Martina Schäfer (editor)
in cooperation with K. Mallikharjuna Babu, Daniel Kammen, Noara Kebir and Daniel Philipp

MICRO PERSPECTIVES FOR DECENTRALIZED ENERGY SUPPLY

Proceedings of the International Conference

BMS College of Engineering, Bangalore
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Micro Perspectives for Decentralized Energy Supply

Proceedings

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FOREWORD by the Chairs of the Scientific Board - 3rd International Conference "Micro Perspectives for Decentralized Energy Supply"

Dear distinguished guests, dear colleagues, dear friends

The MicroEnergy Systems (MES) Conference Series started in 2011 as an interdisciplinary and interactive forum for academics and practitioner-experts from around the globe to share and discuss the latest research and current trends in the field of decentralized energy supply and demand. Since then, we had seen several slow and uneven actions in the off-grid, micro-energy, and remote energy sectors. This has been accompanied with a steady flow of innovation, spanning new models, concepts, practical research and commercial ventures, and a widening suite of researchers, industries and both public sector and government interest.

Specific activity and innovation in Pay-As-You-Go solutions, international technical standards focusing on emerging markets, dynamic mini-grid models and new trends in impact investment highlight just a few of the rapidly changing activities. After two events (2011 and 2013) in Berlin, and a special expert forum in Berkeley (2014), we are proud to host this year's MES Conference in Bengaluru, India, together with the BMS College of Engineering.

It is very important to us to have this event hosted in an emerging economy so that we can strengthen the global commitment of a strong mutual transfer of knowledge between and among the Global South and North. We are further excited to see what the coming years will bring, particularly in light of the high expectations raised by the anticipated agreement on the Sustainable Development Goals which we anticipate will be signed in New York this September This time, unlike in 2000 during the formulation of the Millennium Development Goals (MDGs), we believe that energy for all will be recognized as an explicit goal.

Using our - so far rather vague - indicator of electricity access to the national grid and dependency on biomass, respectively, the world has made major progress in the past two decades. Compared to 20 years ago, an additional 1.7 billion people benefit from national grid electricity today, and additional 1.6 billion people are supplied with less-polluting non-solid fuels. With approximately 306 million people without any electricity and 705 million with a non-solid fuel access deficit, India represents the country with the highest impact opportunity in off-grid electrification and provision of modern cooking fuels. Our host, India, is an example of both the current rate of progress - a 1.9 % , or roughly 24 million added people with access to electricity – and the importance of long term, universal access goals. India's solar sector is flourishing and is strongly backed by the Government, where current plans call for power to reach about a third of the off-grid population with mini-grids, home systems and lanterns by 2020, all based on solar.

However, simply counting connections to the grid is insufficient as a measurement of energy access too coarse a metric to evaluate the extent of energy poverty. Urgently needed is a consensus on what measurement framework would be most useful to track energy access and services,. . Second, this understanding should reflect that energy is not simply a commodity, but is a service central to economic growth and quality of life. This work can evolve from the current state of knowledge on what forms of energy – centralized or decentralized, urban or rural based, fossil-fuel or renewable – most directly impact the access equation. The value of diversity and the demand for quality service has been instrumental in driving innovation. This strive should also be reflected in our measurement frameworks.

It is in this spirit that we are honored to welcome researchers from all over the world to present their research in this year's MES conference in Bengaluru. We will start off with young academics presenting their research ideas in the form of investor pitches in our energy access business plan competition (April 21-22). This event is followed by an expert workshop with the goal of enabling low-income market through clean mini.grid solutions (April 22). We will then, during our core conference days (April 23-24), have the pleasure to hear from researchers on topics such as new testing frameworks for pico PV systems, droop control mechanisms in DC-type nanogrids, the role of microfinance, reflections on the new global tracking framework, historical perspectives of decentralized electrification, including case studies from India, Bangladesh, Egypt, Ethiopia, Kenya, Nigeria, Tanzania, Brazil, among others. For those further interested field trips in the wider Karnataka area are being organized.

We would like to thank our cooperation partner MicroEnergy International and our long-term sponsor the Hans-Böckler Foundation. We further thank ADA Microfinance, the Smart Villages Initiative, the Karnataka Renewable Energy Development Limited, TEQIP, energypedia, ADB-Energy for All, ME SOLshare, New Ventures India and EMerge Alliance for their support. Our sincere gratitude also goes to our distinguished Scientific Committee that took the time to review and provide feedback on the papers.

We wish you all a productive conference and enjoyable days in Bengaluru.

Prof. Dr. Dr. Martina Schäfer (Technische Universität Berlin, Germany)
Dr. K. Mallikharjuna Babu (BMS College of Engineering, Bangalore, India)
Prof. Dr. Daniel M. Kammen (University of California, Berkeley, USA)

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I. Technology and Services

Design, Construction and Experimentation of a Cabinet Type Solar Dryer for Food Industry Wastes

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Abstract

The present work deals with the study, design and construction of a cabinet type solar dryer of food, agricultural products and industrial wastes of food processing industry. The results of the study would contribute to the development of efficient dryers using solar energy as an economical, durable and clean energy source. The developed cabinet type dryer was constructed by using locally available cheap materials. In addition to its low cost, the dryer is simple to use due to the absence of any sophistication. In order to assess the performances of the developed dryer, many experimental tests were carried out and the effect of many parameters such as geometry and meteorological conditions on its behavior has been studied. Measurements have been taken out by taking into account such parameters as height, length, drying air temperature and air humidity. The results showed that the parameter which has a predominant effect on the drying time is air temperature. An increase in air temperature inside the dryer causes the drying speed to increase. When drying some food wastes (red pepper and apple), it was noticed that the drying rate is highly dependent on the height of tray on which the product is spread. The lower is the location of the tray, the higher is the drying rate which would be allowed to the fact the drying air humidity increases as it passes through the trays and hence its absorbing capacity decreases.

Keywords: Solar dryer, Irradiance, Temperature, Drying rate.

Introduction

According to UN projections, 83 % of the world population (8.5 billion people) will live in developing countries by 2025 [1]. This population growth will lead to a net increase in food demand which would involve a change in our consumption and necessitate further development of food processing industrial activity. Unfortunately, a high growth of this industry will lead to a very high demand for water and huge amounts of wastes will be generated which is considered as a source of pollution disease for the environment if not treated correctly.

The drying is a unit operation that involves a transfer of material (liquid leaves the product and passes to vapor state) and heat transfer (responsible for the change of state of the liquid) (Daguenet, 1985). Solar drying seems to be an efficient solution to deal with this kind of problems. The proposed solution is to recover the food waste just at the outlet of the processing line To ensure property of the material and then proceed to solar drying to reduce its water content and block all microbiological activities. The dried product can be stored for long periods, transported easily or reused in animal food as additive. In order to master this type physical treatment (drying), one should master and control such parameters as drying temperature, air humidity and air flow rate through the dryer. Early works known in the field of solar drying were initiated by M. Daguenet (1985), and were followed by several other authors, especially in Africa, who were looking for efficient and economic solutions to deal, mainly, with food conservation problems (Houhou, 2010; El mokhtar et al., 2004).

At UDES (Unité de Développement des Equipements Solaires), tests conducted on an indirect forced convection dryer have shown that solar drying of food wastes would be an efficient solution for physical treatment and reuse of this kind of wastes. These results have been used to design and construct a new cabinet type solar dryer to deal with large amounts of food waste (Trad et al., 2014; Debiani, 2013). This study focuses on design, construction and testing of a new cabinet type solar dryer destined for wastes generated by food conservation and processing factories in order to reuse them in animal food formulations.

Description of the Developed Dryer

The cabinet type solar is designed at UDES with a triangular geometry. It is composed of four faces; the southern one is glazed and contains an opening at the bottom front side for ambient air inlet and a second at the top backside of the device for humid warm air outlet. The glazed surface is inclined by 36°. Both of the walls facing east and west are thermally insulated by polystyrene sheets and wood which is covered by aluminum sheet in order to resist to moisture from the dried waste and to cope with sunray aging. The inner surface of the dryer is painted with a black paint.

The drying chamber contains three trays made of screened steel to allow perfect air passage through the spread material to dry. They are made with 4 metal bars welded together forming a rectangle area of 0.54 m^2 (600mm*900mm). The bottom of the rectangle is made of a screen of iron welded to the side bars.

Sizing

The cabinet type solar dryer object of the present study was designed to dry food waste brought from the outlet of the production lines of food industry factories. To size the dryer production amount, fresh product amount to be dried must be known in advance to avoid over sizing of the system. In our case, the amount of fresh product to be dried is assumed to 3 kg per day (Debiani, 2013).
It is therefore to withdraw a quantity of water Mi from the fresh product to be dried and then passing from an initial water content mi to a final water content mf in a period of time t by a hot air stream for which the flow rate is given by the following formula:

$$\boldsymbol{Q_{se}} = \frac{(\boldsymbol{m_i} - \boldsymbol{m_f})\boldsymbol{M_i}}{\boldsymbol{t_s}} \qquad [1]$$

The flow rate allows us to estimate and to now the quantity of water Me to extract from the product and hence its water content passes from eighty five percent (85 %) to around five percent (5 %) which is the adequate moisture value that permits good conservation of the dried product for long periods of time (Amadou, 2007). The equation is given as follows:

$$M_e = Q_{se}\, t_s \qquad [2]$$

In order to ensure sufficient air flow inside the dryer, sizing of bottom front side and the upper backside opening is very important. Under the effect of solar radiation and greenhouse effect produced by the gazing, air temperature will be increased, its moisture absorbing capacity increased and air flow rate increased as a result of its specific weight reduction. As a result of that the hot air will escape from the dryer from the upper opening because of gravity effect. Assuming that D_a is the flow rate of hot air inside the dryer, it is given by the following formula:

$$\boldsymbol{D_a} = \frac{\mathbf{1000}\boldsymbol{M_e}}{(\boldsymbol{t_s}\boldsymbol{\rho_{air}}(\boldsymbol{X_m} - \boldsymbol{X_a}))}\boldsymbol{\eta_s} \qquad [3]$$

Where X_a and X_m are respectively water contents of the inlet and outlet air given in grs of water/kg of dry air, ρ_a is the density of dry air and η_s the drying efficiency.
The water content of the inlet air X_a is given by the humid air enthalpy diagram and X_m is determined from the air evaporating capacity of the drying air as affected by humidity and ambient temperature as shown in the formula:

$$\rho_a(X_m - X_a) = (\rho_a e_a)/2 \qquad [4]$$

The evaporative capacity is determined from Table 1.

Table 1: Evaporative capacity of the drying air **Ea** considering its temperature and humidity.

Relative Humidity (%)	**Air temperature (°C)**							
	20	**30**	**40**	**50**	**60**	**70**	**80**	**90**
10	4.5	7.0	9.0	10.5	12.5	14.5	16.0	19.0
20	4.0	5.5	8.0	9.0	10.5	11.5	12.0	16.0
40	3.5	4.5	5.0	5.5	8.0	8.5		
60	2.5	3.0	3.0	3.5	5.0			
80	1.0	1.5	2.0	2.0	2.5			

The width of the opening can be determined from the following equation:

$$l = \frac{D_a}{V * L} \qquad [5]$$

With:
V : Air velocity, m/s.
L : Dryer width, m.
l : Height of opening for air inlet, m.
For the design of the dryer, the following data parameters were considered:

1. Initial water content of the fresh product, m_i = 85 %
2. Final water content of the dried product, m_f = 5 %
3. Estimated ideal drying time, t_s = 24 hours
4. Ambient temperature, T_a = 35 °C
5. Relative humidity, H_r = 40 %
6. Estimated waste drying efficiency, η_s =25 %.

Finally, a width of 0.082 m of the outlet opening to allow hot air to circulate at a flow rate of about 0.041 m3.

Experimental Tests

Testing Conditions of the Cabinet Type Solar Dryer

The present work has been performed at UDES whose geographical position is characterized by the following: latitude = 36.75 °N, longitude = 3 °E and altitude = 5 m above sea level.
The tests have been held outside during the days of August 18–21, August 26–28 and September 02–04 of the year 2013. This is to ensure experimentation of the device under different conditions and to study the effect of parameters on its behavior.
On the other hand, the first sets of device functioning tests have been performed without the use of any product to dry in order to ensure correct running of the dryer. The second part of the tests was dealing drying operations of food wastes brought from local food industry. The waste consists of all the parts of the fruit or the vegetable that are rejected by the production line. It is important to notice that about 5 % to 7 % of the processed products are rejected at the end of the process as waste. The waste is generally composed of grains, skins and fibers (see figure1).

Figure 1: Food waste as recovered at the exit of the processing line.

Measuring Instruments and Methods

Temperature measurements have been performed using K- type temperature sensors that were connected to a data logger Hydra type. The sensors have been mounted inside the drying chamber as follows: on the transparent cover, at the middle of the east, at west and bottom wall, at each of the three trays and at air entrance and air exit of the drying chamber. The positions at which the sensors have been placed were changed to study and verify the temperature distribution inside the drying chamber. For this reason, sensors have been placed at different heights and lengths. The developed solar dryer is shown in figure.2 where the waste product is deposited on the three trays.

Figure 2: The solar dryer with a deposited waste product on the three trays

The air relative humidity inside the drying chamber was measured with ‘Testo’ type thermo-hygrometer provided with a memory card. The radiometric and climatologically data were provided by the weather station installed at UDES close to the experimental set.

In order to follow the weight loss of the drying product with time, the dryer was designed and equipped with externally mounted precise electronic balances on which trays were deposited. This system allowed us to get the remaining weight of the product without opening the dryer.

Results and Discussion

Evolution of Air Temperature Difference Between Inlet and Outlet

In Fig. 3, 4 and 5 are shown the inlet and outlet air temperatures of the dryer when functioning without drying product inside. It is observed that depending on the degree at which the apertures opening (fully opened. 25 % opened. Or 35 % opened). The temperature difference is more important as the degree of opening decreases. This would be explained by the fact that at low air flow rate in case of low opening degree. The air residence time is higher and hence it absorbs more heat. These tests were carried out for sunny days (clear sky) for which global solar radiation has reached 850 W/m^2.

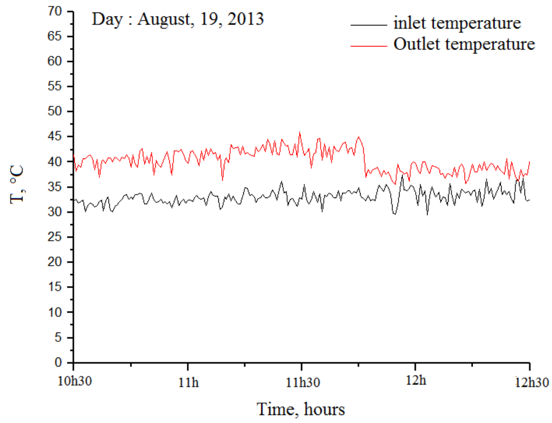

Figure 3: Dryer inlet and outlet air temperatures in case of totally opened apertures

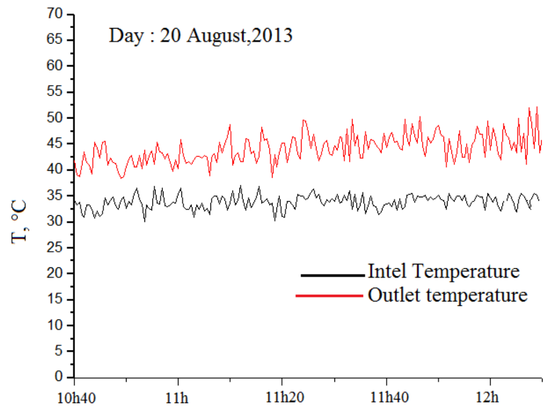

Figure 4: Dryer inlet and outlet air temperatures in case of 35 % apertures opening

A preliminary test with totally closed apertures has been conducted and show that the temperature inside the dryer has reached 80 °C very rapidly which can cause rapid deterioration of the product to be dried. Indeed. it has been shown that optimal temperatures for food drying is around 52 °C with variable drying times depending on the food physical properties .

For an opening equal to 35 %, the temperature inside the dryer reached values of around 30 °C with a small difference in air temperature between the inlet and the outlet.

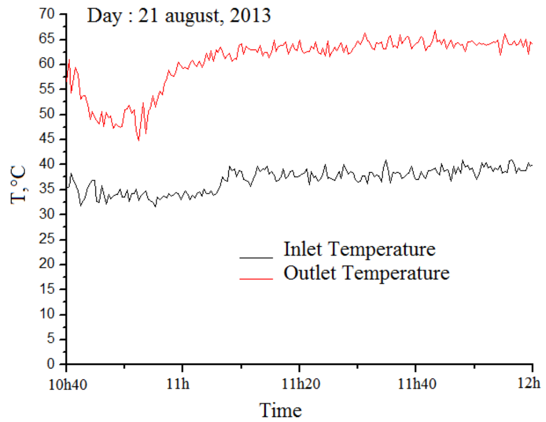

Figure 5: Dryer inlet and outlet air temperatures in case 25 % apertures opening

Moreover, opening at 25 % causes temperature to rise up to 50 °C after one hour of time. This level of temperatures is indeed the one adequate for good quality drying. It is observed also that drying temperature is highly influenced by air flow rate which is also dependent of aperture opening.

Effect of Global Irradiance on Drying Time

The first real tests of the new dryer were performed on food wastes (grains and fibers) brought from local industry. Three (03) kgs of red pepper were deposited equally and uniformly on the three trays. Temperature sensors and weighing scales have enabled the respective monitoring of temperature and weight of the product for one clear sky and another cloudy one (see Figure 6 and 9).

In Figures 6, 7, 8 and 9 is shown how the drying behavior of this waste is affected by the solar illumination of the day.

The effect of illumination on the drying time is significant. Indeed. When the sky is clear, the time required to decrease the weight of the product (80 %) is 5 hours while at a cloudy sky this value exceed 6 hours. This indicates that there is a proportional relationship between solar irradiance and

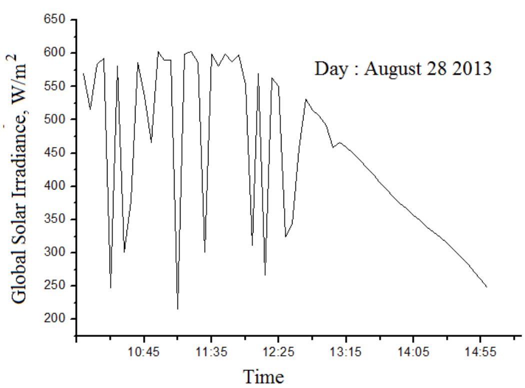

Figure 6: Measured global solar irradiance for the 28th of August 2013

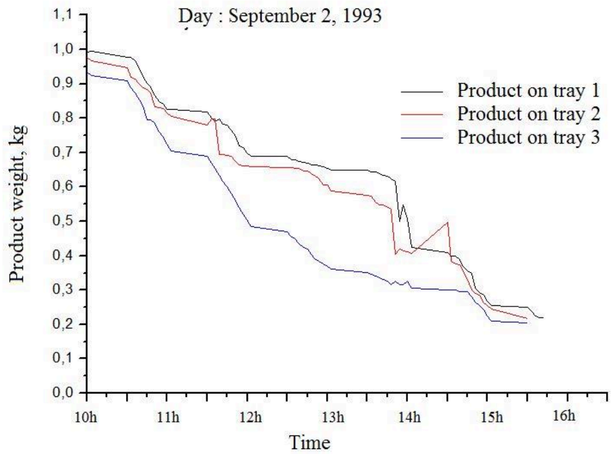

Figure 7: Effect of tray position on weight loss of the product as function of time for partially cloudy sky

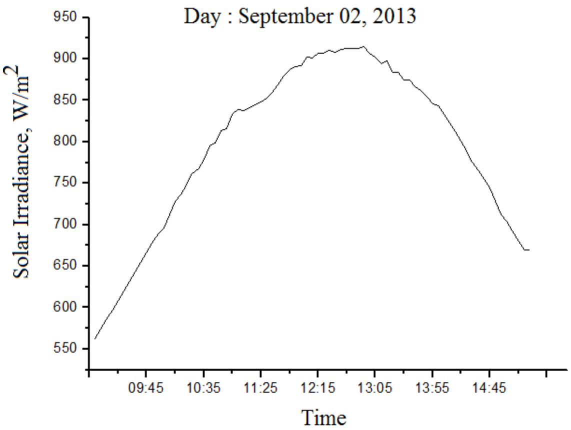

Figure 8: Measured global solar irradiance for the 2nd of September 2013

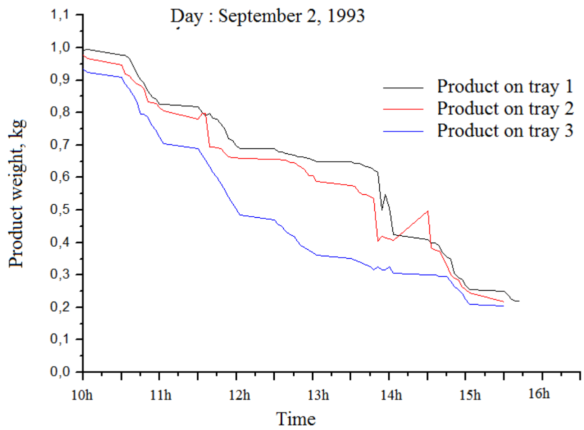

Figure 9: Effect of tray position on weight loss of the product as function of time for clear sky

Drying Time Comparison for Two Different Products

To investigate the behavior of different products in the dryer, the drying curves of two different products were compared. Indeed.

The first product was composed of fibers and grains of red pepper and the second is consisting of fine apple skins and grains. The results are shown in Figures 10 and 11.

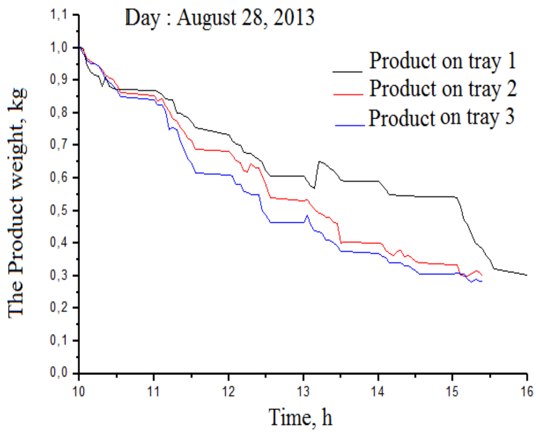

Figure 10: Red pepper waste weight loss as function of time

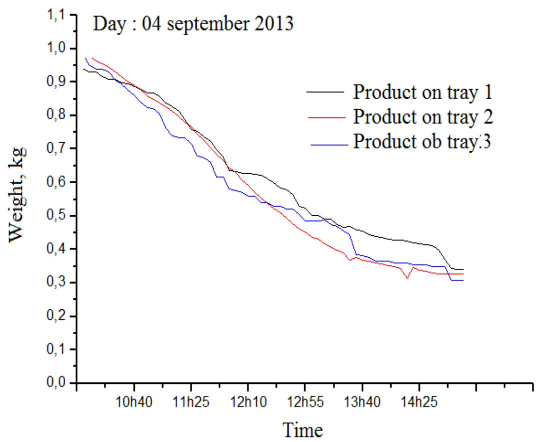

Figure 11: Apple skin waste weight loss as function of time

This is because the drying process is highly dependent on how water diffuses from the product to the surrounding air. This diffusion phenomenon is affected by the nature of the product itself, its shape and thickness. Grains and fibers of red pepper have s a greater thickness than apple skins.

Conclusion

The present work is part of a big research project which aims to the development and mastery of the different solar drying techniques that would respond to the needs of many agricultural and industrial fields.

The experimental results obtained from tests performed on industrial food wastes allowed us to conclude that solar drying could be considered as an efficient clean solution to deal with this kind of very sensitive and fragile wastes. Once the waste is dried correctly, it is easily reused as additive in animal food production.

The present work has shown, also, that the mastery of air flow rate through the dryer is a very important parameter which allows the control air temperature and drying speed.

The results show that regardless of the food waste type. The drying time still very low as compared with fruit and vegetables; This is due to the fact that all the waste products are recovered at the exit of the production with a very fine particle size and a random shape which is an enhancing parameter of water diffusion from the product.

In perspective, a techno-economic study should be conducted to determine the cost of installation.

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Mitigating the effects of spot shading on the power output of a solar module

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Abstract

Shading of half a single cell in a crystalline solar module results in over 30 % loss in power output. The power recovered by the shunt diodes in a partially shaded module averts the hot spot problem but this recovered energy is not used productively in the external circuit. Partially shaded conditions create multiple peaks in the power curve of the module that increases the complexity of MPPT techniques implemented in charge controllers. Solar Home Systems comprising single-module installations, commonly found in sub-Saharan Africa are especially vulnerable to partial shading conditions with small shading resulting in an entire installation being disabled.

Keywords: Solar Module, Shading; Bypass diodes.

Introduction

Out of 76 systems tested in a quality assurance exercise across the country in a recent survey, over 40 % of the systems performed below expectations (African Solar Designs, 2013). Experimental evidence reveals that a loss in power output of approximately 30 % to 50 % results from shading of a single cell in a crystalline solar module made up of thirty six cells (Silvestre and Chouder, 2008). Current solutions used in mitigating the effects of shading are predominantly designed for relatively large solar systems. One such solution is the use of Maximum Power Point Tracking (MPPT) techniques in Photovoltaic (PV) systems to optimize power output from the panels by operating the system at its Maximum Power Point (MPP) (Ishaque & Salam, 2013; Reisi et al, 2013; Esram & Chapman, 2007). Partial shading conditions result in several maxima along the power curve of the PV installation, a condition that increases the complexity and the cost of a remedial MPPT solution (Chia et al, 2011). Single-module solar home systems that are commonplace in rural Africa are particularly vulnerable to the effects of shading with a small shade capable of rendering the entire installation unproductive (Ubisse & Sebitosi, 2009). Since shading reduces the power output of a string of solar cells, a microcontroller-based shade detection device is proposed to sense the voltage of the partially shaded cells, boost the voltage via a DC–DC converter and feed it to the voltage of the un-shaded solar cells thereby ensuring that the solar module produces power at its predetermined design voltage.

Background

In a series connected string of cells, all the cells carry the same current. A shaded cell produces less photon current but this cell is forced to carry the same current as the other fully illuminated cells. The shaded cell exhibits reverse biased conditions in its P-N junction and becomes resistive to the passing current thereby dissipating power in the form of heat (I^2R). If the system is not appropriately protected with bypass diodes, a hot-spot problem can arise, resulting in irreversible damage (Herrmann et al., 1997).

Duffie & Beckman (1991) and Twidell & Weir (1986) presented the non-linearity of the *I–V* and *P–V* characteristics when the solar module system is illuminated uniformly with sunlight. At any given insolation and temperature, a PV module has a unique maximum power point, MPP, the point on the I–V curve at which the module produces maximum power at the optimum current and voltage. The MPP varies according to the amount of solar irradiance and temperature of the module. Maximum power point tracking, MPPT, algorithms as discussed by Ishaque & Salam (2013), Reisi et al. (2013), Esram & Chapman (2007) are able to identify and track the MPP during both uniform illumination conditions and also during changing atmospheric conditions. Some of the simplest to implement include Open Circuit Voltage (V_{OC}), Short Circuit Current (I_{SC}) described by Reisi et al. (2013), Perturb & Observe described by Chin et al. (2013), Ishaque & Salam (2013), and Incremental Conductance described by Esram & Chapman (2007).

The problem of partial shading was introduced by Quaschning & Hanitsch (1996). The inherent difficulties in maintaining the shade profile and controlling the external environment when studying partial shading using an actual solar PV module was discussed by Herrmann et al. (1997); Kaushika & Gautam (2003); and Woyte et al. (2003). For this reason, they focused on simulation studies with the help of computer modeling. Alonsoet et al. (2006), Karatepe et al. (2007) focused on the effect of partial shading in reducing the output power of the solar PV array and how the power dissipated by the shaded cells affects the array life and utilization of the array.

The causes of non-uniform irradiation may be dust, bird droppings, shadows from clouds, trees, objects in the built environment such as chimneys, TV antennae and adjacent buildings. When the PV module is under Partially Shaded Conditions (PSC), its I–V characteristics become more complex with multiple MPPs. If there are multiple peak points in the power curve, the aforementioned MPP tracking methods require an additional initial stage to bypass the unwanted local maxima and bring operation close to the real MPP. Towards this end, novel MPP tracking methods that use soft computing techniques have been widely discussed to overcome the effects of partial shading. These include Artificial Neural Networks (ANN), Fuzzy Logic (FL), and Extremum Seeking Control (ESC) methods. In a review of current MPPT techniques, Ishaque & Salam (2013) and Reisi et al. (2013) argue that despite the effectiveness of these new methods, the complexity of the methods as well as software and hardware costs are major constraints for using them in low-cost installations.

When shaded and un-shaded cells are connected in series, a mismatch of their electrical characteristics occurs (Overstraeten & Mertens, 1986). This mismatch often leads to the shaded cells being operated in reverse bias voltage. During such conditions the shaded cells are taken out of the string using a shunt diode wired in parallel with the solar cells. Whenever the negative voltage in a shaded string reaches the transmission voltage of the diode, illustrated in Figure 1, the diode turns on and the current of the un-shaded string flows around the mismatched cells through the diode.

