCCC, 2012, p. 6)

Appliance	Load [W]	Usage [h/d]	Daily Demand [Wh/d]
5 CFL lights	30	4	120
Black and white TV	10	3	30
Mobile Charger	3	4	12
Total			162

Hence, the daily energy consumption adds up to 162 Wh. However (Khadem, 2006, p. 4) argues, that the actual – possibly not supplied for –demand is 240 Wh per day for an SHS with similar load structure (around 30 W of lights plus small TV and radio). To take this actual demand into account, it is assumed that once in a week the daily demand reaches this high value. This is simulated by giving a 86.71 % probability to a 162 Wh load day and a 14.29 % probability to a 240 Wh load day.[49] User behavior, such as decreased demand when charge controller indicates a low SOC is not taken into account. The load distribution over the day is taken from (Khadem, 2006, p. 4).

In addition to the above, a daily noise level of 15 % and an hourly noise level of 20 % is added as suggested by (Hafez & Bhattacharya, 2012, p. 8), as shown in the exemplary profile in Figure 3.

In the simulation, loads are modeled as a variable resistor. The value of the resistor is calculated by taking an average battery voltage of 13 V into account.

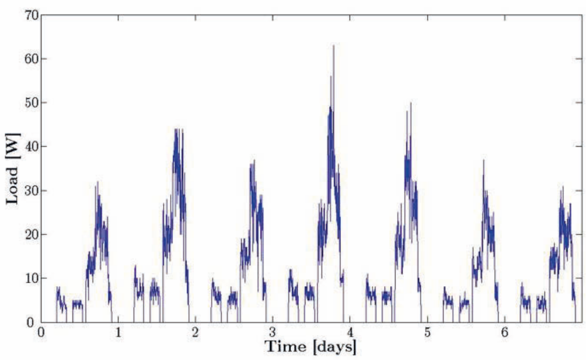


Figure 3: Exemplary weekly load profile for one SHS

Results

For the simulated SHS located in Bangladesh, generation significantly exceeds the demand. Figure 4 shows how the daily generated energy is much larger than the daily demand for large parts of the year. Only in the beginning of the second half of the year does the daily demand occasionally exceed the daily generation.

Table 3: Simulation Results

Parameter	Value	Unit
Total potential generation	97.5	[kWh]
Total excess generation	31.1	[kWh]
Ratio excess generation	31.9	[%]
Total demand	62.0	[kWh]
Total disconnected load	0.0	[kWh]

Over the course of a year a total potential energy generation of 97.5 kWh was obtained, of which 31.9 % was dumped. The total demand of 62.0 kWh was completely supplied for, as given in Table 3.

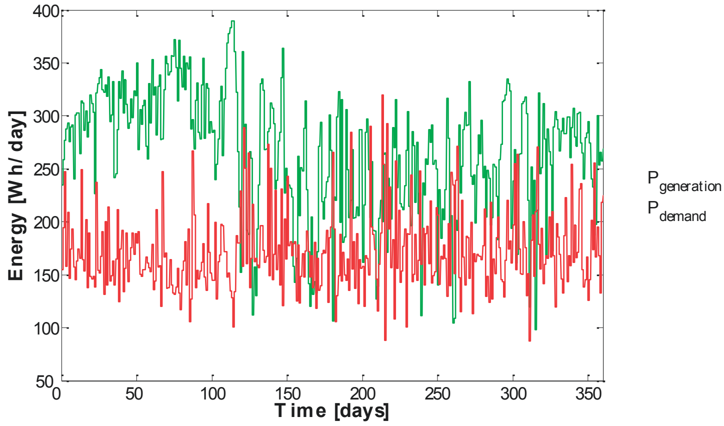


Figure 4: Daily generation (green) and demand (red)

The state of health (SOH) of the battery, defined as the ratio of the remaining capacity over the initial capacity, is at 96.8 % at the end of one year. The loss of capacity amounts to 2.5 % due to corrosion and 0.7 % due to degradation. The reason for this healthy operation is indicated in the SOC curve, as given in Figure 5. The battery hardly goes into low SOC values in normal operation. The SOC falls under 80 % on only one occasion during the second half of the year.

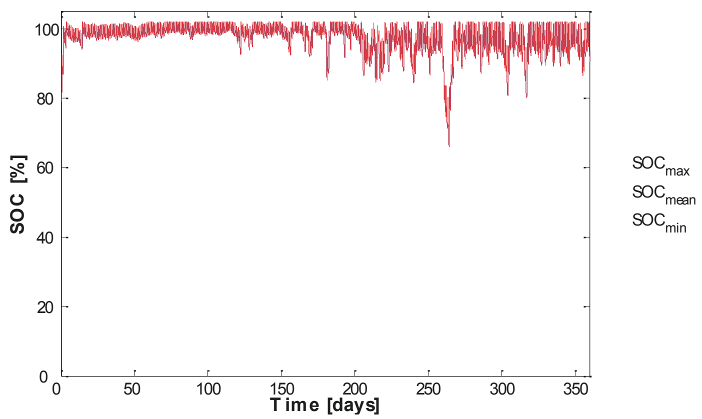


Figure 5: SOC over the course of a year

[49] These *odd* numbers come from the fractions 6/7 and 1/7 respectively.

Discussion

The results of this paper show a strong potential for interlinking SHS with other units. More than 30 % of the energy generated was dumped. However, there are a number of losses that have not been accounted for including reflection, dirt, shading or losses in the domestic wiring which could influence the outcome of this value. The assumptions made for the load profile play a critical role. In particular, seasonal load variation is not being accounted for which could have a large impact.

Nonetheless, there is a significant amount of energy hidden and available to be sold from the SHS owner to a small microgrid cluster. The initial connection to another household with a small battery that can store and use this energy and thus does not require any separate generation capacity could be the starting point for such a bottom-up electrification scheme.

References

Boldt, F. (2012, March 8). Simulation of micro electricity systems for on and off grid applications-focusing on the analysis of battery ageing and design of a system controller (M.S. thesis, Dept. Eng.). Hochschule für Technik und Wirtschaft Berlin, Berlin.

Boxwell, M. (2013). Dhaka Average Solar Insolation. Solar Electricity Handbook. Retrieved August 27, 2013, from http://solarelectricityhandbook.com/solar-irradiance.html

Groh, S., Philipp, D., Edlefsen Lasch, B.,Kirchhoff, H. (2013). Swarm Electrification – suggesting a paradigm change through building microgrids bottom-up. In Energy Systems in Transition: Inter- and Transdisciplinary Contributions (pp. 212–217). Karlsruhe: Helmholtz Association.

Hafez, O., & Bhattacharya, K. (2012). Optimal planning and design of a renewable energy based supply system. Renewable Energy, (45), 7–15. Retrieved from http://www.scribd.com/doc/121420013/Optimal-planning-and-design-of-a-renewable-energy-based-supply-system-for-microgrids

Hansen, A., Sørensen, P., Hansen, L., & Bindner, H. (2000). Models for a stand-alone PV system. Risø: Risø National Laboratory. Retrieved from http://www.risoe.dk/rispubl/solenergi/sec-r-12.pdf

IDCOL. (2013, November). Renewable Energy Projects- IDCOL Solar Energy Program. Retrieved January 30, 2014, from http://www.idcol.org/energyProject.php

IEA. (2011). World Energy Outlook 2011—Executive Summary. Paris: International Energy Agency. Retrieved from http://www.iea.org/publications/freepublications/publication/WEO2013_Executive_Summary_English.pdf

Khadem, S. K. (2006). Feasibility study of wind home system in coastal region of Bangladesh. Homer Energy, Colorado. Retrieved from https://homerenergy.com/webcast-downloads/WE58_FeasibilityWHS_Bangladesh.pdf

Kyocera. (2007). KC65T- high effiency multicrystal photovoltaic module (Datasheet). Retrieved from http://www.kyocerasolar.com/assets/001/5170.pdf

Legros, G., Haver, I., Bruce, N.,Bonjour, S. (2009). The energy access situation in developing countries; a review focusing on the least developed countries and Sub-Saharan Africa. New York: United Nations Development Programme and Worldh Health Organisation. Retrieved from http://content.undp.org/go/cms-service/stream/asset/?asset_id=2205620

NREL. (2005, March 5). Solar: hourly solar (direct normal (DNI), global horizontal (GHI), and diffuse) data for select Bangladesh stations from NREL. OpenEI. Retrieved August 27, 2013, from http://en.openei.org/datasets/node/507

Tenenbaum, B. W., Greacen, C., Siyambalapitiya, T., & Candelaria, J. (2014). From the bottom up: how small power producers and mini-grids can deliver electrification and renewable energy in Africa. Washington, DC: The World Bank.

UNFCCC. (2012, May 29). Installation of solar home systems in Bangladesh. UNFCCC. Retrieved from http://cdm.unfccc.int/filestorage/b/s/6QC1EKXSAP052ZGOLYM3HDTRNI8FVJ.pdf/Bangladesh%20SHS_CPA1-DD_ver9.pdf?t=cll8bXM2c3RtfDBzrqLX5m2Ra5EUb1gt_mxT

Unger, K., & Kazerani, M. (2012). Organically grown microgrids: Development of a solar neighborhood microgrid concept for off-grid communities. In IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society (pp. 5663 –5668). Montreal. doi:10.1109/IECON.2012.6389060

United Nations Foundation. (2012, June). Energy access practitioner network—towards achieving universal energy access by 2030. Retrieved November 11, 2012, from http://www.sustainableenergyforall.org/images/content/FINAL%20ESG%20ALL.pdf

Villalva, M. G., Gazoli, J. R., Filho, E. R. (2009). Comprehensive approach to modeling and simulation of photovoltaic arrays. Power Electronics, IEEE Transactions on, 24(5), 1198–1208. doi:10.1109/TPEL.2009.2013862

The Energy Centre Model: An Approach to Village Scale Energy Supply

Charles Muchunku (charles.muchunku@camcocleanenergy.com)
Camco Advisory Services (K) Ltd
P. O. Box 76406-00508, Nairobi, Kenya

Kirsten Ulsrud (kirsten.ulsrud@sosgeo.uio.no)
Department of Sociology and Human Geography University of Oslo
P. O. Box 1096, Blindern 0317 Oslo, Norway

Abstract

A model for off-grid, village scale power supply has been developed through the Solar Transitions research project, led by the University of Oslo. Through a participatory approach the project developed an energy centre model which became operational on March 20th, 2012.

The model creates affordable and accessible basic lighting and electricity services for off-grid households and businesses through a financially sustainable design. It is designed to be operated by local residents on commercial principles. Today, it provides lighting and other services to about 150 households.

The paper describes and rationalizes the model and shares experiences from the first 1½ years of operation. The financial performance is documented and suggestions are provided on how the model could be improved

Keywords: Solar; Energy Center Model; Households.

Introduction

Access to electricity has a positive impact on a wide range of factors influencing rural communities, from improved health, to access to communication and information, to better educational facilities, economic prosperity and improved standard of living. However, finding ways to expand energy services to marginalized households in developing countries is one of the most pressing challenges facing the world today.

Globally, there is no universal approach to provision of access to electricity in marginalized areas. The UN uses a three-step scale to denote various types of energy access[1]: Level 1 - Basic human needs (electricity for light, education, health, communication and community services, and modern fuels/improved stoves for cooking with biomass), Level 2 Productive uses and Level 3 - Modern society needs

Research Objectives

The action research project was aimed at identifying a sustainable approach for energy service delivery suited to local conditions of the selected location. These conditions included the local dynamics of the area i.e. the type of settlement, density of the population, ability to pay and the available energy resources.

[1] http://www.un.org/millenniumgoals/pdf/AGECCsummaryreport[1].pdf

Methods

The project was initiated and carried out by a team of social scientists and practitioners from Kenya, India, Norway and Austria through the Solar Transitions research project, led by the University of Oslo. Through a participatory approach with the local community, the project developed an energy centre model in Ikisaya, Kenya which became operational on March 20th, 2012.

The energy centre model is based on a 2.16 kW solar PV system which provides energy for a range of services i.e. lantern charging and renting, charging of mobile phones, IT-services (typing, printing and photo-copying) and television and video shows. Fees are charged for the provision of these services to cover operation and maintenance costs (e.g. battery replacement) and generate a surplus for energy centre improvement and expansion. The centre has the capacity to serve up to 200 households (1,000 people).

The total investment cost for the centre was 43,000€[2]; 11,000€ for the building structure which houses the energy centre and 32,000€ for the solar PV equipment, furniture and appliances.

Results

The energy centre is designed to be run by the local community under a concessional arrangement. Under the terms of the concession, ownership is not transferred; the energy centre and the equipment therein remain the property of the project. In addition, the operator is required to submit quarterly operational financial reports and an annual audit. The operator is also required to make an agreed upon monthly deposit to a joint bank account for the battery replacement and maintenance fund. If the operator fails to adhere to these terms and no suitable remedial action is identified and effected, then the concession is terminated and the system reassigned or relocated to another community

The services provided by the centre generate an average revenue of 460€/month. Operation and maintenance costs average 400€/month. This includes staff salaries, petty cash, consumables, general maintenance and contribution

[2] Excludes costs related with developing the model, training the staff and follow ups. At the time of implementation, 1€ = 110KES.

to a battery replacement fund i.e. to raise 4,600€ every 2-3 years (130-190€/month).

The revenue trends from 18 months of operation are summarized in Table 1 below. They indicate that the lantern renting and mobile phone charging services are by far the highest and most consistent source of revenue; they represent 70% of all revenue generated by the energy centre and about 50% of the costs. They essentially subsidize the other services provided at the centre i.e. the IT services and TV/video shows. Whereas, these are viewed as important services by the local community they are not sufficiently subscribed to cover their operational costs.

The lantern charging and renting service has evolved from a centralized model where the lanterns and lantern charging system were all housed at the energy centre to a decentralized model where lantern renting services are also provided in neighboring villages through agents. The Ikisaya energy centre currently has 5 agents located in other trading centers that are 10km or more from the energy centre. The lantern charging capacity of the energy centre and the 5 agents is currently: Ikisaya – 56, Endau – 56, Kalwa – 20, Kathua – 20 and Yuiku – 20.

The total number of services used and paid for in a given day now averages about 169; an increase of 44% over 5 months. Lantern renting and mobile phone charging are the most used services; they together represent 77% of all services used at the centre. The usage of other services is: IT services -13%, TV/Video-7% and hair cutting-3%.

Table 1: Average Monthly Revenues Oct-Dec 2012 and Apr-Jun 2013

Business Section	**Services**	**Average daily users (Oct-Dec12)**	**Average Monthly Revenue (Oct-Dec12)**	**Monthly Revenue/ Section**	**Average daily users (Apr-Jun 13)**	**Average Monthly Revenue (Apr-Jun13)**	**Monthly Revenue/ Section**
Charging Services	Lantern charging	26	7,930	13,563	40	11,940	21,373
	Mobile phone charging	9	5,513		31	9,433	
	Battery charging		120				
Agents	Lantern charging	55	16,390	16,390	52	15,690	16,687
	Mobile phone charging				3	997	
IT Services	Photocopying & Sale of Envelopes	15	4,622	9,292	16	4,800	6,003
	Typing and Printing	2	1,387		4	1,203	
	Laptop charging		3,283				
Retail Outlet	Lanterns		667	2,053	2	667	667
	Powapacks		1,387				
Multipurpose room	TV & Video Shows	7	2,165	2,432	13	3,917	4,083
	Room Hire		267			167	
Other Services	Hair cutting	3	912	912	7	1,960	1,960
Totals (KES)		**117**	**44,642**	**44,642**	**169**	**50,773**	**50,773**

The projected and actual average monthly expenditure for the energy centre are shown in Table 2 below. On average the energy centre's expenditure has not varied much over the course of its operation. Staff salaries and the battery replacement fund represent the largest operational expenditures.

The battery replacement and maintenance fund is based on raising an estimated 506,000KES (4,600€) every 2-3 years. This amount is to cover future battery replacement costs and unexpected system component repair or replacement costs. The centre target is therefore to set aside 21,300KES every month towards this fund. The actual amount raised is typically the difference between the monthly revenue generated and the recurrent monthly operational expenditure; as at the end of August 2013, the centre had managed to set aside a total of 168,500KES (1,532€).

Table 2: Average Monthly Expenditure Nov12-Jan2013 and Apr-Jun 2013

Energy Centre Expenses	**Details**	**Projected Expenditure per month**	**Average Monthly Expenditure (Nov 12-Jan 13)**	**Average Monthly Expenditure (Apr-Jun 13)**
Salaries	Manager	8,000		
	IT clerk	6,500	6,500	7,167
	Centre technician	6,500	6,500	
	Evening attendant	5,000	5,000	6,333
	Part time accountant	4,000	4,000	6,000
Other Staff Payments	Overtime (evening attendant)		999	745
Agents Commission	Commissions for lantern renting agents		3,289	1,851
Consumables	Printing paper	480		760
	Cartridges black	1,560	2,167	2,723
	DSTV monthly subscription	4,300	2,150	1,015
Petty Cash		4,000	2,296	3,142
Transport	Monitoring of agents		850	1,500
Business Permit	County Council Payments			440
Maintenance fund contribution	Estimated 500,000 needed after 2 years for battery replacement and other emergency maintenance requirements	21,300	13,600	12,333
Total expenditure, monthly (KES)		**61,640**	**46,735**	**44,010**

Discussion

With a typical solar PV system life span of 15 years, the project is low-cost compared to other options for provision of basic energy services to low density off-grid communities. Considering the average population density in the general areais 9 households/km^2 and conservatively assuming that 1km of low voltage grid network would be sufficient to connect 10 households; the total cost for a electricity grid to connect 100 households would be about 80,000€. In Kenya, this would theoretically be financed through the rural electrification fund. In addition, each connected household or business would be required to pay a connection fee of 150-320€.

The significant upfront investment required for the energy centre and small margins make the model uninteresting for private sector investment. In its current form, the model would not attract businesses that could easily generate quicker and more substantial returns elsewhere. A capital subsidy would therefore be required if an identical model is to be replicated.

Nevertheless, components of the model could be interesting for private sector investment.Revenue and expenditure trends indicate that the lantern renting and mobile phone charging services are the highest and most consistent source of revenue; they represent 70% of all revenue generated by the energy centre and about 50% of the operation and maintenance costs. An analysis of investment costs also indicates that a model that targets only the provision of lantern renting and mobile phone charging services would require less than one third of the investment costs used for the Ikisaya energy centre.

A key lesson is that location is a key consideration when selecting the services to be provided and best way to deliver them.In areas where household incomes are low it may be necessary to focus on the provision of the most basic services i.e. lighting services (lantern renting) and phone charging only. In economically active areas, the demand for TV and IT services would be higher, as would be the ability to purchase lanterns or small solar home systems. For purposes of standardization and replication, it may therefore be necessary to develop criteria for assessing and categorizing sub-locations based on socio-economic activity and then develop services best suited for each category.

References

The UN Secretary-General's Advisory Group on Energy and Climate Change (2010).Energy for a Sustainable Future: Report and Recommendations(pp. 13).

The Kenya Bureau of Statistics (2009). Population Census

Lessons from the Edge

Peter Newell (pnewell@bmntpartners.com)
BMNT Partners
Palo Alto, CA, USA

David Kerner (david.kerner@taurigroup.com)
The Tauri Group, LLC
Alexandria, VA, USA

Scott Thomas (scottt@stetsonengineers.com)
Stetson Engineers Inc.
Diamondhead, MS, USA

Abstract

Lessons learned by the Army in changing how it meets energy needs on the battlefield can well inform how energy solutions are brought to rural areas around the world.The high human cost of delivering energy on the battlefield led the Army to reexamine its assumptions about how energy is provided and used.Changing the way they framed the problem led to better energy solutions, saved lives, and made the missions more resilient.The resilience paradigm is also well suited to rural energy applications.Based on the Army's lessons learned, the authors describe the attributes of a resilient system and discuss how these terms can be applied to instill energy resilience in rural communities.

Keywords: Army energy; Resilience.

Introduction

Late in 2010, the US Army and other forces in Afghanistan were faced with a growing trend in Improvised Explosive Device attacks that no amount of technological advantage seemed to abate.With no clear path to a technical solution to the problem, experts began looking for ways to reduce the number of Soldiers exposed to potential attacks.This fresh look at a decade-old problem also coincided with a growing desire to find a way to curb the growing costs of providing fuel to fixed sites throughout the country by inserting renewable energy systems as a source of power.

These weren't the first attempts to insert renewables onto the battlefield; there had in fact been several others dating back to early-2006.Unfortunately, the driver in previous attempts was a desire to save dollars, something that is a tough sell to Soldiers who are most concerned with just making it back to base in one piece every day.

Real progress did not come until the Army targeted a reduction in resupply efforts at the far reaches of the battlefield, where resupplying fuel was largely a human capital-intensive endeavor.

In these locations, for these units on the "tactical edge" -- the burden of providing power and energy relies primarily on the force on the ground where the operational costs to deliver power and water are the greatest.At the tactical edge, sustainment operations are tactical operations that consume combat power, and at the tactical edge, savings will likely be measured in lives rather than gallons of fuel saved.

As we learned to ask the right questions, leaders across the country discussed the challenges of resupplying ever more distant Combat Outposts and their associated Observation Posts.The problem was most telling in one Brigade's area along the Afghanistan-Pakistan border, where logistics resupply operations between a battalion-level Forward Operating Base and a Combat Outpost was a 10-hour trip - one way - all on routes that had to be cleared of improvised explosive devices and then secured lest they be repopulated with more. From that Combat Outpost it was a five-hour walk up a mountain to reach the closest Observation Post (OP).At the OP there was no landing zone; at best, there was only a single touchdown point with barely enough room for a helicopter to get two wheels on the ground.That Observation Post was within two and half kilometers of the Pakistani border and was in near daily contact with insurgents.

Two squads of Infantrymen who rotated into the site every seven to ten days manned the Observation Post. They lived and worked in open bunkers and had only minimal power requirements -- just enough to power their radios and Intelligence, Surveillance & Reconnaissance (ISR) systems and recharge their batteries. Their sole source of power was a single 5-kilowatt generator that they had somehow managed to get to the Observation Post. Unfortunately, the generator was unreliable and difficult to repair, no surprise given that the power draw on it was less than 20 percent of its capacity.

The Observation Post relied on air resupply for fuel and water, something that could not always be counted on in the winter. Close by were three other Observation Posts along the border in similar conditions.

Our observations indicated that "spot power" was a reality for small units who moved often and changed missions and operating bases as often as they change socks. At these locations there were no grids, save those installed on the fly by very industrious Soldiers.

At one small Combat Outpost representative of the problem, we found power provided by five generator sets.

The first generator ran the Combat Outpost's Command and Control node with 15 computers, three large screens and number of monitors and six radios. That 60-kilowatt generator was running at 17 percent of its capacity. The second generator we found was powering the Combat Outpost's living areas and dining facility -- this 60-kilowatt generator was operating at 36 percent capacity. The third generator, also a 60-kilowatt unit, operated a single pump at the shower point that had a power draw of just 750 watts. The fourth generator our team found was the best utilized, with 53 percent of its capacity being used to power the four refrigerator vans that supported the dining facility. The final generator set we found was a 15-kilowatt set that was used to provide the 1.2 kilowatts of power needed to run the Combat Outpost's Rapid Aerostat Initial Deployment (RAID) tower.

Our visits to the forward edges of the battlefield, our site surveys, and our efforts to curb their energy problems taught us many lessons.

First, energy solutions must be developed in open, transparent, and collaborative environments. Several of our early efforts lacked this coordination. For instance, in the early days of foaming tents for insulation, we failed to load-balance the generators that powered the air conditioning for the tents. While we were successful in reducing the temperature inside the tents, the reduced load on the generators caused them to be more inefficient and resulted in more fuel burned.

Likewise, at the tactical edge the operators are Infantrymen, cooks, and medics, not electricians. Clearly, materiel solutions delivered for these Soldiers' use had to be robust yet functionally easy to integrate, operate and maintain.Additionally, training had to go beyond simple maintenance procedures and include the principles of power management.

Third, our Highly Qualified Experts and assessment teams had to be 'solution agnostic.'These teams had to be useful from the day they arrived onsite.Their initial duties included helping to optimize what was already present while also gathering the data required to help us determine the right solution.We also found that we had to gather data not just from one part of the system but had to check downstream to insure the solution didn't cause a bigger problem someplace else.We certainly could not assume that the improved effectiveness of a single device in a system would mean that the entire system would be better optimized.

We came to understand that fuel reliance is just part of the sustainment problem for tactical units; access to clean water and waste removal account for a significant portion of our sustainment convoy requirements and must be addressed as well.

We recognized the real power of our organization was in our ability to bring together teams of subject matter experts from other organizations in order to more rapidly understand and solve complex problems. We became heavily reliant on partnerships and collaboration with other government organizations, academia and industry, all of whom had the skill-sets necessary to support rapid requirements analysis, unit coordination, accelerated procurement, contracting, training, assessments and sustainment.

Our most significant lesson was that despite our tremendous resources, we truly lacked resiliency in our ability to sustain ourselves at the remote areas.While our method of brute force accommodation made up for that lack of resiliency in most cases, when it failed, the results were catastrophic.And those same accommodations - massive resupply convoys - became assailable weaknesses for others to exploit.

In the future, we have much more to learn about solving challenges in austere environments.

Understanding the Challenge

How we characterize the problem, a step that explicitly or implicitly embodies our assumptions and expectations, is a central concern.This steers how we define 'success,' what terms we choose for analysis, our metrics for measuring progress towards goals, and the technologies and strategies we select to achieve those goals.

If our focus is exclusively on economics, we inherently assume certain things about what will be good for the affected stakeholder.In the case of energy delivery in Afghanistan, the original assumptions included that energy supplies would focus almost exclusively on the use of military-grade JP-8 fuel, an assumption that carried mortal implications for those who delivered, retrieved, and relied upon that singular approach.Once we reframed the narrative, leaders were able to understand the full implications of logistics choices; the calculus no longer focused on economics, but on Soldiers' lives and mission effectiveness.

In a similar manner, efforts to meet rural energy needs often focus on narrow economic considerations, such as the cost per unit of energy delivered or the overall energy capacity installed for a given amount of money.Job creation and second-order effects may be included in the calculation, but the emphasis tends to be on the energy delivered.We argue that, just as the military energy supply problem was refocused from just supplying energy to the broader goal of ensuring the mission – which carries with it the need to protect troops, reduce reliance on singular supplies of a resource, ensure mission capabilities in the face of disruptions – so too the rural energy initiatives should focus on the community's existential needs to function and carry forward its character and identity.

A Resilience Perspective

The focus, then, must be on resilience.While several definitions exist for the term, the one of greatest use for open systems such as a rural economy derives from what natural resource managers have observed about ecosystems that adapt, survive, and thrive despite a wide range of stresses and disruptions.Systems characterized by uncertainty and unpredictability appear more tractable when examined from this ecological systems perspective.In this context, resilience has been defined as the capacity of a linked social-ecological system (SES) – very much a description of a rural society – to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity (Holling, 1973; Walker et al., 2006; Walker and Salt, 2006).How much disturbance can the system – people, infrastructure, resources - accommodate while still maintaining its basic structure, capabilities, and capacity to function? How far can it bend and adapt without breaking?

Systems often fail in unpredictable ways, but resilient systems continue to function despite the challenges. Planning assumptions do not always hold true, and planners often fail to ask how well the system will function in the face of large, unexpected challenges, or the accumulation of many smaller stresses; these include market failures; geopolitical and demographic shifts; resource shortages (e.g., water, fuel, fertiliser, minerals); epidemics; climate change; and technology disruptions (NAS, 2012).

Many systems appear to share attributes by which resilience can be characterized and assessed. Kerner and Thomas have investigated which system attributes relate specifically to the ecological definition of resilience, asking, “What attributes reflect whether a system will be able to continue to function and retain its identity in the face of existential challenges?”They considered attributes for all types of systems, including natural and manmade, physical and institutional, small and large, simple and complex. Building on others’ efforts (e.g., Holling, 1973; Lovins, 1982; Walker et al., 2006;), they have delineated and defined common resilience attributes. These attributes, the full collection of which is the subject of a forthcoming paper, fall into three overarching categories that help us to understand the resilience ‘posture’ of a given social-ecological system:

Stability: The degree to which a system can continue to function if inputs, controls, or conditions are disrupted. It is a reflection of how minor a perturbation is capable of rendering the system inoperable or degraded; the types of perturbation to which the system is especially vulnerable; whether the system can ‘ignore’ certain stresses; and the degree to which the system can be altered by surprise. Stability entails a number of attributes including controllable degradation, resistance, dispersion, and others.

Adaptive Capacity: The ability of a system to reorganize and reconfigure as needed to cope with disturbances without losing functional capacity and system identity. It reflects an array of response options and the ability to learn, collaborate, adapt, and create new strategies to ensure continued functionality. Adaptive Capacity entails a number of attributes including response diversity, connectivity, learning capacity, and others.

Readiness: How quickly a system can respond to changing conditions. It is affected by the physical, organizational, social, psychological, or other barriers, internal or external that might impede timely response. Readiness is a measure of responsiveness; its converse is entanglement, a measure of the forces impeding responsiveness. Readiness entails a number of attributes including situational awareness, preparedness, simplicity, and others.

Put simply, we want to know if the system can survive a challenge as things currently stand (Stability), have the ability and options to respond if necessary (Adaptive Capacity), and understand if there are factors that help or hinder that response (Readiness).

Energy Resilience

In meeting the needs of a rural community, we seek energy resilience as one of the key enablers of the community. We define energy resilience as the ability to maintain the community’s identity and function – to keep it alive and thriving – in the face of energy supply perturbations. This definition refocuses energy policy from assuring supply to assuring preparedness, thus setting the framework for stakeholders to improvise, adapt and overcome the effects of potential supply interruptions (Thomas and Kerner, 2010).This shift in the narrative moves us to consider all of the factors that keep the community viable, and how those factors are affected by different energy strategies.

So how does a rural community measure success? Some goals include local employment, enduring social and cultural integrity, self-determination, safety and security, self-reliance, and multiple sources of energy, water, and other resources. Changing the focus to energy resilience leads to solutions that ensure societal functions such as farming, transportation, education, public safety, waste disposal, etc., can endure energy supply disruptions; adapt to accomplish those functions in new and different ways; and respond in a timely manner, unencumbered by dependencies and constraints. A resilience perspective considers the totality of the energy-water-food-livelihood nexus.

Solutions for rural energy concerns will be more varied than just a short list of grid and alternative power (photovoltaics, wind, hydro, etc.) options. Appropriate technologies – those of a size, simplicity, and sustainability commensurate with the particular community – should resonate with the inherent goals of that community and may fit well here. It should be noted, though, that solutions will not only be technological in nature, but will likely require organizational, regulatory, and procedural changes. Moreover, leadership and initiative, highly important traits in the Army, will play a crucial role in realizing any resilience goals. Finally, it should also be noted that efficiency measures, while important, should not be equated with resilience; depending on less of something is not the same thing as being less dependent on it.

Conclusions

Military forces are designed to be highly resilient in a number of ways, but they have been dependent upon reliable delivery of large quantities of specific, high-quality energy resources. Defending the vulnerable supply lines to which forces have been tethered skews the "tooth to tail" ratio and places additional service members in harm's way. This energy dependency has created significant vulnerabilities and limits force resilience. By reframing the planning considerations to a resilience perspective, new solutions emerge that both ensure the mission and protect the lives of Soldiers.

The narrative we choose steers outcomes and affects whether change is palatable. Framing rural community energy decisions in terms of resilience leads to outcomes that favor a community's existential needs; a focus on a monetary return on investment skews decisions to favor cost factors. As such, a resilience "return on investment" is not defined by dollar metrics, but by metrics associated with the continued identity and function of the community. Resilience can be assessed, developed, and maintained within a social-ecological system – e.g., a rural community – to avoid tipping points and ensure its existence for tomorrow. Focusing on system resilience provides a broad framework for selecting between options, prioritizing investments and initiatives, and making decisions about vital issues affecting the fate of rural communities.

References

Holling, C. S.1973.Resilience and Stability of Ecological Systems.Annual Review of Ecology and Systematics.4: 1-23.

Lovins, Amory and L. Hunter Lovins, 1982.Brittle Power:Energy Strategy for National Security.Brick House Publishing Co., Inc., Andover, MA.

National Academy of Sciences (NAS).2012.Disaster Resilience:a National Imperative.National Academy Press.Washington, DC.

Thomas, Scott and David Kerner.2010.Defense Energy Resilience:Lessons from Ecology.Strategic Studies Institute.United States Army War College.Carlisle, PA.

Walker, B., L. Gunderson, A. Kinzig, C. Folke, S. Carpenter, and L. Shultz.2006.A handful of hueristics and some propositions for understanding resilience in social-ecological systems.Ecology and Society. 11(1) : 13.

Walker, B. and D. Salt.2006.Resilience Thinking:Sustaining Ecosystems and People in a Changing World.Island Press.Washington, DC.165 pp.

Scientific Papers

X. Value Chain Analysis

Advanced Solar-Irrigation Scheduling for Sustainable Rural Development: A Case of India

Hari D. K. (hari@fluxgentech.com)
FluxGen Engineering Technologies Pvt. Ltd., Bangalore, India

H. Mitavachan (mitavachan@gmail.com)
FluxGen Engineering Technologies Pvt. Ltd., Bangalore, India
Postgraduate Program Renewable Energy, Oldenburg, Germany

Suresh K. R. (suri.civ@bmsce.ac.in)
BMS College of Engineering, Bangalore, India

Ganesh Shankar (ganesh@fluxgentech.com)
FluxGen Engineering Technologies Pvt. Ltd., Bangalore, India

Abstract

In the past few years, there have been large migrations from the rural to the urban areas of India as the country has developed. This has led to shortage of agricultural manpower in rural India, a region which is essential for the country's food security. Also, groundwater depletion in rural areas is affecting agriculture. Automating some agricultural tasks in a sustainable, scientific way could address this, leading to decreased water and energy use and increased crop yields. We develop a research platform to implement proof-of-concept of a system for precision agriculture incorporating renewable energy sources and information technology. Data collected by this system will be used to design a low-cost, commercial version of this technology for the rural Indian farmer.

Keywords: precision agriculture; renewable energy; solar irrigation; Indian farmer; information technology; water management.

Introduction

India is basically an agrarian society wherein around 60 percent of land area is cultivated for agriculture and about 50 percent of the population directly or indirectly depends on agriculture. Agriculture in India is mainly dependent on the monsoon. Due to crop failures from monsoon variability, water scarcity, increasing cost of cultivation and many other unsustainable agricultural and trade related practices, the number of farmer suicides in rural areas has assumed alarming proportions. An estimated 250,000 Indian farmers have committed suicide since the mid-1990s (Mishra, 2008). Moreover, recent climate change studies indicate that fluctuations in temperature and precipitation on the Indian sub-continent (especially in the monsoon) are very likely to increase in the near future(Turner & Annamalai, 2012). This will lead to increasing occurrences of droughts and floods, which in turn will increase conflict over scarce resources, especially land and water, impacting Indian agriculture negatively as a direct consequence (Jamir, Sharma, Sengupta, & Ravindranath, 2013; Pullenkav, 2013).

The Kharif crop is mainly rain fed (monsoon), whereas the Rabi (winter) and summer crops require irrigation. The increasing unreliability of the monsoon and the scarcity of electricity in rural areas are forcing Indian farmers to depend on diesel fuel operated tube wells for irrigation. The high operational cost of diesel based irrigation pumps is forcing farmers to practice deficit irrigation, and as a result crop yields are much lower than their potential (Pullenkav, 2003).

Given that India has more than 300 sunny days per year in most regions, the alternative option of solar water pumping has been seen as an obviously promising one. Although the growth of the solar water pumping market has been insignificant so far due to various regulatory, market and technological barriers (Pullenkav, 2013), India's recent national solar mission (JNNSM) is expected to bring a significant change in this direction. It is estimated that around 70 million solar PV pumps can be installed in India by 2020(Purohit & Michaelowa, 2008).

As of 2010, there were around 9 million diesel irrigation pump sets installed in India. If solar photo-voltaic (PV) pumps replace at least half of these, then about 225 billion liters of diesel can be saved per year. The cost of solar PV water pumping without any subsidy comes to around 64.2% of the cost of a diesel pump over ten years, and has a payback time of around 4 years (from diesel savings.) The levelized cost of solar PV pumping works out to be Rs.8.6 per kWh compared to Rs.13.9 per kWh for diesel pumping for a lifetime of 25 years and without taking into account any subsidies for solar PV (Raghavan et al., 2010). Hence, it is becoming obvious, especially with the increasing diesel fuel prices and the significantly falling PV prices, that solar PV water pumping for irrigation is a promising and cost-effective solution for India.

However, just going solar for agricultural irrigation is not enough. (Rodell, Velicogna& Famiglietti, 2009) in their study based on satellite observations provide evidence that unsustainable consumption of ground water for irrigation and other anthropogenic uses is leading to significant ground water depletion in various Indian states. The study further highlights that, as a consequence of this, these states might experience reduction in agricultural output, shortages of potable water and serious socioeconomic stresses, if proper measures are not taken very soon. Hence, irrigation techniques and water harvesting methods have to be very efficient.

All these facts make the following evident. First, Indian agricultural fields inevitably need better irrigation; second, there is an urgent necessity to take proper safeguards so that the adopted irrigation techniques are climate friendly and really sustainable ones. In this paper, the authors try to address this dual problem by developing a novel technological method of integrating solar PV pumping technology with information technology (IT) and environmental parameter sensing.

Research Objectives

This research project[52] aims to develop and deploy advanced sustainable technology for efficient irrigation of agricultural land in rural India. The technology developed will be based on sound principles from scientific/precision agriculture and incorporates renewable energy sources as far as possible. This is to make the technology sustainable in places where grid electricity access is limited or absent. In this paper we document the development of a proof-of-concept system based on these ideas.

Methods

The aim of our studies is to design and test a system that uses computer-controlled solar water pumping and closed-loop irrigation scheduling of a target agricultural field containing a given crop. “Closed-loop” irrigation scheduling means that the irrigation to the field is controlled on the basis of the soil moisture content in the field, apart from other environmental parameters.

The primary research methodology is to quantify the amount of electricity and water consumed, and the yield obtained after the crop life-cycle, using this method of irrigation scheduling. The next set of experiments will compare these parameters with the existing system of irrigation prevalent in rural India (flood irrigation), which does not use any form of feedback control for scheduling of irrigation in agricultural fields. The intent of these experiments is to come up with good engineering design decisions when developing and commercializing this technology at the lowest possible unit cost for the rural Indian farmer.

We now present background material that will allow an understanding of the technology we have developed.

Soil Moisture Sensing

The moisture content in a sample of soil is the ratio of the volume of water in the sample to the total volume of the soil sample (Black, 1965) and is generally abbreviated “VWC” (Volumetric Water Content). Several techniques have been devised to allow automated and non-destructive measurement of soil moisture, ranging from neutron scattering to soil dielectric constant based instrumentation (Walker, Willgoose & Kalma, 2004). In our research, we use capacitive soil moisture sensors of the “soil dielectric constant” type. These sensors return a voltage from which the VWC of the soil surrounding the sensor probe may be inferred.

Soil Parameters

We now explain the main parameters related to soil moisture (Doorenbos & Pruitt, 1977) that are used by the irrigation scheduling algorithm. The Field Capacity (FC)of a soil is the moisture held in the soil after excess water has drained away and the rate of downward movement has decreased. This usually takes places 2-3 days after rain or irrigation in pervious soils of uniform structure and texture. The Permanent Wilting Point (PWP) for a given crop is the minimal point of soil moisture that the plant requires not to wilt. If the moisture falls below the PWP, the plant will be damaged. The Readily Available Moisture (RAM) for a particular crop in a soil is the range of available water that can be stored in the soil and is available for crop growth. The RAM is computed as the difference between the FC and the PWP. The Maximum Allowable Depletion (MAD) is the portion of the RAM that is allowed for crop use prior to irrigation. It is expressed as a percentage of the RAM, usually between 50% and 70% based on the crop type.