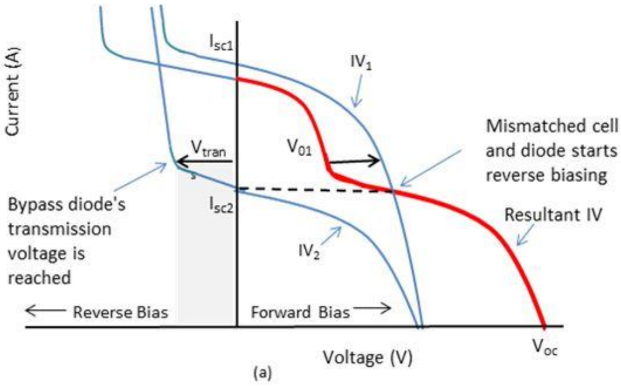

Figure 1: I–V characteristic of partially shaded module with two bypass diodes (Source: Vorster & Dyke, 2005)

Research Objectives

1. Develop a method that will enhance the energy yield from a conventional 36-cell solar photovoltaic module operating under partially shaded conditions.
2. Investigate the power output from a conventional 36-cell solar photovoltaic module subjected to various hard and soft shade profiles.
3. Design a microcontroller-based shade detection device to sense the voltages from two sub-modules that are subjected to various shade conditions.
4. Boost the voltage from a partially shaded sub-module using a DC-DC converter, and safely add it to the voltage produced by an un-shaded sub-module.

Methods

Conceptual Framework

A conventional module consists of 36 series connected solar cells with a bypass diode across a group of 18 cells to prevent non-recoverable reverse-bias breakdown of the solar cells as illustrated in Figure 2.

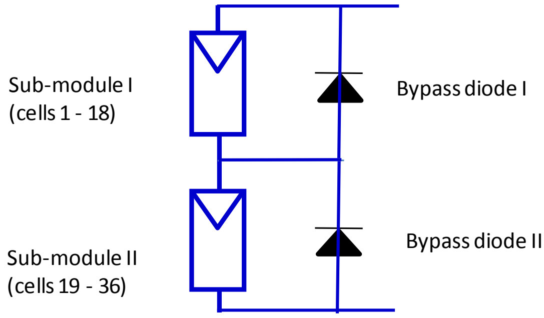

Figure 2: Conventional PV module

A sub-module essentially consists of 18 series-connected solar cells. When one of the cells is subjected to shading, the power output of the sub-module is reduced. An algorithm implemented in a microcontroller can be used to detect this reduced power (and voltage) and initiate a switching mechanism to feed this reduced voltage into a boost DC–DC converter and subsequently add this boosted voltage to the voltage from the un-shaded sub-module.

Investigate the power output from a shaded conventional 36-cell solar photovoltaic module.

A shading element is simultaneously placed across selected cells of a 36-cell, polycrystalline 54 Wp Kyocera solar module. The setup is exposed to solar radiation and the power output from the module measured by a Portable I–V MiniKLA Curve Tracer. The solar module is set up so as to receive radiation normal to its surface. An OMEGA Type K Surface Mount thermocouple with a Fluke multimeter was used to measure the operating temperature of the module under test. A “hard” shade is simulated by covering the selected module surface with opaque material while a “soft” shade is simulated by raising the opaque object so as to enable it cast its shadow on the chosen module area.

Microcontroller-based shade detection device.

The 2 sub-modules of a 36-cell solar panel are separated and using an I–V curve tracer, their current and voltage characteristics are obtained when these sub-modules are subjected to various shading conditions.

Using the I–V characteristics obtained from these measurements, a microcontroller will be modeled to switch transistors depending on the voltage levels across the sub-modules as illustrated in Figure 3. The microcontroller continuously monitors sub-module-1 voltage V_1 and sub-module-2 voltage V_2 and compares their values to stored nominal values. Where the two tests are TRUE, switches A, B, and C should remain ON. Where one of the tests is FALSE, the microcontroller switches the affected sub-module voltage to a voltage booster. Where both sub-modules' tests are FALSE, the microcontroller displays an appropriate message

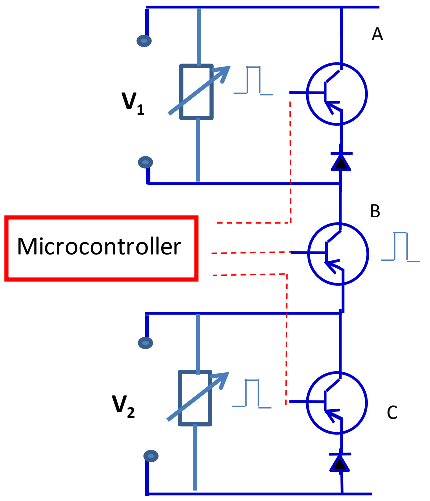

Figure 3: Sub-module with microcontroller and switching transistors.

The shade detection circuit is designed and implemented as illustrated in Figure 4. The microcontroller shall connect the respective sub-module to a circuit with a Standard Resistor, R_o, and a Hall Effect current sensor.

The sensed current is proportional to the current, I_c, flowing through the Resistor, R_o. When the sub-module is subjected to various shade conditions, the sensed current will vary accordingly. Because the output of the Hall Effect sensor is connected to the Analogue to Digital input pins of the microcontroller, the sensed values are compared to the stored nominal values thereby enabling the microcontroller to decide when and where to switch in the boosted voltage. The design parameters used by the microcontroller in controlling the switching between the shade detection and voltage boosting circuits, are obtained by comparing the current and voltage values from the I–V curve tracer and those obtained using the shade detection circuit.

A Microcontroller-based Voltage Boosting Circuit

Using a microcontroller and DC Solid State Relays (SSR), the circuit in Figure 5 will be designed and implemented that will boost the voltage from a partially shaded sub-module using a DC–DC converter, and safely cascade this voltage to the voltage produced by the un-shaded sub-module.

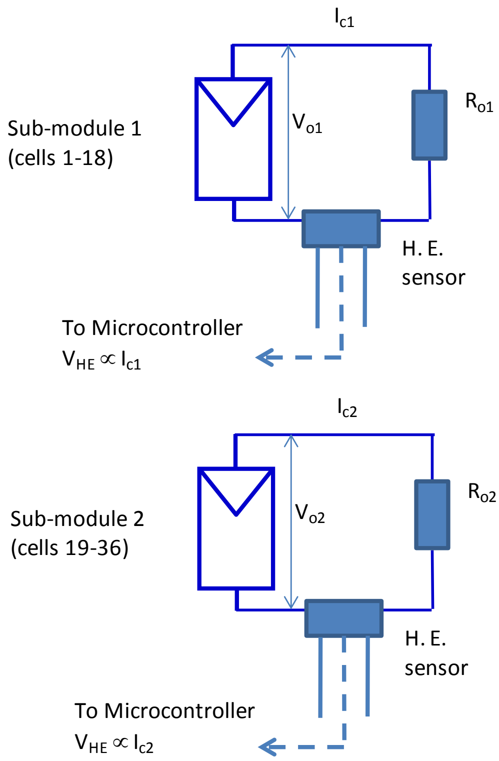

Figure 4: Shade detection circuit

The circuit illustrates the situation when sub-module-2, represented by voltage input V_2, is partially shaded. The microcontroller switches the respective SSRs as illustrated thereby connecting the reduced voltage from sub-module-2 into the DC–DC converter. The output voltage from the converter is then cascaded to the output from un-shaded sub-module-1, represented by a higher voltage output V_1.

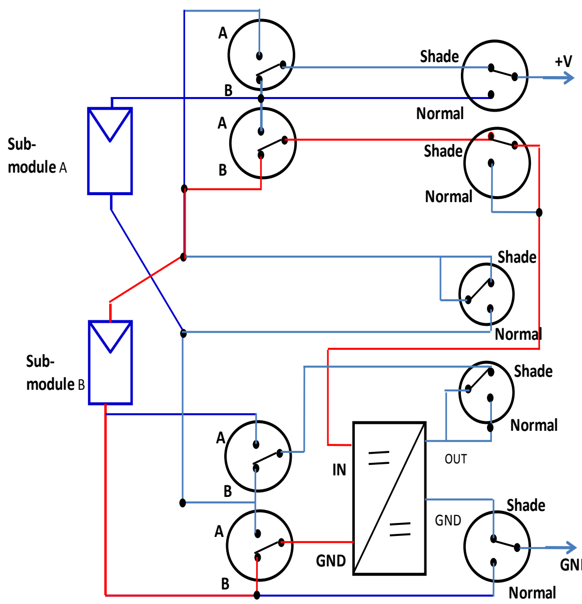

Figure 5: Schematic of the voltage compensation circuit.

Results

When each of the 36 cells is hard shaded, an I–V curve results that is characterized by two peaks described here by MPP1 and MPP2 respectively. MPP1 is however attained at voltages below 8 V in each instance. MPP2 on the other hand is attained at relatively higher voltages of up to 14.7 V.

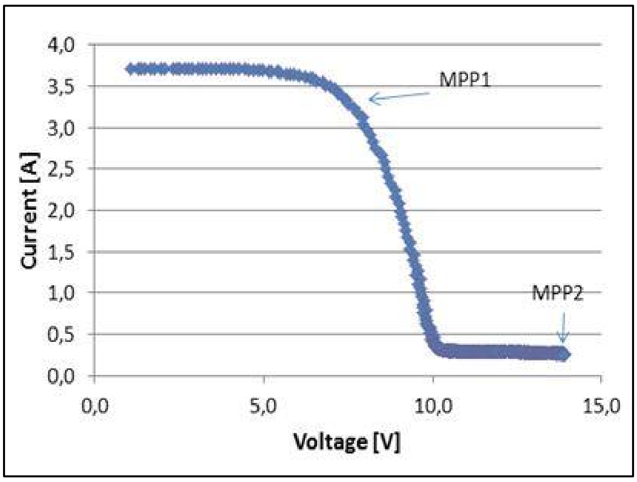

Figure 6: Two peaks in the I–V curve produced by hard shading a single cell.

Soft shading each of the 36 cells results in values of MPP1 attained at voltages below 8 V and MPP2 attained at voltages above 20 V.

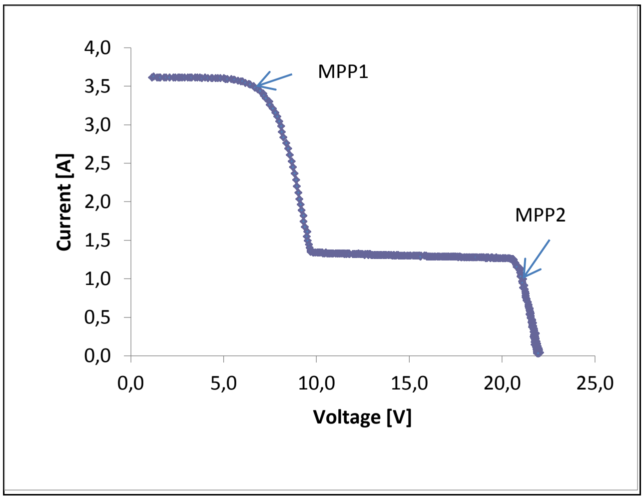

Figure 7: Two peaks in the I–V curve produced by soft shading

Discussion

In a conventional solar home system of 12 V nominal voltage, using a regular charge controller, the voltages at MPP1 produced by a hard shade on the module are incapable of charging a 12 V battery. The voltages at MPP2 can produce a minor charge into the battery since the corresponding charge currents at these voltages are held at a relatively low 0.3 A. Soft shading produces voltages at MPP1 that are incapable of charging a 12 V battery. The voltages and current at MPP2 can produce an appreciable charge.

Whilst the scope of the research remains a single 36-cell conventional module, further research can be carried out on 4 sub-modules comprising of 9 cells each, or on 6 sub-modules comprising of 6 cells each, or on 18 sub-modules of 2 cells each and finally each of the 36 cells in the module can also be tested as a separate entity. The point at which the benefits of the increase in recovered energy from the respective sub-modules of a shaded module outweigh the costs, complexity and bulkiness of implementing the circuitry represent the limits of this particular research.

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Development of a test framework for evaluating USB charging ports of pico PV systems and solar home systems

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Abstract

Increasing market penetration of stand-alone PV systems and mobile phones in developing countries has necessitated the development of specifications and test methods for USB charging ports in this context. This paper focuses on the development of a multiple-perspective low-cost test framework to ensure the quality of USB charging ports of stand-alone PV systems. The methods for assessment of steady state conditions, dynamic behavior and energy balance of the systems are described, together with their evaluation by means of pilot tests to define the evaluation criteria and to assess the reliability of the test setup. The successful test framework development will ensure USB charging port quality and protect consumers from malfunctioning of mobile phone chargers.

Keywords: Quality assurance, stand-alone PV system, USB battery charging, off-grid lighting, solar home system, SHS, pico PV system.

Introduction

Rapid changes in modern off-grid lighting markets and energy systems in developing countries have recently led to the establishment of the Lighting Global Quality Assurance Program (Lighting Global, 2014). The joint program between the World Bank and the International Finance Corporation was established to provide customers with a reliable technical specification through the development of a test framework and minimum quality standards for system verification.

As mobile phone use has become an important part of daily life in rural areas, most pico PV systems and solar home systems (SHS) are now equipped with a USB port for charging mobile phones. Universal Serial Bus (USB) has become a standard bus and the most used interface for charging mobile phones and portable devices. However, charging mobile phones via USB requires safety precautions by means of power management including operating range, type of port, and power source detection algorithms specified in the USB battery charging specification (USB BC 1.2), published by the USB Implementers Forum in 2010.

Figure 1 shows a typical stand-alone PV system with USB charging port. The port is powered by the battery (at night, or at day with insufficient sunlight) and by the PV module (at day with sufficient sunlight) through the DC-DC converter. A step-down or step-up converter is used to convert the system voltage to the USB voltage of 5 V. The DC–DC converter plays an important role to keep the voltage regulated at the level required to charge the mobile phone. On the other hand, the losses in the DC-DC converter also influence system efficiency and thus system run time (Park et al., 2013).

A minimum input voltage of 4.5 V is required for the mobile phone to charge its internal lithium-ion battery, which will thereby reach a maximum voltage of 4.2 V (Kim & Kim, 2012). Therefore, the battery charging specification requires that the voltage range at the port should be from 4.75 V to 5.25 V for high power (500 mA) ports, and from 4.4 V to 5.25 V for low power (100 mA) ports (USB Implementers Forum, 2010; Sherman, 2010).

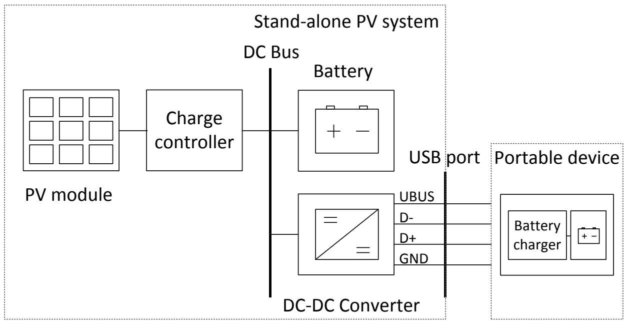

Figure 1: Stand-alone PV system with USB charging port configuration.

Since the USB BC 1.2 is a *de-facto* standard for USB battery charging, the design of systems can either be compliant with the specification or noncompliant (Park et al., 2013; Sherman, 2010). If the port is USB BC 1.2 compliant, it can provide up to 500 mA (after enumeration[1]) in case of a standard downstream port (SDP), and 1.5 A in case of a charging downstream port (CDP) or a dedicated charging port (DCP) (Sherman, 2010). Port detection by mobile phones specified by USB BC 1.2 involves port voltage detection, data contact detection, primary detection, and optionally secondary detection on the data lines of the USB port (D+ and D-) (USB Implementers Forum, 2010).

Research Objectives

This research aims at developing a fast, low-cost, and reliable test procedure for evaluating USB charging ports of pico PV systems and SHS. In order to develop a reliable procedure, quality measures for stand-alone PV systems regarding USB charging ports have to be defined. Investigations were conducted to characterize ports and to establish safety considerations for the internal circuits of the mobile phone's battery charger and of the USB port.

[1]The data exchange between the device and the port to identify the device at initial stage (Sherman, 2010).

Also, the minimum quality standard, which includes truth-in-advertising (TIA) criteria, should be met by the port. A test method for performance assessment of the energy service capability of systems with a mobile phone charging feature is also developed within the research scope. The influences of different charge controller types and irradiance levels are investigated as well.

Methods

The following tasks were carried out during the test framework development:

Investigation of mobile phone charging characteristics:

A preliminary research was conducted on the charging characteristics of mobile phones. Typical basic mobile phones (as are used in the rural areas of Africa) were measured, and a smartphone. As the basic mobile phones measured are not featured with data lines, the smartphone was used to understand the interaction behavior, and the data handshakes through the data lines, between the smartphone and the USB charging port. The results, such as typical charging currents and charging methods, were then used as an empirical reference to develop the testing procedure for charging ports of pico PV system and SHS.

Development of the type of test:

The test type was defined based on parameters that had to be characterized. As the port is powered via a DC-DC converter, the characterization included the ability of the port to keep the output voltage within specified limits (regardless of variations of PV or battery voltage and load current), the self-consumption when the system is in the standby state, the efficiency of the converter, and the transient response of the output voltage when current steps or pulses are drawn from the output.

Development of the test configuration and specification of the measurement devices:

One of the goals of defining the test configuration was to ensure consistency and repeatability of the tests between test laboratories in developing countries. Figure 2 shows the test setup and the measurement devices used. A PV simulator and a power supply with source and sink capability were used to replace the PV module and the battery of the device under test (DUT) respectively. The accuracy of the measuring instruments, and the place to measure the voltage and current, were also specified in order to minimize the measurement errors.

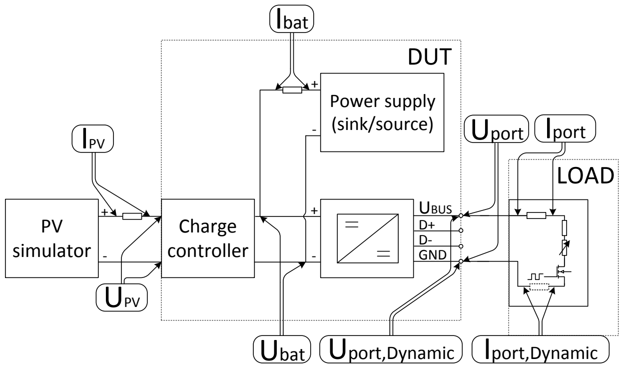

Figure 2: Test configuration.

Development of the data processing and evaluation criteria:

The data processing and evaluation criteria included the necessary calculations to characterize the port, and the pass or fail criteria for the results. The parameters used to verify the results were: the USB BC 1.2 specifications, the DUT datasheet, and the typical input ranges of mobile phone internal battery charging circuits.

Pilot tests for evaluating the test procedure:

Pilot tests for validating the reliability of the preliminary test procedure were conducted by testing a pico PV system and a SHS, both specified in Table 1.

Table 1: Specification of the pilot-tested products.

Parameter	Pico PV system	SHS
System voltage:	6 V	13 V
Battery type:	NiMH	$LiFePO_4$
Battery capacity:	2100 mAh	9800 mAh
USB ports quantity:	1	2
USB ports nominal voltage:	4.4–5.1 V	Not specified
USB ports nominal current:	750 mA	500 mA

Results

The developed test framework encompasses three different tests: steady state test, dynamic test, and energy-based test. Each of the tests is discussed in more detail below.

Steady state test

The test is intended to assess the DC-DC converter behind the USB charging port with respect to its ability to maintain its output voltage in the specified range, given changes in the load and in the battery's voltage. This test involves the DUT, a power supply, multimeters (with shunt resistors for current measurement placed at the high side), and a safety resistor (to prevent unintended overcurrent) in series with a variable resistor (to control the load current).

Two input parameters (the load current and the battery operational voltage) are varied during the tests. The load current is varied to 0 %, 10 %, 20 %, 40 %, 60 %, 80 % and 100 % of the maximum current stated in the DUT's specification. Three different voltage levels of the DUT's battery are used, which correspond to: just above low-voltage disconnect voltage, typical operational voltage, and the initial discharge voltage. These values are obtained from the results of a separate charge controller test of the DUT.

The input voltage and current (battery terminal) and the output voltage and current (USB port) are measured. For evaluation, the input and output powers and the battery-to-load efficiency are calculated.

The port voltage vs. port current, port voltage vs. port power, efficiency vs. port current, and efficiency vs. port power at each battery operational voltages are plotted. The evaluation is done by assessing whether, at the maximum current (500 mA), the operating voltage at the port is in the range specified by USB BC 1.2 (from 4.75 V to 5.25 V). The lower and higher limits are set to provide the correct voltage for operation of the internal battery charger in the mobile phone. A very low voltage may lead to inability of the lithium ion battery to get fully charged, and an excessively high voltage may cause damage to the internal mobile phone battery charging circuit. The efficiency curves are important for the energy service calculation of the energy required for mobile phone charging. Truth in advertising is assessed by comparing the test results with the manufacturer specifications.

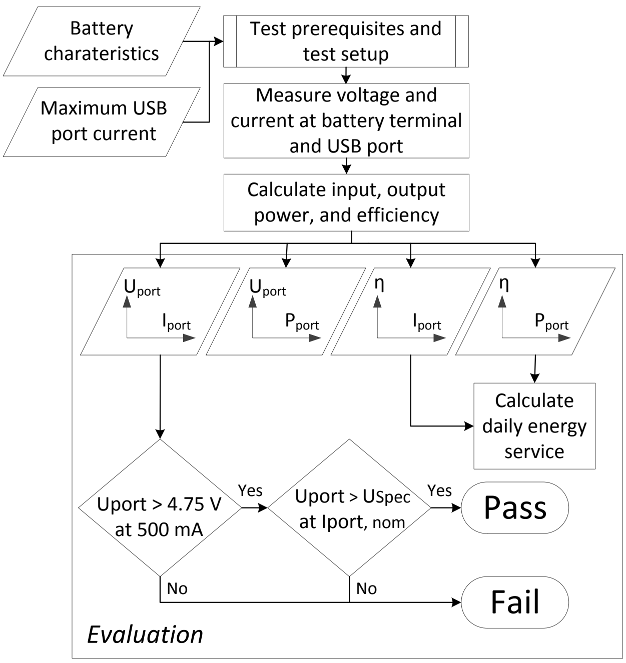

Figure 3: Steady state test flow chart.

Dynamic test

As one of the charging methods of the mobile phone is pulse charging, the dynamic behavior test is performed to evaluate how the DUT responds to a fluctuating charging current. This test is done to ensure that the ramping-up of the current does not cause the port output voltage to drop below the input voltage which is detected by the mobile phone as valid.

The transient responses, such as voltage overshoot, voltage undershoot, and transient time, are observed during this test, as shown in Figure 4. This test requires a data acquisition device with a minimum rate of 1000 samples per second and a variable pulsed load with electronic switch (MOSFET with low on-state resistance) controlled by a pulse generator, to represent the charging behavior of a mobile phone with pulse charging method.

The pass/fail evaluation is done by assessing the voltage overshoot and undershoot peaks, which should not be above 6 V or below 4.1 V respectively. The voltage should also not drop below 4.75 V for more than 10 ms, as specified in the USB BC 1.2. A droop test, which is carried out if the system has multiple USB charging ports, evaluates the dynamic port behavior when it is loaded with constant maximum current, while the other port is burdened with a dynamic load.

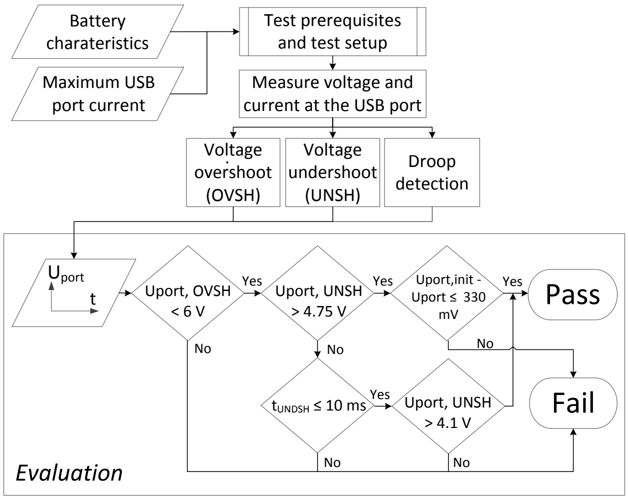

Figure 4: Dynamic test flow chart.

Energy-based test

The energy-based test is conducted in order to determine the full-battery runtime for charging typical basic mobile phones and to assess manufacturer claims concerning the number of mobile phones that can be charged in one day. In this test, the USB port behavior in the day situation (with solar charging) is evaluated.

Figure 5 shows that the assessment is based on the calculation of energy efficiency to charge the battery at day with sufficient sunlight followed by the calculation of daily energy service. This test requires a pulsed load, which corresponds to the typical charging current of a mobile phone, based on the results of the preliminary research on the basic mobile phones (500 mA). The pulse is set to 0.1 Hz with duty cycle of 90 %, which represents typical charging patterns.

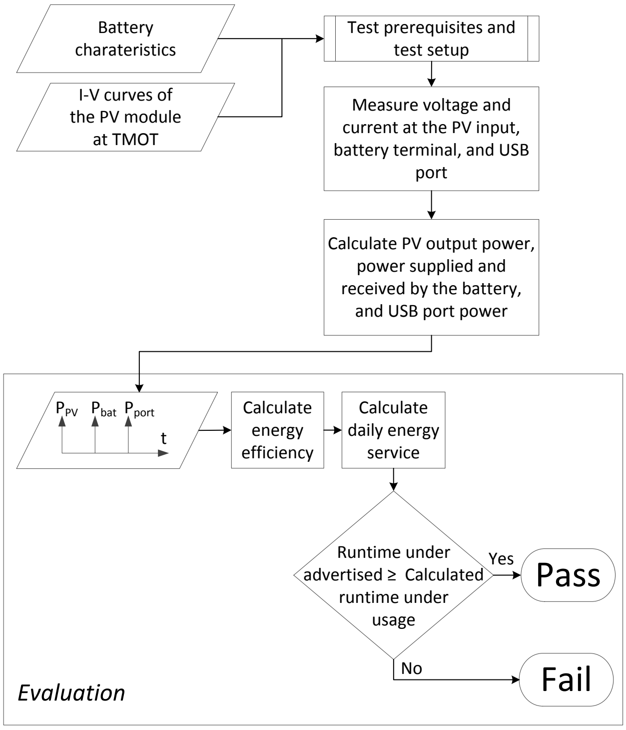

Figure 5: Energy-based test flow chart.

A bidirectional power supply is used and set to just above low-voltage disconnect voltage to represent a deeply discharged battery. A PV simulator simulates the I–V characteristics of the PV module at different irradiance levels on a standard solar day with an irradiation of 5 kWh/m^2/day. A data logger registers the voltage and current over the charging period at the PV output, battery terminal, and port output. As evaluation, the efficiency for charging the mobile phone is calculated for every two hours. This is based on the assumption of fully charging a 1000 mAh mobile phone's battery at 500 mA charging current.

Pilot test results

The steady state and dynamic tests were conducted to evaluate the procedure, the test setup, and the evaluation criteria.

Figure 6 depicts the characteristic of the USB charging port's output voltage over current of the example pico PV system and SHS at three different battery voltages. It shows that the output voltage varies with battery voltage, especially for the pico PV system, which uses a buck-boost converter. Three different battery voltages were used to evaluate whether the output voltage was still in the allowed range, especially at low battery voltage. In this case, the USB BC 1.2 voltage tolerance was violated by the pico PV system for load currents above 300 mA.

Figure 7 shows the efficiency of the DUT at different output powers. The plot is used to calculate the runtime of the DUT based on the typical power consumption to charge a mobile phone.

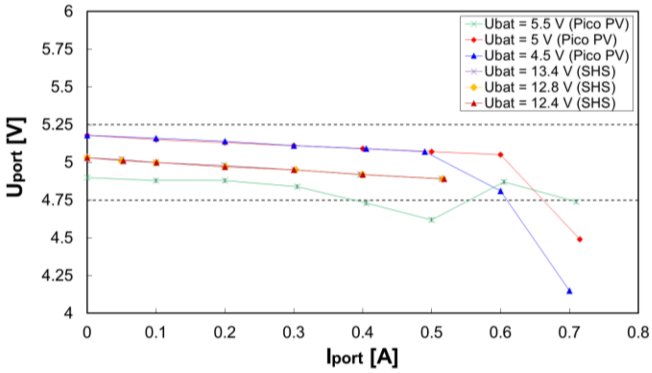

Figure 6: USB charging port voltage over current characteristic at different battery voltages.

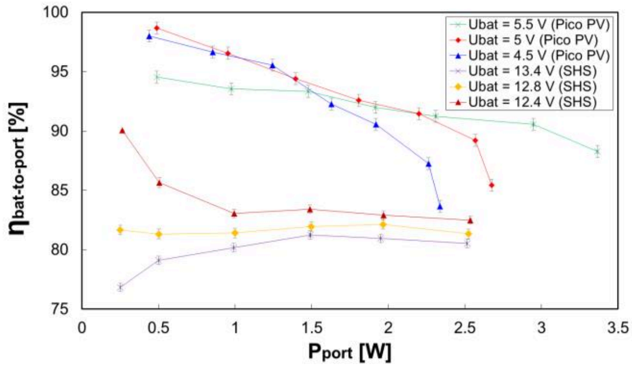

Figure 7: Efficiency vs output power plots at different battery voltages.

The voltage and current transients when the port is loaded with a pulse load are illustrated in Figure 8. The waveforms show that a considerable overshoot voltage occurs, when the current falls, in both the pico PV system and the SHS. Nevertheless, the controller was able to keep the voltages below the maximum limit. A violation of the minimum voltage threshold by the pico PV system was detected, where upon triggering the pulse the voltage dropped to 4.26 V, with a peak undershoot voltage of 3.83 V, which leads to a failed result.

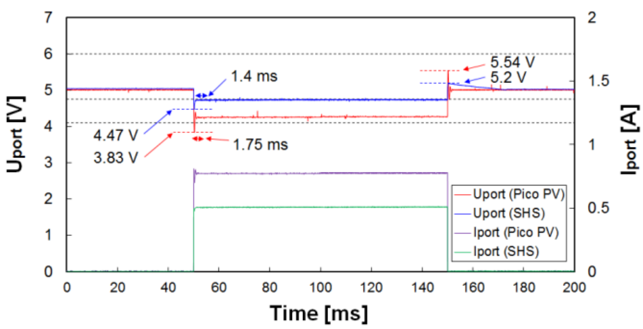

Figure 8: Transient voltages at the port when the pulse is triggered.

Discussion

Investigation results show that the USB charging port voltage varied significantly with changes in battery voltage and load current. The procedure to validate the truth-in-advertising of the DUT's specification was also developed, covering the output current capability and output voltage of the port. The result shows that the port of the pico PV system was not able to maintain the specified nominal voltage at 700 mA, which implies inaccurate nominal voltage labeling of the port by the manufacturer (Table 1).

A problem will arise if the DUT advertises its capability of charging a particular portable device, which requires the DUT to be tested by using a specific portable device (or emulator) with a proprietary port detection algorithm which is noncompliant with USB BC 1.2. An alternative solution might be to conduct the primary detection algorithm for DCP (dedicated charging port) as specified in USB BC 1.2, followed by measuring the data lines voltage (relative to U_{BUS} and ground), to identify the divider mode protocol that is normally implemented by smartphones (Texas Instruments, 2012).

As a next step, the energy-based test has to be evaluated for the efficiency to charge the battery at day (with sufficient sunlight), which will contribute to estimating the DUT's runtime. In the future, the evaluation of the test procedure will be done with more samples of different types of SHS to obtain a higher level of confidence in the test framework.

Acknowledgement

This work was supported by World Bank/IFC. We also thank our colleagues from the Schatz Energy Research Center at the Humboldt State University, Arcata, California and the Postgraduate Programme Renewable Energy at the University of Oldenburg for their valuable supports and discussions on this research topic.

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Improving the Performance of Solar PV Installation in Rural Locations in Nigeria: A Case Study

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Abstract

Many rural communitites in Nigeria lack access to basic ameneities such as clean energy and water, with negative impacts on development. Efforts by government to provide these services using solar PV have often failed. This paper describes a study of the implementation of PV systems in two villages. This found a lack of a holistic approach in deployment, and a complex interplay of factors in the underperformance of the systems. The paper therefore presents recommendations that could lead to improved deployment procedures and enhanced performance of solar PV installations in rural communities in the country

Keywords: Rural location, RE Systems.

Introduction

Whereas the availability of social amenities such as water and electricity is taken for granted in most urban cities of developed countries worldwide, the absence, or acute shortage of these amenities, is prevalent in many rural isolated settlements of developing countries. Most of these locations are characterized by high level of poverty and underdevelopment (Baguma et al., 2013; Rahman et al., 2013). "Energy Poverty" and "Water Poverty" are concepts that are used to describe the inability of a society to provide adequate energy and water access, respectively, to its people. Although governments of many countries have deployed various means to improve the access of rural people to enhanced energy and water provisions, these people still represent a large portion of those that lack such access (IEA, 2013). In Nigeria, governments at various levels have attempted to use renewable energy (RE) technologies to improve the energy access of the people. Specifically, Solar PV has been used for street lightings in urban areas and for improved energy and water services in isolated rural communities. Due to the dispersed location and low population density of many such communities, grid extension is often an impracticable and uneconomical option for providing these services.

Research Objectives

In Nigeria, despite the abundance of solar resources, efforts by the federal, state and local governments to provide isolated rural communities with improved energy and water services using solar PV technology have not recorded much success; with many of the installations not functioning effectively beyond the first few months of being installed. The failure of these installations suggests deep underlying problems and has discouraged government and policy makers from supporting solar PV and, as an extension, other forms of RE projects as viable options for such locations. Since the use of solar PV for pumping water and for lighting purposes has been a main thrust of the Nigerian government in the provision of improved energy and water services to its rural populace, it is therefore necessary to understand the reasons for the dismal failure in these efforts, and to develop improved means of achieving the purpose.

Methods

A study on the varied reason for the underperformance of Renewable Energy Technologies (RETs) in Nigeria requires a multi-dimensional approach that can capture a wide spectrum of possible causes. A balanced study as such, will require meeting and relating with different stakeholders involved in the deployment and utilization of RETs, obtaining relevant information from these stakeholders, observing the use pattern of the installations, evaluating the physical state and performance level of the installations, etc. This will involve insights, discovery, and interpretation of information. Subsequently, stages involved in this study explained below.

Identification and Selection of Sites for the study

RETs installations located in two rural locations were chosen for study based on (i) the villages are remotely located, hence, are typical isolated communities with near-zero probability of having grid electricity in the near future, (ii) The installations are typical government-deployed community solar PV installations for the provision of improved water/light services to rural dwellers in isolated locations (iii) the locations provide a possibility of conducting research studies safely without endangering either the researcher, the respondents or any other participants in the study. This is against the backdrop of prevailing insurgent attacks and unrests in some parts of Nigeria.

The chosen locations are Ide Village and Sagbokoji Village in Lagos state, Nigeria.

Site Visits and Data collection

Before setting out to conduct the study at the locations, approval was sought from local authorities by means of a formal letter highlighting the aim and objectives of the study, and assuring that the purpose of the study is devoid of tribal, religious, or political undertones.

After obtaining permission, the sites were visited for the purpose of physical evaluation and assessment of the installations; to carry out a general observation of the daily activities of the communities in relation to the installations and to have informal chats and interviews with the dwellers who are the users of the installations.

Ide village was visited three times over a period of one and a half years while Sagbokoji Village was visited twice over the same period. The primary data collection method was in form of both semi-structured and unstructured interviews that were aimed to obtain true responses from respondents on issues, attitudes, behaviours, and experiences with respect to the deployment and performance of the solar PV installations in rural locations. Respondents were allowed to tell their stories in their own words while the interviewer drew out detailed information and comments from their responses. Interactions with rural dwellers were carried out in the local language, which the leading researcher communicates fluently.

Stakeholders from the supply side (officials of government agencies), and from the demand side (rural dwellers end users) participated in the study. Hence, data collection involved relating with uneducated rural dwellers that converse only in their native languages; with government workers that, most times, are reluctant to provide information.

All participants in the study were informed about the purpose of the study, how the information obtained would be used, what was required of the participants and that their participation was voluntary. The choice of unstructured and semi-structured rather than structured interview was employed because it offers sufficient flexibility to approach the different respondents.

Recording and Analysis of Data

The main points in the responses of those interviewed were taken down as notes since the respondents were not receptive to having audio recording of the interview sessions. While this mode of data capturing was not the ideal method, the researcher would rather have the full cooperation of the respondents and obtain unprejudiced information by consenting to their request of not having their responses tape-recorded than otherwise.

Pictures to reflect the condition of the installations and the activities of the rural dwellers were taken within the confines of ethical considerations. An inductive approach is used to analyse data collected from the interviews and discussions held with the various stakeholders and from the observation and evaluation of the RETs in the locations of study. Patton (1990) defines inductive analysis as when "the patterns, themes, and categories of analysis come from the data; they emerge out of the data rather than being imposed on them prior to data collection and analysis". Specifically, the data were analysed to reveal the various process, factors and actors involved before, during and after the deployment and of RET Installations to rural locations and how they may have contributed to the (under) performance of the installations in these places.

Results

Interview Sessions with officials of Ministry of Rural Development

The semi-formal interview/discussion held with the officials of the Ministry of Rural Development (MRD) revealed the procedural steps in the deployment of RETs to communities

As highlighted by the officials, a main issue that normally confronts the Ministry is the determination of which communities are to be installed with RET since at any point in time, there are usually a number of them reckoned to be in need and regarded eligible for such installations. They stated that RE installations are deployed to rural communities (i) as a form of government intervention (ii) through requests made by communities and, (iii) through request made by philanthropists, in which case, a philanthropist sponsors the project financially and also decides the rural location to site it. They however explained that most RE installations in rural communities in the state are deployed as means of government intervention aimed at achieving improved water/electricity services in such locations. The officials further explained that since the agency lacks both the financial and technical abilities of achieving a 100 % spread of RET installations to rural communities where such needs have been established, they endeavor to be unbiased in its deployment.

The stages involved in the deployment of RE by the agency is given below.

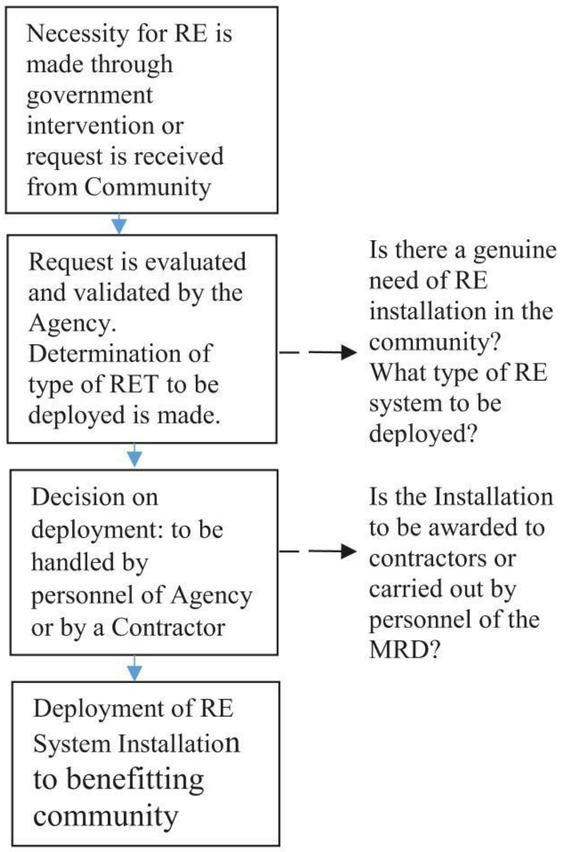

Figure 1: Stages of RE Deployment

Furthermore, the officials explained that upon the completion of an installation to a community, the MRD carries out the following:

Transfer of Ownership to benefitting Community

This is done publicly, usually during the commissioning of the installation and is backed with an official document which is handed over to the community head or the Community Development Association CDA (if such is in place). The officials explained that the essence of this is to imbibe a sense of ownership on the community so as to provoke good operation and maintenance culture of the installation on the part of the residents.

Basic Operation and Maintenance of Installation

The officials revealed that after installation of the RE system, the installers (i.e. personnel of the MRD or the Contractor) trains some community members on basic operations of the installation. This would include how to carry out minor maintenance operations e.g., repair of broken taps.

Provision of Security

The MRD officials mentioned that the ministry ensures that the installations are either fenced or barb-wired on completion to discourage unauthorised access which could compromise the operation and performance of the installations.

Visits to Locations of Installations

1st Case Study: Ide Village

The Installation at Ide Village is a battery-free solar PV-powered water system (Figure 2) designed to pump water to two overhead tanks that feed the community through five water tap outlets that are located at strategic points in the village. Prior to the installation of this water system, a well has been the main source of (unhygienic) water for the dwellers. During the visit, which was made 6 months after the Installation was completed the dwellers explained that the community provided the piece of land for the installation and the labourers used for the foundational works. The residents were unanimous in accepting that the installation has affected them positively. “It’s a life changer!” one of them exclaimed, while they all chorused, “we now get clean water from the taps”.

Figure 2: Solar Installation at Ide Village

However, a noticeable feature of the installation was the large pool of water that formed around it. A close check revealed that water was gushing from the surface pump of the installation. The dwellers explained that the installation started having problems barely 3 months after it was installed; three out of the five water taps became blocked and ceased to serve as outlets for water while the surface pump experienced water leakages, leading to a pool of water being formed around the installation (Figure 3).

Figure 3: Leaking surface water pump of the solar installation at Ide Village

Upon enquiries on why the problem had not been fixed, the residents stated that no one among them is equipped with the ability/knowledge to carry out any repair on the installation, and nobody from the community was trained by the installers on basic maintenance procedures. They added, “We have been instructed not to go near the installation” but explained that security measures are taken by the community to ensure that the installation was not tampered with by unknown or unqualified persons. On being asked about the steps that have been taken to have the fault repaired, they replied that they have contacted the installers by phone. According to the respondents “When the person (technician) initially came around after about two weeks, he said he did not have the right tools with him to repair the fault and, will therefore, have to come back another time”. They further explained that it took the technician over 1 week before coming around again to have the fault repaired eventually. Overall, it took over 4 weeks before the leaking surface pump was repaired. Responding to another enquiry on the ownership of the installation, the respondents replied that although the community benefits from the installation, the ownership of it remains with the government and not with the community.

2nd Case Study: Sagbokoji Village

The solar PV installation in this village was installed in 2008 by the Ministry of Science and Technology, and was the first of its kind in the state. The installation was meant to power the community building, the primary school, a church, a mosque, sixteen streetlight units, and a water

pump that was installed at the village well to push water into an overhead tank.
The installation, or rather what remained of it, was in a dilapidated and non-functional state, with obvious signs of unkempt and abandonment. It was also observed that many of its component parts such as the batteries, charge controller, switches, and other related accessories were missing, and the only hardware remaining are the PV panels that are now being used to spread out clothes for drying (Figure 4).


Figure 4: The non-functional Solar-Powered System at Sagbokoji Village

When asked about when and how the installation got to be in such a state, some residents explained that “the installation functioned for barely 3 months after it was installed before it developed problems and ceased to function”. This, they claimed, abruptly ended the euphoria experienced by the residents and plunged them back to the same situation they were prior to its installation. Shedding light on the steps taken after the installation ceased to function, the village head explained that at the onset of faults, messages were sent to the government agency (the Ministry of Science and Technology) that installed the system, but not long after repairs were carried out, the installations developed further problems. He stated that “after the first time, the installation developed faults on three other occasions and on each occasion, the installers were called to fix the fault which they did. However, after the last fault, the installers came around like the previous times but could not repair the fault, and since then, they did not show up again”. Upon being accosted with insinuations that the cause of the recurring breakdown was due to illegal connections made by some members of the community, the village head conceded that although such allegations and suspicions were rife, and may actually have been true, he maintained that they could not be substantiated. He added “since the government agency failed to repair the fault, we have become helpless, as no member of the community was trained to carry out basic repairs on the installation”.

Further enquiries from the residents and village head on the circumstances that led to the installation to be in the present dilapidated state revealed that the community initially provided appropriate security for the installation right from the time it was installed and during the period it was functional. However, the security arrangement, which was in form of a number of vigilante groups constituted by members of the community that kept turns in watching over the installation in order to protect against unauthorised access, was discontinued after the installation broke down and was not repaired for a number of months. To this, the village head noted “it became illogical to continue providing security for a non-functional installation”. According to him, “when, after a long period of time, the technicians from the agency that installed the system no longer showed up to effect repairs on the recurring faults of the installation, the security provided for it could not be sustained; the withdrawal of which led to the installation being vandalised and the battery banks and other accessories carted away by unknown persons”.

On present actions being taken to restore the installation to a functional state, one respondent despaired that after 3 years of non-functionality, it appears all hope was lost, as most of the residents have come to accept the notion that the system may not become functional again. Another respondent added “it is for this reason some of the dwellers now use the solar panels as planes to spread out laundries for drying while others simply dump rubbishes there”. Yet, another respondent added “we now use generators for our electricity while we collect water from the village well”. On the part of the village head, while he maintained that technical factors were probably responsible for the initial malfunctioning of the units, he was more worried by the present dilapidated state of the installation due to occasions of sabotage on it. According to him, “the present state of the installation may discourage any further attempt by the government agency to restore the installation to a functional condition due to the apparent increased financial implications such an exercise will require”.

Discussion

While the installations met some of the water needs of dwellers, occurrence of fault at an early stage after installation were recorded. Apart from misuse by the dwellers, as alleged in Sagbokoji village, use of low quality materials and improper construction may have contributed to this. In addition, the absence of any member of the communities that are trained to carry out minor repairs of the installations, coupled with the slow response in carrying out repairs on the part of the supervising agency may increase period of time of underperformance/breakdown of such installations, after which a technician is sent by the installer to appraise and rectify the fault. The importance of having local members trained in minor repairs is underscored by the fact that many of these rural communities are isolated, hence, it could take days for a technician from the supervising to get to such a location to repair even a simple fault. It may also be necessary to enable a better understanding of the nature of a fault such that a technician sets out for repairs with the right replacement parts and equipment. In addition, it was observed that, contrary to the explanation made by MRD officials that transfer of ownership to benefitting communities are normally done publicly, the responses by residents of the community conveying that the ownership of the installation remains with the government, indicate that the MRD either did not carry out such transfer, or it was not done publicly to the knowledge of the residents.

A prominent issue evident by the dilapidated state of the installation in Sagbokoji community is that actions and decision taken by stakeholders may be both dependent and interconnected, and may combine to contribute to the breakdown or underperformance of installations. This is underscored by the fact that when the system started having problems shortly after it was installed, illegal connections to the system by the residents were alleged. Although this could not be established, ignorance of the users on the inimical effects of such actions, or the use of low quality materials for the installations are likely causes. In addition, when the supervising agent ceased to repair the fault, the installation became non-functional and non-beneficial to the community. This, according to the head of the community, defeated the purpose of providing security for the installation. The initial slackening and eventual withdrawal of the security exposed the installation to being vandalised by unknown persons, thereby leading to its dilapidated state. This is depicted in Figure 4.

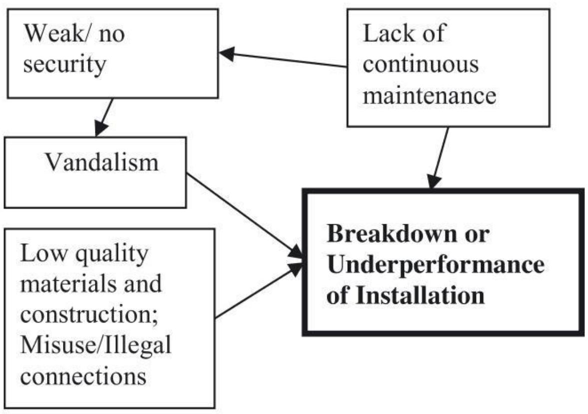

Figure 4: Interconnected factors leading to breakdown of Installation.

Recommendations and Conclusion

Similar claims of not having any local resident trained in basic operations and maintenance of the installations were made at the other two study locations. However, while such empowerment may enhance the functionality of the installations by enabling basic operations and repair of mechanical faults such as blocked water taps (as experienced in Ide village) to be carried out by local residents, thereby reducing the time between occurrence and repair of faults, the issue of "who pays for such repairs?' may need to be equally addressed, as this could be a stimulant to elicit interest in such endeavours. For the training, preference may be given to locals with basic competencies in carrying out related repairs. These may include bicycle repairers, blacksmiths etc., while they are also provided with relevant repair tools. In addition, locals can be enlightened on how to exploit modern technologies to reduce the downtime of an installation. This could be as basic as using the camera features of mobile phones to take pictures of installation when experiencing visible faults and sending same to the supervising agency using the Multimedia Messaging Service (MMS), rather than making voice calls only.

Mobile phone technology has been used by farmers in rural India to help ease their workload by enabling them to turn on water pumps which irrigate their crops without having to walk miles to the location of the pumps (BBC, 2012). A system in which solar photovoltaic systems in rural locations can be remotely monitored using GSM voice channel as presented by Tejwani et al. (2014) could also be introduced. In reference to Ide village, the time lost by the technician by having to go for the right tools after appraising the faults on the installation may have been avoided if such measures had been put in place. In addition, as encountered in Sagbokoji village, it is found that the factors that could lead to the underperformance or breakdown of an installation are often inter-connected, and that the presence of one or more of these factors could trigger some other ones into existence (Figure 4). This underlines the importance of all stakeholders, including installers and end-users to adhere to standard practices towards ensuring enhanced performance of RE installation in rural locations.

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Influence of the state of the grate and the combustion chamber at the performance of improved stoves model Inkawasi by the Energising Development Program EnDev – German Cooperation GIZ

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Abstract

The purpose of the present report is to 1. Evaluate the effect of deterioration of the grate and combustion chamber on thermal efficiency and specific fuel consumption of three improved wood stoves of the Inkawasi type 2. Make an estimation of the life span of the stoves. Short: the study presents the results of the level of influence that exist between the damage of the grate and the combustion chamber at the performance of three models of Inkawasi Stove[1]. For this, destructive tests on the grates and the construction chambers were carried out. Nine water boiling tests (WBT 4.2.2)[2] were applied to each model; this made a total of 27 WBT per stove.

Keywords: grate, combustion chamber, deterioration, stove

Introduction

In the last worldwide scope, almost half of the population – say more than 3 billion million people[3] – depend on solid fuel for cooking food, boiling water and heating their homes. The difficulty with this practice lies on the technology used – open fire or rudimentary stoves where biomass such as firewood, dung or harvest waste is burned – which is not adequate to cook food in an efficient, secure and healthy way. The WHO has categorized this daily way of cooking as the fourth main serious threat in health. Thus, the energetic inefficiency hinders taking advantage of the maximum potential of biomass and/or distributing efficiently the generated heat. Those aspects affect the familiar economy, the forest growth – because of firewood removal – and the generation of greenhouse emissions. With regard to this, there is a technology to replace traditional stoves namely improved cooking stoves which main goal is the reduction of indoor emissions where food is prepared and the biomass use reduction[45].

In Peru, approximately 2.4 million households use biomass for cooking their food and produce near 16.000 (kt) CO^2, which represents 33 % of the total emission that the country produces[6]. From those more than 2 million persons, the Energising Development Project EnDev[7] reached with other strategic partners around 300.000 households and social institutions (schools, communal places) through its technical assistance[8]. This means that it has penetrated 15 % of the rural market between 2009 and January 2014. Even though a tremendous effort in penetrating the market has been done, there are still 2 million households that cook in open fire mainly because of the geographical difficulty in reaching remote rural areas.

[1] Inkawasi stove models: Uk, Tawa and Pichqa. The names of the stoves have their origin in the Peruvian Quechua language, which mean one, four and five respectively. This is the chronological order in which the stoves were designed

[2] The water boiling test is a simple boiling process that aims to calculate how efficient is a stove by using fuel for boiling water in a pot and the quality of produced emissions during this process. http://community.cleancookstoves.org/files/405 (Accessed on 27th January 2015). Each single test consists of three tests, which makes a total of 27 tests per stove, meaning a total of 81 tests for the whole study.

[3] In the case of Latin America, it is estimated that more than 18 million persons use solid fuels to cook. This information was generated in the basis of the WHO report *"Energía doméstica y salud: combustibles para una vida mejor"* (2007). Data was published in "*Propuesta para la formación de la Alianza Latinoamericana para Cocinas Mejoradas*".

[4] The study "*Uso de cocinas mejoradas por las familias beneficiarias del proyecto disminución de la contaminación del aire intradomiciliario al preparar los alimentos en las viviendas a través de la implementación de 2.557 cocinas mejoradas en el distrito de Santiago de Chuco"* which was carried out by EnDev, showed that people who use an improved cooking stove saves more time at collecting firewood than people who use open fire (see page 38 for the results of the study http://media.wix.com/ugd/fddb43_63c3ef290f3b717a396f190d3472ff16.pdf (Accessed on 27th January 2015).

[5] Fuel savings through the use of improved cooking stove is also proven by the study "*Impacts on households fuel consumption from biomass stove programs in India, Nepal and Peru"*. See page 14, for largest savings of fuel from 66 %. For the whole study: http://media.wix.com/ugd/fddb43_475fa854ecc383200fe6343fc217b856.pdf (Accessed on 27th January 2015).

[6] The main focus of this study is to measure the energetic efficiency of the stoves when certain parts are damaged. Even though particle emissions are also influential at health risk, tests done by Sencico (Laboratory that certifies improved cooking stoves in Peru) show that if a certified stove has a chimney, this reduces indoor pollution in 90 %: http://www.cocinasmejoradasperu.org.pe/catalogo.html (Accessed on 27th January 2015).

[7] For more information about the Energising Development Project implemented by the German Cooperation GIZ: http://www.endevperu.org/#!home/cm0j (Accessed on 27th January 2015).

[8] EnDEv alone reached approximately 180.000 households and social institutions through its technical assistance.

Research Objectives

1. Evaluate the effect of deterioration of the grate and combustion chamber[9] on thermal efficiency and specific fuel consumption of three improved wood stoves of the Inkawasi type: UK, Tawa and Pichka 2. Make an estimation of the life span of the three improved wood stoves with the aim of developing strategies for a longer span of use.

In order to influence the state of the grate and the combustion chamber by the performance of the stoves, combinations of the state of the grate and combustion chamber were done and a WBT 4.2.2[10] was applied in each combination. The stove models differentiate themselves in the material type in which the combustion chamber is manufactured. In the Inkawasi Uk, the combustion chamber is composed by refractory clay. The Tawa Inkawasi is made of *pastelero*[11] with *pandereta*[12] bricks and the Inkawasi Pichqa is made of mechanized *pandereta* brick. It is important to mention that this was an intervention for the mass use of the stoves, initiated by the Peruvian Government. The materials that are used for each of the stoves are chosen because of their availability in the different regions where the stoves were installed[13]. The total cost for the stoves, including installation costs and the families´ investment is: Uk S/.255.80; Tawa S/.261 and Pichqa S/.247.20[14], which means $ 85.28, $ 89 and $ 82, respectively.

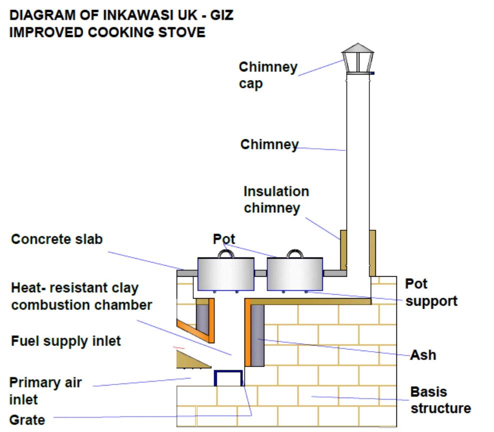

Figure 1.1: Diagram of Inkawasi UK-GIZ

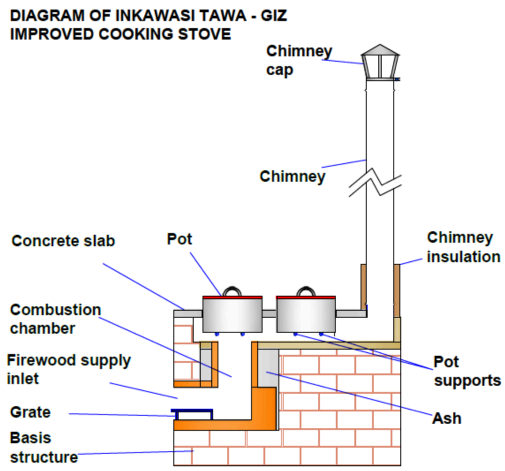

Figure 1.2: Diagram of Inkawasi Tawa-GIZ

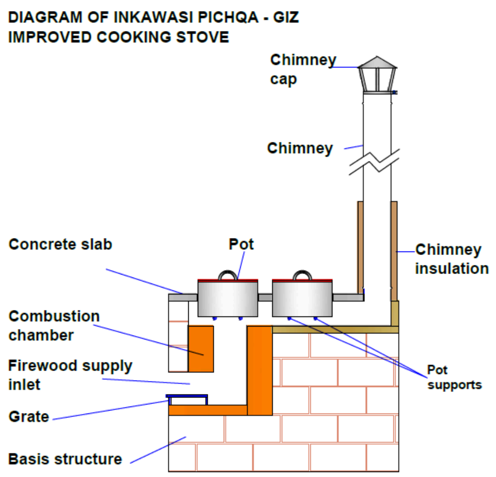

Figure 1.3: Diagram of Inkawasi Pichqa-GIZ

9 The chimney and the grate are the parts that were analyzed because they are the most sensible towards deterioration according to the study done by EnDev 2013: "Evaluación del nivel de información del buen uso y mantenimiento de cocinas mejoradas entre usuarias"

10 The WBT test 4.2.2 evaluates the performance of the improved cooking stove when completing a standard task (boiling water and cooking over a low heat) in a controlled environment and determines its efficiency for heat transfer and the specific fuel consumption at low firepower. It is a simple method in which the manufactured stoves in different places and with different boiling applications could be compared through a standardized and replicable test. Plus, it shows the technical performance of a stove but it is not necessarily what can be reached in real households.