The Irrigation Scheduling Algorithm

The algorithm works as follows. The system contains a database of soil parameters across twelve different types of soil (e.g. clay, loam) and 13 crop types (e.g. maize, sugarcane). The parameters maintained in this database are the FC, the PWP, the RAM and the MAD, as explained before. The lower threshold for activation of irrigation scheduling is computed using the RAM and the MAD. When the soil moisture level falls below the lower threshold, the irrigation valve is opened. Once the soil moisture increases to cross the FC, the irrigation valve is closed. This is a form of closed-loop control with hysteresis. We emphasize that this is the basic algorithm; one of the aims of our research is to come up with more efficient variations on this theme.

Weather Parameters

A precision weather station relays real-time environmental parameters including ambient temperature, daily rainfall, solar irradiation, wind speed and wind velocity to the software, which logs all these parameters continuously. There is a two-fold utility in logging these parameters. Firstly, it may allow a “weather forecast” to be computed. If a computed weather forecast indicates that it will rain within some period, making irrigation superfluous, water savings may be increased by appropriately pre-empting the next irrigation.

Logging weather data also allows correlation studies to be performed between the weather conditions and the irrigation schedule. In the final version of this product, some components (e.g. the weather station) may be removed in order to deliver it to the end customer (an Indian farmer) at the lowest possible unit cost. The research system with full weather instrumentation allows us to infer a logical rule-set which may be implemented when localizing the product (without the weather station) to a particular region with a known climate through the year.

[52] This work is a joint effort between BMS College of Engineering, Bangalore and FluxGen Engineering Technologies pvt. ltd., Bangalore.

Renewable Energy

The pumping of water into an overhead storage tank is performed under computer control. The pump is a commonly available "solar pump" of efficient design that is powered by (in this case) a 50 Watt-peak solar PV module. In the field version of our system, all hardware, including the weather station and the embedded controller, run from renewable energy sources. We note that the technology we present is a naturally compatible "application" for a rural renewable energy microgrid.

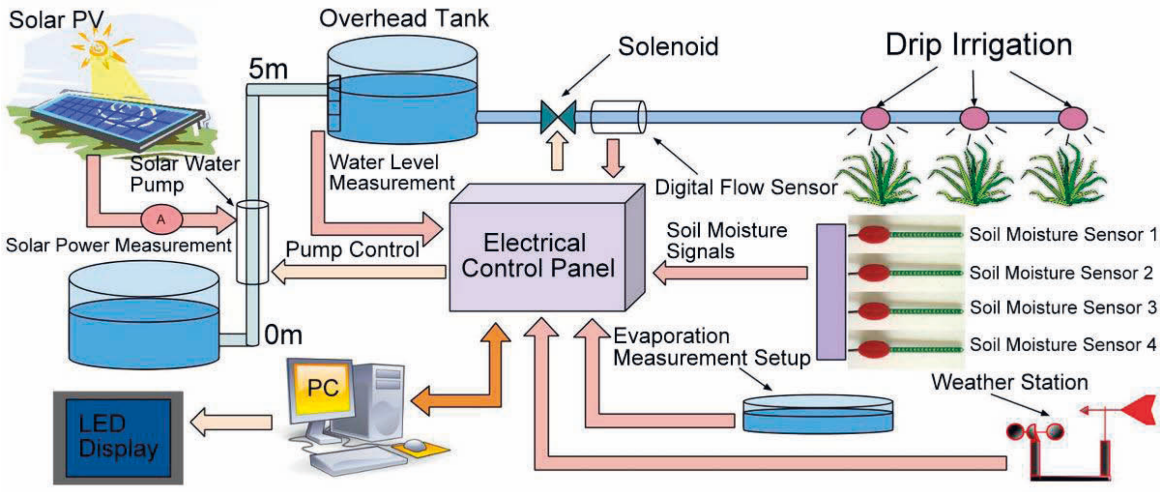


Figure 1: Block diagram of the proof-of-concept system

The Role of Information Technology

IT is central to our approach to problem-solving in this domain. The system we have developed acquires and logs several parameters of interest, including the pumping and irrigation schedules, weather parameters and energy usage. This data allows for extensive analysis of the performance of this type of system under various environmental conditions. Having these logs allows us to reuse the data for other academic and industry projects related to renewable energy, rural electrification systems and water management.

Since our system is built using versatile tools from National Instruments (http://www.ni.com), we are able to easily develop, test and deploy improved irrigation scheduling algorithms. Specifically, we utilize the LabVIEW platform and RIO-based reconfigurable hardware from National Instruments in this system. For further technical details of our system, please see (Hari D.K., Shankar, Kumar & Voleti, 2013).

Results

As a concrete first step towards this technology, we have developed a proof-of-concept system[53] for research and development (R&D) in this area incorporating all the techniques outlined previously. As shown in Figure 1, irrigation is provided by drip irrigation sprinklers placed in a crop field. The irrigation is controlled (switched on and off) using the solenoid, which is under digital control of the computer (PC) running custom software. The computer also controls the solar water pump, which is powered by solar PV panels or a renewable energy microgrid. The power delivered from the solar panels for pumping over the course of the day is measured and logged.

The soil moisture sensors return a voltage related to the

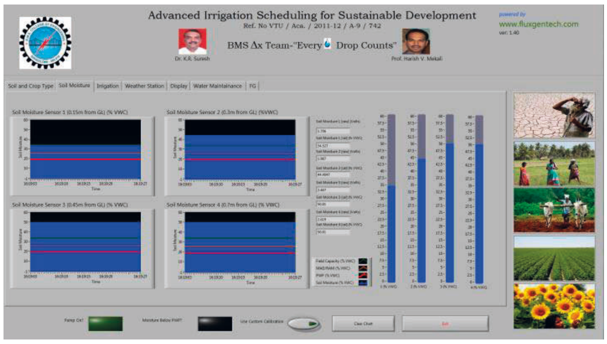


Figure 2: Display screen, showing soil moisture levels

level in the overhead tank to which water is pumped, and daily evaporation (measured in a special setup.) The latter allows for fine-tuned corrections to the irrigation scheduling algorithm based on moisture loss due to evaporation. The electrical control panel contains all the field wiring housed in a weatherproof enclosure, and transmits signals over a bus to a computer in the lab.

The system continuously acquires and logs all parameters. It displays them in graphical format on the Display (see Figure 2). The most important feature implemented is the closed-loop irrigation scheduling, as explained previously.

A major use of the system we have developed is to research and test innovative irrigation scheduling algorithms in-field. For example, would it make more sense to irrigate only at night, when the water loss due to evaporation is less? What soil moisture sensor placement is required for a robust reading? Similarly, questions may also be posed and answered regarding the optimum solar water pumping schedule, efficiency of renewable sources, etc.

The use of software to perform the irrigation scheduling allows us to test the hypothesis that we can use the same basic algorithm across any crop or soil type, allowing for an economy of effort in developing and commercializing

[53] Patent pending.

this technology for rural India. Our technology currently supports 13 crops (e.g. maize, sugarcane) across 12 soil types (e.g. loam, clay).

The system has been running autonomously since July 2013 at a field site at BMS College of Engineering, Bangalore. The crop being grown is maize in a clayey soil. We currently use four soil moisture sensors located one below the other at sensing depths of 15 cm, 30 cm, 45 cm and 70 cm under the ground. The irrigation scheduling algorithm currently being tested contains a simple linear root water uptake model (Prasad, 1988) so that, in effect, the soil moisture level is determined across the current depth of the plant's root system.

We have also developed a completely portable version of the research system based around the RIO embedded technology from National Instruments (Hari D.K. et al., 2013). This version contains all the functionality of the proof-of-concept system without need of a PC.

Discussion

The technology described in this paper will find application in areas where there is land suitable for agriculture, but inadequate supply of water and/or electricity. In grid-connected rural areas of Karnataka, the government currently provides free electricity for a limited period during the night ("Karnataka Farmers", 2014). The practise in these areas is to pump water into an overhead tank as soon as the electricity comes on in the night, and then use this to perform flood irrigation of the crop the next day. In flood irrigation, which has been traditionally followed for thousands of years, there is usually a massive overuse of water. This translates to a much higher energy usage (for water pumping) than is actually necessary for crop growth.

In the system we have proposed, water saving (and therefore energy saving) is achieved by a combination of drip irrigation and closed-loop irrigation scheduling. Every drop of water is counted, and irrigation is scheduled based on the actual crop demand. From our field trials, which are in progress, we have seen water savings of up to 30 to 40 percent. This water saving translates to lowering of the size, and therefore cost, of the solar panels required for pumping water. Hence our system can also be used as a retrofit for extending solar irrigation to a larger agricultural area without extra investment on larger solar panels. The system is also appropriate as an efficient and sustainable replacement technology for the existing diesel-based water pumping.

A major factor suggesting adoption of this technology is the dropping groundwater levels in India, as mentioned previously. Dropping groundwater levels in rural areas makes agriculture unsustainable and forces migration of people from the rural to urban areas, resulting in loss of skilled manpower. Hence adoption of this system may increase food security in India even though labour costs are increasing and the size of the agricultural workforce is decreasing. If this technology is successful and leads, for example, to increased yields and therefore increased incomes for Indian farmers, their livelihood may be improved.

As groundwater levels are dropping even in urban areas, the technology may find application, after suitable modification, in urban spaces like apartments, parks and botanical gardens. The final product we are developing can be used without specialist knowledge of agriculture. It may therefore become a useful tool for those entering the farming profession from a non-agricultural background.

A challenge in moving this technology out of the lab and into rural India is making it cost-effective for the end user. The most expensive components in the field version will likely be the solar panels, batteries if present and the various sensors. Indigenization of some components for the Indian scenario may be required to make this technology affordable to the Indian farmer.

Our future pathway for developing this technology is to continue research at BMS College of Engineering and field sites in rural Karnataka. There are many steps to achieving the full potential of this technology, including solving technical problems, performing rigorous field trials, making it economically viable, educating farmers on scientific agriculture, exploring financing options and building the supply chain, market and distributor network for the final product. We hope to involve many students and faculty across disciplines in this effort, which will give them first-hand experience of the challenging real-world problems that must be solved in order to bring this technology to life.

References

Black, C.A. (1965), *Methods of Soil Analysis: Part I – Physical and Mineralogical properties*, Madison, USA: American Society of Agronomy.

Doorenbos, J., & Pruitt, W.O. (1977). Guidelines for predicting crop water requirements. *FAO Irrigation and Drainage Paper*, *24*, 15-29.

Hari D. K., Shankar, G, Kumar, T, & Voleti, L (2013). *Performing Advanced Irrigation Scheduling for Sustainable Agriculture Using LabVIEW and NI Single-Board RIO*. Retrieved from National Instruments Web Site: http://sine.ni.com/cs/app/doc/p/id/cs-15713

Jamir, C., Sharma, N., Sengupta, A., & Ravindranath, N. (2013). Farmers' vulnerability to climate variability in Dimapur district of Nagaland, India. *Regional Environmental Change*, *13*, 153–164.

Karnataka farmers to get 7 hours three-phase power supply. (2014, January 24). *The Hindu*. Retrieved on 29 Jan, 2014 from http://www.thehindu.com

Mishra, S. (2008). Risks, Farmers' Suicides and Agrarian Crisis in India: Is There a Way Out? *Indian Journal of Agricultural Economics*, *63*(1), 38-54.

Prasad, R. (1988). A linear root water uptake model. *Journal of Hydrology*,*99*(3), 297-306.

Pullenkav, T. (2013). Solar water pumping for irrigation: opportunities in Bihar, India. GIZ (Indo-German Energy Program - IGEN). Retrieved from http://www.igen-re.in/files/giz__2013__report_solar_water_pumping_for_irrigation_in_bihar.pdf

Purohit, P., & Michaelowa, A. (2008). CDM potential of SPV pumps in India. *Renewable and Sustainable Energy Reviews*, *12*, 181–199.

Raghavan, S., Bharadwaj, A., Thatte, A. A., Harish, S., Iychettira, K. K., Perumal, R., & Nayak, G. (2010). *Harnessing Solar Energy: Options for India*. *Center for Study of Science, Technology and Policy, Bangalore*.

Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. *Nature*, *460*, 999–1002.

Turner, A. G., & Annamalai, H. (2012). Climate change and the South Asian summer monsoon. *Nature Climate Change*, *2*, 587–595.

Walker, J. P., Willgoose, G. R., & Kalma, J. D. (2004). In situ measurement of soil moisture: a comparison of techniques. *Journal of Hydrology*, *293*(1), 85-99.

Value chain thinking and energy projects – A problem-centred value chain approach to energy based upgrading of rice farmers in the Philippines

Henrik Beermann[1](beermann.henrik@gmail.com)
International Joint Master Programme in Sustainable Development, Leipzig University
Grimmaische Straße 12, 04109 Leipzig, Germany

Utz Dornberger (dornberger@uni-leipzig.de)
International SEPT Programme, Leipzig University
Beethovenstrasse 15, 04107 Leipzig, Germany

Ben Sebitosi (sebitosi@sun.ac.za)
Centre for Renewable and Sustainable Energy Studies, University of Stellenbosch
Matieland 7600, South Africa

Sebastian Groh (grohztg.tu-berlin.de)
Research Group Microenergy Systems, Technische Universität Berlin
Center for Technology and Society × Secr. HBS, Hardenbergstr. 16-18, 10623 Berlin, Germany

Jonas van der Straeten (straeten@ztg.tu-berlin.de)
Research Group Microenergy Systems, Technische Universität Berlin
Center for Technology and Society × Secr. HBS, Hardenbergstr. 16-18, 10623 Berlin, Germany

Abstract

This paper conceptualizes the link between value chain theory and productive use (PU) focused energy projects based on microfinance mechanisms. Its main argument is that all PU of energy projects focusing on micro, small, and medium enterprises (MSME) development can be interpreted as value chain upgrading attempts. It is argued that successful upgrading greatly depends on the MSMEs embeddedness in specific market contexts. For that reason, the context must be assessed to derive energy based intervention points that cause additional income for MSMEs and consequently development. Based on this rationale, a problem-centred value chain approach is proposed. A case study of the Philippine rice market illustrates the usability of the method by outlining some risks and opportunities the rice value chain context poses to energy based upgrading attempts of rice farmers.

Keywords: productive use of energy; value chain theory; systems theory; microfinance; development.

Introduction

Be it ecosystem degradation, global warming, persistent inequality and poverty, or food insecurity - most of the challenges making up the poly-crisis of today's world are in essence system failures [Swilling and Annecke 2012]. Solutions to these problems must be based on holistic thinking rather than separating the problem into small, isolated pieces and solving them stepwise [Batie 2008]. Fueled by advanced communication technology, trade agreements and globalized cross-border capital markets, cross-border trade and production has linked the state and future prospects of evolving countries micro, small- and medium-sized enterprises (MSMEs) to the (global) market system they participate in [Kula et *al.* 2006]. Value chain thinking anticipates these challenges by assessing MSMEs development potential from the viewpoint of the market system they are part of. Energy projects fostering the utilization of energy services by MSMEs, but develop interventions solely at the firm´s level of energy need and use patterns, risk overlooking key external drivers‟ growth and competitiveness [Wolfe and Page 2008].

Research objectives

The power of energy technology for MSME development is based on the multi-facetted opportunities energy services pose for altering the way these firms interact with market systems. It's not surprising that Fakira [1994] states that energy is one of this critical resources to liberate MSMEs from low value, low productivity and low income activities. Amongst development practitioners, a general consensus exists in regard to the high relative potential energy technology has for MSME development. Groh [2014] argues that based on the existence of an energy poverty penalty, it is likely that households‟ and micro-businesses‟ development path is inhibited or at least delayed. According to Kirubi [1999], energy is a necessity, though not a sufficient means for MSME development. This implies that, even if energy is considered as a barrier to development, removing this barrier does not necessarily cause additional income economic growth. To cause profound changes, complementary factors, such as infrastructure, access to capital, the availability of information, skills or social services must be integrated in the design of energy based development interventions [UNDP 2011]. Despite those basic insights, literature that systematically assesses the importance of context for energy based MSME development projects remains scarce. Against this backdrop, this paper aims at answering the following research question: Which role can value chain theory play to support energy projects aiming at MSME development? The question is addressed by conceptualizing PU focused energy projects as value chain upgrading attempts. On this basis, a problem-centred value chain approach is proposed. The practical relevance of the approach is tested by assessing the risks and opportunities the rice value chain in the Philippines poses to energy based upgrading of rice farmers by means of solar based drying technology.

The systemic value chain approach

Agricultural goods usually pass through many hands as they move from farm to fork. The goods move along a value chain, defined as "the full range of activities and services required to bring a product or service from its conception to sale in its final markets" [Kula et *al*. 2006].

The value chain approach centers on the "interrelatedness of those actors gradually adding value to product or service as they pass it from one link of the chain to the next" [UNIDO 2011:1]. These different actors undertaking value adding activities are linked by the flow of products, finance, information and services [KIT and IIRR 2010]. Value chain assessments analyse key market actors, the relationships between them, and other factors that influence the performance of an industry. The assessment is centred on the chains metabolism: Flows of information, finance, knowledge and information as well as the formal and informal relationships determining these flows. Limiting factors to increased efficiency, productivity and competitiveness are identified and strategies to overcome these barriers are developed [Fries 2007, Miller and Jones 2011]. These strategies are based on value chain interventions - concerned activities that facilitate a systemic change of the value chain in regard to an intended goal, such as increased competitiveness of the chain or single firms. The advantage of such an approach for development projects is that interventions can be tailored according to the context. However, researchers are endangered by losing sight of the bigger picture because one gets easily caught in particular value chain details [UNIDO 2011]. A systematic and systemic analysis of the factors affecting the performance of the firms in a value chain is needed: Systematic in a sense that the process of data gathering must conducted according to an organized method guided by the assessments purpose, and systemic in a sense that that the gathered data must be analysed from viewpoint structuralism. As there is "no single instrument or a defined „recipe" to follow" [Miller and Jones 2010], it's up to the researcher to decide on how to do that. The approach applied herein is based on the value chain framework propose by USAID. It applies a

"Market system perspective to analyse microenterprises needs and opportunities to […] prioritize programming options available" [Wolfe and Page 2008]. According to the framework, "value chains have both structural and dynamic components. The structure of the value chain influences the dynamics of firm behaviour and these dynamics influence how well the value chain performs"

[Kula et *al.* 2006]. The systemic nature of this causal model becomes obvious when comparing Kula's statement with Sherman's [2000] explanation of the basic rationale of systems theory: "The behaviour of a system arises from its structure. The structure consists of feedback loops, stocks and flows, and nonlinearities created by interaction of the physical and institutional structure with the decision-making processes of the agents acting within it". A solid understanding of the systems structural patterns is necessary to understand how they cause behavioural patterns. This, in turn, is a prerequisite to indentify places to intervene in (market) systems, and to develop interventions in order to change the system's behavior according to a given goal [Senge 1990, Meadows 2008]. As such, the value chain framework is an application of this fundamental rationale and therefore can be subsumed under the systems theory umbrella. Systems theory and value chain theory form a nested hierarchy. Just like a matryoshka doll, systems theory represents the highest level of analytical abstraction and the value chain approach an application of basic insights of systems theory (see Figure 1). On a further subordinated level, PU projects can be subsumed as value chain upgrading attempts, an aspect that is discussed in the following section.