11 Pastelero brick is a brick which is flat and square, usually used for the construction of housetops. To see an exact picture: http://www.ladrilloslark.com.pe/techos2.html

12 Pandereta brick is a brick which is usually used for the construction of walls. It is rectangular, with 18 holes. To see an exact picture: http://www.ladrilloslark.com.pe/productos.html

13 The Uk model was mainly installed in the Arequipa and Apurimac regions. The Pichqa model in Huancavelica, Junin, Amazonas and Cajamarca regions; the Tawa model in Ayacucho, Cusco and Huancavelica. Although the transport of the materials means a cost increase, the cost benefit in terms of saving money and time is considerable (See study by Universidad Privada Antonio Orrego *"Uso de cocinas mejoradas por las familias beneficiarias del proecto disminución de la contaminacion del aire intradomiciliario al preparer los alimentos en las viviendas a través de la implementación d*e 2.557 cocinas mejoradas en el distrito de Santiago de Chuco": http://media.wix.com/ugd/fddb43_63c3ef290f3b717a396f190d3472ff16.pdf .

14 One Dollar is equivalent to S/2.99 Nuevos Soles, according to the data from 24.01.2015 from the Peruvian Central Bank: https://estadisticas.bcrp.gob.pe/estadisticas/series/diarias/tc-otras-divisas (Accessed on 27th January 2015).

The damage of the pieces was carried out through destructive processes at the laboratory.

Table 1: State of the parts

State of the parts		
Good	**Partially damaged**	**Totally damaged**
It brings together the technical specifications recommended at the technical files.	It underwent geometrical changes as a result of the thermal strain at the entrance area for firewood and at least two sides of the fire zone are split	At least one side is totally split and the entrance opening for firewood has suffered a great corrosion towards the sides

Table 2: Used equipment for the WBT

Name of the equipment	Technical specifications	Quantity of equipment
Digital weight in scale	Capacity of 6 kg; resolution of 0.001 kg	1
Digital thermometer	With precision of 1 ºC, with immersion thermocouple	1
Chronometer	Digital chronometer with precision of 1/100 s.	1
Aluminum pot	Aluminum pot number 26, higher capacity, more than 6 liters.	2
Metal tray	Minimum capacity of 2 liters of water	1
Pliers	Brass pliers of 12 cm to manipulate charcoal	1
Trowel	50 cm long with a wooden handle.	1
Glove	Glove with thermal protection	1

Methods

With the "survival function" of Kaplan Meier (probability of survival) the probability of occurrence of negative events, total distortion of grate and total damage of combustion chamber, was simulated. Damage of these essential parts requires replacement to ensure optimal performance of the stove.

Three improved stoves were built: Inkawasi Uk, Inkawasi Pichqa and Inkawasi Tawa. The models differ from each other on the type of material that the combustion chamber is made of. The Uk is made of seven pieces of heat-resistant clay of artisanal production. The Inkawasi Tawa is made of nine *pandereta* bricks and 5 *pastelero* bricks, whereas the Pichqa is composed by exclusively 17 *pandereta* bricks and connected by improved clay (see figure 1.1; 1.2 and 1.3).

A water boiling test (WBT) was used to investigate the wear and tear of the two main components, the grate and the combustion chamber of the three different improved cookstoves: Inkawasi Uk, Inkawasi Tawa and Inkawasi

Table 3: State of the grate

State of the grate		
Good Grate with entire supporting legs and at the maximum with a worn out stick due to the high temperature (15 % of the supporting sticks for firewood is deteriorated)	**Partially damaged** Grate with slight damaged supporting legs due to corrosion and damage of the support sticks for firewood between 15 % and 45 %.	**Totally damaged** Grate with two totally damaged supporting legs and with corrosion of the support sticks for firewood higher than 45 %. The firewood was not oxygenated (similar to not having a grate)
		

Pichqa. These stoves were selected as they are the ones that have been most disseminated of all stoves promoted by the Peruvian Government with a technical assistance of EnDev. A total of 27 Water Boiling Tests (WBT) were carried out, three for each stove and the state of the parts: grate and combustion chamber in good, partly damaged and damaged state.

Results

The results of the WBT show that when the removable grate of the Tawa and the Pichqa models are totally deteriorated, they affect the firewood saving negatively. It is below 30 % in relation to the open fire. The deterioration test clearly showed that a damaged metal grate significantly effects stoves efficiency in a negative way. According to the projection made, the regions of Arequipa, Cusco, Ayacucho and La Libertad were identified as those with a high number of stoves that require replacement of this essential part. The results showed that the deterioration of the grid negatively affects firewood savings of the Tawa and Pichqa model. While the partial or total deterioration of the combustion chamber has little influence on firewood savings of the first mentioned model, it has a negative effect on the Pichqa stove. In comparison, the total deterioration of the grate and the combustion chamber do not affect fuel savings of the Uk model. Even with damaged parts, it still fulfills the EnDev minimum requirements of 30 % savings for chimney stoves[15].

Grate

The damage of the grate affects also negatively the firewood saving in the use of Tawa and Pichqa.

[15] According to field and laboratory experience and tests from the EnDev project, which is currently involved in 24 countries: 15 in Africa, 5 in Asia and 4 in Latin America, the average of 30 % was determined. For more information about improved cooking stoves and criteria: http://endev.info/content/Technologies_Used (Accessed on 27th January 2015).

According to figure 1, the grate is used for placing the firewood and as an entry for oxygen for a better combustion. This explains the negative effect that causes that the grate is totally damaged.

Combustion chamber

The partial or total deterioration of the combustion chamber has little influence in the firewood saving with exception of the Pichqa model that affects it negatively.
The combustion chamber of the Pichqa model is composed of mechanized *pandereta* brick. The isolation grade is smaller than in the other models (see figure 1). When it deteriorates totally, some bricks show heat leak in a lateral way; this is why it diminishes the efficiency values on less than 30 % in firewood saving.

Perfor-mance degree	Units	test 1	test 2	test 3	Ave-rage
Thermal efficiency in high power	%	10.1 %	10.1 %	8.9 %	9.68 %
Specific consump-tion in low power	Mj/(min·l)	0.144	0.147	0.133	0.141
Total firewood consump-tion	G	4838	4866	5240	4981.33

Table 4: Results by performance degree

The composition of the combustion chamber of the Tawa model where the combustion is produced is of *pastelero* brick (see figure 1). In the case of the Uk, the combustion chamber is made of heat-resistant clay. Both chambers are joined by wire N° 16 and they are thermal isolated with ash.

For this reason, when it is partially or totally deteriorated (cracked) in any of its places, the ash does not move to the interior of the camera, maintaining the thermal isolation. Because of this, the firewood saving is higher than 30 %.

Table 5: WBT tests

		Combustion chamber		
	State of the parts	**Good state**	**Partially damaged**	**Totally damaged**
Grate	Good state	3WBT tests	3WBT tests	3WBT tests
	Partially damaged	3WBT tests	3WBT tests	3WBT tests
	Totally damaged	3WBT tests	3WBT tests	3WBT tests

In the case of the Uk model, all the states of the grate and the combustion chamber are always efficient. The reason is because of its structural composition. It has an opening for the firewood supply and another one for the ash. When the combustion chamber deteriorates totally, the firewood is hold by the brick wedge, which plays the role of a grate.

Table 6: Results of the WBT tests, done with the three Inkawasi models and state of the grates and combustion chamber

		Combustion chamber								
		Good state			Partially damaged			Totally damaged		
	State of the parts	**Uk**	**Tawa**	**Pichqa**	**UK**	**Tawa**	**Pichqa**	**Uk**	**Tawa**	**Pichqa**
Grate	**Good state**	43.68 %	38.06%	33.97%	44.20%	39.03%	38.61%	36.50%	38.91%	32.03%
	Partially damaged	42.90 %	34.17%	30.00%	41.83%	40.34%	33.67%	35.00%	31.42%	28.80%
	Totally damaged	36.45 %	25.27%	21.40%	38.77%	28.04%	25.51%	37.07%	26.62%	18.60%

Discussion

Based on these results, the estimation of the life span of the stoves disseminated by EnDev Peru between 2007 and 2013 and the need of replacement of the metal grate and the combustion chamber was calculated. Due to economic considerations, no separate study was carried out; instead it was taken advantage of the available information of a survey, using a representative sample, done by EnDev in charge of IPSOS[16]in 2012. The results were applied to the projects database in order to know how much of the grates and combustion chambers have to be replaced in 2014.The calculation revealed an average lifespan for grates of 45 months and for combustion chamber of 52 months. Thus, the good or perfect condition of those parts warrantee a better functioning of the stove, which means that the less emissions it will emit and the less fuel the families will need. Both will improve the economy and the health aspects of the end users.

Therefore, there is still a need to improve the intervention and following recommendations were defined after the study:

1. To identify alternative material that is available in the market for the production of the grate and that has a longer lifespan.
2. To consider that in the design of the combustion, a primary air supply which is more homogeneous and unsettled in order to optimize the firewood combustion.
3. To consider a boost of secondary air at the design of the combustion chamber with the aim of increasing the temperature of the combustion gases.
4. To test an improved cooking stove combining the dimensions for the chimney to measure the influence of its draw and its performance.
5. To deduce the saving or increment of CO^2 emissions by the number of improved cooking stoves that are installed, so that they are energy efficient over time (The firewood saving and the less smoke a stove produces is proportional to the amount of emissions).

In fact, this study also threw a result that motivated EnDev to change its strategy in this new intervention phase which is to develop strategies for the post-sale stage for the replacement of those parts. In order to reach even the poorest quintiles of the population, a public-private partnership among the state, private enterprise (mining enterprises, construction firms, among others looking for strategies for social corporate responsibility) and the families is being developed with the technical assistance of EnDev[17]. Furthermore, a great emphasis will be put in informational campaigns, where the users' awareness will be raised in how to maintain their stoves, where to buy the parts and who to call in the local community or nearby when it comes to any difficulty or a replacement. With this intervention, a local and sustainable solution will be developed.

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[16] IPSOS is a Peruvian company for social investigation. To learn more: http://www.ipsos-apoyo.com.pe/ (Accessed on 27th January 2015).

[17] 17 A subsidy from the Peruvian Government through social programs will be given, as it was the case during the mass installation program. There are already social programs such as Mi Chacra Emprendedora from the Ministry for Social Inclusion, in which improved cooking stoves are subsidized.

Treatment of Reverse Osmosis Rejected Water Using Solar Energy - A Case Study

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Abstract

Millions of people in the world live on less than 3 gallons of water per day. 1 in 5 do not have access to safe drinking water. To meet the societal water demand, people often depend on ground water resources. In many places, ground water is not potable due to the presence of excess salts/chemicals concentration and Reverse Osmosis (RO) is the one which is majorly used for desalinating the water. The major concerns associated with RO process is, it consumes electricity and rejects highly concentrated water as a byproduct. This calls for a development of an eco-friendly domestic water treating system. In this article, experimental studies on treating the household RO rejected water is carried out using a solar still coupled with vacuum tubes for climatic conditions of Bangalore (12.96 °N lat. and 77.56 °E long), India. The average distillate yield for the study period is found to be 5.154 kg per 12 hours (7 am to 7 pm). The distillate obtained is compared with Indian Drinking water specifications, IS 10500:2012, and is found to be fit for drinking. It is also found that the drain water at the end of the day can be used for the domestic purpose. The developed system is simple and sustainable.

Keywords: RO rejected water; Solar Still with vacuum tubes

Introduction

The available water resources for human consumption is limited. Availability of potable water is a major problem faced by both the developing and under developed countries (Gude et al., 2009).It is one of the key issues for the social wellbeing. Urbanization and industrialization have increased the demand for water and have put lot of stress on the available water resources. Presently about 54 % of world's population live in urban area and the same set to increase to 66 % by 2050 (UN Department of Economic & Social Welfares, 2014). An increase of 32 % of urban population has been recorded in India for the year 2014 (Worldometers, 2014). This increase in urban population led to increasing demand of potable water supply in urban areas. Due to insufficient potable water sources people started looking for technologies to use brackish and sea water for the daily needs by adopting desalination process (Ali et al., 2011).

Desalination is one of the oldest technology adopted by people throughout the world (Sampath Kumar et al., 2010; Qiblawey et al., 2008). The process of removing salts from brackish water is desalination. The desalination process results in two distinguished products i.e., one with low salt concentration (treated water) and other with higher salt concentration which is higher than feed water concentration (Concentrate).

Thermal and Membrane technologies are the two major categories of desalination process. Thermal technology includes Multi-stage Flash Distillation (MSF), Multi-Effect Distillation (MED) and Vapor Compression Distillation (VCD). The Membrane Technologies includes Electrodialysis (ED) and Reverse Osmosis (RO) (Al-Karaghouli et al. ,2009). In Reverse osmosis process, saline water will be made to pass through semi permeable membranes under excess osmotic pressure which separates water from the saline solution (Gude et al., 2009).

Approximately 60 % (Figure 1) of worldwide desalination process encompasses RO process (IRENA Technology Brief I12, 2012).With the technology advancements after the year 2000, around 9 % of annual growth was observed in RO systems against 5 % annual growth in MSF for desalination of water (Ali et al., 2011).

RO and most of the desalination process consumes electrical energy for their operation. With the present energy crisis, application of these desalination process has become a bit expensive and has lead to greenhouse emissions. High initial investments, operational and maintenance cost of existing desalination process is making a way to adopt sustainable desalination process (Sampath Kumar et al., 2010). The RO system results in large volume of rejected water which depends on input water quality and amount of water to be treated.

Many parts of India receive abundant annual solar radiation of about 4 to 6 Kwh/m^2 and an average of 250–300 clear sunny days in a year (Ministry of new and Renewable energy – GOI, 2014; Bhattacharyya et al., 2013). Solar stills can be a solution to produce potable water. In solar still, evaporation and condensation process happens within the same system due to green house effect by directly using solar thermal energy for the distillation process (Li et al., 2013).

Khanna et al. (2008) conducted a case study of Chui village, Nagaur District, Rajasthan and they concluded that solar still can be used to treat water for remote areas of Rajasthan. Antwi et al. (2011) carried out a study in Bongo district of Ghana, a 96 % reduction in Fluoride concentration was observed for bore well when water was treated using solar still.

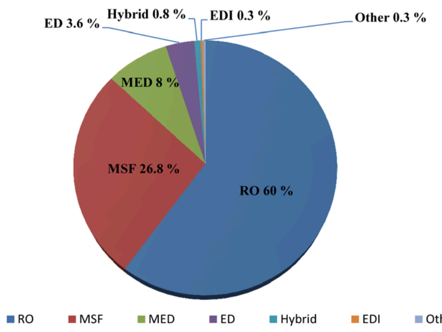

Figure 1: Desalination Technology Market

The drawback associated with a simple solar still is less yield (Kaushal et al., 2010). This has led to modification of existing passive solar still into active solar still. Voropoulos et al. (2004) modified the solar still by coupling it with solar collector and a hot water storage tank. The advantages associated with the system were higher yield and supply of hot water. Singh et al. (2013) studied the performance of a solar still coupled with 10 vacuum tubes for different depths of water (0.03 m and 0.05 m). His studies revealed a maximum output of 3.8 kg/m^2-day for the basin water depth of 0.03 m. Praveen et al. (2014) developed a low cost single slope single basin solar still integrated with evacuated tubes in natural mode to treat bore well water for rural areas. The studies showed that the rate of evaporation increases due to thermo-syphon process.

Research Objectives

Several works have been carried out to treat saline/brackish water using conventional sources of energy. Even though, RO is one of the major process adopted to produce potable water, it has a major drawback i.e., large quantity of highly concentrated rejected water as a byproduct. Keeping these factors in mind the current study intends to:

1. Treat the household RO rejected water using single slope single basin solar still coupled with vacuum tubes for climatic conditions of Bangalore, Karnataka, India.
2. Study the influence of various temperatures and solar intensity on distillate yield for typical days from May, 2014 to July,2014 with basin water depth of 0.02 m.
3. 3.Study the performance of the system in removing/reducing concentration of various chemical contaminants present in RO rejected water. Chemical characteristics of the inlet and outlet water samples are analyzed and compared with Indian Drinking Water Specification, IS 10500: 2012.
4. Check the feasibility of using the byproduct (basin water at the end of the day) for domestic purpose.

System Design

A single slope single basin solar still is designed and fitted with vacuum tubes (mounted on diffused reflector) using rubber gaskets. The still consists of one inlet through which water from the feed tank goes into the system, two outlets through which the potable water comes out through a drain, which is used to remove water in the solar still basin. The present system is also provided with an opening which helps in inserting thermocouples into the system. Four slant water channels are made into the still which connect to the outlet so that every drop of potable water comes out and gets collected. The window glass is fixed on the still using rubber beadings. Finally the solar still is sealed using silicon sealant and is made leak proof. Black powder coating is done to the still so as to absorb maximum solar radiations.

Table 1: Specification of the solar still coupled with vacuum tubes

Solar Still	
Material and thickness	Galvanized Iron sheet/ 0.002m
Inner basin area	0.51 m^2
High side and low side	0.290 m and 0.174 m
Volume (for 0.02m depth)	21 litres
Glass Cover	
Thickness	0.004 m
Inclination	13° to the basin.
Insulation	
Material	Nitrile rubber
Thickness	0.025 m
Vacuum Tube	
No of tubes	10
Length	1.5 m
Inner and outer diameter	0.037m and 0.047m
Centre to centre spacing between two adjacent tubes	0.095m
Inclination	13° to the horizontal.
Aperture area of evacuated tube collector	1.353 m^2
Others	
Aluminium reflector	1.6 × 1.03 × 0.001 m
Feed tank	20 ltr.
Insulated storage tank	Mild Steel , circular(0.245m Ø, 0.340m height)

The whole solar still is insulated with Nitrile rubber to avoid heat losses from the setup to the atmosphere. To collect the distillate, jars are placed at the end of the outlet pipes. An insulated storage tank is used to store the hot water drained out of basin. The cost involved in fabrication of entire system is Rs.7350/-. The whole setup is mounted on the iron stand. The specifications of the developed model are as shown in Table 1.

Procedure

The developed system is shown in the Figure 2. The RO rejected water is collected from household RO system having Thin Film Composite membrane (TFC) with a pore size of 0.0001 micron. The proportion of purified and reject water flow in the RO system is observed to be 1:3. The feed water (household RO rejected water) is filled into the system through the inlet from the feed tank. Both the basin and vacuum tubes gets filled with the water sample. The solar radiations strike the glass cover of the solar still, penetrate into it and heat the basin water. Vacuum tubes heat up the water present in them. Due to the thermo-syphon process, the temperature of basin water increases which inturn aids the evaporation process. Water evaporates leaving back the salts and chemicals in the basin. As the inner glass surface is cooler, the water vapors gives away its latent heat and condenses. The condensed water drips down the glass and gets collected into the slant channels. The distillate coming out of the outlet pipe is collected in the jar. The distillate water obtained is tested for its chemical contents and compared with the Indian drinking water specifications, IS 10500: 2012.The whole system is mounted facing south. The experiments are conducted in BMS College of Engineering, Bangalore which lies at 12.96 °N lat. and 77.56 °E long., during the period from May 2014 to July 2014 from 7 am to 7 pm. The parameters like solar intensity, various temperatures and distillate yields are recorded. The hot basin water is drained out and stored in the insulated tank. Temperature of water into the insulated tank is noted during the day end (7 pm) and next day morning (7 am). The various instruments used in the experiments are shown in the Table 2. Instruments used in the present study have some tolerances and accuracies. For simplicity purpose the error bars are not taken into consideration.

Results and Discussions

The experiments are carried out in BMS College of Engineering, Bangalore from 4th May 2014 to 26th July 2014. The variation of solar intensity and various temperatures with time for the month of May, June and July, 2014 is as shown in Figure 3. The solar intensity increases from 9 am to 2 pm and the total solar radiation for the typical days ranges from 6200 to 6650 W/m^2. During the study period, the ambient temperature varies from 24 °C to 38 °C. The basin water temperature at 7 pm is found to be around 89 °C.

Figure 2: Photograph of experimental set-up with various instruments

The hourly variation of yield for the water depth of 0.02 m is as shown in Figure 4. The results are tabulated in Table 3. The experiments are conducted from morning 7 am to evening 7pm. In India, Monsoon sets in the first week of June and reaches peak during July, August. During this monsoon season, solar intensity reduces drastically because of clouds. In Figure 5, considering only the typical sunny days for the weeks starting from 4th May to 26th July, 2014, the variation of distillate yield is recorded. The decrease in average distillate yield is recorded from 5.46 kg to 4.73 kg per 12 hours(7 am–7 pm) during 4th May to 26th July 2014. It is also observed that there is a reduction of 10 % in the yield during July month compared to May month. The results are shown in Table 3. The maximum distillate yield of 5.57 kg/day (7 am to 7 pm) is recorded. The average daily yield efficiency of 26.5 % (with respect volume of basin 21 liters for 0.02 m water depth) is observed for specific period .

At 7 pm the temperature of water in the basin is observed to be high i.e. in the range of 67–70 °C. This water is drained from the solar still and stored in an insulated tanks so that the heat of water is retained till the next morning. When the temperature of stored water is measured the next morning at 7 am, it was found to be in the range of 64–67 °C. Some amount of heat is lost because of vapor leakage and transfer of heat to the walls of the container. This hot water can be used for domestic purposes like washing or bathing which in turn helps to reduce the carbon emissions to the atmosphere or can be the input water for the solar still. The higher temperatures of feed water will increase the efficiency of the system. If a bigger still is used then, a large amount of water can be stored, which can be used for bathing purpose of household or the community people.

Table 2: Instruments used in the experiments

Parameter	Instrument	Type/ Make	Range	Accuracy
Temperatures	Thermocouple with 6 channel digital temperature indicator	K-Type (Cr-Al)	0-200°C	±1 °C
Distillate yield	Measuring Cylinders	Borosil	0-250 ml 0-1000 ml	± 1 ml ± 3 ml
Solar Radiation	The data is collected from the weather station setup at the BMS College of Engineering, Bangalore where the experiments are carried out.			

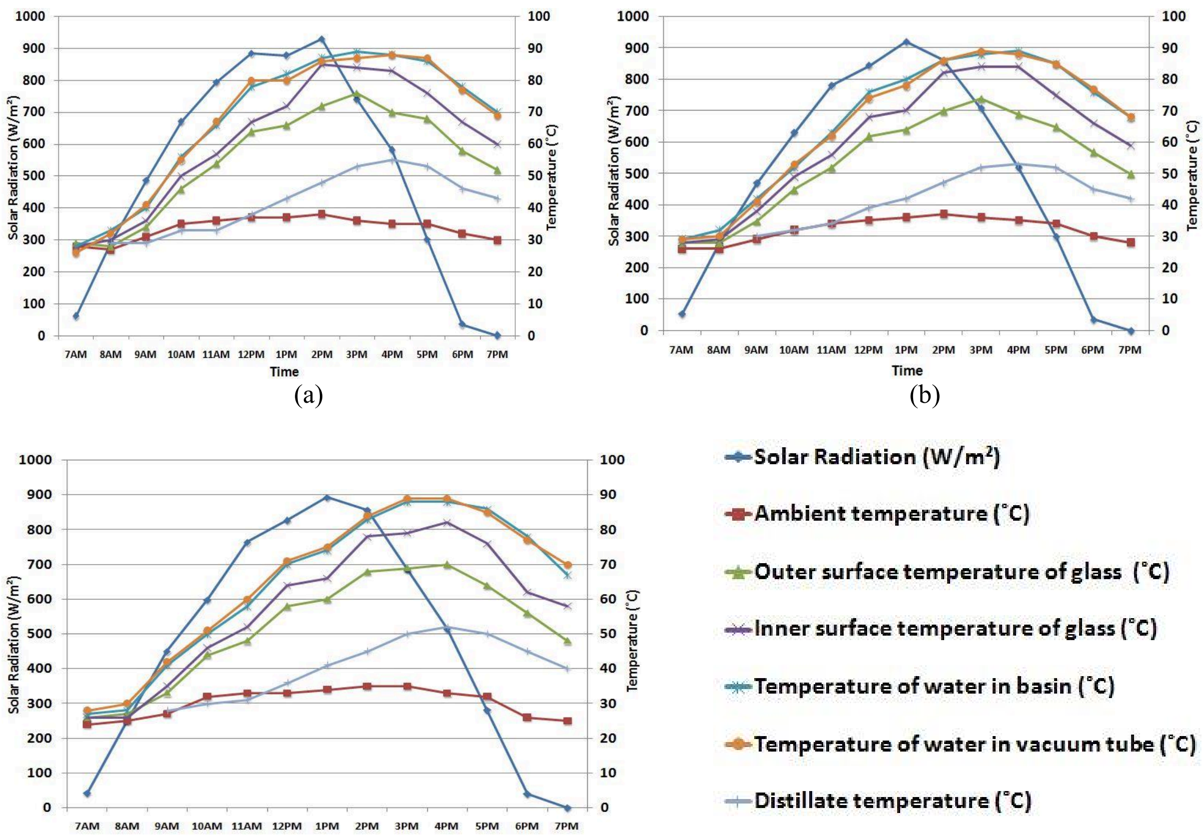

Figure 3: Hourly variations of solar radiation and various temperatures on (a) 11th May 2014 (b) 10th June 2014 and (c) 12th July 2014, for Bangalore location

Chemical Analysis of Water

The chemical characteristics of the RO rejected water and treated distillate are examined in the laboratory using standard methods as per the American Public Health Association (APHA) and the results are as shown in Table 4. The obtained chemical compositions for both the water samples are compared with IS 10500:2012, Indian standard drinking water specifications. Table 4 clearly shows that chemical composition of the output distillate are well within the limits. The results revealed that the output distillate is fit for drinking and for other domestic uses.

Table 3: Variation of Distillate Yield during the study period (7am–7pm)

Month	Average Daily Yield in kg	Maximum Hourly yield in kg	Time period during which Max. Yield is obtained
May	5.46	0.88	3 pm–4 pm
June	5.26	0.848	2 pm–3 pm
July	4.74	0.83	2 pm–3 pm

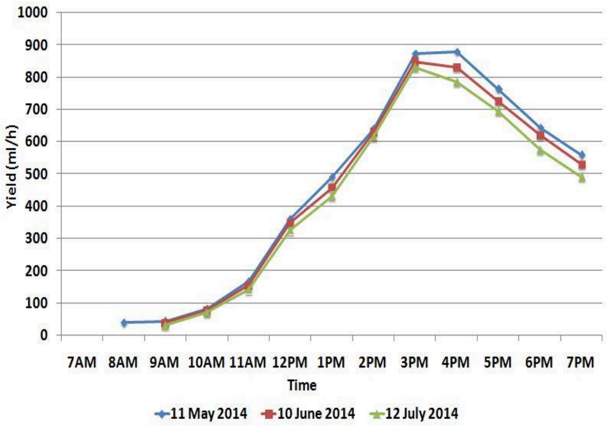

Figure 4: Hourly variation of yield with water depth of 0.02 m for unique days in different months

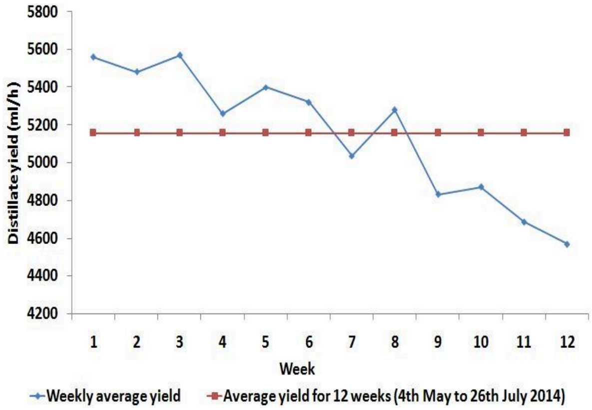

Figure 5: Average distillate yield for 12 weeks (4th May to 26th July 2014)

Table 4: Comparison of Chemical Characteristics of RO rejected water and Distillate yield with IS 10500:2012

Parameters	**Feed Water**	**Acceptable limit as per IS10500: 2012**	**Distillate**
pH	7.7	6.5–8.5	7
TDS – mg/l	907	500	18
Electric conductivity – µS/cm	1523	_	35
Total Alkalinity(as $CaCO_3$) – mg/l	940	200	71
Total Hardness (as $CaCO_3$) – mg/l	740	200	51
Calcium hardness (as $CaCO_3$) – mg/l	558	_	29
Magnesium Hardness – mg/l	152	_	22
Calcium (Ca) – mg/l	223	75	11
Magnesium (Mg) – mg/l	36	30	5
Chloride (Cl) – mg/l	259	250	21
Nitrate (NO_3) – mg/l	14.9	45	3.6
Sodium (Na) – mg/l	2.4	200	<0.01
Potassium (K) – mg/l	0.8	_	<0.01

Conclusions

Based on the results obtained from the experiments, the following conclusions are drawn.