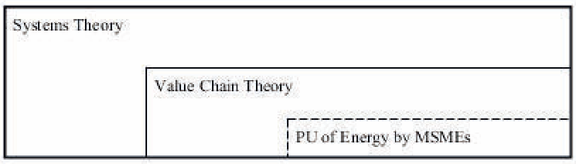


Figure 1: Nested hierarchy of systems theory, value chain theory, and PU of energy

Value chain theory and PU of energy

From a value chain perspective, a firm's decision to invest and thereby foster an intended economic evolution is a dynamic response to an opportunity to do so: This opportunity is posed by the interplay of a value chain's structural and dynamic elements. In value chain theory, this process is understood as upgrading, defined as the process of implementing an innovation that increases the value a firm adds to a good or service [Pietrobello and Rabelloti 2004]. Following Schumpeter [1939], an innovation is an economic decision to adopt a certain intervention in order to cause an intended economic change. Value chain literature distinguishes between five upgrading types, namely process upgrading (improving production efficiency), product upgrading (improving a products quality), functional upgrading (doing things different, performing higher level stages of the chain), channel upgrading (tackling different end markets), and sectoral upgrading (applying skills gained in one value chain to participate in another) [e.g. Humphrey and Schmitz 2002; Miller and Jones 2010]. The nature of a successful innovation process, in other words the application of a single or combination of these upgrading strategies, depends on the market structure an MSME is embedded in. Productive use (PU) of energy is defined as the utilization of energy "either directly or indirectly for the production of income or value" [White 2002]. The definition is based on a contemporary understanding of the term development, as goes beyond the sole increase of financial income [see Sen 1999]. However, for the sake of this discussion, PU of energy is understood as the utilization of an energy service in a way that the financial income of an MSME in increased. The term "energy service" is used herein to apply an end-users-perspective to energy projects. Energy itself does not make a difference in poor people's lives"; it is rather the service the energy provides such as cooling, heating, or communication [Allderdice et al. 2007].]. Following this logic, microfinance institutions (MFIs) are showing an increased interest in diversifying their portfolio [Kebir and Heipertz 2010]. PU focused interventions shall cause an intended economic change that increases the value a MSME adds to a good or service. Hence, PU of energy can be interpreted as value chain upgrading based on an energy service related intervention. This implies that every energy project focusing on PU of energy by MSMEs can be interpreted as one or a combination of the 5 upgrading types. In theory, access to energy services can generate income in three major ways: First, a currently used energy source can be substituted by a more cost efficient alternative (substitution effect). Second, access to energy can offer new business opportunities and thereby promote the emergence of new firms (entrepreneurial affect). Third, access to energy services can offer the possibility to alter a firms production process in a way that the value added to a good or service is improved (development effect). It is this income effect that constitutes the link between energy projects and value chain theory. By means of four examples, this link is exemplified in Table 1, which illustrates energy specific upgrading types.

Table 1: Linking energy technology and value chain upgrading

Energy Technology	Energy Service	Improvement	Upgrading Type
Energy efficient refrigerator	Cooling	Reduced (post harvest) losses	Process upgrading
Solar Tunnel Dryer	Drying	Improved quality of agricultural goods	Product upgrading
Energy efficient electric vehicle	Mobility	Ability to bridge exploitive middlemen	Functional upgrading
Solar home system (SHS) to provide energy for internet access	Information	Ability to respond to changing market conditions	Channel upgrading

Proposal of a problem-centred value chain approach

What are the implications of the previous discussion for energy based development projects? The basic rationale of the applied value chain approach is that an investment in energy technology must be seen as a dynamic response of a market actor in terms of an opportunity the value chain context poses. The context consists of different structural elements and dynamics – with each of these either supporting an investment opportunity, posing a risk to an investment opportunity, or being neutral. It is the sum of these influences that determines whether or not an opportunity to invest exists [for a generic discussion of these causal linkages see Dunn 2006]. Value chain assessments are undertaken ex-ante to the development of a context tailored intervention. However, despite the importance of market based information for the design of energy based MSME development projects, conventional value chain theory seems to be incommensurate with the reality of energy based development work. New projects are often started with a given, idea of where and how to intervene in a firm system, as well as an assumption in regard to the financial benefits of such an intervention. Undertaking an open-ended (in terms of the intervention) value chain assessment is resource intensive and therefore out of realm of most energy projects. Hence, the question is how to bridge both approaches – how to utilize "intervention-open" value chain thinking in order to support "intervention-closed" PU of energy project? As a first attempt to answer this question, this paper proposes to reverse the value chain rationale and undertake problem- centred value chain assessments. In this regard, problem centered means that all gathered information is related to an ex-ante defined upgrading strategy. The data collection process is limited to the influence (supportive, hindering, neutral) the value chains structural and dynamic elements have on a given energy based upgrading strategy. Thereby, market-related risks and opportunities to the given upgrading strategy are derived, which enables decision-makers to design a project in a way that the risk/benefit ratio of the project is optimized and the income generation effect maximized.

Case study: Energy based upgrading of rice farmers in the Philippines

The problem-centred value chain approach is applied herein to the case of energy based upgrading of rice farmers in the Philippines. Ex-ante to the assessment, a financially promising intervention has been proposed, which is the alteration of the drying process of rice farmers by means of solar based drying technology. Hence, the energy service this upgrading strategy is based on is "drying" of rice. The focus on this intervention is justified on the basis of the projects baseline-scenario, which is the current palay-drying practice of agricultural smallholders: Farmers usually dry their palay on public roads, a practice with the consequence that parts of it is consumed by free-range livestock, grains are contaminated by livestock and cracked by vehicles, the drying process depends on climatic conditions, etc. The total assumed income generation effect of the intervention must be seen in relation to business-as-usual case. The assumed financial benefits of improving the farmers drying process are: (1) Increased market value of a higher quality produce, (2) prolonged quality preservation of dried product due to lesser contamination, and (3) more efficient drying in a high humidity environment. It is assumed that all of these alterations are increasing the farm-gate price of palay. The problem-centred value chain approach contextualizes these assumptions by relating them to the local rice market. It discards, enhances, or adjusts the assumed benefits and serves as a basis for a realistic calculation of the financial viability of investing in the upgrading strategy. The gathered information serves as a basis for deriving the project's feasible design space – potential project settings that are in line with the projects goals function while taking into consideration the projects constraints and local market conditions. On this basis, the project can be designed in a way that the income generation effect for palay farmers is maximized, which, in turn, minimizes the lending risks MFIs.

Method

The data collection process was explorative and mainly based on qualitative interviews with value chain internal market actors and value chain external experts. The major problem of attempts to analyze the rice market in the Philippines is the unwillingness of certain market actors to talk with strangers about their business practices, a condition that defies an approach based on a large sample survey over a wide area with standardized questionnaires [Hayami et *al.*1999]. As discussed in the previous section, the data gathering process has been guided by challenge of designing a project in a way that the financial benefits of the drying based intervention are maximized. Structural and dynamic parameters potentially impacting on this goal have been detected during the research process - which is only possible in an explorative manner. Based on this rationale, 48 open-ended explorative interviews with key value chain actors and local rice market experts have been undertaken between August 13th and October 10th 2013 on the Philippines main island Luzon.

Analysis

Following the rationale of the problem-centred value chain approach, and given the limitations of this paper, most conventional features of value chain assessments (e.g. a map of the market, discussion of value chain actors) are excluded from this case study. Instead, a few selected aspects of importance are explained and their relation to the projects goal function discussed.

End market conditions: The value chain approach is driven by the principle of demand-driven supply. End-markets play a central role in the value chain study, as they determine demand characteristics terms of quality, quantity, timing, and pricing [see Kula et al. 2006]. The rice value chain must be subdivided into the palay chain (un-milled rice), and the rice chain. Both are connected by the miller. The end-market of interest for farmers is defined by the palay chain, with its different market segments defined by the specific needs of palay buyers. According to the assumptions, quality increase caused by upgrading the drying process leads to income increase on the level of farmers. However, quality is a multidimensional concept, with its subjective assessment being related to a specific end and the resources to achieving it [Allaire 2012]. Whether, and to which extent an income generation effect is caused depends on the end-markets notion of quality, which determines their willingness to pay for quality alterations. Three end-markets segments have been identified: (1) The governmental National Food Authority (NFA) applies a very differentiated price mechanism based on a matrix incorporating several quality related attributes, (2) Local buyers who apply a straight payment scheme mainly based on the type of rice and the moisture content (often reduced to "wet" and "dry", as well as the type of palay), and (3) buyers connected to institutional markets, who are in the need to supply large quantities of high quality rice. The crux of benefit maximization is to link farmers to those of these end-market segments that (financially) acknowledge the quality alteration, which is in this case segment 1 or 3.

Enabling Environment: Policies, institutions, climatic conditions, and other attributes collectively creating the external business setting in which value adding activities take place are subsumed under the term enabling environment [Christy et al. 2009]. Various variables of this structural element are of importance. One brief example is representing all not mentioned findings: During the last decades, the developmental policy of the

Philippines has been characterized by free "dole-outs" of financial and technical means, a practice that caused several unintended consequences: (1) A "dole-out mentality" has been caused that makes farmers wait for governmental interventions rather than proactively causing change. (2) Governmental presence in development projects undermines the peoples willingness to pay (WTP) for micro-loans. (3) Governmental dole outs of technologies are wrecking market-based efforts to provide these technologies. The dynamic interplay of these aspects is depicted in figure 2. Governmental institutions are providing a whole range of supporting services for development projects like this. However, it must be assumed that cooperation could negatively impact on the WTP of farmers for loans. This could negatively impact on the repayment rates. For that reason, a potential cooperation with governmental institutions must be seen as very critical.

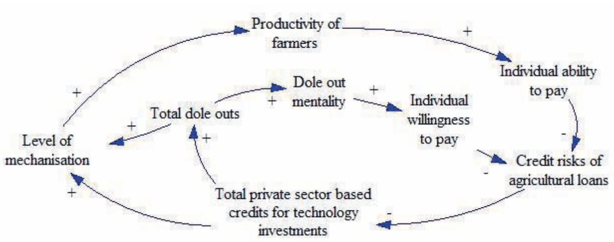


Figure 2: Causal loop diagram illustrating the dynamics caused by governmental dole-out programs

Vertical and horizontal linkages: According to the United Nations Industrial Development Organization [UNIDO 2011:8], "networks and linkages are the building blocks of collective efficiency". Vertical linkages are the relationships between market actors at different value chain nodes. Horizontal linkages refer to the relationship between market actors undertaking the same activity in a value chain. Of critical importance herein are the linkages between palay farmers and segments of potential buyers. As mentioned earlier, the NFA is applying a price setting mechanism based on several quality determinants. By upgrading the drying process of palay farmers in the intended way, the farmer's ability to meet these determinants is improved. For this reason, farmers could theoretically realize higher palay prices by selling to the NFA. However, some aspects are questioning this approach: (1) The NFA is a governmental entity. For that reason, cooperation could cause a dole out mentality amongst farmers. (2) The complicated bureaucratic application process constitutes transaction costs. These must be seen in relation to the paid premium. (3) Research indicates that the NFA does not necessarily pay farmers immediately. More than the fact that farmers need cash immediately after harvest, the uncertainty whether or not the NFA is capable to pay entails high planning risks for the project. In sum: Although the NFA appears to be a market segment worth tackling, the assessment of the farmer-NFA linkage revealed some of the obstacles such an attempt is prone to.

Supporting Services: Supporting services can be subdivided into either formal or informal (1) financial services (e.g. lending), cross cutting services (e.g. legal advice), and (3) sector-specific services (e.g. the availability of a certain technology) [Campbell 2008]. Agricultural smallholders are usually excluded from the formal financial system. However, agriculture is an investment-intensive activity, with returns only realized at the end of the cropping season [MCPI 2010]. Palay buyers are usually stepping in to fill this finance gap. By providing farmers with the financial means or inputs necessary to initiate the next harvest, trader-credits are crucial for the functioning of the rice market and for ensuring food supply. However, the public perception of these credit tie-ups is rather negative; as they are often characterized by excessive interest rates (e.g. one interviewed trader charged 28% interest per month). Farmers usually pay back in kind after harvest by accepting prices dictated by the traders. For that reason, many farmers are depended on new loans and trapped in a state of constant indebtedness. This aspect must be from the viewpoint of *utang na loob*, which is the Philippine concept of moral indebtedness. Once indebted, farmers are obliged to show gratitude even when the financial debt is settled. From the viewpoint of designing a project that upgrades the drying process, the discussed issues have two major implications: (1) Local traders usually apply a straight buying scheme that reduces the quality determinants to class A (bad quality), class b (average quality), class C (good quality), as well as the moisture content (either "wet" or "dry"). Upgrading the drying has a positive impact on various other quality determinants (e.g. whiteness, aroma, foreign matter, milling recovery, etc.). For maximizing the financial benefit of the upgrading attempt, farmers have to be linked to an end-market that is willing to financially acknowledge these alterations, which most probably isn't the local trader.

However, *utang na loob* might force farmers to stick to their traders, even though their financial debts are settled and another market segment offers higher prices. (2) The risk management rationale of the project is based on the income generation effect of improving the energy service "drying" – Maximizing the income generation effect means minimizing loan failures. But what if farmers are indebted by traders or even by some other suspicious external parties like 5 6 Bombay lenders[3]? It can be assumed that the party applying highest social or even physical pressure is paid first - which won't be the MFI providing energy loans.

Discussion and concluding remarks

The conceptualization of PU of energy projects with the aim of MSME promotion as upgrading attempts provides a new viewpoint on PU projects. By connecting these previously unconnected dots, a new, intrinsically transdisciplinary discursive way to think about energy projects is offered. From the viewpoint of the systemic value chain approach, it is the value chain system that poses an opportunity to invest in energy technology. Energy projects neglecting the importance of the market context will a priori limit their space of interventions to those located within the borders of the individual firm. Such a self-imposed restriction does not meet the opportunities offered by the multifaceted applicability of energy services, as the state and future development paths of MSMEs is often determined by forces located outside the firms" borders., and access to energy services offer the opportunity to tackled intervention points beyond fuel substitution on a firm level. Furthermore, especially if an intervention is developed without proper knowledge of the local market conditions, the external market context poses risks to a given upgrading strategy that can't be overseen and managed in advance. It might seem to be worthwhile to increase the productivity of an agricultural smallholder, but how does that make sense if the end-market is already saturated? How does it make sense to improve the productivity of Philippine banana farmers producing for the European market, if the European standard for bananas will be changed soon, challenging the farmer to alter the quality of their produce, not the quantity? Whereas traditional micro-lending neglected questions like this, there is a growing recognition amongst MFIs that a broader, market-based approach to the design and utilization of their services is needed. One of the leading Philippine MFIs in this regard is the CARD Bank. Based on their past experiences in MSME lending, the institution came to the conclusion that "most of its clients, after attaining commercial-level status through its financial services, are now in need of essential non-financial services to fully develop their businesses. This range of non-financial services, known as business development services (BDS), represent the entire spectrum of services a business requires to attain sustainability when analyzed within the context of value-chain analysis. Within this context, assessing what specific types of BDS enterprises require is the first vital step in addressing the goal of helping enterprises fully realize their business potentials" (Alip et *al.* 2009). Energy services offer a huge development potential, but[1] only if their implementation and application is contextualized. The problem-centred value chain approach is a first attempt to utilize the power of value chain thinking for overseeing and managing the risks and opportunities a particular context poses to a pre-defined energy based intervention. By means of a case study on upgrading of Philippine rice farmers, the approach has been tested. The discussed aspects are only a fraction of the insights gathered during the research process. However, they are sufficient to illustrate how external, value chain related factors are limiting the feasible design space of energy projects. Neglecting the local market context, and assuming an energy project can be designed in a way that the risk/benefit ratio is optimized, leaves interventions with the risk of causing adverse effects which can otherwise not only be mitigated but development effects be strengthened.

Acknowledgment

The case study was partly conducted in the framework of the Energy Inclusion Initiative, an initiative by ADA and MicroEnergy International. We thank both institutions for their support.

References

Alip, J., Guarin, R. & Magampon, M., (2009). *BusinessDevelopment Service. The Case of Card MRI*.Retrieved from http:// http://cardbankph.com/

Allderdice, A., Wienicki, J. & Morris, E., (2007). *Usingmicrofinance to expand access to energy services. Summary of findings*. Washington DC:The SEEPNetwork.

Batie, S. (2008). Wicked Problems and Applied Economics. *American Journal of AgriculturalEconomics*. 90 (5), 1176-119.

Christy, R., Mabaya, E., Wilson, N., Mutambatsere, E. & Mhlanga, N. (2009). Enabling environments for competitive agro-industries. In C. Da Silva, D. Baker, A.W. Shepherd, C. Jenane & S. Miranda da Cruz (Eds.). *Agro-industries for development.* (pp. 136– 185). Wallingford, UK: CABI, with FAO and UNIDO.

Fakira, H. (1994). *Energy for micro-enterprises.* Energy (Policy Research and Training Project.Energy and Development Research Centre. University of Cape Town. Paper No. 12: 16-25.

Fries, B., (2007). *The Value Chain Framework, RuralFinance, and Lessons for TA Providers and Donors*.Presentation at the Asia International Conference Agri Revolution: Financing the Agricultural Value Chain, Mumbai, India.

Groh S. (2014). The role of energy in development processes - The Energy Poverty Penalty: Case study of Arequipa (Peru). *Energy for SustainableDevelopment*. Volume 18, February 2014, Pages 83–99.

Hayami, Y., Kikuchi, M., & Marciano, E. (1999). Middlemen and peasants in rice marketing in the Philippines. *Agricultural Economics*. 20(2). 79–93

Kebir N, & Heipertz J.(2010). *Financing energy. The roleof microfinance institutions*. UMM Work-shop Report.E-MFP Action Group. Bergamo: Planet Finance.

Kirubi, C., (2006). *How important is modern energy formicro-enterprises? Evidence from rural Kenya*.Berkerly: University of California.

KIT & IIRR, (2010). *Value chain finance: Beyondmicrofinance tor rural entrepreneurs.* Nairobi: RoyalTropical Institute Amsterdam and International Institute of Rural Reconstruction.

Kula, O., Downing, J., & M. Field., (2006). *Globalizationand the Small Firm. A Value Chain Approach to Economic Growth and Poverty Reduction* (AMAPBDS Knowledge and Practice microREPORT No. 42). Retrieved from Microenterprise Learning Information & Knowledge Sharing website: http://www.microlinks.org/sites/microlinks/files/resource/files/ML5023_mr_42_strategy_paper.pdf

Meadows, D., (2008). *Thinking in Systems. A Primer*. Chelsea Green Publishing: Vermont.

Microfinance Council of the Philippines (MCPI). (2010). *AGRI–MF.AgricultureMicrofinance.Guidebook.* Pasig City: MCPI.

Miller, C., & Jones, L. (2010). *Agricultural value chainfinance. Tools and lessons*. Rome: FAO.

Pietrobelli, G. & R. Rabelotti (2005). Upgrading in Global Value Chains. Lessons from Latin American Clusters.
World Development. 33(4). 549-573.

Schumpeter, J. (1939). *Business Cycles. A Theoretical,Historical, and Statistical Analysis of the Capitalist Process*. New York: McGraw-Hill.

Sen, A., (1999). *Development as Freedom*. Oxford: Oxford University Press.

Senge, P., (1990). *The Fifth Discipline. The Art &Practice of The Learning Organization.* New York:Currency Doubleday.

Sterman, J. (2000). *Business Dynamics. Systems Thinkingand Modelling for a Complex World*. Boston:Irwin/McGraw-Hill.

Swilling, M. & Annecke, E. (2012). *Just Transition.Exploration of Sustainability in an Unfair World*.Cape Town:Juta.

United Nations Development Program (UNDP). (2011). *Towards an energy plus approach for the poor.* NewYork: UNDP.

United Nations Industrial Development Organization (UNIDO) (2011). *Pro-poor Value ChainDevelopment. 25 guiding questions for designing and implementing agroindustry projects*. Vienna: UNIDO.

White, D. (2002). *Productive Uses of Renewable Energy.Experience , Strategies , and Project Development.* Workshop Synthesis and Report. Rome: FAO.

Wolfe, J. & C. Page, (2008). *Nepal Inclusive EconomicGrowth Assessment*. Microenterprise Development.Washington, D.C.: USAID.

[1] Their name is a play on their lending scheme and origin: For every 5 pesos, 6 have to be paid back after one month.

Towards a Waste Management System for Solar Home Systems in Bangladesh

Alexander Batteiger (batteiger@ztg.tu-berlin.de)
Postgraduate Program Microenergy Systems
Center for Technology and Society
Technische Universität Berlin
Sekr. HBS 1
Hardenbergstr. 16-18
D-10623 Berlin

Abstract

One of the most recognized rural electrification programs in the world is the SHS-Program in Bangladesh. Based on the steadily growing high installation rates of SHS future waste generation was estimated on a country level. In 2012 at least 200.000 lead-acid batteries (LABs) from SHS-Program were disposed. Lifespan of LABS is the crucial factor for the estimation of future waste generation. Depending on the average lifespan, between 800.000 and 1.2 Million LABS equaling an amount of 6.000 to almost 10.000 metric tons of Lead per year is estimated to enter the waste management system of Bangladesh in 2016. Further research on regional levels and mass flows should be conducted to prepare the waste management system of Bangladesh for the estimated waste.

Keywords: Solar Home System; Lead-Acid Batteries; Waste Management System, Waste Generation Estimation; Bangladesh.

Introduction

The main objective of the United Nations sustainable energy for all initiative is universal is to ensure universal access to modern energy services for all until 2030[55]. Off-grid areas of countries should be electrified by using decentralized energy systems based on renewable energies. Especially Solar Home Systems (SHS) [56] have already proven that they can be possible solutions for rural off-grid electrification. Bangladesh is worldwide known for the successful implementation of SHS[57]. The yearly installation rate of SHS grew from about 100.000 in 2008 to more than 600.000 in 2012 (WB 2013a). By the end of 2013 more than 2.7 Million SHS were installed and SHS and they SHS are close to be economical viable without subsidies. To fulfill the goal of 6 Million SHS by the end of 2016 (IDCOL 2014), yearly installation rates have to exceed one million SHS.

In the first round of the “Rural Electrification and Renewable Energy Development Project” no environmental impacts other than CO_2-Mitigation were assed. Nevertheless, in the final report was stated that the project helped to increase standards in battery recycling (WB 2013a). In 2012 the second round of the project was launched, since than regular assessments of environmental impacts have to be reported (WB 2013b). In the first environmental and social impact report of IDCOL, two major environmental impacts related to the SHS-Project were reported: Improper disposal of lead-acid batteries (LABs) and Solar Panels (IDCOL 2013) .

In 2010 the Blacksmith Institute (2010) in cooperation with the Green Cross published a report about the six worst pollution problems of the world, with lead being one of it. About three quarter of all lead is used for Batteries (Roberts 2003). In low- and middle-income countries car battery recycling is one of the main sources of lead pollution (BSI 2010). According to a recent research photovoltaic energy systems are expected to become a significant new source of lead pollution in China and India (Gottesfeld and Cherry 2011). Lead losses over a lifecycle of a battery in countries with advanced infrastructure are around 5 %; and up to 30 % in developing countries. In the informal sector losses only in the recycling phase can be as high as 50 % (Hoffmann and Wilson 2000).

So far assessments of the SHS have mainly focused on social impacts and CO_2-Mitigation. The goal of this paper is to identify future waste-flows on a country level to integrate them into the existing waste management system.

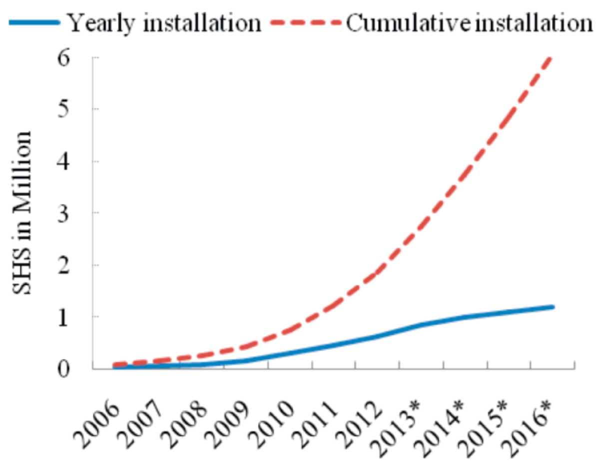


Figure 1: SHS in Bangladesh (WB 2013a; IDCOL 2014; own calculations based on IDCOL 2014)

[55] www.se4all.org/our-vision/our-objectives.

[56] A SHS consists in general of a) Solar modul b) lead-acid-battery c) charge controller, d) light bulbs or LED e) Mounting structure, f) Installation kits and g) Cables and connecting devices (UNFCCC 2013).

[57] The Solar Home Systems (SHS) program of Bangladesh is supported by the World Bank (WB), Asian Development Bank (ADB), Islamic Development Bank, Japan International Cooperation Agency (JICA), GEF, GIZ, KfW, GPOBA, USAID and DFID. SHS are being installed under the ongoing Renewable Energy Program of Infrastructure Development Company Limited (ICDOL) in Bangladesh.

Research Objectives

Since high implementation rates of SHS are a comparatively new development, there is little empirical data dealing with end of life of solar home systems. The main focus of most of the studies on environmental impacts is greenhouse gas and indoor emissions. The market for SHS is steadily growing and lower prices for solar panels will make SHS economical viable without subsidies soon. Figure 1 illustrates the expected growth of installation of SHS.

The main objective of the research is an estimation of the future waste generation in particular of LAB due to the SHS-Program in Bangladesh. The total number of LAB and the resulting amount of lead are the estimated parameters. The research is a starting point for a deeper inventory of waste-flows over the whole life-cycle of a SHS. This is necessary to close material cycles, optimize the waste management system and minimize environmental impacts.

Methods

To prepare and adapt a waste management system to future waste generation information on the number of expected devices and the total mass of the waste flows on a country level is necessary. The research is based on literature review. No field research was done. Excel was used as a modeling tool.

Estimation of disposal of lead-acid batteries

Depending on the data availability and quality different standard models for quantifying future waste generation of electronic devices can be used (Wang et al. 2013). Due to data scarcity, especially for the distribution of the lifetime of the LABs, the market supply model - a comparatively simple model - was used. It was already used for assessing waste-processing an generation in the informal sector in Delhi (Streicher-Porte et. al. 2005). Future waste generation is estimated from historic product sales with their respective disposal rates in the evaluation year. The model is represented by the following equation (1):

$$W(n) = \sum_{t=t_0}^{n} POM(t) \cdot L^{(p)}(t,n) \qquad (1)$$

W(n) is the estimated waste generation in year n, representing the number of LAB entering the waste management system. POM(t) equals the historic sales, in this paper the historic installation numbers of SHS.

$L^{(p)}(t,n)$ is the discard-based lifespan, which reflects the disposal rate of LAB used in SHS in the evaluation year n. The waste generation was modeled for different constant disposal rates of LAB referring to different average lifetimes of the Batteries (Laufer and Schäfer 2011; Palit 2013; Khan, Chowdhury, and Khan 2012). Since the solar panel has a significantly higher lifetime (about 20 years) it was assumed that obsolete batteries were replaced by new batteries. In case of disposal of the solar panel it was assumed that no new SHS was installed.

Estimation of lead flows on a country level

Based on the total number of LAB the amount of lead entering the waste management system was estimated. The following equation (2) was used:

$$M(n) = W(n) \cdot m(Ah) \cdot P \qquad (2)$$

M(n) represents the estimated amount of lead entering the waste management system. W(n) is the estimated number of LAB calculated with equation 1). W(n) is multiplied with m(Ah), the average weight of an LAB depending on the capacity. P is the percentage of lead of the mass of a LAB.

$$Ah = W_p \cdot F \qquad (3)$$

The average capacity depends on the average size of the solar panels. Data for the average size of the historically installed and future installations SHS were analyzed (WB 2013a; WB 2014; Brossmann 2013). The factor F defines size of the battery (GSHAKTI 2014; Khan et. Al. 2012).

Results

As installation rates began to grow strongly in 2008 the estimated waste flows of grow with a time delay of about two to three years. In 2006 the model estimates that around 15.000 LAB entering the waste management system. In 2012 a minimum of 200.000 Batteries were disposed. Obsolete batteries are replaced by new ones. This strengthens the difference between the disposal-rates. If the average lifetime was only 2.5 years, which is not unusual (Khan et. Al. 2012), the annual disposal rate would be 0.2 resulting in about 400.000 batteries being disposed in 2012. Due to the high installation rates between 800.000 and 1.2 Million LAB have to be recycled in 2016.

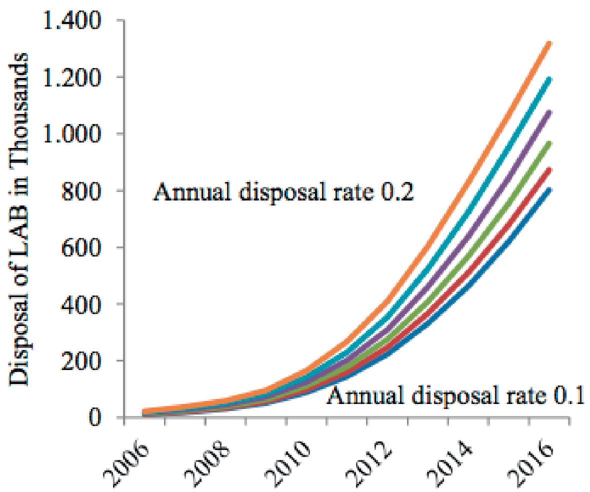


Figure 2: Estimated disposal of LAB

Estimation of lead flows

For estimating the resulting lead flows it is necessary to know the average capacity of LAB. Grameen Shakti has the highest market share in the SHS-Market of Bangladesh and Table 1 shows their SHS-Specification for off-grid Systems. The Factor (Ah/Watt) varies between 1.1 and 1.6. For the estimation of the total amount of lead the factor 1.5 was used.

Table 1: SHS-Specification of Grameen Shakti (GSHAKTI 2014, own calculations)

System Capacity (Watt)	Battery Capacity (Ah)	Factor (Ah/Watt)	Price in USD	Specific Invest. Cost (USD/W)
10	15	1,5	97	9,7
20	30	1,5	178	8,9
30	40	1,3	229	7,6
30	40	1,3	255	8,5
40	44	1,1	332	8,3
50	80	1,6	422	8,4
65	100	1,5	474	7,3
85	130	1,5	579	6,8

The average Panel size was in the first round of the Rural Electrification and Renewable Energy Development Project around $50W_p$ (WB 2013a). In the second round of the Renewable Energy Development Project the average size of a new installed SHS is $35W_p$ (WB 2014). Due to better LED Technology the solar panels need less capacity to provide the same service. By summing up all SHS until 2016, the average size of a solar home system is estimated to be $40W_p$. Therefore the average Battery capacity for the estimation is 60Ah. The result of a quick research on alibaba.com on the weight of LAB with those specifications was around 15kg. The lead content of LAB depends on the battery type and the battery producers and range between 40% and 60% (ANL 2010; Pavlov 2011). The estimation is calculated with 50% lead.

Table 2: Estimation of the total amount of lead in tons

	2006	2008	2010	2012	2014	2016
mass of lead in t (min.)	81	233	666	1676	3469	6015
mass of lead in t (max.)	162	448	1235	3068	6221	9888

In 2012 at least 1.676 metric tons of lead entered the waste management system due to the SHS-Program. The number will grow up to almost 10.000 tons of lead annually depending on the average lifespan of a LAB. A market study conducted on the lead acid battery recycling in Bangladesh stated that the formal recycling sector recovered about 3.400 tons of lead in 2006 annually (Waste Concern 2006). In 2006 the SHS-Program had little impact on the local battery recycling system. From 2006 to 2012 the amount of estimated lead grew by 20 times. In 2010 the national 3R-Strategy[58] of Bangladesh already took into account that LAB used for solar units will increase the number of LAB entering the waste management system (DOE 2010). In the same report it is stated, that on of the biggest battery producer in Bangladesh recently opened a new battery factory with the capacity of recycling 3.000 tons of lead per year. Nevertheless, for integrating the estimated LAB into the waste management system several new factories have to be installed.

Discussion

The objective of the research was a first estimation of future waste generation due to the SHS-Program in Bangladesh. Since a comparatively simple model was used and real distributions of the lifespan of the LAB were not available, further research should be conducted on that topic. The lifespan of the LAB is the main driver of the estimated future waste generation and especially on environmental impacts. Lead losses are very low during the use phase, but are about 30% during the recycling phase even in the formal recycling sector of Bangladesh (Waste Concern 2009). Therefore more research should be conducted on analyzing the distribution of lifetime of LAB.

In 2005 IDCOL developed a policy guideline on the disposal of warranty expired batteries. Costumers should be notified three months before the warranty of five years expires to change their batteries. But, none of the battery recyclers in Bangladesh collects the batteries with the electrolyte, according to IDCOL “the electrolyte is poured here and there” (IDCOL 2013). Depending on the number and local distribution of the disposal of the electrolytes, toxic-emission to the soil and water are expected. Furthermore almost 60% of the SHS-System not having changed their battery during warranty time stated in a survey, that they plan to sell it or hand it to a local battery store, if it is not working anymore (Brossmann 2013, 62).

Therefore a better working collection system needs to be designed for the estimated fast growing future waste streams of LAB. Due to significantly lower lead losses in the regular recycling sector better working collection system should be developed. Since the lifetime of the solar panels is significantly higher (20 years or more) than the average lifetime of batteries, there is still time left to adapt the waste management system to that need.

Acknowledgement

The authors gratefully acknowledge the Hans-Böckler Foundation for funding the postgraduate program micro-energy systems at Technische Universität Berlin and his doctoral thesis.

[58] 3R: Reduce, Reuse, Recycle.

References

ANL (2010). A Review of Battery Life-Cycle Analysis: State of Knowledge and Critical Needs. *Argonne National Labaratory*, Department of Energy (USA).

Brossmann, M. (2013). Off-Grid Rural Electrification and Fighting Poverty. *Master Thesis*, University of Tübingen.

BSI (2010). World´s Worst Pollution Problems Report 2010. *Blacksmith Institute,* www.worstpolluted.org/files/FileUpload/files/2010/WWPP-2010-Report-Web.pdf. [Last accessed 08th of January 2014].

DOE (2010). National 3R Strategy for Waste Management. *Department of Environment. Minstery of Enivironent and Forests*. Government of the People´s Republic of Bangladesh. Dhaka.

Gottesfeld, P. and Cherry, C. (2011). Lead Emissions from Solar Photovoltaic Energy Systems in China and India. *Energy Policy* 39 (9): 4939–46. doi:10.1016/j.enpol.2011.06.021.

GSHAKTI (2014). Grameen Shakti Bank - Price List for SHS, http://www.gshakti.org/index.php?option=com_content&view=article&id=115&Itemid=124. [Last accessed 20th of January 2014].

Hoffmann, U, and B Wilson. (2000). Requirements For, and Benefits Of, Environmentally Sound and Economically Viable Management of Battery Recycling in the Philippines in the Wake of Basel Convention Trade Restrictions. *Journal of Power Sources* 88 (1): 115–23. doi:10.1016/S0378-7753(99)00519-4.

IDCOL (2013). Environmental and social management framework. Infrastructure Development Company Limited, Dhaka. http://www.idcol.org/Download/Harmonised%20ESMF%202013.pdf. [Last accessed 14th of January 2014].

IDCOL (2014) Renewable Energy Projects. http://idcol.org/energyProject.php. [Last accessed 20th of January 2014].

Khan et. al. (2012). Reduced Battery Sizing in a Solar Home System with Respect to the Night Load and Solar Panel Size. In *Developments in Renewable Energy Technology (ICDRET), 2012 2nd International Conference on the*, 1–4.

Laufer, D., and Martina Schäfer. (2011). The Imple-mentation of Solar Home Systems as a Poverty Reduction strategy—A Case Study in Sri Lanka." *Energy for Sustainable Development* 15 (3): 330–36. doi:10.1016/j.esd.2011.07.002.

Palit, D. (2013). Solar Energy Programs for Rural Electrification: Experiences and Lessons from South Asia. *Energy for Sustainable Development* 17 (3): 270–79. doi:10.1016/j.esd.2013.01.002.

Pavlov, D. (2011). Lead-Acid Batteries : Science and Technology : A Handbook of Lead-Acid Battery *Technology and Its Influence on the Product*. Amsterdam ua: Elsevier.

Roberts, H. (2003). Changing Patterns in Global Lead Supply and Demand. *Journal of Power Sources* 116 (1–2): 23–31. doi:10.1016/S0378-7753(02)00701-2.

Streicher-Porte et. al., M. (2005). Key Drivers of the E-Waste Recycling System: Assessing and Modelling E-Waste Processing in the Informal Sector in Delhi." *Environmental Impact Assessment Review* 25: 472–91.

UNFCCC (2013). Solar Home Systems Monitoring report. http://cdm.unfccc.int/filestorage/k/2/AP8S6U5KHY7Z2XJ9BECFW0N4LI1V3M.pdf/SHSMonitoringReport.pdf?t=cjF8bjBiZXptfDDqwkVkqWFI57lw1QhKAkF3. [Last accessed 14th of January 2014].

Wang et. al. (2013). Enhancing E-Waste Estimates: Improving Data Quality by Multivariate Input-Output Analysis. *Waste Management* 33 (2013): 2397–2407.

Waste Concern (2006). Lead Acid Battery Recycling in Bangladesh. http://www.wasteconcern.org/Publication/BatteryRecyclingBroFinal.pdf. [Last accessed 14th of January 2014].

Waste Concern (2009). Waste Data Base 2009. http://www.wasteconcern.org/documents/Waste%20Data%20Base_2009.pdf. [Last accessed 14th of January 2014].

WB (2013a). Implementation Completion and Results Report. Rural Electrification and Renewable Energy Development Project. The World Bank. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/07/15/000333037_20130715125106/Rendered/PDF/ICR26090ICR0Ba00Box377378B00PUBLIC0.pdf. [Last accessed 20th of January 2014].

WB (2013b). Project Appraisal Document: Rural Electrification and Renewable Energy Development II (REREDII) Project. World Bank http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/09/03/000356161_20120903020519/Rendered/PDF/717000PAD0IDA00se0Only090Box370115B.pdf. [Last accessed 18th of January 2014].

WB (2014). Bangladesh - Rural Electrification and Renewable Energy Development II (RERED II) Project : P131263 - Implementation Status Results Report : Sequence 25". ISR13274.
The World Bank. http://documents.worldbank.org/curated/en/2014/01/18819309/bangladesh-rural-electrification-renewable-energy-development-ii-rered-ii-project-p131263-implementation-status-results-report-sequence-25. [Last accessed 24th of January 2014].

Posters

When theory meets practice: Lessons learned from the deployment of solar home lighting systems in rural India

Kartikeya Singh (kartikeya.singh@tufts.edu)
Center for International Environment & Resource Policy (CIERP), The Fletcher School,
Tufts University 165 Packard Ave, Medford, MA 02144, USA

A new global energy access agenda has created a burst of entrepreneurial activity in the solar home lighting deployment sector. Understanding what factors can arise from deployment of these technologies in diverse rural areas is important to ensuring that the sector is strengthened. This study is based on two cases of solar home lighting system interventions in rural India in two unique districts. Through post-installation surveys of households where solar lighting systems were purchased it was determined that access to solar energy helped households save money, improved household health and improved children's education. The two cases reveal insights into technology design, divergent strategies for financing, after sales maintenance and support care which highlight the challenges to successful long-term deployment strategies for this technology in the field.

Keywords: solar home lighting; technology adoption

Wind-Geothermal-Diesel Hybrid Microgrid Development: A Technical Assessment for Nome, AK

Jeremy B Vander Meer (jbvandermeer@alaska.edu)
Department of Physics, University of Oldenburg Oldenburg, Germany

Marc Mueller-Stoffels (mmuellerstoffels@alaska.edu)
Alaska Center for Energy and Power,
University of Alaska Fairbanks Fairbanks, AK, USA

This paper investigates the effect of adding a geothermal electric power source to the remote wind-diesel microgrid of Nome, AK. The proposed geothermal source would displace most of the base load and not be able to load follow. A time step simulation was created to model the grid behavior for different levels of geothermal power and additions to the diesel generator fleet. With increased geothermal power input, the diverted wind energy increased quadratically while the diesel generators' displaced output increased linearly, average load factor decreased and switching increased. Adding diesel generators of varying size to the fleet decreased the diverted wind energy, increased the displaced energy and average load factor of diesel generators, but also increased the diesel generator switching.