1. The maximum distillate yield of 5.57 kg/day (7 am to 7 pm) and average daily yield efficiency of 26.5 % is recorded for the basin area of 0.51 m^2 with the water depth of 0.02 m.
2. The maximum hourly yield of 0.880 kg is obtained during 3rd week May, 2014, because of high solar intensity. Nearly 10 % decrease in distillate yield is observed during the month of July.
3. The Single basin single slope solar still coupled with vacuum tubes proves to be promising system in reducing excess chemical contamination from RO rejected water and the distillate yield is fit for drinking as per the IS 10500:2012.
4. The basin water temperature is around 70 °C is recorded at 7pm end of the day and stored in insulated tank. The next day morning at 7am the water temperature recorded as 64–67 °C. Hence the same water can be used for any other purpose or to any other domestic activities. This reduces the carbon emissions to the atmosphere.
5. The present study has been carried out on continuous mode i.e. fresh water will get mixed with the basin water as and when distillate is produced from the system. And every morning the fresh water is filled to the system by replacing the previous day basin water. Further studies will be planned to know the behavior of the system under batch mode and also on disposal of final residue in the system.
6. The present study has been carried out at laboratory scale however further field studies have to be conducted to know the performance of the system at local conditions. Since the distillate yield production is directly depends on groundwater quality, quantity of water to be treated, weather and geographical condition of the area further field studies will be planned to study the effect of the same on distillate yield.

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Innovative Biogas and Bio-solids Generation from Anaerobic Sewage Sludge Digestion Using Acti-zyme as Biocatalyst as a Sustainable Measure for Developing Countries

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Abstract

Sewage sludge was anaerobically digested using Acti-zyme, a biocatalyst for generation of biogas and bio-solids as an innovative strategy for obtaining biogas. Acti-zyme loadings of 35-50 g/m^3 was employed for sewage sludge loading of 5-10 g/L. day in 250 mL reactors emanating the digesters. The agitation in the digesters was maintained at 60 rpm, at a mesophillic temperature of 37 °C for a period of 40 days. The biogas quantity produced was measured using the water displacement method daily. Samples of the biogas were collected and analyzed for bio-methane (CH_4), carbon dioxide (CO_2) and traces gases composition using gas chromatography. The bio-solids obtained were dewatered for destruction of pathogens and tested for nitrogen, phosphorous and potassium (NPK) content using uv-*vis* spectrophotometry. Optimum biogas quantity was produced at a sewage sludge loading of 7.5 g/L. day and Acti-zyme loading of 50 g/m^3 with 78 % CH_4 unlike in Acti-zyme free digesters were a maximum of 65 % CH_4 was obtained. High nitrogen content bio-solids with 8.17 %, 5.84 % and 1.34 % of NPK respectively were produced. Acti-zyme is therefore an attractive bio-catalyst for sustainable sewage treatment for co-generation of biogas and bio-solids.

Keywords: Acti-zyme, anaerobic digestion, bio-methane, biogas, bio-solids, NPK, sewage sludge

Introduction

Sewage is a type of wastewater that is generated from domestic and industrial use, which in most cases is treated for re-use and recycling purposes as a water scarcity control measure. Though its wastewater, sewage can be managed by sustainable treatment methods to achieve high value economic products. Several methods have been applied in anaerobic sewage treatment with the biological treatment using Acti-zyme, a biological catalyst being one of them (Manyuchi et al., 2014). During the anaerobic sewage treatment process, sewage sludge is obtained during the primary and secondary treatment stages and this can be value added through digestion by harnessing valuable products like biogas and bio-solids as a sustainable sewage management measure (Apedaile, 2001; Cao & Pawlowski, 2012). Sewage biogas is mainly composed of bio-methane (CH_4), carbon dioxide (CO_2), hydrogen sulphide (H_2S), hydrogen (H_2) and nitrogen (N_2) with compositions depending on the quality of sewage sludge used (Herout et al., 2011). Sewage biogas production is a four-step procedure which includes step 1: hydrolysis, step 2: acidogenesis, step 3: acetogenesis and step 4: methanogenesis (Zieminski & Frac, 2012). In addition, the bio-solids (digestate) which are a result of the sewage sludge digestion process can be applied as bio-solids due to the presence of fertilizer macronutrients; primarily nitrogen and phosphorous (NP) (Apedaile, 2001), though there is need to control the pathogenic material content mainly *E. Coli* (Lang et al., 2007; Lang & Smith, 2007).

Acti-zyme has biochemical properties that promote biogas production through hindering hydrogen (H_2), nitrogen (N_2), and hydrogen sulphide (H_2S) at the same time promoting the biodegradability of the sewage sludge (Manyuchi et al., 2014). Absence of sulphate reducing bacteria promotes the methanogenesis process which results in higher bio-methane during sewage treatment (Straka et al., 2007). In addition, Acti-zyme does not contain urease which has a potential of releasing ammonia that can be broken down into nitrogen (Manyuchi, 2014). Nitrogen a constituent found in biogas must be in lower composition (≤ 10 %) as it is a limiting component during the hydrolysis phase in biogas production (Wagner et al., 2011).

Research Objectives

This study focused on biogas and bio-solids production from digestion of activated sewage sludge using Acti-zyme exploiting the biochemical characteristics of Acti-zyme, anaerobically.

Methods

Sewage sludge was obtained from raw sewage obtained from the Chitungwiza Sewage Treatment Plant in Chitungwiza, Zimbabwe. Acti-zyme which was obtained from AusTech Australia was employed as the anaerobic bacteria during sewage sludge digestion. All experiments were repeated thrice and an average value used. Experiments were done for digesters with and without Acti-zyme for through determination of effect of Acti-zyme.

The sewage sludge was filtered and dried to 80 % moisture content using a Mermet oven. 250 mL flasks representing the digesters were put in a water bath set at 37 °C to create mesophillic conditions at atmospheric pressure. The digesters were closed and sealed with aluminum foil paper to ensure anaerobic conditions. Outlets were created for movement of the biogas and sampling. Optimum Acti-zyme loading of 35–50 g/m^3 over retention period of 40 days were used in the digesters for biogas and bio-solids generation (Manyuchi et al., 2014). Agitation in the digesters was fixed at 60 rpm and sewage sludge organic loading ranging from 5–10 g/L. day were employed to determine the optimum biogas production conditions (Hesnawi & Mohamed, 2013).

The biogas quantity from the sewage sludge was measured through the displacement of water with a schematic layout represented in Figure 1 in milliliters per day (mL/day). The biogas generated was taken from the sampling points for composition analysis. A GC 5400 gas chromatography analysis was used for analyzing the biogas content and the composition was expressed as a percentage.

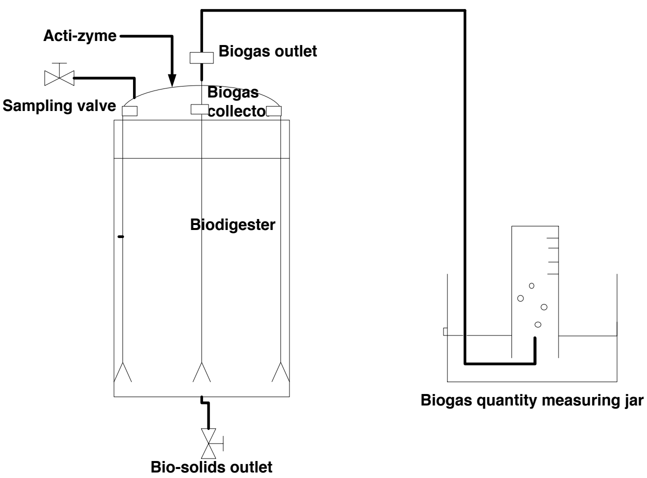

Figure 1: Schematic diagram for biogas generation from sewage sludge using Acti-zyme.

The sewage sludge and bio-solids pH was measured using an HI 9810 Hanna pH electrode. The moisture content in the sewage sludge was determined by heating 5g of sewage sludge sample at 105 °C for 10 minutes and then recording the difference in weight as an indicator of the amount of water removed using an AND moisture analyzer. After the digestion process, the bio-solids were dried as a measure to reduce moisture content from 80 % to 20 %. Nitrogen, phosphorous and potassium (NPK) content in the bio-solids was measured using a Labtronics double beam *uv-vis* spectrophotometer content. *E. Coli* content was measured through the total plate count procedure (Lang et al., 2007; Lang & Smith, 2007).

Results

Biogas production increased with increase in Acti-zyme loadings from 35 g/m^3 to 50 g/m^3 on all sewage sludge loadings from 5 g/L. day to 10 g/L. day as compared to digesters without Acti-zyme (Figure 2). The optimum bio-methane rich biogas of 394 mL/day was obtained at 50 g/m^3 of Acti-zyme and a sewage sludge loading of 7.5 g/L. day. Acti-zyme loading of 50 g/m^3 was found to be optimal in terms of bio-degradability of sewage (Manyuchi et al., 2014) whilst at the same time sewage sludge loading of around 6.9–9.2 g/L. day have been recommended for optimal biogas production (Hesnawi & Mohamed, 2013).

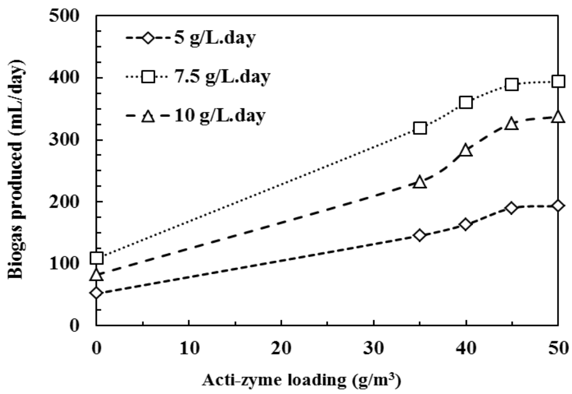

Figure 2: Biogas produced over varying Acti-zyme and sewage sludge loading.

A bio-methane rich biogas was produced with CH_4 composition ranging from 72–78 % with a peak being obtained for sewage loadings of 7.5 g/L. day at an Acti-zyme loading of 50 g/m^3 as compared to Acti-zyme free digesters which had a bio-methane composition of 53–65 % (Figure 3). The biogas also contained CO_2 with ranges from 16–20 % and trace amounts of H_2S, N_2 and N_2. H_2S, N_2 and H_2. The trace gases were in lower quantities in digesters with Acti-zyme due to the capability of Acti-zyme to hinder their production effectively improving the quality of the biogas (Table 1) (Manyuchi et al., 2014). The bio-methane was found in high quantities due to the enhanced bio-degradability of the sewage sludge by Acti-zyme (Manyuchi et al., 2014).

Figure 3: Bio-methane composition in sewage sludge at varying Acti-zyme loading and sewage sludge loading.

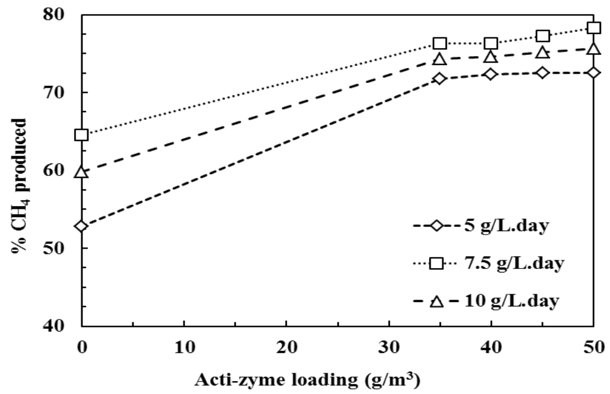

Table 1: Biogas composition from anaerobic digestion of sewage sludge

Gas	% (Acti-zyme)	% (without Acti-zyme)
CH_4	72-78	53-65
CO_2	16-20	22-27
Traces (H_2S, N_2, H_2)	5-9	8-12

The bio-solids obtained from the anaerobic sewage digestion using Acti-zyme had a final moisture content of 20% after drying. The bio-solids NPK content ranged from 8.17±0.15%, 5.84±0.03% and 1.32 ±0.02% as indicated in Figure 4. Therefore, the bio-solids obtained by this treatment method can be classified as high nitrogen content bio-solids (Evanylo, 2009). The reduction of water content in the bio-solids from 80% to 20% as well as the hindering effect of Acti-zyme for *E. Coli* activity resulted in a significant decrease in *E. Coli* content from 10^{12} to 10^{6} cfu/L. Lower moisture levels hinder *E. Coli* growth making the bio-solids safe for application at the same time Acti-zyme inhibits *E. Coli* growth and reproduction in sewage (Lang et al., 2007; Lang & Smith, 2007; Manyuchi et al., 2014). The bio-solids had a pH of 7.26±0.54 and if there is a higher pH needed for application, lime stabilization is recommended.

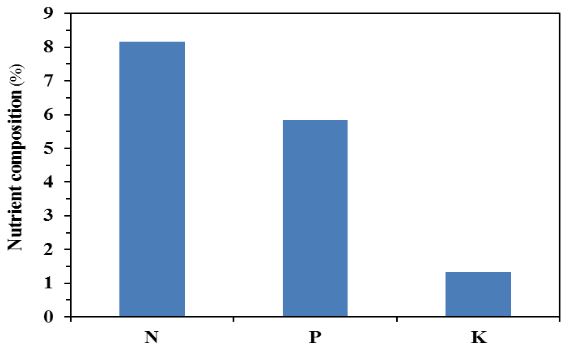

Figure 4: Bio-solids from anaerobic digestion of sewage sludge using Acti-zyme composition.

Discussion

Anaerobic digestion of activated sewage sludge utilizing Acti-zyme promotes production of bio-methane rich biogas which is almost free of H_2S and nitrogen and has lower CO_2 composition. Acti-zyme loading of 50 g/m^3 and sewage sludge loading of 7.5 g/L. day is essential for optimum biogas production over a 40 day period. Additionally, bio-solids which are rich in fertilizer NPK nutrients are produced and can be utilized as bio-fertilizers. This can result in sustainable management of sewage sludge in developing countries high value added products like biogas being used for micro-energy at the same time harnessing bio-solids.

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Scientific Papers

II. Minigrids

Development of a Compact DC-DC Converter with Solar Charge Controller for Solar DC Nano Grid System

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Abstract

This paper illustrates the development of a compact DC-DC converter with solar charge controller for solar DC nano grid systems. Solar PV based electrification has become an affordable solution for the off grid rural areas of Bangladesh. It is a common tendency in the rural areas that the people live in clusters. Generally these clusters are formed by some tens of households to few hundreds. Solar based DC nano grid systems can be a suitable solution for providing basic electricity demand to these clusters and also can provide more flexibility in electricity use than SHS. A compact DC-DC converter with integration of solar charge control mechanism is essential for such types of small grid systems. The development of such low cost DC-DC converter with charge controller is discussed in this paper.

Keywords: DC-DC converter, nano grid, charges controller, development and performance analysis.

Introduction

Approximately 38 % of population has no access to the grid electricity in Bangladesh (BPDB, 2014). Apart from this, there are more than 20 % areas of total area of Bangladesh where supplying grid electricity is highly expensive (MoPEMR, 2014). Solar power can be an alternative clean energy source for the electrification of these off-grid areas. Electricity demand in majority of the rural households are for basic lighting and mobile phone charging. The compact DC-DC converter system can be an effective solution for providing electricity to 5–50 households to meet their basic electricity demand.

Development of nano grid system reduces the unused energy as the system is shared by many people otherwise this excess energy can be used in productive use for the community (Khan, 2012; Khan, 2014).

A Solar-nano-Grid is a small grid network with a power output from few hundreds watts to few kilowatts, whereas a solar home system (SHS) is a standalone system supplying a fixed amount of energy to the consumer household (Chowdhury, 2014).

From the concept of solar nano grid system, it's a source of 500 W to 5 kW power generation system which fulfills electrical energy demand of upto 50 household within short range of area. Where solar PV is installed in a central position and transmitted power in the form of DC current. In solar DC nano grid there is no need of DC-AC conversion.

DC system has the following advantages over AC system:

- All the modern appliances such as LED lights, mobile phone, laptops etc. that run on AC are also fully functional on DC in the same voltage range.
- Solar PV generates DC power, and also the generated energy is stored in DC form. Therefore no need of inverter for the conversion of DC to AC.
- Battery DC voltage (12 V) can't be transferred for long distance due to voltage drop. But on the other hand, the high voltage DC (110 V to 220 V) can be easily transferred in few hundreds meters without any significant losses.
- Adding up of DC system (energy sources) in parallel is much easier than by AC. Paralleling of AC sources need synchronizing of the systems.
- Power factor is not a concern in DC systems.
- DC system has no inductive or capacitive losses.
- Management of harmonics distortion is easier in DC than AC.
- DC cooling fans are more efficient than conventional AC cooling fans (BLDC motors are efficient than induction motors).
- DC power transmission is more efficient and less expensive than AC power transmission. (Paul Savage, 2011)

Research Objectives

The objective of the work is to develop a 12 V to 125 V compact DC-DC converter along with solar charge controller to be used in Solar DC nano grids.

Methods

A push-pull converter (Pressman, 1998) is used for boosting up the voltage level from 12 V DC to 125 V DC. Two ultrafast rectifier diode and LC filter is used for ensuring smooth and constant voltage output. The MOSFET driving pulses are coming from current mode PWM controller IC. Therefore this IC provides option to control output current. That also ensures an overcurrent protection of the device. Whenever the output current increases from rated current, the device controller will give a warning and after 2 minutes it will automatically shut down the output. A micro-controller IC is used here for logical analysis and taking decision. Such as whenever battery voltage decreases from 11.0 V, the PWM controller IC gets logical decision from micro-controller to shut down the output and prevents over discharging of connected battery. Again, when battery voltage reaches to 14.4 V (high voltage disconnect for the battery), it also disconnects the charging MOSFET from solar panel and gives over charge protection. This device also has such kind of intelligence that it transfers power to the load from solar panel first (it is available) and then from battery.

Logical Block diagram

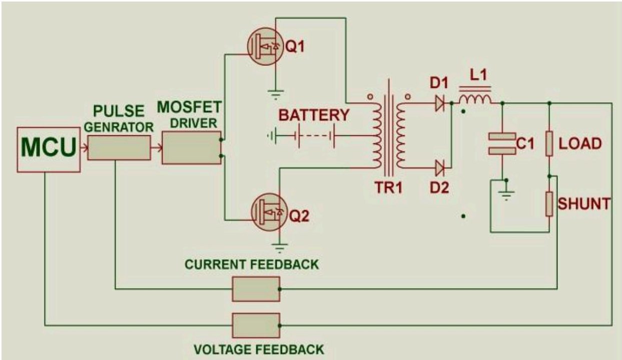

Figure 1: Logical block diagram of a compact DC-DC converter.

In figure 1, the basic DC-DC converter is shown; it uses a push-pull converter. Therefore two MOSFETs (Q1 and Q2) are used to give the pulses to the chopper transformer (TR1). The output of the transformer is high frequency AC signal which is rectified by two ultrafast diodes (D1 and D2). By using inductor (L1) and capacitor (C1) the output voltage is smoothen up. A high and low side MOSFET driver is used to drive MOSFETs properly. PWM signals is the input of this MOSFET driver which comes from pulse generator IC. The output load current and voltage are feedback to the pulse generator and micro-controller accordingly. So, that it can measure output load current and voltage simultaneously. If output current increases suddenly from threshold level then the pulse generator automatically stop the pulses. On the other hand if the output voltage increases from rated voltage level then the micro-controller will sense it and give shut down command pulse to the pulse generator. Therefore at the same time it can ensure the over current, short circuit current and over voltage protection.

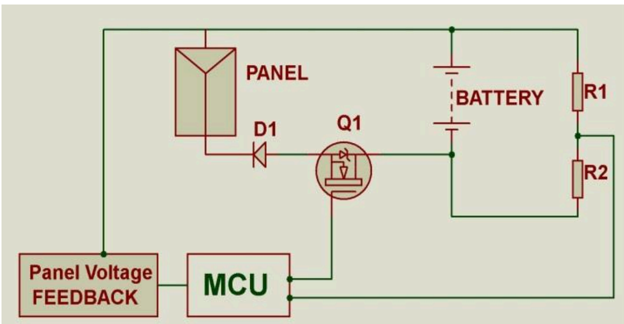

Figure 2: Logical block diagram for solar charge controller of compact DC-DC converter.

In figure 2, the block diagram represents the logical block diagram of solar charge controller build in the compact DC-DC converter proposed here. In this diagram one MOSFET (Q1) is used for switching panel to charge the battery. A Schottky diode (D1) is provided to protect from reverse side current leakage (battery to panel at night time). Two voltage feedbacks are taken, from battery and panel side. Therefore it can measure the battery voltage as well as the panel voltage. By measuring battery voltage, micro-controller can take necessary step to charge and discharge from battery. By measuring panel voltage the charging of battery is ensured as well as taking power first from panel side rather than battery. This brings smartness of the device.

Algorithm and coding

The algorithm of the compact DC-DC converter with solar charge controller mechanism is shown on figure 3. The legends are mentioned in this figure. At the beginning when device is on, it measures the battery and solar panel voltage. If panel voltage is greater than the threshold voltage (13 V or greater than battery voltage) then device will turn on the charging MOSFET and load which is connected via DC-DC converter. Then it checks the battery condition and takes necessary steps. If panel voltage is absent then it will measure the battery voltage and if the battery voltage is higher than LVD then it will turn on the load. Such as if battery voltage is less than 11.5 V, then micro-controller immediately send shut down/load off command to the MOSFET driver shutdown pin. Therefore MOSFET driver will turn off the discharge MOSFET and no output power is transferred. If the battery voltage is more than the LVR (load reconnect) voltage which is 12.5 V, then micro-controller will send turn on command to the MOSFET driver which implies output power is transferred to the load. However, if the battery voltage is higher than HVD (panel disconnect) voltage level 14.4 V, then micro-controller will turn off the charging MOSFET and protect battery from over charged. When the battery voltage is less than HVR (panel reconnect set at 13.8 V) voltage micro-controller will turn on the charging MOSFET.

The Logical flow disgram of the device is given in Appendix-1.

Apart from this charging and discharging operation, micro-controller also measures the output voltage of the DC-DC converter. Whenever the output voltage of the converter increases 5 % from the rated output voltage (125 V DC), then micro-controller immediately send shutdown command (TTL-0 V) to the pulse generator shutdown pin. Else micro-controller always maintains TTL-5 V to the pulse generator shutdown pin. Then micro-controller again measures battery and panel voltage. This functional code is written in while loop, so that it becomes a continuous close loop system.

Results

All the standards and safety measures of solar charge controller for Bangladesh SHS systems (Committee, 2014) have been accomplished in the developed system. The rated power of developed device is 100 W which can be increased up to 500 W by small modification. Achieved overall device efficiency is up to 95 % (discharging) and no load consumption is less than 25 mA. Short circuit and over current protection are provided in an effective manner. Constant output voltage (at load terminal) is ensured for varying input voltage level from 10 V to 25 V range.

Some comparative feature of the developed system is given below with the ones available in the existing market:

- The main DC-DC converter is a push-pull converter. Locally available nano grid devices are flyback converter. A push-pull converter can transfer more power than flyback converter in an efficient way.
- By adding devices in parallel, the overall capacity of the system can be increased.
- The overall charging and discharging efficiency of the proposed device is 97 % and 95 % respectively at rated load, which is much higher than the local available devices.
- The same system can perform from 48 V to 125 V DC-DC conversion by changing the program code of micro-controller.
- The initial equipment cost of the system is slightly higher than locally available device.

For a good DC-DC converter voltage regulation and line regulation is very important (DC Sources, 2014). The proposed device voltage and line regulation output which practically achieved in laboratory test is given in table 1.

Table 1: Voltage regulation of compact DC-DC converter in laboratory testing.

Parameter	Output (Volts)
Output voltage with no load (V_{nl})	125.5
Output voltage with full load (V_{fl})	125.2
Voltage regulation	$= ((V_{nl}-V_{fl})/V_{fl})*100$ =100*(125.5-125.2)/125.2 =0.239 %

Table 2: Line regulation of compact DC-DC converter in laboratory testing.

Parameter	Output (Volts)
Initial voltage measured (Vint)	125.5
After 10 minutes output voltage measured (Vo)	125.4
Line regulation	$= ((V_o-V_{int})/V_{int})*100$ =100*(125.4-125.5)/125.5 = 0.0798 %

Efficiency of a DC-DC converter is another important factor that implies device performance for long run. Table 3 shows the laboratory test result for efficiency of the device at full load and at half full load (50 % of full load). Resistive load in considered for this test.

Table 3: Efficiency table of compact DC-DC converter with full load.

Topic	Output measured
Input voltage (in volts)	12.75
Input current (in Amp)	8.256
Output voltage (in volts)	125.2
Output current (in Amp)	0.798
Efficiency (%)	$= (P_{out}/P_{in})*100$ = 95.14 %

Table 4: Test Efficiency table of compact DC-DC converter with half load.

Topic	Output measured
Input voltage (Volts)	125.3
Input current (Amp)	0.399
Output voltage (Volts)	12.75
Output current (Amp)	4.049
Efficiency (%)	$= (P_{out}/P_{in})*100$ = 96.84 %

The output voltage of the compact DC-DC converter is also measured through oscilloscope. A voltage divider circuit was used to measure the voltage output of chopper transformer without rectifier and LC filter. A 10 k ± 1 % resistor was used for low side resistor and 100 k ± 1 % for high side resistor. The output waveforms of the device on analog oscilloscope are shown in figure 3.

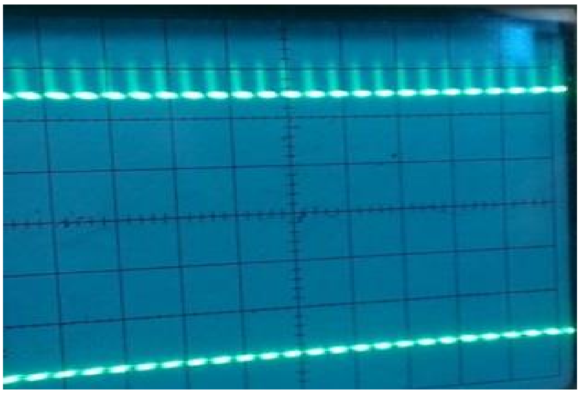

Figure 3: Output of the compact DC-DC converter without rectifier on analog oscilloscope [Scale: 5V/unit and 25 micro seconds].

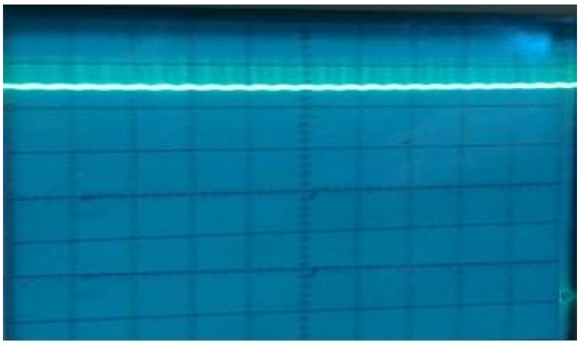

Figure 4: Output of the compact DC-DC converter with rectifer and LC filter on analog oscilloscope [Scale: 5V/unit and 25 micro seconds].

From figure no.3 it is seen that output of the DC-DC converter without rectifier and LC filter is high frequency AC square waves. Wherelse on figure no. 4 the output of compact DC-DC converter with rectifier and LC filter is DC. A toroidal core inductor (100 uH) and electrolyte capacitor (2*470 uF) was used for filtering. Toroidal core inductor was used to reduce the size of the inductor. Use of tantalum capacitor instant of electrolyte capacitor will also reduce the size of the capacitor. For rectification three ultrafast rectifier (MUR 460) diodes were used.

Charging efficiency of the charge controller depends on the loss of the forward diode and MOSFET. A schottky diode (3*1N5822) is used to reduce the loss in diodes. To reduce the loss in MOSFETs, a low R_{ds} (drain to source resistance) MOSFET (IRF3205) is used. Thus charging efficiency of device is achieved upto 97.7 %. For control operation PIC micro-controller (PIC 16F676) IC is used.

Discussion and Conclusion

The proposed DC-DC converter is developed for Solar DC nano grid systems. Solar DC nano grid system can be a good solution for electrification of rural off grid areas of developing worlds where the energy demand per households are low and also the houses are closely situated. The proposed compact DC-DC converter might be a good solution for electrification of rural small cluster of households through nano grids. Using the DC-DC converter the battery voltage can be increased to 125 V, and higher voltage allows to distribute the power from a central storage system to few hundreds meters. Due to the high voltage (125 V) the system can also provide the flexibility to charge laptops, mobile phones, use of color televisions. Thus the DC nano grid system can provide better electricity services than SHS based electrification.

The power rating of the DC-DC converter can be increased by adding similar devices in parallel. The voltage rating of the devices can also be changed. Input voltage can be varied from 12 to 48 V and similarly output voltage can also be varied from 100 to 250 V easily. The discharging efficiency can be further developed by using full bridge converter but that will add additional costs.