Keywords: Microgrid; geothermal power; wind power; diesel scheduling.

Alternative fresh water sources for remote settlements

Yusup Kamalov (yusup-udasa@mail.ru)
Karakalpakstan Branch of the Uzbekistan Academy of Sciences
41 propekt Berdakh, Nukus, Karakalpakstan, Uzbekistan 230100

Examples of fresh water obtaining by condensation of moisture to use in remote areas are provided. During warmer months moisture condenses out of the atmosphere along with preliminary evaporation of salt water into the atmosphere using sun. To evaporate the salt water the outer surface of metal roof is used, and the inner surface -to condensate. Excessive moisture around the building helps to reduce airborne dust and moistening the soil that can significantly reduce amount of water for plants. The cooled air goes to rooms. In winter the moisture contained in the exhaust gases of heaters is used. It is condensed by metal tube having ribbing outside. While freezing weather the desalination by naturally freezing is used additionally.

Keywords: water distillation, remote water supply

Erosive damage of photovoltaic panels by Sahara sandblasting and its effect on the energy efficiency

Said Bouzid (s_bouzid@yahoo.fr)
Lazhar Lalaoui (lalaoui28@hotmail.fr)
Mohamed Bouafia (bouafiamohamed@gmail.com)
Laboratory of applied optics, Institute of optics and precision mechanics,
University Ferhat Abbas Setif 1, DZ-19000 Setif, Algeria

Brittle materials erosion by sand particles is a regular phenomenon encountered in the Saharan regions. In order to reproduce the wind sand on the energy solar panel, a sandblasting device equipped with a manometer enabling the adjustment of particle flux power was utilized. The Sand employed comes from the region of Biskra (North of Sahara, Algeria). Thermographs of solar panel are obtained by infra-red camera to examine the distribution of temperature according to irradiance of the sun. The optical transmission of eroded glass is measured with a densitometer and the sanded glass surfaces are observed with an optical microscope. The effects of particle size and speed air flux on the optical transmission and the relative efficiency of the PV panel are reported.

Keywords: Solar-energy; Photovoltaic; Erosion; Sahara Sandblasting.

Energy Democracy and Innovating Energy Access for Remote Areas

Godwin Uyi Ojo, PhD (gloryline2000@yahoo.co.uk)
College of Arts and Social Sciences,
Igbinedion University Okada
Environmental Rights Action Friends of the Earth Nigeria,
214, Uselu Lagos Road, Benin City, Nigeria.

Against rising energy demand and concerns for energy security for the global north is the lack of energy access to remote communities in the global south. Drawing from case studies, this paper examines such dichotomy against the prevailing microenergy model driven by carbon marketization. Climate change solutions through microenergy delivery could be counter productive if target communities are excluded from the project planning and management process. The notions of unequal exchange in natural resource use between the north and south is central to how policies designed in the north shape development in the south. The paper suggests that microenergy delivery might be enhanced if energy democracy framework achieves decentralization whereby energy ownership, production and supply are managed by locals themselves.

Keywords: Nigeria; energy democracy

Investigating Community Ownership Potentials for Micro-Energy Networks through CultNature in the Ruhr

Robin Chang (robin.chang@tu-dortmund.de)
Transformation of Post-Industrial Regions, Spatial Planning Faculty,
Technische Universitaet Dortmund
August-Schmidt-Str. 10,
44221 Dortmund, Germany

CultNature is a new and innovative concept which aims to transform brownfields into biomass plantations that will serve a decentralized network of micro-energy units in the post-industrial region of the Ruhr. Development and testing of concept strategies are underway, but questions arise regarding the long-term feasibility and success of the concept, and the commitment of local citizens to the idea. Set in a populated and urban region, challenges from economic restructuring are visible at social, economic, and environmental scales (Lehner et al., 2011; Lutzenberger 2013b). Can the concept inspire confidence as a solution? This paper presents an approach to understanding local acceptance, community ownership for community renewable energies in the Ruhr.

Keywords: CultNature; brownfields, transformation; biomass technology; decentralized micro-energy; community ownership; local acceptance

Methodology for Implementation of Sustainable Energetic Solutions to Rural and Remote Communities

Ing. Sandra Yomary Garz. n Lemos,M.Sc. (sygarzon@unisalle.edu.co)
Engineering Faculty of La Salle University
Bogot. D.C., Colombia

This document presents a methodology for implementing sustainable energy solutions in rural and remote zones from specific and special characteristics. This methodology is based on characterization of geographic, technical, socio cultural, economic and environmental aspects, making possible the identification of needs, constrains and limitations, in order to propose solutions accord to own requirements, involving the renewable energies as part of a sustainable solution. The result of this methodology will be an energy solution in-line with community needs, location conditions, and natural resources available, becoming in the energy platform for impulse the development and welfare of the people of this region in a sustainable manner.

Keywords: Energy, Remote communities, Renewable resources, Resilience, Rurality and Sustainability.

MASTER4all: A decision support model for roadmaps towards sustainable energy universal access for policymakers and utilities

Andrés González–García (andres.gonzalez@iit.upcomillas.es)
Institute for Research in Technology (IIT), ICAI School of Engineering, Comillas Pontifical University.
C/ Sta. Cruz de Marcenado 26, 28015 Madrid, Spain.

Ignacio J. Pérez–Arriaga (ipa@mit.edu)
Center for Energy & Environmental Policy Research (CEEPR), MIT, USA
Institute for Research in Technology (IIT), ICAI School of Engineering, Comillas Pontifical University, Spain.

Ana Moreno-Romero (ana.moreno.romero@upm.es)
Department of Organization, Business Administration and Statistics, Sustainable Organizations Research Group,
School of Industrial Engineering, Madrid Polytechnic University, Spain.

To build strategies for universal access to modern energy services, countries and practitioners require decision support tools that estimate the impact of their choices. MASTER4all provides with useful insights about the trade-offs between different technological, financial, environmental and energy policy alternatives specifically focused on the reduction of energy poverty and the transition from traditional to modern energy supply. The proposed model carefully analyses the national energy system starting with the consideration of multiple user profiles and progressing upstream through supply technologies, transportation and generation, up to the energy sources available. By taking into account detailed policy and technological options, the model enables a transparent and flexible direct policy effect modeling for Universal Access.

Keywords: modern energy universal access; energy poverty, electrification technologies, modern fuels, improved cook stoves, static optimization.

"Yatsa Ii Etsari" (Light from our Sun): Lessons for sustainable photovoltaic rural electrification on remote Amazon indigenous communities in Ecuador

Jose Jara-Alvear (josejara@uni-bonn.de)
Center for Development Research (ZEF), University of Bonn
Walter Flex Strasse, 3, Bonn, Germany (Ecuador)

Luis Urdiales (lurdiales@centrosur.com.ec)
Director, Empresa Eléctrica Regional Centrosur C.A
Av. Max Uhle y Pumapungo, Cuenca, Ecuador

Providing electricity to isolated Amazon communities in Ecuador represent a challenge that has been attempted to solved in the last decade. Since, 2010 the project *Yatsa Ii Etsari* has provided electricity to more than 2351 indigenous families (Shuar and Achuar) through Individual Photovoltaic Systems (IPVS), and it is expected to cover the whole area of intervention in the short term with the installation of another 1300 IPVS. Therefore, this paper assess the sustainability of the project "Yatsa Ii Etsari" in its initial stage using existing research methods, providing a first insight into the weaknesses and prospects for solar photovoltaic rural electrification in the Ecuadorian Amazon, as a first attempt to fill the lack of information that could help to scale up DRE in Ecuador.

Keywords: Photovoltaic; Rural Electrification, Sustainability, Amazon,

---

A Novel Control Strategy for Power Sharing Enhancement of an Inverter-Based Microgrid

Alireza Raghami (Raghami@stud.pwut.ac.ir)
Mohammad Taghi Ameli (M_Ameli@sbu.ac.ir)
Faculty of Electrical and Computer Engineering, Shahid Beheshti
University, A.C. Tehran, Iran,
P.O. Box 16765-1719

An innovative power sharing strategy is put forward for active power-frequency management of a couple of inverter interfaced distributed generators encompassed in a microgrid. The presented strategy employs two cutting- edge droop based methods called unit power control (UPC) and feeder flow control (FFC). FFC outperforms UPC in terms of both grid-connected and islanded operation of microgrid. These methods are modified to enrich the transient response of distributed generators concurrent with the steady state behavior. A combination of these methods is applied to control generators of a microgrid where results of numerical time domain simulations substantiate the superiority of the enhanced edition control strategy.

Keywords: Feeder Flow Control (FFC); Unit Power Control (UPC).

Sustainable Energy Access for the Poor: A Means for Promoting Climate Change Adaptation of Communities

Mitalee Gupta (mitalee.gupta@yale.edu)
United Nations Development Programme,
Asia-Pacific Regional Centre Bangkok, Thailand
Yale School of Forestry & Environmental Studies,
Yale University New Haven, CT, USA

Thiyagarajan Velumail (rajan.velumail@undp.org)
United Nations Development Programme,
Asia-Pacific Regional Centre Bangkok, Thailand

Climate change is a continuous phenomenon that lacks certainty in terms of local, regional and long- term effects. Poor communities residing in rural areas are likely to bear significant impact from these changes in the climate. Much of this debate around climate change has now reached to a standpoint where adaptation, particularly for most vulnerable communities, has been determined to be the ideal solution. All societies have some in-built mechanisms to cope with the occasional threats such as climatic variability and natural hazards, but this coping capacity is greatly dependent on the economic and social development of the community. Sustainable energy sources and technologies, if deployed in an appropriate manner, can help empower communities by providing them with a host of productive end uses of energy and diversification of livelihoods. This paper seeks to discuss some of the ways in which access to sustainable energy enhances a community's resilience to adverse and uncertain impacts of climate change, thus enabling them not only mitigate but adapt better.

Keywords: Adaptation, Vulnerable, Sustainable Energy, Resilience, Livelihood

---

Financing Energy Solutions for ASEAN's Needs

Loi Tian Sheng, Allan (esiltsa@nus.edu.sg)
Energy Studies Institute, National University of Singapore
29 Heng Mui Keng Terrace, Block A, #10-01, Singapore 119620, Singapore

Melissa Low Yu Xing (esimlyx@nus.edu.sg)
Energy Studies Institute, National University of Singapore
29 Heng Mui Keng Terrace, Block A, #10-01, Singapore 119620, Singapore

Southeast Asia is home to 567 million people across 10 countries, with nearly 30 per cent of the region still without access to energy. The region, better known through its political and economic organization, the Association of Southeast Asian Nations (ASEAN), has programs targeted at improving energy access financed by various global institutions, national governments, and both public and private banks. Arrangements to deliver such finances to the energy deficient peoples come in different business and financial models such as micro-financing, through Energy-Service Companies (ESCOs), donation model and capability building. This paper explains the role of governments and financial providers as micro-energy risk mitigators, contrary to the popular belief that such institutions should directly finance or subsidize energy access to rural communities. We suggest that lowering credit risk profile of projects can be done by providing such communities with the means to create access to energy in rural communities through guarantee programmes; providing seed capital to small-scale, green field energy projects and absorbing first-mover risk; financing demonstration projects to provide evidence of feasibility and generally effectively deployed as a means of stimulating, accelerating and leveraging private-sector finance through more direct interventions. Special focus is given to Thailand, Cambodia and Indonesia as these are countries with a large share of people living in energy poverty.

Keywords: Energy Financing; ASEAN

End-Use Load Monitoring of a Micro Hydroelectric-Powered Community Micro Grid: A Case Study in Rural Malaysia

Kyle Weber (kweber@masdar.ac.ae)
Masdar Institute of Science and Technology
P.O. Box 54224, Abu Dhabi, UAE

Dr. Scott Kennedy (skennedy@thecenter.mit.edu)
The Dalai Lama Center for Ethics and Transformative Values at MIT
Cambridge, MA, USA

Dr. Peter Armstrong (parmstrong@masdar.ac.ae)
Masdar Institute of Science and Technology
P.O. Box 54224, Abu Dhabi, UAE

Rural electrification designing and planning, especially for micro grid-connected communities, requires quality data to verify results. This data can be difficult to locate in current literature. Case studies which show not only the types of loads encountered in rural off-grid installations, but also the variation of loads and the daily load profile in the context of a limited output system are extremely useful in enabling further research in this field to expand the current pool of knowledge. This paper describes the end-use load monitoring work that has been performed in an East Malaysian village since 2010 and the challenges associated with data gathering and end-use monitoring in a rapidly-developing rural setting.

Keywords: Rural End-Use Load Monitoring; Micro grid; Micro hydro; Micro energy; East Malaysia;

Opportunities and Challenges of Community Energy Systems: Analysis of Community Micro-hydro Systems in South and South-East Asia (SSEA)

Binod Prasad Koirala (b.p.koirala@tudelft.nl)
Faculty of Technology, Policy and Management, Delft University of Technology
Jaffalaan 5, 2628 BX Delft, The Netherlands

Dipti Vaghela (dvaghela@internationalrivers.org)
International Rivers
2150 Allston Way, Suite 300, Berkeley, CA 94704-1378, USA

H Mitavachan (mitavachan@gmail.com)
Postgraduate Programme Renewable Energy, University of Oldenburg
Carl-von-Ossietzky-Str. 9-11, 26129 Oldenburg, Germany

Raveen Kulenthran (rkulenthran@gmail.com)
Hydro Empowerment Network (HPNet) / Janathakshan Limited
No 5, Lionel Edirisinghe Mawatha, Kirulapone, Colombo 05, Sri Lanka

More than 600 million people are still living without electricity access in South and South East Asia (SSEA). Community Energy Systems (CES) can play an important role in providing modern energy access to these remote populations. Micro-hydro if available is the most promising energy systems for rural communities in term of cost and local operation. This research looks into progress of such community based micro-hydro system adoption in SSEA region. Furthermore, opportunities and challenges of these systems are investigated through the careful observation in the published scientific literature, interviews and survey with several local practitioners and organizations from different countries in the region. Although the potential is tremendous, this study finds a need for regional networking and integrated approach for further development of community based micro-hydro systems in the region.

Keywords: Community Energy Systems; Micro-hydro.

System Analysis of Electricity Infrastructure Evolution Using Hybrid Method Simulation Tool

Daye Eom (deom@masdar.ac.ae)
Masdar Institute of Science and Technology Masdar City,
P.O BOX 54224, United Arab Emirates

Scott Kennedy (skennedy@thecenter.mit.edu)
Co-Director
The Dalai Lama Center for Ethics and Transformative Values,
Massachusetts Institute of Technology (W11-004)
77 Massachusetts Avenue, Cambridge, MA 02139, USA

Hybrid modeling method proposed in our work depicts the concept of the electricity infrastructure evolution. In our model, we address the electricity infrastructure as a part of society having socio-economic dynamics. Each agent represents a village and chooses the optimal type of electricity infrastructure based on the independent decision rules. Once the type of infrastructure is determined, the system dynamics of the local environment drives the embedded agent behaviors. The combination of different methodologies can effectively describe the final electricity infrastructure that "emerges" from the integration of individual behaviors of all agents. The study shows sample runs of simulation, yet future work needs to be done followed by case studies.

Keywords: Emergent Behavior; Electricity Planning; Spatial Modeling, Hybrid Method Simulation.

Analysis of decision making for off-grid rural electrification in Colombia

Adriana M. Valencia, PhD (adrianam@berkeley.edu)
Energy Specialist
Washington, DC, United States of America

Due to their implicit costs, the technology options currently selected to expand national energy production and to provide energy to off-grid areas of Colombia lead to higher Government expenses, inflated cross-subsidization from higher-income electricity consumers to other consumers, and to limited electricity services for some. The technology option decision ultimately has an impact on energy access and duration of service. The overall cost of electricity provision through diesel, the fuel most frequently used, often increases in response to costs that are not normally taken into account. Therefore, it is suggested that decision making for off-grid rural electrification be more comprehensive, mindful of final costs of service for the end user, and attentive to the long term sustainability of the service.

Keywords: Off-grid electricity; technology choice, diesel.

Climate change adaptation in the energy sector: Development of Hydropower in India

Shadananan Nair (nair59@yahoo.com)
Nansen Environmental Research Centre (India)
A6, Oxford Business Centre,
Sreekandath Road, Ravipuram,
Kochi-682016, Kerala, India

Maintaining energy security under a changing climate is a challenging issue in India. Demands in energy have been escalating, associated with rising population, industrialization, urbanization and changing lifestyle. There is an increasing gap between production and consumption. Enhancing energy supply and access is therefore, a key component of the national development strategy. Development of environment friendly, sustainable, relatively cheaper and efficient hydropower is one of the ideal sources of clean energy for India in the present situation. This paper assesses the impact of climate change on hydropower generation in India and of the various issues related to energy development. Current policies, management practices and adaptation strategies have been critically reviewed. Guidelines for adaptation under a changing climate have been provided.

Keywords: Climate change; India; energy; hydropower; adaptation.

Special Paper Presentation

Thursday Evening Session

The Battle of Edison and Westinghouse Revisited: ContrastingAC and DC microgrids for rural electrification

Sebastian Groh[#1], Daniel Philipp[#], Brian Edlefsen Lasch[#], Hannes Kirchhoff[#], Didar Islam[##], M. Rezwan Khan[###], Shahriar Chowdhury[###], and Daniel M. Kammen[####]

#Research Focus Microenergy Systems, Technische Universität Berlin, Germany

Solar IC, Dhaka, Bangladesh

###Centre for Energy Research, United International University, Dhaka, Bangladesh

[####] Energy and Resources Group, and Goldman School of Public Policy, University of California, Berkeley, USA

[1]Corresponding author: groh@ztg.tu-berlin.de

Abstract

As distributed renewable energy systems expands rapidly as a means of electrification for off-grid populations, the debate over the relative merits AC- versus DC-based systems has intensified. Given that most of the distributed RE generators as well as batteries deliver DC power and that the majority of appliances being used in rural areas (can) run on DC, it follows that DC-based microgrids are a logical and efficient choice as a solution for electrification. This hypothesis is analyzed in detail for a developing country setting applying the new multi-tier methodology for measuring energy access as introduced by ESMAP. Further, a case study is conducted on an innovative DC nanogrid in Bangladesh as a real world test of practicability. Results show that a re-evaluation of current safety concerns is needed as both theory and commercial practice do not speak against DC here, and that system performances and efficiency results in higher affordability of DC-based microgrids, leading to their comparative advantage. Despite these advantages, the dissemination of DC microgrids still lags far behind AC microgrids. This is due to a number of reasons. Despite a long history, microgrid implementations remain unstandardized and are still in their infancy. Given this relative immaturity, markets tend towards what is already familiar, such as the AC configuration and the prevalence of AC-based appliances that dominates large-scale utility grids, as originally promoted by Westinghouse. Thus, despite the 'new market' that microgrids represent, we see strong signs that lock-in effects from the AC power still prevail despite the advantages of DC power and despite the favorable greenfield environment of rural electrification in the Global South.

Keywords: rural electrification; DC; microgrids; multi-tier approach; Bangladesh.

Introduction

"When two or more - increasing-return technologies' compete' […], for a 'market' of potential adopters, insignificant events may by chance give one of them an initial advantage in adoptions" [Arthur, 1989, p. 116]. This interaction can be clearly seen in relationship observed in the past for a variety of competing technologies. One classic example is that of the standard keyboard layout designed as QWERTY by Christopher Sholes and more ergonomic configurations. Despite the fact that it has been proven not to be the most efficient layout of typing, it has set the standard and a transition is not in sight [David, 1985]. These incumbent roles -often a chance occurrence- early lead in adoption, and can therefore "corner the market of potential adopters, with the other [potentially superior] technologies becoming locked out" [Arthur, 1989, p. 116].The cost and risks of the technology transition can simply be too high given that an initial infrastructure has already been deployed. This insight also applies to the historic "battle of the systems" by Edison and Westinghouse [David, 1992, p. 129]. While Edison promoted direct current (DC)[59] for electric power distribution, Westinghouse commercialized Tesla's invention of alternating current (AC)[60]generation and distribution equipment and managed to corner the market [Marnay and Lai, 2012]. Recent trends, however, may change these dynamics dramatically, re-asking the question of who was right, Westinghouse or Edison, and it may very well turn out that they both were.

Today in the Global South distributed renewable energy (RE) technologies are experiencing a great push as a means of electrification for off-grid populations [Casillas and Kammen, 2010]. Dissemination occurs through so-called Pico PV (photovoltaic) systems, small mobile solar systems for lighting and charging communication electronics, through Solar Home Systems (SHS), individual

[59] "Alternating Current (AC) is a type of electrical current, in which the direction of the flow of electrons switches back and forth at regular intervals or cycles. Current flowing in power lines and normal household electricity that comes from a wall outlet is alternating current" [European Commission, 2014]. Available under: http://ec.europa.eu/health/scientific_committees/opinions_layman/en/electromagnetic-fields/glossary/abc/alternating-current.htm. Last accessed: March 20, 2014.

[60]Direct current (DC) is electrical current which flows consistently in one direction. The current that flows in a flashlight or another appliance running on batteries is direct current [European Commission, 2014]. Available under: http://ec.europa.eu/health/scientific_committees/opinions_layman/en/electromagnetic-fields/glossary/abc/alternating-current.htm. Last accessed: March 20, 2014.

household-scale energy systems with PV generators and batteries used for lighting, communication and entertainment devices, as well as through microgrids. "[M]icrogrid refers to systems of very small scale, with power output ranging from hundreds of watts to a few kilowatts, typically with fewer than 150 household customers" [Tenenbaum et al. 2014]. It thus forms part of the family of isolated grids generally referred to as mini-grids, where much innovation has taken place in the past decade. According to Arthur (1989), lock-in occurs when changing costs are prohibitive. Consequently, the phenomenon cannot apply in a scenario of greenfield development. Having established that, the battle of currents is hence newly fought when transferred to electrification in the Global South. By definition, the targeted populations in rural electrification schemes lack any electricity transmission lines. Therefore, a technology-driven lock-in possibility for AC power cannot occur through the availability of central grid infrastructure, but lock-in resulting from best current practices and experience based on the availability or dissemination of AC vs. DC appliances certainly has, and can, take place. There has been, however, a recent change in terms of availability of these products both in the Global North, thanks largely to the recreational vehicle industry, as well as in the Global South, based on newly created demand[Houseman, 2014]. There is a robust set of appliances and other household items that are designed to run on either 12- or 24-volt DC; which are readily available. Furthermore, renewables promise to serve as the primary source of electricity in off-grid areas in the future [Houseman, 2014]. This trend is triggered by a combination of two factors. First, people that lack a certain level of energy service quality (e.g. lack access to the national grid) spend more money on energy relative to their total income than people who enjoy better energy service quality, and thus they have a higher willingness to pay for energy [Groh, 2014]. Secondly, decreasing photovoltaic panel prices in the world market played largely in favor of an accelerated deployment of solar energy technologies [Khan et al. 2014]. As an example, at the time when significant SHS growth took up in Bangladesh, prices for systems were two times higher than the present day price.

In addition to the increasing availability of DC appliances, the majority of distributed RE generators, as well as the batteries used to store the generated power both operate with DC power. These factors support the argument that emerging infrastructure for rural electrification should equally be DC-based in order to guarantee system efficiency. In literature, there is surprisingly little attention paid to theoretical and practical comparisons between DC and AC grids focused on service delivery in a developing country context. The hypothesis of DC as the preferred choice under the given context is analyzed in detail applying the new multi-tier approach to measuring energy access as introduced by Energy Sector Management Assistant Program (ESMAP), which is expected to form the new standard for the evaluation of different degrees of electrification.

Functionality of DC microgrids

The UN General Assembly has declared the years 2014-2024 to be the "Decade of Sustainable Energy for All"[UN, 2012], underlining the importance of supporting the roughly 1.3 billion people living without access to electricity. The "Energy for All Case" expects that only 30% of rural areas can be electrified via connection to centralized grids, whereas 70% of rural areas need to be connected with decentralized systems, the great majority of them with microgrids [OECD/IEA, 2011].Yadoo & Cruickshank (2013) estimate that about half of the off-grid population today could be best supplied with decentralized microgrids. For the sake of clarity we restate two possible definitions for microgrids [Marnay and Lai, 2012]:*"Microgrids are electricity distribution systems containing loads and distributed energy resources (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded" [CIGRE, 2012, p. 31]*

*"A microgrid 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 microgrid 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].*Key attributes of both definitions, and many others, are the distribution of energy resources, they can as a single controllable entity and the possibility of grid interconnection. Despite these predictions and the fact that microgrids have been employed for village electrification already for over 30 years, literature not entirely focusing on technological aspects still remains fairly scarce leaving the field often to grey literature [Peterschmidt& Neumann, 2013]. This is only gradually changing with recent publications by major development institutions such as Fraerson & Tuckwell(2013), Schnitzer et al. (2014), and Tenenbaum et al. (2014). Still, literature focuses almost entirely on financial, managerial and technical criteria, e.g. Ulsrud et al. (2011). There is surprisingly little attention paid to theoretical and practical comparisons between DC and AC grids focused on service delivery in a developing country context with some notable exceptions discussed below. Tenenbaum et al. (2014) stress the point that AC is the norm despite possible advantages of DC based on lower balance-of-system costs and higher efficiencies. On the other hand, they claim disadvantages for DC as most appliances use AC and low-voltage DC suffers from significant line loss whereas high voltage DC suffers from safety issues. Moreover, Khan [2012] makes the case for DC microgrids in Bangladesh pointing out that despite the success of the solar home system [SHS] model, it has its limitations in terms of usage quality, quantity and diversification. The concept they have put forward is to build a DC grid connecting solar PV arrays and households which will have their own battery storage–to be charged by the DC grid. A similar case can be made in Kenya, where the rapid and early growth of SHS[Acker and Kammen, 1996; Jacobsen and Kammen, 2007] resulted in the dramatic expansion of a market that while meeting the needs for basic services, did not rapidly meet the interests and de-

mands for income-generating small-scale commercial activities. While it is not possible to prove this in the natural experiment was as is the largest off-grid solar energy market in Africa, could have been served differently, and in some assessments, more effectively, with a greater emphasis on DC networks [Roland and Giania, 2011].

The evolution from SHS deployment to local microgrids is partially dependent on the expansion in generation capacity from a single generator technology (the PV panel) to a more diverse set of generators. This allows for the flexibility of distributed placement of PV panels to be connected to the grid directly(i.e., PV panels of different power capacity can be placed in various locations such as rooftops instead of placing them at a single site as done in centralized mini-grids). As such, the scheme can be considered as a clustered form of SHS, where the generated power surplus during the higher sunshine season is large enough to be used for developmental activities such as irrigation, rice de-husking, small-scale flour mills, etc. Also, Sarker et al. (2012) join the case pointing to energy loss reduction, easy system interconnection of PV and the existing practice of DC appliances in off-grid areas. This is particularly true for developing countries where income levels are low and markets are highly cost-sensitive. Reduction in cost even by a small percentage can make a big difference as far as the dissemination of the technology is concerned.

The following chapters aim to make a contribution in order to fill the gap of a more in-depth analysis of AC vs. DC microgrids.

Contrasting AC and DC microgrids along a multi-tier approach

ESMAP's widely discussed framework of a multi-tier approach to measuring energy access is shown in Figure 1 below. The new approach defines energy access as "the ability to avail energy that is adequate, available when needed, reliable, of good quality, affordable, legal, convenient, healthy and safe, for all required applications across household, productive and community uses" [Angelou, 2014]. Most of these attributes vary in a continuous manner and thus are amenable to a tiered measurement reflecting the degree of an energy service quality to a much better degree than previous approaches and making it an ideal tool to run a comparative analysis between AC- and DC-based systems for rural electrification purposes.

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Capacity	No electricity	1-50W	50-500W	500-2000W	>2000W	
Duration	<4hrs	4-8hrs		8-16hrs	16-22hrs	>22hrs
Reliability	Unscheduled outages				No unscheduled outages	
Quality	Low quality			Good quality		
Affordability	Not affordable		Affordable			
Legal Standing	Not legal			Legal		
Convenience	Not convenient				Convenient	
Health & Safety	No				Yes	

Source: Angelou, 2014, adapted by the authors for health & safety

Figure 1: Multi-tier approach to measuring energy access

Below, a comparative analysis is performed based on the evaluation criteria shown in Figure 1.

1) Capacity

The capacity of the DC microgrids is in the kW range. Because the technology is able to power low and medium power tools it falls into tiers 3 and 4. AC mini-grids can serve the same range, but some are designed even for mining sites, hence high power tools (tiers 3 to 5).

2) Duration

The duration of usage depends on the number of users and their corresponding load profiles. Essentially there is no difference between AC and DC microgrids other than the fact that even very small loads such as a single light can be powered for many hours per day at low losses with a purely DC source. Some AC mini-grids are not operated during night hours due to the low relative power consumption (mainly street lights), which is associated with high relative losses in inverters and generators (low load factor).Hence, the daily operation time varies from site to site for both AC and DC grids, but similarly sized DC grids can be expected to not only cater to business usage of a minimum eight hours per day, but to provide a 24/7 service, without the low load factor restrictions of an AC grid.

3) Reliability

The reliability of DC microgrids can be very high as no frequency synchronization is required, and therefore no complex inverter electronics and timing devices are needed. Additionally, modular growth of DC generators and storage devices is possible, improving the ability to meet a changing demand. Unscheduled outages should not occur, allowing for a tier 4 rating. AC grids might also receive a tier 4 rating, as limited runtime during night hours can be considered a scheduled outage. However, the reliability of the AC grid may be compromised with increasing demand on the grid over time, as AC grids pose increased challenges in the integration of new generators and expanded storage [Khan, 2012 and Tenenbaum et al. 2014].

4) Quality

The quality of electricity is a widely discussed topic and comprises different attributes including the reliability of service, the stability of the voltage, the ability to power large loads and very low down-time for maintenance and repairs. These criteria can be met both with DC as well as AC mini-grids and hence allow for a tier 3 rating.

5) Affordability

AC mini-grids still face challenges to implement CAPEX-recovering tariffs that are attractive for both private investors and end-users. DC microgrids, however, are able to tackle a similar target group to SHS solutions, which have a strong track record of affordable energy access. In comparison to AC mini-grids, inverter technologies are not required. Energy delivered as AC is now consumed as DC. In computers, consumer electronics and many small appliances as well as CFL and LED lighting the actual power consumed is DC. That means there is a conversion loss that adds to the energy usage. Similarly there is energy loss in converting from the DC produced by the photovoltaic systems on the roof to AC and then in many cases back to DC. In these cases conversion losses rapidly mount. Although conversion from AC to DC is relatively simple and inexpensive, conversion from DC to AC is much more complicated and the hardware is quite expensive. Compared to the price of solar PV in the present market to be less than USD1.0/Wp, the cost of a moderate sized inverter is more than USD1.0/W [Not more than PV panels we can say almost equal]. This is quite a high price to pay for the conversion, even if we ignore the conversion losses [Khan, 2012] Because DC microgrids still need to prove their affordability on a large scale, this category can be rated tier 3 to5.

6) Legal Standing

In regard to a legal framework, DC and AC mini-grids face similar challenges. In many countries, licenses for generation and or distribution must be obtained, which can translate into high transaction costs. Thus, this category depends on the country of application; in summary tier 2 or 3 may accurately reflect this issue.

7) Convenience

DC microgrids provide the ability to power electric loads of various power and daily energy requirements allowing for convenient usage. Tier 4 is the rating in this category as some businesses would still prefer an AC outlet for standardized machines. Increasingly DC motors have become available, which may alter this preference. A convenient advantage of e.g. 48V DC transmission line over AC is the fact that electricity theft becomes less of an issue as the transmission line output cannot be directly used.

8) Health and Safety

Safety in DC systems has been a controversial discussion. It has been emphasized that for DC systems, “arcing in switches” is a safety concern [Tennenbaum et al. 2014, p.44]. However, there is strong evidence in literature demonstrating adequate DC protection schemes and devices [Justo et al., 2013; Salomonsson et al., 2009] as well as experience with DC systems in the communications, recreational vehicle and PV industries. ESMAP defines this category as "the energy system has not caused in the past, and unlikely to cause in the future, harm from burning, injury, electrocution, air pollution or drudgery" [Angelou 2014, p. 36], and given that DC microgrids have been in operation for years, it can be rated with the same tier as AC at level 4. Both AC and DC systems pose a risk of electrocution, fire and injury, but low voltage DC systems pose a much lower risk. Both AC and DC systems require adequate protection schemes and technologies that are sized according to the requirements of a particular site. Furthermore, an isolated (ungrounded) DC system also presents safety advantages, namely the inability to be electrocuted by touching a single conductor.[61] In an isolated or “floating” system, both conductors must be touched at the same time in order for a foreign body to complete the circuit loop and thereby cause electrocution. In a grounded AC system, however, touching a single conductor can complete the circuit loop, because the current has a return path through the body and through the earth itself back to the point of system grounding. Besides, modern solid state devices can safely be used to switch DC power on and off without causing arcing.

[61]Grounding may become necessary though considering safety and protection of the system during thunderstorms.

General

In general, DC grids have the following advantages over AC grids:

No need for synchronization between different sections of the network

Lower cost and fewer pieces of major equipment required as no inversion from DC to AC is required.

No skin effect, no inductive and capacitive loss and thus less regulation compared to AC grid system for the same load current in AC system.

No 3 phase distribution required for DC systems.

No continuous charging current, no reactive power loss, no need of power factor improvement devices and less switching transients.

DC appliances generally have higher efficiency than AC appliances.

Table 1: Multi-Tier Assessment Overview

	AC mini-grid	DC mini-grid	Δ
Capacity	3...5	3…4	-0.5
Duration	3…5	5	+1
Reliability	3…4	4	+0.5
Quality	3	3	+/-0
Affordability	1...3	3…5	+2
Legal Standing	3	2…3	-0.5
Convenience	4...5	4	-0.5
Health & Safety	4	4	+/-0
Overall sum	**28**	**30**	**+2**
Overall average	**3.5**	**3.75**	**+0.25**

Overall

The overall scores, as shown in Table 1, reveals that AC and DC mini-grids are both highly attractive rural electrification technologies.[62] DC systems still lack behind in regard to convenience for usage in power tools and are not yet fully on the radar of policy makers. Nonetheless, high affordability, efficiency and flexibility are clear advantages of DC microgrids.

Case Study: Nanogrids in Bangladesh[63]

In Bangladesh 40% of the population has no access to the national grid representing 65 million people [World Bank, 2013]. In the rural areas, the un-electrified population is 58% [World Bank, 2014]. Solar Home Systems (SHS), currently consisting of a 20 to 85Wp solar panel, battery, and charge controller, have begun to electrify Bangladeshi rural communities [IDCOL, 2013]. Close to three million

[62]c.f. "mini-grids typically provide service up to Tier 3 or 4"[Tennenbaum et al. 2014, p. 44].

[63] The case study is for illustrative purposes. Another example for a successful implementation of a DC microgrid can be found in Tanzania: http://www.devergy.com.Last accessed: March 20, 2014.

SHS are already installed through microfinance schemes implemented by so-called Partner Organizations (POs), who are expanding their customer base at a rate of 65,000 systems per month, making Bangladesh the fastest growing SHS market in the world. However, the use of SHS has certain limitations in terms of daily time of usage – often limited to 4 to 5 hours per day–as well as lack of variation in compatible appliances. As a consequence, new models are starting to find their way into the Bangladeshi off-grid market. One of them is the so-called DC nanogrid implemented by *SolarIC*[64], a local company that made its mission to reduce per unit cost of renewable energy through community energy solutions based on DC. The DC nanogrid takes advantage of the fact that houses are frequently clustered together in rural areas in groups of about 50 houses within a diameter of less than 500m. In the nanogrid system, a basic 1.5 to 3kWp PV system is installed in a small cluster of households within a short radius of each other (ideally 230 to 250m) and power is distributed to the households from this system. The centralized generation and storage unit of this system operates on a 48 VDC level. However, the distribution to the households is via DC/DC converter at 220 V DC, just asend-use voltage, which offers the user use of most common AC appliances such as televisions, computers and other electronic devices. Such appliances are insensitive to DC or AC and can run on DC power, as long as the voltage matches the required input voltage of the device, normally ranging from 90 V to 270 V.

The individual case study is based on the experience of Aswini Barua[65], a local poultry farmer in a village called Lohadi in the region of Kapasia which is about a 100km to the north of Dhaka.[66]Lohadi is considered an off-grid village although the national grid runs only two kilometersnearby. Mr. Barua has two chicken cages both hosting about 800 chickens and lives from the sales of the eggs. Total monthly revenue amounts USD 2,070 per month at a monthly accumulated cost of USD 1,670.In order to increase productivity, chickens are exposed to artificial light. Until recently this power came from a diesel generator. Capital investment cost was USD 362 with running diesel costs of up to USD647 per month. Mr. Barua also has a SHS for residential lighting and entertainment purposes, but a couple of months ago he decided to become connected to the village based nanogrid that supplies his house and poultry farm with electricity 24/7 at a priceof Tk. 0.1 per Wh as the actual prize provided for the nanogrid power. The nanogrid consists of a 3kWpPVpanel generation capacity and a 3kVAdiesel generator as a back-up combined with a 34kWh battery bank that is operated by a local entrepreneur. The system has been running for more than half a year interconnecting 53 households based on 220V DC gridlines running in cabling buried10-15 inches underground. Payment is organized by the local entrepreneur and facilitated through an advanced pre-paid meter with an automatic maximum load factor switch-off function. Operation and maintenance cost comparisons between former diesel generator and the new nanogrid show a decrease from USD 647 to USD 362 monthly. This implies a 44% decrease in monthly operating electricity costs, which translates into a 4x profit margin not including individual CAPEX, in fact with USD 52connection fee much lower than for the diesel generator (USD 362), among other advantages of the nanogrid. Please refer to Table 2 in the appendix for a brief overview of these figures. Based on these numbers Mr. Barua is currently building up a third cage which will equally be fueled by the nanogrid. There are six more poultry farms in the wider village. The diesel generator and SHS are currently no longer in use.

Conclusion

Current trends in available technologies for off-grid electrification tend to favor DC microgrids. This statement finds support in a comparative analysis between AC and DC based microgrids based on a multi-tier approach to measuring energy access. It is essentially a re-evaluation of current safety concerns, an increasing availability of low power consuming appliances running on DC and most importantly system performances and efficiency leading to higher affordability. Despite this, the dissemination of DC microgrids still lags far behind AC microgrids. This may be based on a number of reasons. Despite a long history, implementations of microgrids are still in its infancy. Given this prematurity, markets tend to stick with what is already familiar, including the configuration of AC utility grids originally promoted by Westinghouse. This leads to the conclusion that lock-in effects for AC power must still prevail despite the advantages of DC power and the greenfield environment of rural electrification in the Global South. This lock-in takes effect, however, not based on prohibitive changing cost, but on a lack of confidence and knowledge transparency of the alternatives. Therefore, the authors encourage researchers as well as practitioners to step forward into this field and share the latest research and implementation results of DC power.

[64]Solar IC: http://www.solar-ic.com/newsite/about-solaric/.

[65] Original name was changed.

[66] The following information is based on the indications by Mr. Barua himself in an interview led on March 7, 2014. Mr. Barua agreed on the publication of his data which has been confirmed by Solar IC staff. Nevertheless, data should be considered indicative but still underlining the business case and practical feasibility of the technology. All numbers have been converted to UN Operational Rates of Exchange (Tk. 77.25 as of March 1, 2014) and later rounded for reasons of clarity.

References

Acker, R. and Kammen, D. M. [1996] "The quiet (Energy) revolution: the diffusion of photovoltaic power systems in Kenya," *Energy Policy*, 24, pp. 81 - 111.