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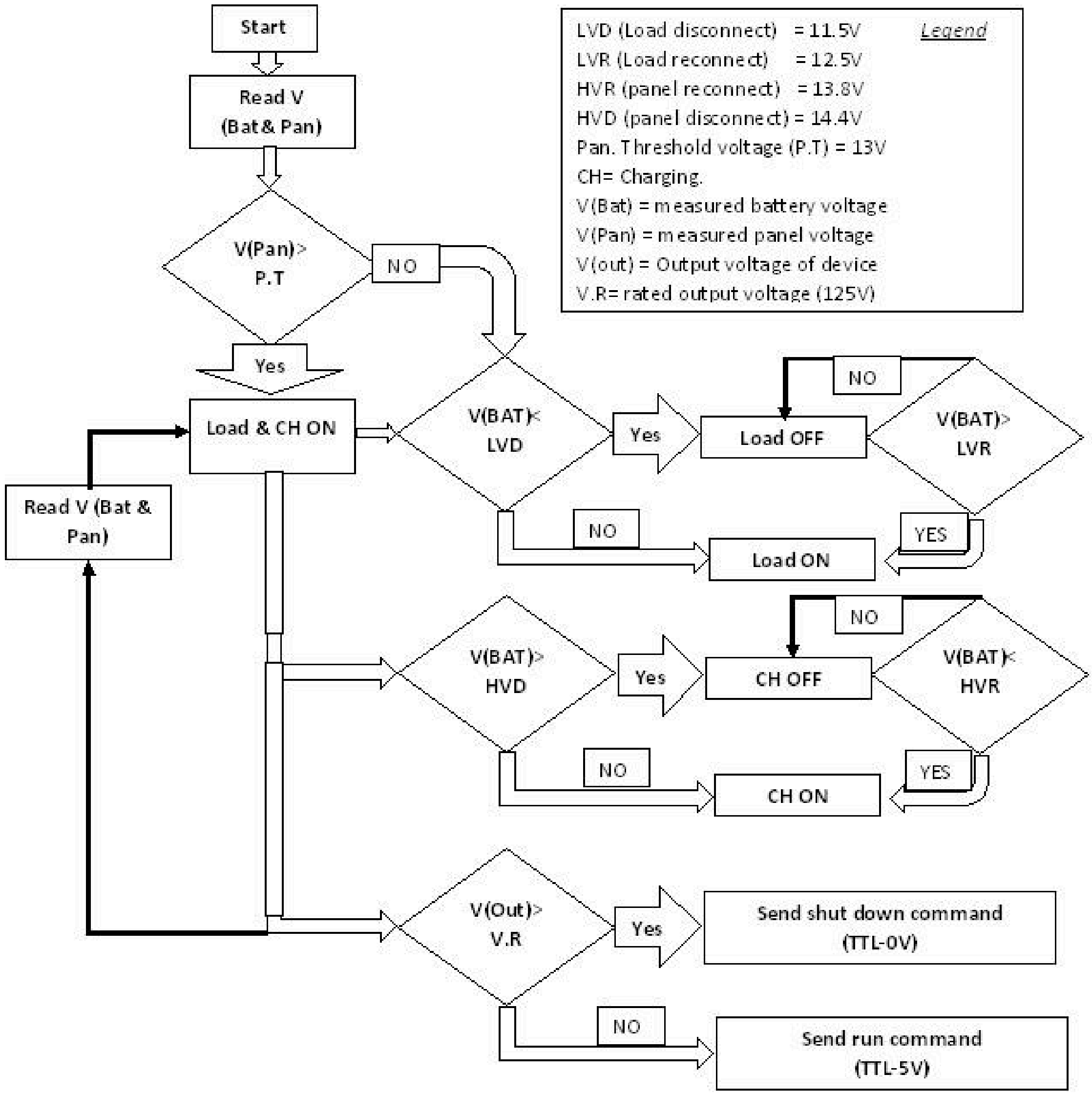
Appendix-1: Logical flow disgram of the device



Energizing rural India using micro grids: The case of solar DC micro-grids in Uttar Pradesh State, India

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Abstract

Traditionally AC mini-grids have been implemented to provide electricity services in many un-electrified habitations in India, which are not covered through the main grid. However, with the advancement of LED technology and lowering cost of PV panels, the DC micro-grids seem to be coming up in a significant way to enhance energy access. Many initiatives, both in private and public sector, are now taking DC micro-grid route to provide energy for basic lighting and mobile charging. This paper attempts to examine nuances of solar DC micro-grid development in India with special focus in the state of Uttar Pradesh. The paper, drawing from literature reviews, interview with key stakeholders and field survey to selected sites, shares the experiences of the solar DC micro-grid programmes for rural electrification.

Keywords: Micro-grids, Solar energy, Rural electrification

Introduction

Almost 96 % of the inhabited villages in India are electrified through conventional grid extension. However, statistics indicate that almost 77 million households were living without electricity in the year 2011. While 75 % is the average household electrification rate in India, the rural electrification rate is only 67 % (WEO, 2012). In addition to the conventional grid based electrification, renewable energy technologies (RETs) such as solar photovoltaic (PV), biomass gasifier and mini/micro hydro have also been used for providing electricity access in remote areas, forested habitations, islands and hamlets (Palit & Chaurey, 2011). These off-grid communities are economically unattractive for electricity distribution companies (discoms) to extend the grid due to their nature of remoteness, low-income households and scattered settlements. While discoms find grid extension economically unattractive to remote rural areas, they have also not attempted to electrify these off-grid areas with distributed generation and supply systems, though they are the licensees to provide electricity services in all areas.

The Ministry of New & Renewable Energy (MNRE), Government of India and State Renewable Energy Development Agencies (SREDA) in the different states, has worked significantly to address this vacuum. Specifically, Remote Village Electrification Program (RVEP) has electrified 10,154 villages and hamlets as on 30th June, 2013 (MNRE, 2014). In addition, NGOs have also implemented number of solar projects by raising fund from donor agencies and Corporates. Entrepreneurs have also ventured into providing access to solar lighting foreseeing the business prospect (Palit, 2013).

The high initial cost of extending grid to far-off remote areas, growing recognition of the effectiveness of RE systems, better modularity of RETs such as solar PV to meet the energy requirement of small communities and associated positive environmental effects have spurred the expansion of mini and micro grid program in rural areas of India (Bhattacharyya, 2006). Also, enabling policy initiatives for RE based decentralized power production and distribution have accelerated the electricity access through RE based mini-grids in the last decade.

While AC mini-grids have been implemented in India since the early nineties (details of AC mini-grid program in India can be traced in Palit & Sarangi, 2014), the solar DC micro grids are also being implemented in rural areas, especially in the state of Bihar, Odisha, Madhya Pradesh and Uttar Pradesh (UP). Especially in the state of UP, thousands of hamlets which do not have grid access or are not getting regular electricity supply during the peak hours are now covered through DC micro-grids, set up by private developers, NGOs and the SREDA.

Research Objectives

This paper attempts to examine the nuances of solar DC micro-grid development in India with special focus in the state of UP. The paper present an analysis of DC micro-grids employed for rural electrification and analyzes multiple dimensions such as technical features and sizing, service delivery and financial mechanism, tariffs, operation and maintenance aspects and social impacts.

Methods

A framework was developed to analyse the technical, institutional, financial and household impacts of DC micro-grids. A survey was conducted in the state of UP, covering beneficiaries of solar DC micro-grids, operating under different agencies belonging to private, NGOs and government sector. Further, the districts were selected where the DC micro-grids are in operation for more than one year (Table 1). Finally, the actual households were randomly selected from 2–3 villages/hamlets, from the identified districts. An effort was made to cover equal number of households being served by different type of agencies so as to avoid predisposition of the results. The analysis has been done for a total sample size of 250 households out of 2217 solar DC grid beneficiary households in the selected districts, with confidence interval of 2.55 at 95 % confidence level.

Solar DC micro-grids in India

The first solar DC micro-grid of 5 kWp capacity was reportedly commissioned almost 30 years back in a small village in UP. It provided electricity for domestic light connections using fluorescent lights, streetlights, community television viewing facility, which were considered state-of-the-art at that time. There was a complete lull in DC micro-grid implementation till it regained importance only during current decade especially for providing lighting and charging mobiles, because of introduction of highly efficient LED lamps and reduction in the price of the solar panels.

Table 1: Village survey details

Type of Agency	District name	Villages	Households surveyed
NGO - TERI	Azamgarh	2	40
	Amethi	2	50
Government - UPNEDA	Siddharth anagar	3	38
	Hardoi	2	17
	Basti	2	15
Private - MGP & Minda	Sitapur	2	40
	Unaao	3	50

In 2010, Mera Gaon Power (MGP) piloted the DC micro-grid technology in the village Swuansi Khera in Kanpur Dehat district to provide LED based lighting (Jaisinghani, 2014). While the initial experience for MGP was not successful and they had to withdraw from the village because of social issues such as non-payment by consumers. Thereafter, they re-launched their programme in Sitapur district in the central region of UP to cover un-electrified hamlets that are not likely to be covered through main grid. MGP has reportedly set up DC micro-grids in 900 villages covering around 20,000 households.

TERI also initiated a project during the similar time to connect households and markets through solar DC micro-grids following an entrepreneurial delivery mechanism. The pilot project in 2010 was installed in Jagdishpur of UP serving around 10 households. TERI then installed a solar micro-grid plant in the same village providing lighting to 40 shops and 8 more micro-grids to serve around 20 households each in the year 2011. TERI further had set up 30 DC micro-grids in the six districts across UP under the Norwegian Framework Agreement (NFA) connecting 130 households and 1,100 commercial units, providing them with lighting and mobile charging facility. The activity was further expanded through the Lighting a Billion Lives (LaBL) campaign, which has till date connected 11,040 households in 243 villages across six states namely, Bihar, Jharkhand, Madhya Pradesh, Meghalaya, Odisha and Uttar Pradesh.

Similarly, the Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA), developed a 1.2 kW DC micro-grid plant in the year 2011–12 in an un-electrified village called Mathia in Gonda district which was designed to serve upto 200 households. With this experience, UPNEDA further expanded the program to set up 23 solar micro-grids in 11 districts in the year 2011–12, covering around 4,000 families (Srivastava, 2013).

While an AC micro grid has a benefit to utilize existing AC grid technologies, protections and standards but stability and requirement of reactive power are the inherent demerits of it. On the other hand, DC micro-grid has no such demerits of AC micro-grid and assures reliable implementation of environment-friendly distributed generation sources. Literature also highlights that DC micro-grids can provide a reliable, efficient and sustainable smart grid, and often at a lower cost with greater effectiveness than measures applied to the AC grid (Savage et al, 2007). DC micro-grids also have a superior compatibility of the DC power with electricity storage. Further, in a DC system, only the voltage needs to be considered, whereas AC systems require each element to have identical wave shapes or have to be synchronized to operate. The DC micro-grid is more flexible and accommodating of the load and can create power systems that are efficient and more compatible with the fastest growing segment of the electronic devices load today.
A structured discussion on various aspects of solar DC micro-grid developments in India is presented below:

Technical features and Sizing

Different agencies have attempted to differently design the capacity of micro-grids. However, the underlying principle seems to be that the micro-grids are designed for providing only lighting and facility to charge mobile phones. The micro-grids designed under UPNEDA provide 4–5 hours of electricity in the evening from a solar power plant of 1.2 kWp capacity (Srivastava, 2013). During survey it was found, each household has been provided with 2 LED lamps of 2 W and 1 W, which provide brightness of 100 lm/W, and a mobile charging port. A prepaid meter and timer has reportedly been provided for each connection, though during the survey no such meter or timer was observed in the household.

TERI followed a flexible approach and implemented micro-grids of different capacities to serve 20 to 100 households from each micro-grid. The supply is done at 24 V for providing lighting services for 4 hours in the evening using LED lamps of a total of 3–6 W per households (1–3 light points/household, 100 lm/W) and power to charge mobile phones. TERI considers 8 % cable losses for grid length of less than 200 meters, which is the usual configuration. In case distribution length is higher, say around 600 meters, then 20 % loss is considered. As per discussion with TERI field staff, the voltage drops to around 20 V at the end of 600 meters of grid.

MGP provides 5–7 hours of electricity through 1 W LED lamps (75 lm/W), primarily for lighting and mobile charging in the evening, with their DC micro-grids. Each connection has two 1 W LEDs and one mobile charging point. Users may choose to pay extra for additional lights, however, a maximum of eight 1 W LEDs is provided. Twenty households are usually connected from each micro-grid of 240 Wp capacity within a maximum grid length of 90 metres to keep the technical loss and the installation cost at the minimum. For MGP, the average voltage drop to the final house is reportedly less than 4 %. The technical loss is less, as MGP has restricted the grid length from the centralized solar panel, whereas, grid length in case of TERI's projects varies from 100 to as high as 600 metres. This is because the TERI model is based on individual village level entrepreneurs who sometimes are unwilling to set up multiple solar panels in a village as it is difficult to manage by them. Minda uses 240 Wp solar panels and provides electricity for lighting using 2 LEDs of 1.5 W (100 lm/W) each with maximum grid length of 250 metres.

Delivery models

The delivery model followed by UPNEDA is of Built, Operate and Maintained by UPNEDA. They engaged technology providers to install the micro-grids and then engaged local operators to run them. The local operators are paid salary and the monitoring is done by UPNEDA. In case of TERI, local youths were identified and motivated by TERI staff to become energy entrepreneurs (EE) and invest in the micro-grid business. TERI also provided all technical support, assisted in procurement and installation of the micro-grids and trained the entrepreneurs to operate and manage the micro-grids.

MGP has implemented the solar DC micro-grids using a micro-utility approach, where they design, install, operate, maintain and provide the service to consumers in lieu of a fee or tariff (Palit & Sarangi, 2014). The MGP charges a connection fee and a weekly tariff on a prepaid basis. They formed Joint Liability Groups (JLGs) with all the users of a single micro-grid acting as one JLG to ensure timely collection. Minda installed the micro-grids and handed them over to rural entrepreneurs after an initial hand-holding by way of training. These rural solar entrepreneurs are made responsible for all operations, maintenance and revenue collection from end-consumers.

Financial Mechanism and Tariffs

TERI's pilot model, which electrified 10 households and 40 shops, had 100 % EE investment, while in the second phase installation of 8 micro-grids, TERI provided 60 % subsidy and the remaining 40 % was invested by the EEs and the micro-grids installed under the NFA had 45 % financing shared by the EE and the bank or wholly by the EE and the remaining 55 % as subsidy given by TERI. Under NFA project, out of total 30 EEs, 15 availed the facility of 30 % loan from the bank and the others invested 45 % of the cost on their own. The average cost for plant installation was INR 2,00,000 for covering 50 households. In case of MGP, while they made the entire initial investment, they have also been supported partially through grants by different agencies towards the capital cost. The average installation cost for MGP is INR 55,000 for connecting 30 households. A major component of the capital costs for UPNEDA has come as a subsidy with MNRE providing 30 % of the capital cost and the balance shared by UPNEDA. Similarly, Minda received around 30 % of the project cost (INR 107,000 for connecting 40 households) as subsidy from MNRE and the remaining 70 % was contributed by the local entrepreneurs. The higher installation cost for TERI is due to use of higher wattage as well as higher lumen output LEDs thereby requiring higher capacity of solar panels and batteries.

The tariff for the micro-grids in the surveyed districts was found be levied on a flat basis at INR 100–150/month/household. The UPNEDA and Minda operator charges monthly tariff of INR 150 and INR 100 per household respectively. In case of TERI, the tariff is INR 5/household/day is collected by the entrepreneur or an operator. The MGP charges a connection fee of INR 50 and a weekly tariff of INR 25 on a prepaid basis and the JLG assures that the payment is made every week. While for TERI, MGP and Minda, the survey result indicates 100 % collection of tariff, in case of UPNEDA owing to the absence of ownership, social awareness and training, the service is poor resulting in low average collection efficiency of only 56 %. The better collection efficiency except for UPNEDA may be attributed to easy mode of payment taken on a daily or weekly basis.

Operation and Maintenance Aspects

In case of UPNEDA, a person from the community was identified and deployed for operation, maintenance and collection of user charges. This operator is responsible for day-to-day repairs and maintenance and the collection of monthly tariff. The onus of replacement of batteries has been kept with UPNEDA, out of the accumulated user charges (Srivastava, 2013). On the other hand, both TERI and Minda model have stressed on the ownership by the entrepreneurs, therefore, the operation and maintenance is monitored by the locally operating EE who have also partially invested in that plant.

During the survey, when asked about the training given to operators, UPNEDA operators could not mention anything about training received which shows that they may not have been given any formal training. Whereas, TERI and Minda operators were reported to have been given formal training regarding operation and maintenance such as panel cleaning, battery refilling and replacement, checking of connections, simple troubleshooting and understanding basic faults. As MGP works on a micro utility model, they maintain a dedicated team to take care of preventive and any breakdown maintenance. During interaction with MGP team, they reported that they try to respond breakdowns within 72 hours. In case they are unable to provide power supply for more than 24 hours, they take less tariff for the weekly proportionate to the time of downtime.

While the micro-grids under TERI, MGP and Minda are found to be operating without any faults, in case of UPNEDA, all plants have been found partially operating with some faults. The households retaining connections have thus come down to around 50 % as compared to originally connected. Some commonly faults found during the survey are loose connection, decreased bulb illumination and short circuits and it was found that these are timely rectified by the local operators/technicians.

Project Impacts

During the survey, it was found out that the grid supply has been very poor, providing electricity during the times it is not usually required such as afternoon and late night and not during the times it is mostly required such as evening hours (Figure 1). Around 93 % of the households are reported to use lighting for studying and carrying out household chores which on average takes about 2 and 3 hours respectively. The remaining 7 % is used in business such as weaving and small grocery stores, and agriculture activities (Figure 2). While, 99 % of respondents reported spending of INR 80–150 towards kerosene before solar light and 1 % spent between INR 150–200, after solar light this expense came down to nil for 68.4 % users and less than INR 50 for 31.6 % households (Figure 3).

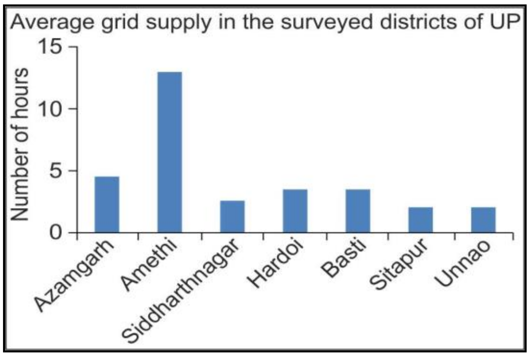

Figure 1: District-wise average grid supply

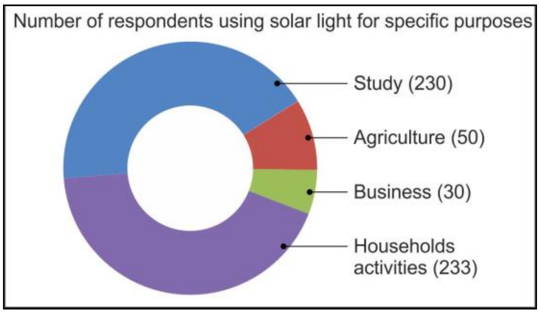

Figure 2: Number of respondents using solar light

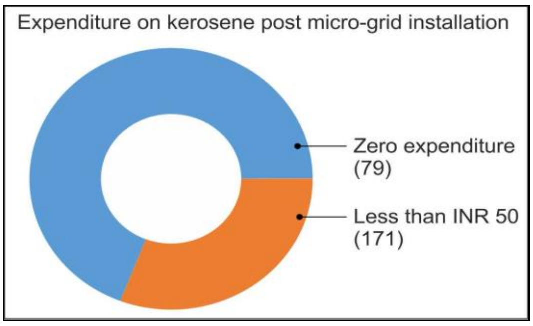

Figure 3: Monthly expenditure on kerosene

As anticipated there is a positive impact in terms of education and women's health. Post solar light, on an average children are studying for 2 hours and prior to that, they were studying for only 1 hour in kerosene light. The survey also indicates that women felt that after ceasing the use of kerosene, their health problems such as red eyes, blackened nostrils, headache, watery eyes and other problems like coughing or breathing difficulty have reduced considerably. Further, the results also indicates that 94.4 % of the households found the solar light quality very good and the remaining 5.6 % of the households reported satisfaction with the quality of light.

Conclusion

The potential market for micro-grids in India, whether AC or DC is huge with large number of population still living without any electricity services. While more than half a million villages have been electrified through conventional grid extension, there is reportedly similar number of hamlets where extension of the grid may not be cost effective. The prospect of so many customers has made development of micro-grids a good sector for the private-sector and social enterprises to step in and serve the population. A report by the World Resources Institute and the Center for Development Finance estimates that the market for micro-grids in India and other clean energy consumer products could reach upto $2.1 billion annually. However, these startups' prospects might be extinguished in a moment if regular power lines marched into these hamlets, so appropriate and enabling policies need to be developed for co-existence of both main grid and micro-grids in the rural electricity sector in India. With advent of new interconnection technologies and more clarity on the policy front, the micro-grid and the regular power grid might one day converge on the same village and complement each other, making the village's power supply cleaner and more robust.

Acknowledgements

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Passive Droop Control in a Decentralized 12V DC Energy Access Microgrid with Lead Acid Batteries

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Abstract

In this paper, a passive droop controlled 12 V DC energy access microgrid that utilizes natural droop control features is analyzed. The reliability of this control approach is investigated upon in a simulation with eight houses. Four SHS feed into this microgrid and four household systems with batteries but without panels take energy out of the system. The control of the 12 V DC grid can be achieved without any central control elements which represent a technology option for the implementation of bottom-up microgrid development path.

Keywords: DC microgrid, decentralized control, energy access technology, lead acid battery

Introduction

For the implementation of bottom-up grids as an approach for the decentralized mode or "second track" of electrification (Tenenbaum, Greacen, & Siyambalapitiya, 2014) the concept of swarm electrification[1] has been advocated (Groh et al., 2014). As these grids grow modularly on a step by step basis, as also suggested by (Unger & Kazerani, 2012) a core feature of the grid is that of modularity and high ease of handling even by low skilled personal. Hence, the control of these grids should be automated without the need of central elements.

The control of the power flow is an essential technology design component that enables the operation of a microgrid. Two of the most important criteria are functionality and reliability. Since a microgrid consists of several power generation, energy storage and load components, a key task of the control is the coordination among these different elements. In (Anand et al., 2013), three categories are proposed to assess control schemes: voltage regulation, load sharing and modularity. *Voltage regulation* refers to the stability of the voltage and *load sharing* to the even distribution of load current among different generation units. *Modularity* is a category which address the degree of flexibility for expansion and the costs of the infrastructure needed to operate the microgrid. These three categories are used below to discuss the control concepts given in the following overview. It should be noted that this paper will focus on DC microgrid control only. AC microgrids are different in their control. One the one hand it is advantageous to have the frequency as a global parameter for decentralized control in AC microgrids, on the other hand synchronization is more difficult to realize, in particular when the microgrid is meant to be operated in island mode as well as grid-connected mode.

Overview and Common Control Methods

A basic distinction between different control concepts can be made in regard to the communication topology as well as regarding the speed of communication. Communication topology refers to the infrastructure in place for communication between the different units in a microgrid. In *centralized control*, the individual units have no control but are being controlled by a single central unit. The voltage regulation is very precise because there is a single location with all relevant information (Anand et al., 2013). On the other hand, modularity is very low due to the high dependency on a high-bandwidth communication link. The control will be vulnerable to communication errors and comes with high cabling costs (Schönberger, 2005, 36). Due to its low degree of redundancy and high requirements for the communication and controller capacity, a pure centralized controller is hardly used other than in very small systems.

The opposite of the centralized control is the *decentralized* concept where all information is obtained locally and the control decisions are made locally as well. This concept is highly modular but voltage regulation and load sharing are very imprecise. Ideally, control concepts without central control elements are truly *plug-and-play* as emphasized by (Grillo et al., 2014).

A reduced centrality is given in *distributed control*, where information is again global but the control is decentralized. In this control concept, some communication link is needed, but it can be low-bandwidth, for example via a controller area network (CAN). In distributed controlled microgrids, load sharing is very precise while voltage regulation is of reduced quality. Modularity is higher than in centralized control (Anand et al., 2013).

[1] Swarm electrification describes an electrification pathway that starts with decentralized status quo infrastructure like solar home systems which are connected in a step by step bottom-up manner into an organically growing microgrid (Groh et al., 2014; Unger & Kazerani, 2012).

Mixtures of the above mentioned concepts are hybrid central control and hybrid distributed control (Schönberger, 2005). *Hybrid central control* is also commonly referred to as hierarchical control. It works with different levels of controls which are derived from the control of AC-grids, using a set of control loops: primary, secondary and tertiary. The primary control loop is on the local level at each unit and ensures proper load-sharing through droop control. In the *secondary control loop* voltage deviations are addressed and communicated via a low bandwidth link from the central controller to the primary control loop to ensure stable voltage. The *tertiary control loop* is optional and needed only for gird-connected mode. By adjusting the voltage level, power flows to and from the microgrid are controlled by giving a reference voltage to the secondary control loop (Guerrero et al., 2011). An example for such a topology is given by (Nasirian et al., 2015), where control is taken place in a decentralized scheme while controllers "cooperate" which each other, using a point to point communication link. Voltage regulation and load sharing work fine with this concept but modularity is reduced as each unit needs a separate communication link.

The fifth general concept is that of hybridized distributed control. Here, low- bandwidth communication does not take place via an explicit communication wire or radio signal but via the line/bus. Examples of this type of communication are voltage variation based control (Chen et al., 2013) and DC-bus signaling (DBS) (Cvetkovic, 2011; Schönberger, 2005). The key advantage of this system is the combination of the ability to communicate without the need for additional communication infrastructure between the units. Voltage regulation is not as precise as in the centralized concept[2] but load sharing and modularity are high.

Modularity is a very important criterion for the proposed microgrid. Centralized elements should be reduced or eliminated if possible to allow for a maximum flexibility in installation and modification. Hence, decentralized control concepts are favorable for the microgrid being described on in the following sections.

Methods

An important goal of droop control is the ability to manage the sharing of power between different sources without and explicit communication link (Strunz et al., 2014). Since the current flow across a line depends on voltage difference between the nodes, the node voltage is the critical parameter. Only by changing the voltage levels, the current flow can be controlled. This is the underlying principle for droop control. If a load current IL is requested from the microgrid, the voltage level of the distributed generation units (DG) and the line resistance will determine the power flow from each of these units towards the load. To ensure that all DGs are participating in the supply of this load, droop control, which is a decentralized control method, is commonly used. The effects of droop control are shown with the example given in Figure 1 which also underlines the benefits and limits of droop control.

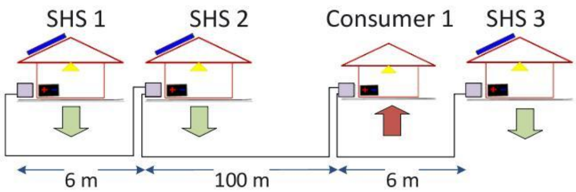

Figure 1: Example for the application of droop control

Consumer 1 seeks to draw current from the microgrid, all other units are willing to supply. Without droop control, only the neighboring units are able to supply. SHS 3 is the closest neighbor and supplies almost 95 % of the demanded power, SHS 2 supplies the rest. As there is no voltage drop between SHS 1 and SHS 2, SHS 1 is not participating. However, with droop control, all units ready to supply will supply a part of the load. However, it must be noted that the relatively large voltage drop across the cables has a significant impact, resulting in differences of the power share, in particular when facing a long distance as between SHS 2 and Consumer 1.

Droop control in DC systems is similar to the droop control in AC systems and is a single input single output (SISO) system. In its simplest form such as in (1), V_{out} is the output voltage of the DG, V_{ref} is the reference voltage, k is the droop coefficient and P_{out} is the outgoing power (Justo et al., 2013). The lower the k value, the higher the voltage and hence the higher the current flow from this DG.

$$V_{out} = V_{ref} - k * P_{out} \tag{1}$$

As proposed by (Guerrero et al., 2011) it can be further reduced as in (2) to the output current I_{out} and k can be replaced by a virtual impedance R_D. The virtual impedance is a fictional impedance that is determined by the quotient of ε_v / I_{max} with ε_v being the maximum allowed voltage deviation and I_{max} the maximum output current.

$$V_{out} = V_{ref} – R_p * I_{out} \tag{2}$$

For the design of a passive droop control regime, it must be considered that the voltage drop in the lines must be overcome. Only if the voltage reduction due to droop control is significant in comparison with the voltage drop on the wires can power flow be controled. For 1.5 mm² wires of 10 m distance, the resistance amounts to 0.6 Ω (Häberle et al., 2009), which is significantly higher than the internal resistance of lead acid batteries (AmaraRajaBatteries, 2003). Therefore in this case the droop effect needs to be amplified with another passive

[2] It has been emphasized in the literature that voltage stability is actually not desired- in contrary voltage differences are used for communication (Diaz et al., 2014).

component. This is undertaken by placing a shunt resistor in series with the battery.[3]

Due to the passive character of this approach, a significant amount of heat is produced to achieve the voltage reduction as shown in Figure 2. It must be noted that a point to point loss of 25 % for a 1.5 mm cable is in the magnitude of a 48 V system, where two DC/DC conversions are required.[4]

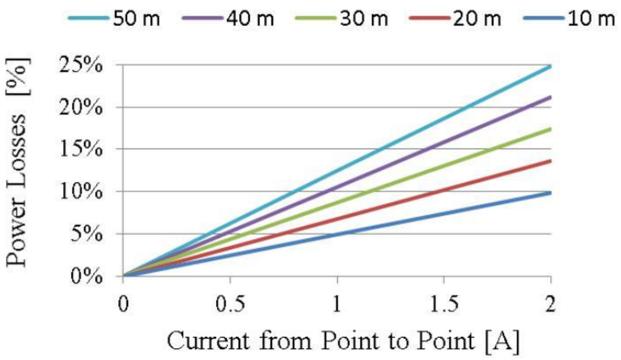

Figure 2: Power Losses due to voltage drop and droop

Simulation

The approach taken is analyzed further in a SimPower Systems Simulation with Matlab/Simulink.
Initially, a microgrid connected as shown in Figure 3 is modeled for their behavior over a day cycle (8:00 until 24:00) to examine the basic functionality of the control scheme. The microgird consists of two SHS with own generation and two consumer systems without own generation capacity. The systems are placed in a line, 10m apart from each other so that the maximum distance between a SHS and a consumer unit is 30 m.