Angelou N. [2014]: A New Multi-Tier Approach to Measuring Energy Access. Energy Sector Management Assistant Program. Available online under http://www.esmap.org/sites/esmap.org/files/DocumentLibrary/Multi-tier%20BBL_Feb19_Final_no%20annex.pdf.Last accessed: March 20, 2014.

Arthur W.B. [1989]: Competing technologies, increasing returns, and lock-in by historic events. The Economic Journal, Vol. 99, No. 394, pp. 116-131.

Casillas, C. and Kammen, D. M. [2010] "The energy-poverty-climate nexus," *Science*, 330, pp. 1182 – 1182.

David P.A. [1985]: Clio and the Economics of QWERTY. The American Economic Review.Vol.75, No. 2, Papers and Proceedings of the Ninety-Seventh Annual Meeting of the American Economic Association (May, 1985), pp. 332-337.

David P.A. [1992]: Heroes, Herds and Hysteresis in Technological History: Thomas Edison and 'The Battle of the Systems' Reconsidered. ICC. 1(1), pp. 129-180.

Frearson L. and Tuckwell M. (2013): The future of microgrids: from low cost to high value. Using demand driven design to maximize revenue and impact. Asian Development Bank. Manila.

Groh S. (2014): The role of energy in development processes - The Energy Poverty Penalty: Case study of Arequipa (Peru). Energy for Sustainable Development, 18, February 2014, pp. 83–99.

CIGRE (2012): Electricity supply systems of the future. CIGRE AG Network of the Future. Athens. http://ec.europa.eu/dgs/jrc/downloads/events/20130926-eco-industries/20130926-eco-industries-hatziargyriou.pdf. Last accessed: March 20, 2014.

Houseman D. [2014]: IEEE Smart Grid Experts Roundup: AC vs. DC Power – A New Battle of the Currents. Institute of Electrical and Electronics Engineers. Available online under http://smartgrid.ieee.org/questions-and-answers/902-ieee-smart-grid-experts-roundup-ac-vs-dc-power.Last accessed: March 20, 2014.

Jacobson, A. and Kammen, D. M. [2007] "Engineering, Institutions, and the Public Interest: Evaluating Product Quality in the Kenyan Solar Photovoltaics Industry", *Energy Policy*, 35, 2960 - 2968.

Justo J.J., Mwasilu F., Lee J., and Jung J. (2013): AC-Microgrids versus DC-Microgrids with Distributed Energy Resources: A Review. Renewable and Sustainable Energy Reviews 24. Pp. 387–405.

Khan M.R. (2012): A Stand Alone DC Microgrid for Electricity Supply in Rural Bangladesh. Proceedings of International Conference on the Developments in Renewable Energy Technology, Dhaka, Bangladesh.

Khan M.R. and Brown E.D. (2014): DC Nanogrids: A Low Cost PV Based Solution for Livelihood Enhancement for Rural Bangladesh. Proceedings of International Conference on the Developments in Renewable Energy Technology, Dhaka, Bangladesh.Upcoming.

Marnay C. and Lai J. (2012): Serving Electricity and Heat Requirements Efficiently and with Appropriate Energy Quality via Microgrids. Electricity Journal.Vol 25(8).

OECD/IEA (2011): Energy for All. Financing Access for the Poor.Special early excerpt of the World Energy Outlook 2011, Paris.

Peterschmidt N. and Neumann C. (2013): Scaling up Successful Micro-Utilities for Rural Electrification. Sustainable Business Institute.Oestrich-Winkel.

Rolland, S. and Glania, G. [2011] *Hybrid Mini-grids for Rural Electrification; Lessons Learned (*Alliance for Rural Electrification).

Salomonsson, D., L. Soder, and A. Sannino."Protection of Low-Voltage DC Microgrids." Power Delivery, IEEE Transactions on 24, no. 3 (2009): 1045–53. doi:10.1109/TPWRD.2009.2016622.

Sarker M.J., Asare-Bediako B., Slootweg, J.G. et al. (2012): DC microgrid with distributed generation for rural electrification. Universities Power Engineering Conference (UPEC), 2012 47th International. London.

Schnitzer D., Lounsbury D.S., Carvallo J.P. et al. (2014): Microgrids for Rural Electrification:A critical review of best practices based on seven case studies. United Nations Foundation. New York.

Tenenbaum B., Greacen C., Siyambalapitiya T. et al. (2014): From the Bottom Up - How Small Power Producers and Microgrids Can Deliver Electrification and Renewable Energy in Africa. The World Bank. Washington.

Ulsrud, K., Winther, T., Palit, D., Rohracher, H. and Sandgren, H. (2011) The Solar Transitions research on solar microgrids in India, Energy for Sustainable Development, 15 (3).

UN (2012): United Nations General Assembly. Press release.Available online under http://www.un.org/News/Press/docs/2012/ga11333.doc.htm.Last accessed: March 20, 2014.

US DOE (2012): OE Microgrid R&D Initiative. US Departmetn of Energy. Available under: http://energy.gov/sites/prod/files/EAC%20Presentation%20-%20OE%20Microgrid%20R%26D%20Initiative%202011%20-%20Smith.pdf. Last accessed: March 22, 2014.

World Bank (2014): US $600 Million to Improve Electricity Supply in Rural Bangladesh Benefitting 25 Million People. Available online under: http://www.worldbank.org/en/news/press-release/2014/02/27/electricity-supply-rural-bangladesh-25-million-people. Last accessed: March 20, 2014.

Yadoo, A. and Cruickshank, H. (2012): The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy microgrids with case studies in Nepal, Peru and Kenya. Energy Policy 42, pp. 591–602.

Appendix

Table 2: Sution effect in nanogrid (original values)

	Diesel Generator	Nanogrid
CAPEX	Tk. 28,000	Tk. 4,000
Running cost per month	Tk. 50,000	Tk. 27,000
Supply time	6h per day	24/7
Volatility	high	None
Total revenue per month	Tk. 1,60,000	Tk. 1,60,000
Total cost per month	Tk. 1,52,600	Tk. 1,25,000
Profit per month	Tk. 7,400	Tk. 31,000
Profit margin per month	4,63%	19,38%

Conference Summary and Closing Keynote from the organizers of MES-BREG 2014

Jonas van der Straeten
Sebastian Groh
Brian Edlefsen Lasch
Dimitry Gershenson

What's moving the off-grid world? A status quo analysis.

At the beginning of the 21st century, the global energy landscape is changing profoundly. Rapidly improving technologies for decentralized electricity generation are challenging the centralized topology and markets of the energy sectors– and not only in the Global North. They also provide new perspectives for access to modern energy in the Global South. In the World Energy Outlook 2011 the International Energy Agency presented a scenario for universal modern energy access by 2030. In this scenario 70% of rural areas are either connected with mini-grids or with small, stand-alone off-grid solutions (OECD/IEA 2011). In the past decade, we have seen a surge of interest globally in this topic of energy access, among academics as well as practitioners, investors, and politicians. This could be seen in the small symposium our California-Germany team planned this past April at UC Berkeley, which quickly turned into a fully-fledged conference event with 100 participants from all over the world and presentations covering the whole gamut of innovations in rural energy access.

"From the bottom up" – the decentralized track of electrification

As national governments are becoming increasingly aware of the limits of top-down, supply-driven electrification approaches, the political landscape is changing as well. "From the bottom up" – the title of a recent World Bank publication by Tenenbaumet. al. (2014) is programmatic for the current shift in electrification policies all over the world. There is an increasing political support for the "decentralized track" of electrification, defined as "a bottom-up approach in which grid electrification occurs through the creation of isolated or connected mini-grids operated by private, cooperative, or community-based organizations". This can be seen for example, in in the fact that the decentralized track appears as a recommendation in virtually every national electrification strategy across Sub-Saharan Africa (Tenenbaum et al. 2014, 1).

The future of rural electrification – learning from Bangladesh

For small, stand-alone off-grid solutions we are no longerin need of proof that they can provide sustainable green electricity to millions of people – we have it! The rural electrification of Bangladesh, where Solar Home Systems are installed at a rate of around 50.000 per month, is a well-known success story. In his presentation at the MES-BREG conference, Professor Rezwan Khan illustrated that success story and gave us an outlook into the future of rural electrification in Bangladesh and potentially many other countries of the Global South: new uses of solar PV for irrigation and cold storage of agricultural products, the clustering of PV panels and the establishment of DC-nanogrids, and ultimately the connection of SHS clusters and stand-alone grids to the national grid system.

The future of rural electricity use

As profound as the changes of the supply side of rural electrification may seem – the changes of electricity uses over the last decade deserve similar attention. Innovation, efficiency gains and rapidly falling prices for end-user devices, above all for mobile phones, solar panels and LED lamps, have changed the off-grid world more than any extension of national grids.For more than a hundred years, telecommunication and sufficient lightinghavebeen a privilege for urban elites in countries of the Global South but are now becoming accessible and affordable to large numbers of rural off-grid and low-income clients. In the first decade of the 21st century, the number of mobile phone users in Africa has risen from 16 to 650 million (Etzo&Collender 2010, 659). For the second decade, the commercial breakthrough of off-grid solar lighting in Africa is predicted. The Lighting Africa initiative of the World Bank and IFC forecasts 20-28 million cumulative sales of solar lighting products in Africa by 2015 (Lighting Africa 2012).The rapid spread of these small and mobile electrical appliances leads to the fact that being connected to a grid or even owning a larger solar home system or diesel generator is no longera necessary precondition for two key uses of electricity: communication and lighting.

Innovative approaches for new markets

As demand and willingness to pay for off-grid electricity grows, regulatory frameworks are becoming more favorable.Likewise, as synergies with growing markets like the ICT sector evolve, an increasing number of companies and start-ups are looking to enter the off-grid market. They have developed a range of new innovative business and implementation models during the last years. In doing so, they have come up with creative ways to overcome the biggest barriers for the dissemination of small-scale energy systems in rural areas. For example, our panelist from AngazaDesign has shown potentials to lower the high transaction costs for distribution, service and maintenance by using mobile payment and remote monitoring. The second track of electrification is getting faster – there is definitely some momentum in the off-grid energy sector.

What does that mean for academia? Insights from the conference

What do these changes mean for us as academics then? What are the questions that need to be addressed by researchers in the next years? The paper presentations, the keynote speeches and discussions of this conference have revealed a number of fields for future research:

Energy and ICT

Mobile connectivity has grown beyond the electricity grid in most emerging markets. As we have learned in our session on ICT and Energy, there are more than 643 million people worldwide covered by mobile networks but without access to electricity, representing up to 53% of the global off-grid population. The mobile industry is pushing the demand for decentralized electricity supply in remote areas – it also provides a range of new channels for innovative energy business models and projects: the off-grid telecom tower infrastructure, mobile operators distribution networks, machine to machine connectivity, mobile payments and mobile services. Much more research is needed to explore the synergies between the ICT and energy sectors, but also the challenges e.g. in regard to privacy and consumer protection.

The nexus of energy and Big Data

The increasing use of mobile payment and remote monitoring in off-grid energy business models offer new potentials for the collection and management of user data, for example energy usage profiles or payment track records. What can and should this data be used for? This was the central question of our panel on Innovating at the Nexus of Big Data and Energy Access this morning. Our panelists, Kate Steel from Google, LesleyMarincola from Angaza Design and Michael Nique from GSMA all agreed on the value of this data but raised the questions: who gets access to it, for what purpose, and how to monetize it? These questions need to be answered in the coming years as well as a number of other questions, some of them critical: What happens when hundreds of thousands of off-grid users become more "legible" to big companies and potentially governments? What are the dangers of the ability to remotely control the usage of energy and mobile payment services?

Minigrids, microgrids

Some purport that minigrids and microgrids hold the promise of becoming the most cost-efficient technology for the "decentralized track"of electrification. Still, as we learned from case studies from Bangladesh (Khan&Huque, this issue, 47-51), India (Chandran-Wadia et al., this issue, 52-56) and Malaysia (Weber et al., this issue, 27-29) at our conference, there are still some major challenges to overcome during the next years: the inability to attract private investors, the slow dynamics of matching the supply and demand of a particular site, and the dilemma between affordability of energy access versus a sustainable business model. Some presenting authors have come up with important design considerations (Chowdhury&Aziz, this issue, 57-61) for mini-grids, as well as innovative participatory approaches for design and planning of micro-grids (Abdullah&Kennedy, this issue, 81-85). Others have tackled the problem of matching supply and demand on the level of electrical devices by presenting a way of optimizing device operation with a local electricity price (Nordman&Bugossi, this issue, 14-18).

Paradigm change ahead? Bottom up vs. top down; AC vs. DC

Some authors go as far as suggesting a complete paradigm shift. Instead of a top-down planning and operation, Sebastian Groh and his colleagues have suggested the concept of Swarm Electrification, a bottom-up approach for building up micro-grids by interconnecting existing small-scale generation units, mostly Solar Home Systems (Groh et al., this issue, 76-80). This also allows for making use of the excess energy that remains unused during the daytime, the hidden resources in Solar Home Systems, as Hannes Kirchhoff has described and quantified them in his presentation (Kirchhoff, this issue, 134-137). Building rural electrification upon the existing power sources and end-user devices brings back into question a transmission technology that hasn't been seriously debated for more than a hundred years: In an inspiring special paper presentation titled "The Battle of Edison and Westinghouse Revisited: A Comparative Analysis of AC/DC Micro-grids for Rural Electrification", Brian Edlefsen Lasch and his colleagues made a powerful argument for DC transmission technology (Groh et al., this issue, 170-176). This was supported by Rezwan Khan in his paper presentation on DC Nanogrids: A Low Cost PV Based Solution for Livelihood Enhancement for Rural Bangladesh (Khan&Brown, this issue, 86-90). In 15 to 20 years, he predicted in his closing keynote, Bangladesh will have converted its national grid to DC. Paul Savage from Nextek Power Systems, vividly illustrated in his keynote speech that not only researchers working in the Global South should have DC technology on their radar–80% of all electricity worldwide is used by native DCpower electronics, and DC domain segments are rapidly expanding.

Financing access to sustainable energy

Access to sustainable energy largely remains a financing problem. For this reason we are enthusiastic and grateful that ADA has supported this conference as the lead sponsor and brought their worldwide microfinance expertise to the table.

Their commitment exemplifies yet again that the microfinance sector has begun to understand its crucial role for the transition to a green economy – a particularly challenging hurdle for countries in the Global South. Appropriate finance mechanisms to overcome the investment barrier for sustainable energy technologies and climate adaptation on the level of households as well as micro, small and medium enterprises are still largely underdeveloped. For this reason, Natalia Realpe presented a paper on the question of how to scale up green microfinance loans (Realpe, this issue, 107-110), and Satish Pillarisetti presented innovative products through group approaches in the session on energy and microfinance (Pillarisetti, this issue, 111-114). Still, research on the potentials and impacts of green finance instruments is still in its infancy. Future projects need look into the appropriate design of green finance tools to support value chains for energy efficiency, renewable energies and other climate mitigation and adaptation initiatives.

The demand for energy loan products and their role in value creation processes

For the development of energy microfinance loans it is crucial to look into a number of context-specific preconditions: What is the willingness and ability to pay for sustainable energy or energy efficiency? What existing sources of energy are used and can potentially be substituted? What is the role of energy in local value creation processes? These remain the major questions that all business and project developers have to deal with. The conference provided a number of valuable contributions to the debate on the right approaches and methods to answer these questions: Two papers on demand assessments were presented, one on the financing needs for thermal insulation measures for housing in Kyrgyzstan (Bakteeva&van der Straten, this issue, 31-35) and one on the demand for Solar Home Systems in Pakistan (Ajaz&Taylor, this issue, 36-41). Other authors focused on productive uses of energy. Henrik Beerman proposed an innovative conceptional framework for energy based upgrading in agricultural value chains and illustrated it the example of rice farming in the Philippines (Beermann et al, this issue, 151-156). Using the case of rural India, Suresh Kumar introduced methods of advanced solar irrigation scheduling (Hari et al., this issue, 146-150). Robert Aitken contributed with a presentation on the potentials of solar powered LED lights improve the profitability of night fishing on Lake Tanganyika in Tanzania (Aitken&Scholle, this issue, 129-132).

End of life – Looking at what will be left from the SHS boom

For a long time, the question of the disposal of small-scale energy technologies has been neglected in academia. Today, as the first solar program in Bangladesh reached a scale of millions and installation rates are steadily growing, it can be no longer ignored, as Alexander Batteiger convincingly argued in his contribution. Between 800,000 and 1.2 Million lead-acid batteries equaling an amount of 6,000 to almost 10,000 metric tons of lead per year are estimated to enter the Bangladeshi waste management system in 2016. In his presentation, he proposed an analytical framework and next steps towards a waste management system for solar home systems in Bangladesh (Batteiger, this issue, 157-160). More academic research is not only needed to assess the environmental impacts of decentralized energy systems (using methods such Life-Cycle Assessment or Material Flow Analysis), but also to develop appropriate concepts for disposal and recycling.

What's next?

Next steps for the energy access research community

As we have seen from this conference, many potential research questions remain to be addressed by the international research community on energy access and decentralized energy systems. Having emerged as a rather interdisciplinary, problem-focused and practice-oriented field of research, we need the support of the established disciplines to tackle the above mentioned challenges. For this reason the empirical problem– the lack of access to sustainable energy worldwide– needs to be introduced and emphasized in the mainstream theoretical debates in these disciplines. At the same time, we need to maintain our close connection to the practitioners in the field, the entrepreneurs, the consultants, and to the decision makers. We shall stay connected and continue the discussions we had at this conference at other forums and events, at the latest during our next MES conference in Spring 2015.

Rewriting the history of electrification?

In the western world today, there is a common narrative of the history of electrification at the end of the 19th and the beginning of the 20th century. It is astory of how gradually every household and every company in Europe and the US were electrified through the extension of centralized grids. By today, the ubiquitous supply of electricity has become self-evident and sometimes passes for a barelynoticed feature of peoples' daily lives in the industrial world. For many countries in the Global South, however, there is still a long way to go. We do not know today, what historians in 100 years will write about the path to universal access to modern energy in South Asia or Sub-Saharan Africa. Maybe, they will write about the technology transfer of mobile payment and DC grids –from the Global South to the North. We can't know the story yet – but as a research community we all have the opportunity to make our contribution to it.

Thank you

We have received overwhelming positive feedback from the participants of this conference. Thank you very much for that highly encouraging response, which will set the tone for us leading the way towards the next MES conference in spring 2015. Our sincere gratitude goes to our distinguished Scientific Committee that took the time to review these papers and provide authors with valuable feedback. We are extremely grateful to continue to count on MicroEnergy International, this time side-by-side with BREG in leading the conference management. The Berlin based MEI consultancy provides an example for us all with their determined pursuit of the energy for all mission. Further, we thank ADA as our partner in this endeavor, the Luxemburg NGO dedicated to microfinance, for their generous support to the symposium and dedication to enable researchers to publish their findings on the intersection of microfinance and the environment. We would also like to express our thanks to the Hans-Böckler Foundation for their continuous financial support of MES, as well as to GIZ/Bangladesh, the Pakistan Poverty Alleviation Fund and to REEEP for their financial support for researchers from the Global South to be able to come to Berkeley. We thank BERC and Trojan Batteries for their financial support in hosting the cocktail reception and poster session. Finally, we are very grateful to energypedia, our official media partner for this event, making sure that the main take-aways remain accessible for the wider community around the world.

References

Etzo S. & Collender G. (2010): The Mobile Phone ‘Revolution’ in Africa: Rhethoric or Reality?. African Affairs, 109 (437), 659–668.

Lighting Africa (2012), Market Trends Report. Overview of the Off-Grid Lighting Market in Africa, Nairobi.

OECD/IEA (2011): Energy for All. Financing Access for the Poor. Special early excerpt of the World Energy Outlook 2011, Paris.

Tenenbaum B., Greacen C., Siyambalapitiya T. et al. (2014): From the Bottom Up - How Small Power Producers and Microgrids Can Deliver Electrification and Renewable Energy in Africa. The World Bank. Washington.

Universitätsverlag der TU Berlin
ISBN 978-3-7983-2693-4 (Druckversion)
ISBN 978-3-7983-2694-1 (Onlineversion)