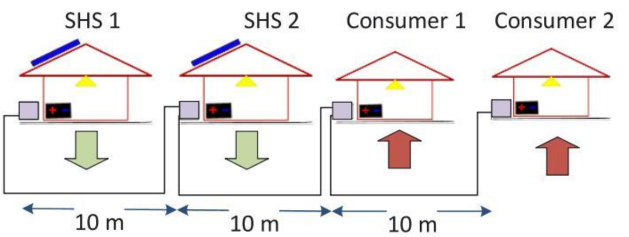

Figure 3: Simulation over a 30m distance

In a second run, this microgrid is expanded to eight houses using the topology shown in Figure 4 with four SHS and four consumers, each spaced 10 m away from each other. For all simulations, SHS are equipped with a 65 W_P solar panel and a 100 Ah battery, consumer units with no panel and a 25 Ah storage.

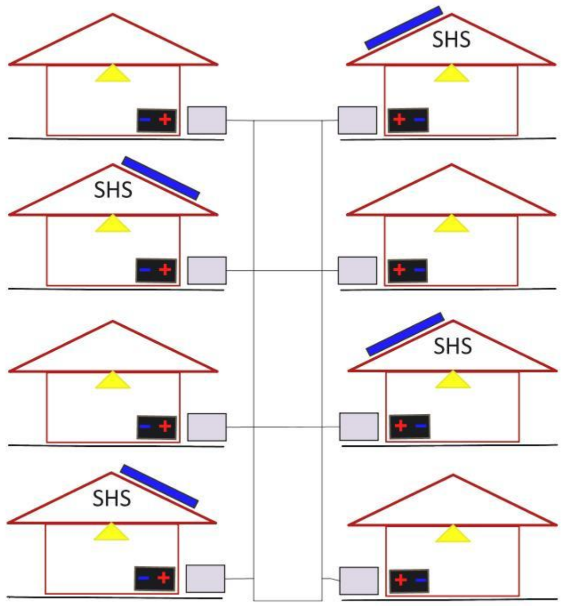

Figure 4: Simulated Microgrid Topology

Results

The current exchange curves for the first microgrid (Figure 3) as displayed in Figure 5 show a clear ratio of power exchange between SHS 1 and SHS 2. It must be noted that energy from a SHS's panel flows directly to the other houses without the need to buffer it in the SHS' battery. Because SHS 2 is located closer to both consumers, its current flow is generally higher during most part of the day. However, in the late afternoon (around 17 h) this system is not providing energy anymore. SHS 1, which has not shared that much energy yet continuous to provide electricity to the two consumer systems. Even though consumer 2 is located behind consumer 1 in the network topology, this system receives a significant amount of energy. The reason behind that is the small line loss at the current rate of less than 1 A (c.f. Figure 2).

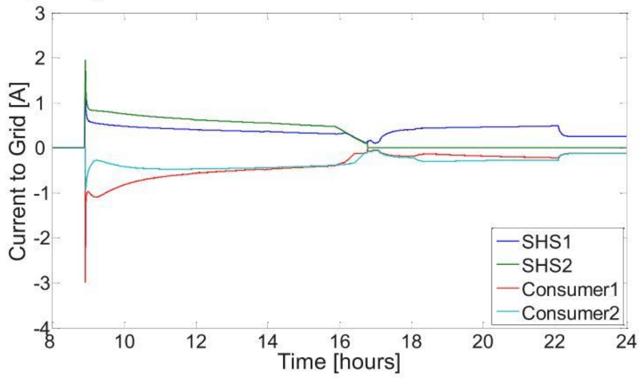

Figure 5: Current exchange with four systems

The detailed results for the larger microgrid with eight systems are given in

Table 1 1. All four SHS can share any excess energy with the grid, hence with the pure consumers. All loads are supplied for and the battery storage units on the consumer's side have an increased state of charge (SOC).

[3] It must be noted that through this method, the droop factor is fixed. Augustine et al. showed that better results in voltage and current regulation can be achieved when changing the value of R_D (2015).

[4] Assuming same voltage drop calculations on the line and a 90 % efficiency of the DC/DC converters: power loss 24 %.

The feed-in and take-out portions among the units are very uniform.

Table 1: Key Simulation Inputs and Results

	SHS				Consumer			
Inputs								
Battery Size[Ah]	100	100	100	100	25	25	25	25
SOC start [%]	80	80	80	80	30	30	30	30
Panel Size [Wp]	65	65	65	65	0	0	0	0
Daily Supply [Wh]	207	207	207	207	0	0	0	0
Daily Load [Wh]	162	162	162	162	40	40	40	40
Results								
Feed-in [Wh]	75	76	79	74	0	0	0	0
Take-out[Wh]	0	0	0	0	75	75	75	75
SOC end [%]	77	77	77	77	41	41	41	41

Discussion

This paper showed that there is a potential for passive droop control systems to control the power flow in low voltage 12 V energy access microgrids. The storage unit on the consumer's end was placed to ensure supply to this customer and reduce immediate dependence on the neighbors but might be subject to discussion. Further research needs to be undertaken to examine the precise control parameters once the model for the batteries to be used is available. To ensure a reasonable life time of the lead acid battery on the consumer side, a full recharge in regular intervals is required which is a critical technical success factor. The next step for this approach is a laboratory and field test to validate the concept. Due to the seasonal variations in sharable excess energy incentives for demand response need to be discussed. The goal of an implementation is to reduce the costs for SHS owners by selling their excess energy to neighbors who otherwise would not be able to access electricity.

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Development of a heuristic algorithm to design stand-alone microgrids for rural electrification projects considering distributed generation

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Abstract

Electricity supply in rural areas by means of renewable energy based microgrids has been advocated as a sustainable solution to increase the access to electricity in developing countries. Due to the challenges linked to their design, several tools are available to facilitate their planning stage. Even though widely used tools have been successfully utilized in multiple electrification projects, they do not design the electrical network of the microgrid and do not consider multiple generation points. A proper design of these aspects could greatly contribute to the sustainability of the project and to keep an adequate electrical behavior of the microgrid. For this reason, this study presents a heuristic algorithm to design solar energy-based microgrids, considering distributed generation. The algorithm is capable of designing both the electrical network and multiple generation points. Moreover, the algorithm is validated by comparing its results to different scenarios, based on standard design approaches.

Keywords: microgrid, distributed generation.

Introduction

Worldwide, 1.3 billion people lack access to electricity, out of which 84 % are located in rural areas (IEA, 2011a). To achieve the objectives of *Sustainable Energy for All (SE4ALL)* by 2030, efforts must be made towards the universal access to modern energy, improvements in energy efficiency and increase of the share of renewable energies. Having such targets, it is clear that small off-grid applications play an essential role. Specifically, it is estimated that mini- and microgrids will have to provide around 40 % of the new power capacity required to achieve universal modern energy access by 2030 (IEA, 2010).

In general, the design of off-grid systems based on renewable energy technologies (RETs) is characterized by a high complexity (IEA, 2011b). Furthermore, when the design of the electrical network is considered, finding the cost effective solution becomes a problem difficult to overcome. Consequently, several tools have been developed to support to design process. Some of the most widely used tools in off-grid projects are HOMER, RETScreen and Hybrid 2. These tools have been validated in multiple rural electrification projects worldwide (Longe et al., 2014), greatly simplifying the design process. However, they do not generally consider the design of the electrical network, but rather just focus on the optimization of the generation system of the microgrid. Nevertheless, big efforts have been made separately on the optimal design of urban distribution networks (Gilvanejad et al., 2007).

In (Ranaboldo et al., 2014), a design model is presented, where the electrical network and generation system are designed, but based on a single generation point for each microgrid. To our knowledge, there are no tools capable of designing both the generation system and the electrical network of the microgrid, considering distributed generators (multiple generation points within a single microgrid), leaving aside the multiple potential benefits of such scheme.

Research Objectives

Taking into consideration the high level of complexity of planning and designing RE-based microgrids, which involve distributed generators (DGs), and the evident gap on the research of models that facilitates the design process, this study aims at making a contribution by proposing a heuristic algorithm capable of designing microgrids based on solar energy, considering DG for rural areas while minimizing the investment set by the required equipment. The algorithm was designed based on a combination between Reduction and Monte Carlo Methods, where the space of solutions is firstly restricted in order to simplify the problem, so that in a later stage, the search can be better performed.

As the goal is to ease the design process, the algorithm is able to solve the number and location of DGs, as well as the topology of the microgrid. Additionally, to properly size the DGs considering the local conditions in order to cover the power demand, the optimal number and type of each device can be found. .

Methods

Architecture of the algorithm

Unlike the design process of islanded microgrids based on centralized generation, when planning microgrids based on distributed generation, the process becomes more demanding and complex due to the inclusion of additional variables such as size, number and locations of multiple DGs, each one affecting the electrical behavior of the microgrid. In consequence, the planning becomes a challenging optimization problem with additional

variables where several criteria must be satisfied to achieve stability, losses and costs reduction.
The solution hereby proposed consists of a heuristic algorithm designed to define the location of the DGs within a microgrid, as well as the sizing of the required components for the generation points (i.e. PV arrays, charge controllers, bank of batteries, inverters) and the configuration of the radial AC electrical network to minimize the up-front cost of the microgrid. Such up-front cost is given by the investment required for the components of the generation points. Hence, the algorithm builds the different microgrids considering their geographical locations and electric demand, the local solar resource and a pre-defined set of commercial components.
The proposed algorithm is structured in three main phases, as shown in Figure 1.

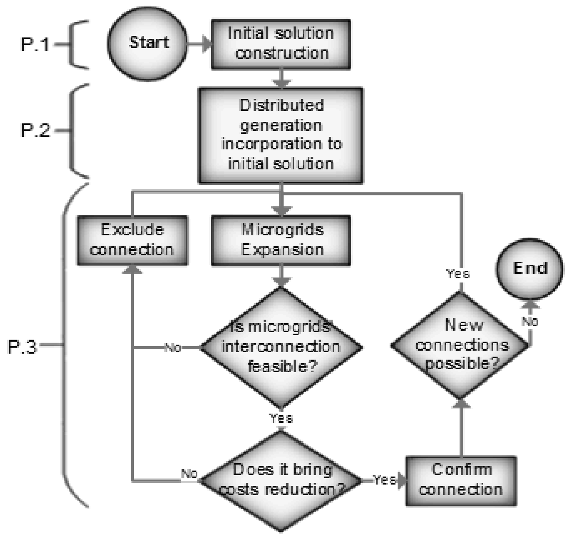

Figure 1: Main phases of the proposed algorithm. The description of each phase is shown next.

Phase 1: Initial solution construction

The initial solution construction begins with the selection of a first generation point from the overall set of consumption points. Such selection is done based on the demand indicator proposed in (Ranaboldo et al., 2013), aimed at evaluating the demand concentration around a single point.
Once the initial point is selected, the algorithm tries to extend the microgrid to its closest consumption points, considering the maximum voltage drop allowed in the network, estimated from the initial point. When the next possible connection produces a voltage drop beyond the acceptable limits, the microgrid is finished and a new initial point is selected. The procedure is repeated until all the points belong to a microgrid or until all points are analyzed. Consequently, the output of this stage is the set of different microgrids that can be formed from a centralized perspective, while keeping their maximum voltage drops within the limits.

Phase 2: Distributed generation incorporation

Starting with the microgrids formed in the previous phase, the next step consists of the optimal location for the DGs within the microgrids. However, it is important to firstly determine how many DGs should be installed in each microgrid. This step allows the algorithm to substantially reduce the solution space of the problem – composed by the possible number of DGs and their locations – and focus the next phases to the reduced search zone.
Each possible number of DGs contains a local optimum that differs from the other alternatives, as illustrated in Figure 2. Its value is given by the optimal mix of devices that bring the lowest investment and, to a lesser extent, by the location of the DGs, as long as it is ensured that they are properly distributed. Therefore, by selecting the amount of DGs that can produce the lowest overall investment, it is possible to greatly reduce the solution space. For example, the reduction of the search space to the scenarios produced by installing two and 'n-1' DGs (See Figure 2) focuses the search on areas with more probabilities of having the lowest investment costs.
It is important to point out that the modularity of the components of the generation system has big effects on the up-front costs of each alternative, highly depending on the available capacities of the commercial components and their associated costs. Hence, higher costs can emerge from using many smaller DGs than a few bigger ones to supply the same demand, or vice versa. Following this idea, the algorithm chooses the best alternatives based on the assumptions of the estimation, by calculating the required cost of using each potential amount of DGs.

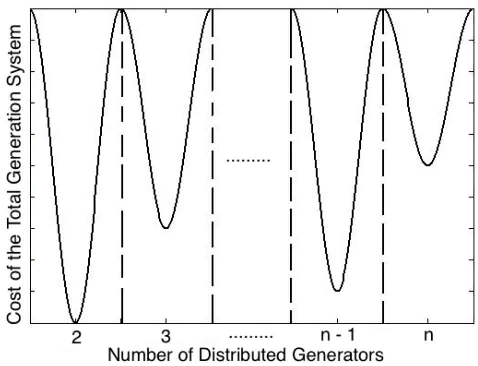

Figure 2: Representation of the solution space.

This is achieved considering that a certain number of DGs can equally contribute to cover the demand and, thus have similar power capacities. Therefore, their power capacities can be calculated by splitting the demand into the total number of DGs plus the contribution on losses, which at this stage are assumed as a certain percentage of the overall demand. Using these capacities, the required investment is calculated according to the costs of the available commercial components.
Once the cost per DG is calculated, the overall investment necessary for a certain amount of DGs can be derived, allowing for the selection of the best alternatives given by the assumptions. At this point, the algorithm assumes a low sensitivity of the investment cost to the location of the DGs, which is ensured in the next phases by focusing on the scenarios close to the optimal among the ones considered.
After the selection of the potential number of DGs, different scenarios can be simulated, where multiple locations are assessed for each microgrid built in Phase 1. This is achieved by integrating into the algorithm a power

flow, giving robustness and reliability to the solutions considered in later stages. Therefore, the assessment of the DGs locations permits the accurate selection of candidate solutions that comply with the voltage drop limit, low power losses, feasibility of implementation and reactive power constraints. Furthermore, it calculates the total power that each DG must supply on the scenarios considered on each microgrid.

The power flow method selected is an improved version of the Backward/Forward Sweep due to its simplicity, flexibility, robustness and computational efficiency when solving radial networks (Zhang et al., 2009). This method was improved from its original version to handle PV nodes, which corresponds to the appropriate model of the solar energy-based DGs on this study. Hence, the generation points were considered as PQ nodes, while an injection/absorption of reactive power is performed in each iteration, so that the voltage levels at the generation nodes are controlled and kept close to the nominal.

Finally, the sizing of the DGs is carried out for each scenario, where the components of the generation system are sized according to the results of the power flow described above. Therefore, the algorithm solves the optimal number and type of components based on a set of commercial components, minimizing the overall investment. Such calculation links each scenario with its respective investment, so that the cheapest solution within the analyzed scenarios can be selected for each microgrid.

Phase 3: Microgrid expansion

During the Phase 3, the algorithm tries to expand each microgrid, by interconnecting it with the neighboring ones. This stage builds bigger networks and avoids sudden separation of consumers in densely populated areas, separations that might otherwise be caused by the voltage drop limitations considered in Phase 1. This phase takes advantage of the improvements of the voltage profile produced by the incorporation of the DGs, allowing the microgrids to be further expanded. For this reason, each potential connection among microgrids is ensured to comply with the electrical constraints of voltage drop, feasibility and reactive power limits. Moreover, new location scenarios are assessed in order to find alternatives that bring to a lower investment when connecting both microgrids, rather than keeping them disconnected.

If the connection between two microgrids under the cheapest feasible scenario produces a lower investment cost than having both microgrids isolated, the connection is confirmed, repeating the procedure with the remaining connections. Consequently, at the end of this stage, the different microgrids are ensured to have the lowest costs among the considered scenarios. Furthermore, the optimal number and types of the commercial components of each DG that cover the demand are also calculated, including the cables of the electrical network.

Results

In the previous sections, the proposed heuristic algorithm to design stand-alone microgrids based on solar energy, considering distributed generators, was presented. To test it, properly analyze and compare it, the heuristic algorithm was applied to a case study. The case study selected is an electrification project in Sonzapote, a rural community located in Nicaragua. This is a pilot project aimed at boosting the governmental investment on RE solutions, to increase the rural electrification rates in the country.

The project includes 33 non-electrified households and one church. For this reason, the energy and power demand had to be estimated based on similar projects implemented in the region. The estimation showed a base energy and power demand per house of 240 Wh/day, and 195 W respectively, considering one inhabitant per house and an increment of 45 Wh and 15 W per person for multiple inhabitants. For the case of the church, the energy and power demand are 1500 Wh/day and 900 W respectively.

The minimum solar irradiance reaching the community occurs in November, corresponding to 4.7 kWh/m^2. As mentioned before, the proposed algorithm requires a set of potential commercial devices to be used in the generation system and electrical network to carry out the necessary calculations and decision-making. In Table 1, the equipment considered is presented, taking into account local prices. Additional electrical parameters such as efficiencies, temperature constants and security margins were also considered. Additionally, a maximum voltage drop of 7 % was set as a constraint.

Table 1: Equipment alternatives for the Case Study.

Inverters	Capacity [W]	Cost [USD]
Type 1	200	46
Type 2	300	70
Type 3	400	92.5
Type 4	1500	444
Batteries	**Capacity [Wh]**	**Cost [USD]**
Type 1	1290	325.47
Type 2	2520	693.21
PV Modules	**Capacity [Wp]**	**Cost [USD]**
Type 1	55	359
Type 2	150	800
Type 3	250	1002
Charge Controllers	**Capacity [W]**	**Cost [USD]**
Type 1	72	92.5
Type 2	300	400
Type 3	540	721

The solution proposed by the algorithm is presented in Figure 3. As it can be seen, for the rural community in Sonzapote, two independent microgrids were built. Microgrids 1 and 2 supply energy to a demand of 6.1 kW and 2.8 kW respectively (PF = 0.9). Furthermore, two DGs supply the required energy by each microgrid, and are located as indicated in Figure 2. It can be noted that the DGs in Microgrid 2 are located close to each other, while in Microgrid 1 the opposite occurs. Such results are linked to the fact that Microgrid 1 has a higher power demand and length, which would require more dispersed DGs to avoid higher voltage drops and losses. This effect is not as relevant in Microgrid 2 due to its lower overall power demand. As well, since the algorithm tries to set similar sizes to the DGs and bigger microgrids that tend to have higher load distribution variations on their different branches, the algorithm is forced to distribute the DGs so that they can similarly contribute to cover the demand.

It is important to point out that the algorithm selects a low number of DGs due to the cheaper USD/Watt normally involved when selecting bigger equipment. However, limitations in the maximum number of devices can change the decision towards more expensive ones. The construction of two microgrids instead of one is related to the cost of the cable required to connect them, as well as to the voltage drop constraints, and the low savings linked to the new configuration possibilities when having a bigger microgrid in this case.

The initial investment of the electrification project proposed by the algorithm, considering PV modules, inverters, charge controllers, bank of batteries, and cables, was calculated to be USD 61,510. In order to properly compare this result, but also due to the lack of similar models, the same electrification project was designed for two common approaches widely used in rural electrification projects.

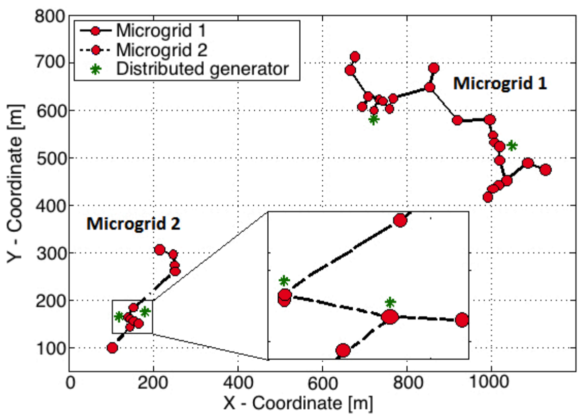

Figure 3: Solution proposed for the Case Study.

The first one considers all the consumers being supplied by SHS, which means that there is no interconnection between them. The second scenario is based on an islanded microgrid supplied by a single generation point (centralized scheme) supplied a PV system. These scenarios were designed based on the same design criteria and commercial components presented above to make them comparable. The results of the total required initial investment of each scenario is presented in Table 2.

Table 2: Comparison between the solution costs of different scenarios.

Scenarios	Cost [USD]	Difference
Proposed Algorithm	61,510	--
Solar Home Systems	73,221	-19%
Centralized generation	63,364	-3%

As it can be seen, the algorithm produced a solution 19% cheaper than using SHS for all the consumers in Sonzapote, reflecting important savings for the project. On the other hand, when compared to the solution following a centralized configuration, the required investment is 3 % cheaper. It is important to point out that these three solutions represent different topologies. Therefore, the advantages and disadvantages of using each one differ. On this sense, by using a decentralized scheme within the microgrid the reliability of supply as well as the voltage profile of the microgrid can be greatly enhanced, improving the service given to the consumers contributing to the sustainability of the project. As it was presented, a proper design of the electrical network and location of the DGs can also achieve additional cost savings, as well as further benefits of this configuration.

Discussion

This study presented a heuristic algorithm to design stand-alone microgrids based on solar energy and considering distributed generation. It is capable of designing the electrical network of the microgrid as well as the multiple generation systems, given the geographical location of the consumers and a set of commercial components to use in the project. The results showed that the solution proposed by the algorithm for the Case Study is cheaper than the solution given by standard design approaches. Moreover, it includes the advantages of changing the paradigm to a decentralized generation within the microgrids improving their electrical behavior and reliability, highly contributing to the sustainability of the project.

The algorithm hereby presented is part of an ongoing research that aims at filling the existing gap presented in the design models of RE based microgrids using DG. Aspects related to the integration of SHS in the solutions or DC-based microgrids that can be more suitable under certain conditions, as well as new approaches such as *"swarm electrification"* (Groh et al., 2014) are within the scope of the research.

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Solar DC Grids for Rural Electrification

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Abstract

Bringing off-grid areas under grid quality electricity is one of the main challenges of the 21st Century. Renewable energy especially solar PV based rural electrification plays a vital role in the context of energy access challenge in the Global South. Among the available technologies, solar-diesel hybrid decentralized grid systems are proven to be one of the suitable options for off grid electrification. Despite a world-wide application of hybrid mini-grids, these tend to use topologies based on alternating current. This paper discusses other options with direct current, giving an in-depth overview of different topologies for developing DC grids for providing electricity to the off grid area depending on socio-economic and techno-economic perspective. Benefits and areas of application for the case of Bangladesh are elaborated on.

Keywords: DC grid, Rural Electrification, Decentralized Systems,

Introduction

UNDP is pioneering the “bottom-up” energy agenda within the Sustainable Energy for All (SE4ALL) initiative, including scaling up decentralized, off-grid solutions to provide electricity to the off grid areas (Motlana, 2013). Approximately 38 % of the population of Bangladesh has no access to the grid electricity (Ministry of Power). This also includes those households in 20 % of Bangladesh’s area where transporting grid electricity may be highly expensive because of remoteness and a poor load factor. Solar power plays an important role as an alternative clean energy source for the electrification of these remote areas (Palit, 2013). Small Solar-grid system has a good potential for rural electrification in the Global South. Nowadays solar based isolated small grid concept are also Receiving an increased attention. Yadoo & Cruickshank (2012) even estimate that about half of the today’s off-grid population of 1.2 billion globally could be best supplied with decentralized micro-grids. Literature observes that demand in most of the rural households is for electricity for basic lighting and mobile phone charging (Chowdhury, 2011). In the off grid rural areas people live in small clusters of households. A compact DC-DC converter system can be an effective solution for providing electricity to 5–15 households to meet their basic electricity demand. Currently this solution has been tested by organizations like Schneider and Solaric (Electric, 2015; Islam, 2014). However, safety in DC systems has been a controversial discussion (Justo et al., 2013) and a full risk-based performance analysis as suggested by Gabber et al. (2012) is still to come. Though generic reviews on AC and DC structures have been performed in the past (e.g. Justo et al. 2013; Gopalan et al., 2014), this is a pioneering attempt to systematically review the solar small DC topologies taking the case for Bangladesh. Literature indicates that about 30 % of the energy produced in the solar home systems, that are implemented in Bangladesh on a large scale, goes potentially unused (Kirchhoff, 2014). A diversification effect through the development of a nano grid system can optimally utilize this unused energy as the system is shared by many people with productive and consumptive uses alike (Groh et al., 2014a). Furthermore, a densely populated country like Bangladesh (1033 persons/km^2), is very suitable for this kind of rural electrification (Mondal, 2010).

Definition

There is no specific definition yet for naming of small isolated grids. Some well-known names for isolated grids are nano, micro, mini and mega grids. Technically they work on the same principle but depending on the installed PV capacity they are named differently. We define nano grids for a small self-sufficient power system which can be scaled-up on demand. A solar nano grid stands for a grid with a generation capacity which is solar PV module and a distribution system for a small community having 10–25 household as shown in figure 1. In addition, there should be some means of storage system to store the solar PV power to be used at night. The capacity of the storage system depends on the night load and also the autonomy to be served by the system. Sometimes a small diesel generator is added to the nano grid as an additional backup power source. Generally the size of a solar nano grids ranges from hundred Watt peak to several kilowatt peak. We define micro grids as to be larger in capacity, ranging from few kilowatts to some tens of kilowatts. Mini grid refers to hundred kilowatts to several hundred kilowatts and Mega grids refer to the grids which has the installed PV capacity in megawatt range A schematic of a DC solar nano grid is given in figure-1.

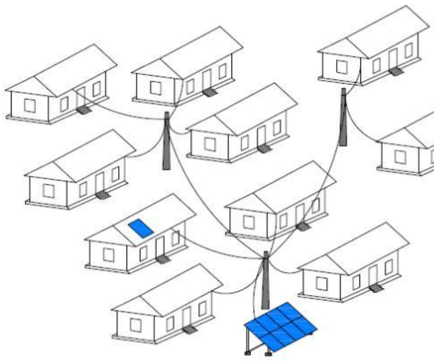

Figure 1: DC nano grid

Why DC instead of AC

Renewable energy based rural electrification is easier and convenient in DC format as number of renewable energy to electricity conversion technology are in DC formats and other conversion technology can be coupled easily in DC format.

In addition, there are several advantages of DC based electrification over conventional AC system (Groh et al., 2014b; Savage, 2011). For example,

- Larger AC mini grids have been found not to be financially sustainable in Bangladesh (Bhattacharyya, 2015).
- A large number of traditional electric appliances which run on AC 220 V can also run on DC in similar voltage range without any modification for example, mobile phone charger and laptop charger, incandescent lamp, LED and CFL lamp and so on.
- DC systems eliminate the AC-DC conversion loss and about 33 % (weighted average) of energy can be saved avoiding the conversion of AC to DC (Garbesi, 2011).
- Conventional AC cooling fan (ceiling fan) are higher wattage than from the same output of ceiling fans made of modern DC ceiling fans (Brushless DC motors).
- A 120–220 V DC system can easily be transmitted DC electricity up to a kilometer range similar to AC system. (SOLARIC system (Islam, 2014)).
- The 12 V DC from a battery can also easily be converted to 120–220 V using DC-DC converter with minimal efficiency loss
- In any underground transmission system DC is also more cost effective than AC, as the AC cable sizing needs to consider several issues like line inductance, capacitance etc.
- To scale a power system for increasing capacity in an AC system is complex as it needs proper synchronization. On the other hand, DC system can easily be scaled up by adding devices in parallel.

Conventional Solar PV Systems

Conventional Solar PV system either be grid connected or off-grid are AC systems. A typical grid connected AC solar PV system is shown Figure 2. This is connected to the grid via an inverter with synchronizing circuit.

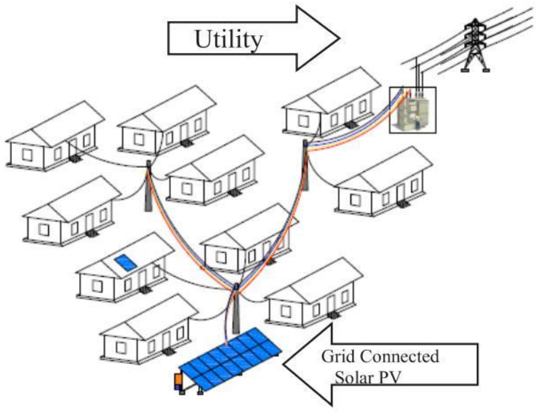

Figure 2: Conventional grid connected solar PV system

The inverter is designed in such a way that it produces an exact sine wave with the same voltage level as that of the grid and synchronizing circuit controls the output wave shape of the inverter to have the same phase as the grid voltage so that any mismatch in the voltage level or phase is avoided. The grid connected PV generators only generate power during the day time depending on the available sunshine and produce no power during the night. This type of system does not need any storage systems as the system is connected to the existing grid.

In case of an isolated grid, there is an additional factor to consider. The consumers connected to an isolated grid need power during the night hours as well to be supplied by the local grid structure, light being the most important requirement at night. Solar PV panels do not produce any power at night due to the absence of sunshine, supply of power during the night is usually provided from energy storage devices like batteries, that stores energy during day time. Sometimes this system is associated with a diesel generator for backup power. The schematic diagram of a stand-alone AC mini-grid is shown in figure 3. This is a popular system as it gives provision of using conventional AC appliances.

Figure 3: Stand-alone AC mini grid

AC mini-grid and its limitations

In AC mini-grid system, apart from daytime usage, energy is also stored to be used after dusk. Therefore, several conversions are needed to feed the power to the mini-grid distribution system, which results in power loss (~ 5–10 %). In case more than one inverter is used, they require parallel connection requiring additional feature of synchronization. All these make the control mechanism in AC grids sophisticated and expensive. Hence, the capital costs for heavily increased (Bhattacharyya, 2015), (inverters cost nearly 30 % of the solar PV panel cost, i.e. ~USD 0.20 per watt) and the energy cost is comparatively high, which are often unaffordable for rural people. Mini-grids in Bangladesh are reportedly selling electricity at a rate of US$ 0.35 to 0.40 per kWh of energy [Considering IDCOL model, where the 50 % of the project cost is grant].

Different Protocol for Solar DC grids

Due to the increased flexibility of interconnection, a wide range of grid topologies are possible with DC grid. Considering the method of generation and storage there could be four different options for solar DC isolated grid system, such as:

- Central generation and central storage
- Central generation and distributed storage
- Distributed generation and central storage
- Distributed generation distributed storage

Centralized Generation & Centralized Storage

The configuration for centralized panel and centralized storage system is shown in Figure 4. Unlike the AC grid, the grid voltage in this case is DC. Like the AC grid, batteries are charged by the solar PV panels via charge controllers. The connection from the battery to the mini grid is sometimes done through a DC-DC converter circuit. The DC-DC converter circuit steps up the battery DC voltage to the grid voltage level and the connection does not require any additional circuit operation like synchronization. This opens up the possibility of using small-scale distributed PV generation at convenient locations like roof tops that can be connected to the grid without any difficulty. Majority of the loads can run in DC or AC (e.g. CFLs, TV, LED lamps, Laptops etc.). However, an inverter may be needed to operate some of the loads which cannot be operated in DC. The advantage of the DC grid system lies in its low cost of the converters. Sometimes DC-DC converters are eliminated by increasing storage system voltage equal to the distribution system voltage for example 12 volt or its multiple for a 12 volt battery and multiple of 2 volt for 2 volt cells.

Advantages: this system is ideal from operation and maintenance point of view as whole system can be monitored in a single place. Consumer will need to have an energy meter count their energy usage the do not need to take any other risk on the other hand project sponsor will have to bear the full risk of the system.

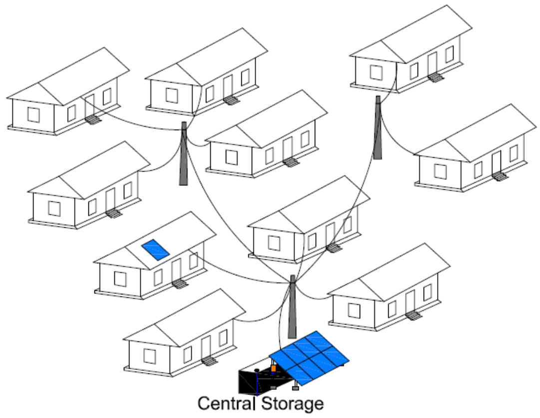

Figure 4: Centralized panel and centralized storage

Application: Nowadays the configuration, centralized panel and centralized storage is very well known for single ownership business model. All the costs and risks of the system need to be carried out by the project developer. However, energy cost of this system is very high. But when implementing the DC version of this mini/micro grid version, the energy cost can be reduced by 15–20 %.

Centralized Panel and Distributed Storage

In this system, solar PV modules are installed in a specific place and the power goes to the grid maintaining a specific voltage level for example 120 V or 220 V. Storage systems (batteries) are installed in households to store energy from the grid during daytime. A controller along with the DC-DC converter can be used to ensure the proper operation of the system and charge the battery at specified voltage level. This method works like a modified solar home system at the consumer end. This system does not have any centralized storage system; therefore, the grid will provide power only during the day time. A generator can also be attached to the system to provide power during autonomy days which will reduce the battery size for individual households. The system is illustrated in figure 5.

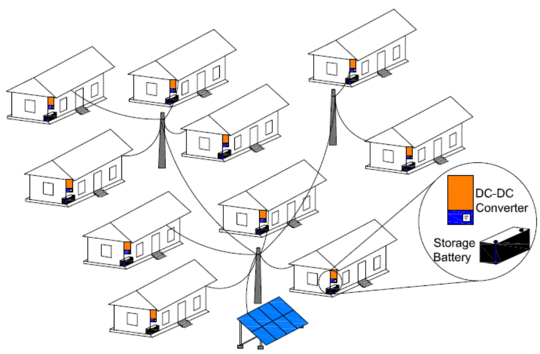

Figure 5: Central generation and distributed storage

Advantages: The storage system is within the individual household. The consumer can choose the storage capacity according to their need and the grid operator may not need to invest for the storage system. Cost of energy at the consumer end is much lower than the previous model. Storage battery and controller can be sold to the customers through micro credit. Risk of investment can also hence be distributed to the customer.

Application: This model is applicable to any off grid area even with predominantly low income customers This system has already been introduced by Schneider Electric (Electric, 2015) in India, Mali and Cambodia (Energypedia, 2015).

Distributed Panel & Centralized Storage

The power is produced in distributed location and stored in a centralized location in this system. At night the power will again be distributed from the centralized storage to the distributed loads. This increases the distribution power loss. In this system, the grid cannot be isolated from the storage system. If it does then high voltage (open circuit) will appear in the distribution grid that can damage the appliances in the households (if no control circuits are installed). This design is not a sound solution for rural electrification from a technical point of view. But can be effective where space is not available for installation of solar PV panels at a centralized location, individual households can be used to install the solar PV panels.

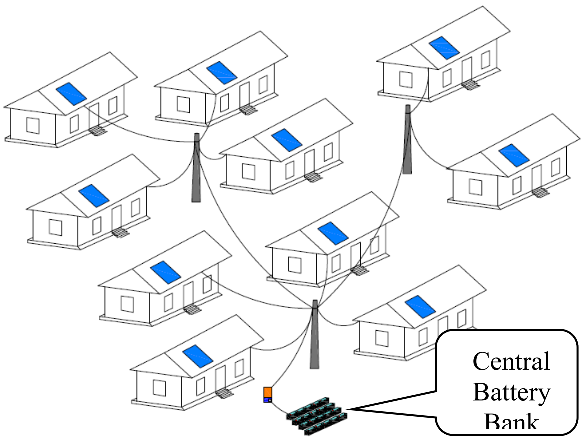

Figure 6: Distributed generation and centralized storage

Distributed Panel and Distributed Storage

In this option, households with shade free large roof tops will be considered to install solar PV on their roof. However, batteries are to be installed in every household to store energy from solar radiation during day time and provide backup at night. This option saves space of installing solar panel thus this option is suitable for those area which do not have sufficient space to install solar PV altogether. Furthermore, a country like Bangladesh where the penetration of solar home system is very high and the replacement of solar home system with another mini-grid system is difficult, this topology can play an effective role.

The household generates power from its roof top solar PV and it is connected directly to the distribution grid. The distribution of PV power is done at higher voltage to reduce the distribution loss. The individual households will draw power from the distribution line to charge its battery. A charge controller associated with a dc-dc converter controls the battery charging and discharging. The system will provide energy to the grid only during the daytime. The consumers have their own storage system according to their demand. An energy meter will be associated with the system to calculate the energy consumed by the user.

Figure 7: Distributed generation and distributed storage

Advantages: New and existing solar home systems can be incorporated with the system. Excess energy can be sold to those who do cannot afford to finance to solar home systems. Scaling of the power system is very simple through adding a large system and new systems. Moreover, integration with grid is also possible in schemes such as *swarm electrification* (Groh et al., 2014b).

Application: Applicable to those places where solar home system penetration is high. This system is suitable in areas where there is lack of land for installing PV panels. This system can be a substitute of the SHSs but can provide flexibility to the users.

Discussion and Conclusion

Solar DC small grids can be a cost effective solution for off-grid area electrification in the developing world. As the off grid areas do not have access to grid electricity and thus they are not familiar with the common AC gadgets, high efficient DC gadgets can be introduced easily in this area. Cost of energy use can be much lower in case of small DC grids than with AC. Every topology discussed here has some advantage but also limitations. The choice of topology depends upon the demand, energy use pattern, local micro climate and availability of land etc. The battery is an integral part of any stand-alone mini grid system. The size of the battery depends on the demand at night and insolation level at the area under consideration. If the sunshine is very steady and reliable, there is no need to store power for more than 1 night. On the other hand, unreliable solar insolation compels the mini grid designer to add significantly higher capacity battery. In a country like Bangladesh insolation varies by a large extent within a day or from one day to another due to rain, cloud, fog and mist. If any alternative energy source like a diesel engine can be added to the mini grid system, then the dependency on the weather fluctuations can be reduced appreciably. A solely solar PV based mini grid may require a battery size that can provide few days autonomy for the system. On the other hand, addition of a small standby generator reduces the required battery size drastically and thus the cost of the system. The modular growth that is enabled through DC technology is reflected upon in all analyzed DC mini grid models and topologies.

Research in the field will proof technological and financial feasibility.

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Scientific Papers

III. Implementation and Business Models

Solar lighting for rural households: A case of innovative model in Bihar, India

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Abstract

Though conventional grid extension has been the predominant mode of electrification in the country, there have been several initiatives and policy support to rural electrification efforts through renewable energy means, particularly solar. This study evaluated a Solar Home System (SHS) project operational in one of the rural districts of Bihar, India and presents the analysis of technical, financial, and institutional aspects of project and its impacts. The study reveals that financial innovations, adopting standard processes, building local technical expertise, sensitization and training of all stakeholders are the key factors for enhancing the operational sustainability of rural renewable energy programs in India.

Keywords: Solar Home System; Energy Access; Rural Development, Solar Lighting

Introduction

Access to electricity in India has been a major concern with around 43 % of the rural population still deprived of access to electricity (Census of India, 2011). While main grid extension has been the predominant mode of electrification with almost 96 % coverage of inhabited villages (CEA, 2014), it has many shortcomings. Many of the grid electrified villages in the states of Bihar, Jharkhand, Uttar Pradesh, and North-eastern states receive electricity supply with frequent blackouts and brownouts. Further, many electrified villages have low household electrification level (Palit & Chaurey, 2011). Various studies highlight the barriers including technical, financial, institutional and governance, existing in provision of electricity services to rural India through grid extension (World Bank, 2010; Palit & Chaurey, 2011; Chaurey et al, 2013; Palit & Sarangi, 2014). Literature also highlights that rural electrification program using renewable energy sources in India, carried out by the Government, NGOs and private sector agencies, in the past three decades have achieved great success (Buragohain, 2012; Harish et al., 2013, Palit, 2013, Palit & Sarangi, 2014, Borah et al. 2014).

Among the various renewables, solar photovoltaic (PV) systems have been mostly adopted for rural electrification, especially for areas where it is techno-economically not feasible to extend the grid or in areas where electricity supply from the grid is inadequate to meet the demand. The State Renewable Energy Development Agencies (SREDA), working under the aegis of the Ministry of New and Renewable Energy (MNRE), has largely supported implementation of solar lighting program using Solar Home Systems (SHS) and Solar Mini-Grids (SMGs). For example, under MNRE's Remote Village Electrification Program, almost 95 % of around 10,000 villages that were covered have been provided with solar lighting systems (Harish et al, 2013). NGOs have also implemented number of solar lighting projects by raising funds from donor agencies and Corporates. A late development is that the private sector has also ventured into access to solar lighting foreseeing the business prospects (Palit 2013). TERI, a not-for-profit organisation, in partnership with various government agencies and NGOs have also taken up initiatives to build and support innovative solar lighting solutions under its flagship program 'Lighting a billion Lives' (LaBL) (Palit & Singh, 2011).

Solar Lighting Program in Bihar

Bihar is often referred to as India's most under-developed state. Bihar has around 54 % of the population living below poverty line and also has a low literacy rate of 63.8 % (UNDP, 2014). Only 16.4 % of Bihar's population use electricity for lighting, the lowest in the country (Census of India, 2011). It is interesting to note that 0.6 % of the population uses solar energy for lighting, which is more than the national average (0.4 %). However, a vast majority (~89 %) is using solar lanterns and the remaining 11 % are using SHS (WISE, 2011).

As part of the LaBL initiative, TERI and Bihar Rural Livelihoods Promotion Society (BRLPS), collaborated to promote SHS to facilitate clean energy access to women led Self Help Groups (SHGs), promoted under the JEEViKA[1] project. As part of the collaboration, SHS were installed in 5000 rural households in the district of Purnia in eastern part of the state (Figure 1). This district was selected due to strong presence of SHGs formed under the JEEViKA project and large number of un-electrified and poorly electrified villages. The beneficiary households in the district were selected mostly from Dhamdaha block with the objective to cover all households and saturate the entire block. Once Dhamdaha block was saturated with SHS, the project moved to other adjoining blocks namely, Barhara Kothi and Baisi block. The entire project was thus implemented in two phases: 1500 households from Dhamdaha block were covered during 2012 and 3500 households from Dhamdaha and the other two adjoining blocks were covered in 2013 (Table 1).

[1] JEEViKA is a project for social & economic empowerment of rural women in Bihar, implemented by Bihar Rural Livelihood Promotional Society of Government of Bihar and World Bank.

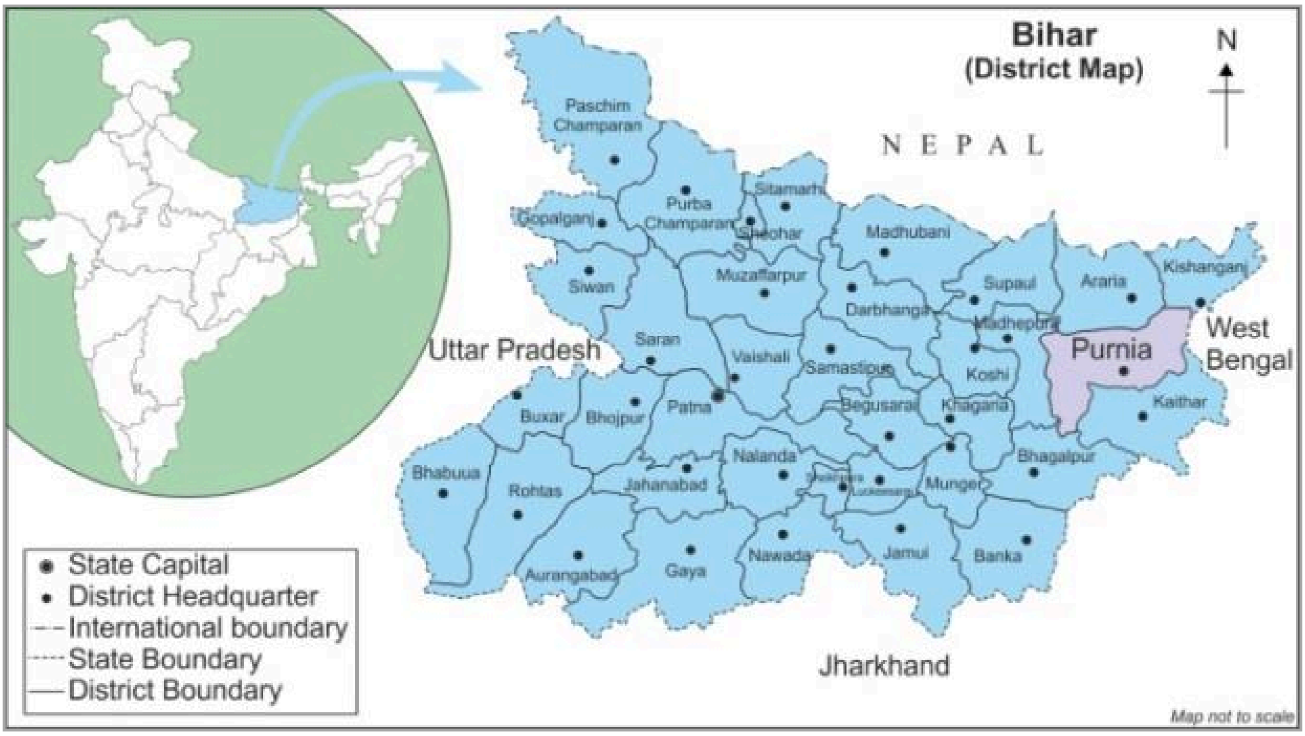

Figure 1: Map indicating the location of Purnia in Bihar

Table 1: Number of SHS installation.

Block Name	Number of Villages	Number of SHS installation
Dhamdaha	30	4340
Barhara Kothi	3	310
Baisi	6	350

Research Objectives

The study conducted an assessment of the project implemented in Dhamdaha block of Purnia district. The objective was to do a comprehensive assessment of the solar lighting project by examining multiple aspects such as technical design, delivery model, financing and impacts. Based on the findings, the paper suggests scaling up mechanism of similar initiatives and policy changes for enhancing the dissemination of solar lighting products to provide off-grid electricity in rural areas of India.

Methods

The methodology adopted to undertake the study consisted of a combination of questionnaire based primary survey of beneficiary households and focus group discussion (FGD) and extensive interaction with various stakeholders including LaBL and JEEViKA program staff. The questionnaire included a number of close ended and open ended questions pertaining to the technical, social, financial and institutional aspects of SHS dissemination. The survey, conducted in Dhamdaha block, considered a sample size of 100 respondents with confidence interval of 4.22 at 95 % confidence level. This sample size was further categorized on the basis of time period of SHS installation in two phases. Forty households were selected from the villages where SHS has been in operation for more than a year and 60 households from the villages in which SHS is in operation for more than 3 months and less than a year. From each group, households were selected randomly for the survey. In addition to the questionnaire based survey, FGD with different stakeholders was carried out to understand the delivery model and qualitative impacts of SHS.

Results

Technical features and performance

The configuration of the SHS in the first phase of the installation consisted of 12 Wp solar panel along with 12 V 10 Ah rechargeable lead acid battery. However during phase 2, solar panel capacity was upgraded to 15Wp without any additional cost, to make the entire system more robust. Each household was provided with two LED bulbs of 2.4 Watt[2] and a port to charge mobile phones. It was found during the survey that a household usually comprises of two rooms – living room and a kitchen. Hence, the aim was to provide a provision of light in the kitchen area to facilitate women in their day-to-day task related to kitchen chores; and one light for the living room for children to study and for all the household members to carry out their daily activities. Mobile charging was found to be a major requirement in the villages as otherwise villagers had to travel to a distant shop or market areas to charge their phones at a relatively high price. The SHS design was found to target the minimum energy requirement of the households.

To support such configuration, a 12 V 10 Ah battery capacity was specially designed under the LaBL program, instead of using battery with a capacity of 20 Ah which is more commonly available in the market. This was done to make the system efficient in terms of performance and

2 The LED bulbs have output of around 200 lumens and 7–8 Lux from a height of 2.5 metre.

cost-effectiveness. While, the cost of conventional battery with 20 Ah capacity was around INR 2500 (US$ 40[3]), the 10 Ah battery was priced at INR 1200 (US$ 19).

The survey indicates that almost 100 % of the systems installed under phase one were functional. While in phase two, 18 % of households faced some kind of inconveniences with SHS such as flickering of bulbs, malfunctioning of charge controller and/or battery and problem in mobile charging port. On discussion with the local technicians, it was found out that some faulty systems came in one consignment and the supplier has assured to replace the same.

Service Delivery & Financial Model

The implementation was a gradual process that started with identification of a block followed by identification of villages and selection of the beneficiaries. JEEViKA selected Dhamdaha Block as it was one of their activity intensive blocks where the SHGs had a strong relationship with JEEViKA. The villages were then identified based on remoteness and un-electrification status and history of repayment by the SHGs. A general meeting was conducted with the SHG members of selected village(s) by JEEViKA staff and community cadre to explain about the SHS program. The list of interested households was made based on SHGs willing to make a down payment, decided through community consultation. Based on the final beneficiaries list, TERI procured and installed the SHS through a local commercially run energy enterprise (EE), set up and trained under the LaBL program.

While TERI provided the required technical assistance, JEEViKA focused on field coordination and post installation supervision of SHS (Figure 2). JEEViKA, in association with TERI, also sensitized its SHG members regarding basic usage and maintenance of the system. The after-sales service is ensured through the same EE in the villages, which provides both preventive (such as battery refilling) as well as break-down services. TERI technical staff conducted training for locally selected technicians of the EE on aspects such as know-how of the entire system, component wise understanding and fault addressing and repairing. On-job refresher trainings are also organised so as to keep the technicians updated about the technological development. TERI makes payment to the EE for their services to SHS users during the warranty period of the system. Post-warranty after-sales service will continue to be provided by EE on payment basis borne by the users.

The cost considered for each SHS was INR 5,050 (US$ 82) which also includes the maintenance cost during the warranty period. While TERI provided a subsidy of 40 %, received as grant from the donors as part of the LaBL program, the balance 60 % was financed by JEEViKA. This 60 % of the system cost is deposited to JEEViKA by its SHG members through down payment and loan4 repayment. The 60 % contribution borne by the users is INR 3,000 (US$ 49), out of which, users made an initial down payment of INR 500 (US$ 8). The remaining amount is paid in installments at 2 % monthly interest rate. The interest payment, however, is not calculated on a compounded basis. In case of payment default, the 2 % interest amount is carried forward and added to next month installment amount. JEEViKA has also kept a flexible period of 5 to 20 months for the repayment.

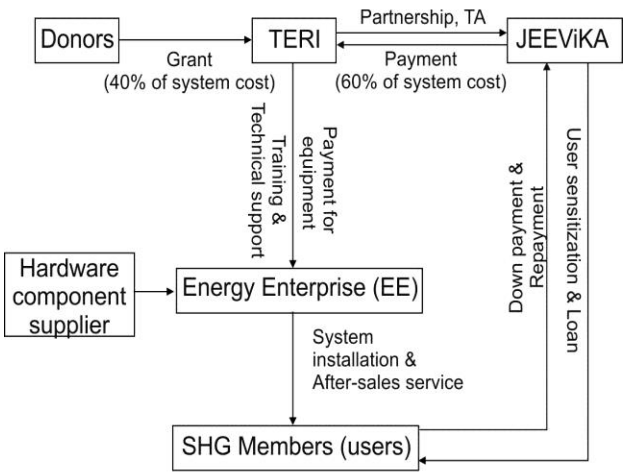

Figure 2: Delivery model

While the monthly installments are pre-decided, it was found during the survey that beneficiaries' repayment varies between INR 200–600 (US$ 3.25–10). The project has been enjoying high loan recovery rate (almost 84 % has repaid the loan amount), mainly due to the reason that SHG members would be refrained from availing other loans from JEEViKA in case of any repayment default. There have not been any noticeable difference in terms of loan repayment across blocks as the SHG members of JEEViKA fall under similar socio-economic category and the adjoining blocks have same external environment. The initial user contribution and easy financing terms made the SHG members accountable and at the same time provided them a sense of ownership. JEEViKA being a government program acts as collateral against the risk of non-payment.

Project Impacts

The survey indicates that 68 % of the respondents are using the solar lights between 4 to 6 hours; only 6 % reported that they are using for more than 6 hours. Thus, the households were found using the lights in line with the system design capacity of providing 5 hours of lighting thereby deriving its full benefits. Further, the results indicates that 90 % of the households found the solar light quality very good and the remaining 10 % of the households reported satisfaction with the quality of light.

The average kerosene consumption was found to have reduced to 2.1 litres from 4.6 litres on installation of SHS

3 One USD = 61.70 INR (as on January 19, 2015)

4JEEViKA extends clean energy loan to its SHG members under "Energy Security Credit". All the SHG members are entitled to avail this loan which helps them in financing SHS. Almost every SHG beneficiaries under the solar lighting project availed the facility of Energy Security Credit.

(Figure 3). The reason behind users still resorting to kerosene use is due to free distribution of a prescribed quantity of kerosene to ration card holders, which the households didn't want to forgo and use of kerosene in lamps in case they have more than two rooms or while commuting post sunset. The average monthly expenditure on kerosene was found to decrease from INR 163 to INR 54 (US$ 2.6 to US$ 0.8). This particular analysis is significant to know that the payback period is around 1.5 years[5]. Further, with the solar light intervention, 4 % of the houses also reported an increase in monthly income due to either increase number of working hours post sunset or starting of indoor income generation activities. The common income generation activities found in the surveyed villages were mostly sewing and grocery shop.

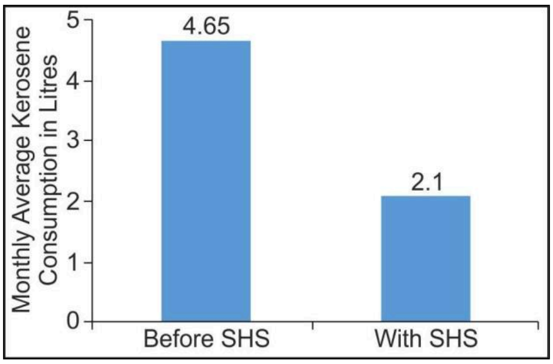

Figure 3: Monthly kerosene consumption

The beneficiaries were also asked if they would like to buy a SHS with higher capacity (i.e. additional 1–2 lights and a fan) and how much more they would like to pay. It was found out that 81 % of beneficiaries are willing to pay more for the mentioned higher capacity SHS (Figure 4). However, there were 5 % of respondents who could at the most pay INR 500 (US$ 8) for an additional light point.

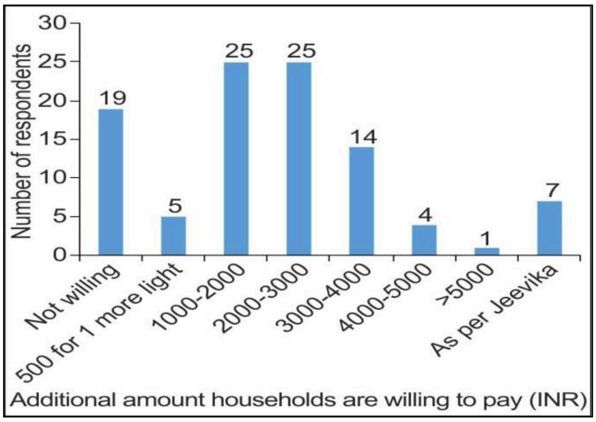

Figure 4: Willingness to pay for higher capacity of SHS

Discussion

While the project has been implemented during 2012–13 and the findings are based on initial impacts, the project offers some key lessons. Some of them are bottom-up approach resulting in structured flow of service and funds; easy loan mechanism which is evident in high loan recovery rate of 84 % within one year of system installation and, strong institutional presence required for scale up in rural areas. We can draw the following key lessons learned, which can provide insights on designing policy for scaling up decentralised solar program in India:

First, poor functionality has been observed in many of the programs that are subsidized either partly or wholly. The main reason for poor functionality is due to absence of proper institutional delivery structure along with after-sales services (Borah et al, 2014). However, in this case, an EE was facilitated and trained at the beginning for installation as well as to provide maintenance services. The minimum service charge required for providing after-sales service during the warranty period was also included within the capital cost to ensure that service provider regularly get the due revenue from TERI against the services being provided to the households.

Second, JEEViKA arranged financing of the SHS at easy and flexible terms without any collateral requirement. An issue worth highlighting is that lack of suitable financing mechanism was regarded in a survey as most significant barrier to the uptake of SHS, and was considered to be of more importance than technical and policy issues (Urmee & Harries, 2009).

Third, the flexibility in loan repayment by the beneficiary is allowing the poor households to make the payment based on their earnings, which in most cases are irregular in nature.

Lastly, the customization of the product configuration also helped in reasonable pricing of the systems (after subsidy under LaBL) within the ability of the consumers to pay.

Based on the initial success, the project is now being expanded to cover 25,000 households spread across three districts of Bihar using similar delivery model. In addition, project design is also expanded to cover clean cookstove working on a force draft mode with a small fan that can also run using the energy from the same solar panel to ensure households get access to energy for both lighting and cooking.

5 The total money saved per month on reduced kerosene use and mobile phone charging was found at about INR 184 (US$ 3). The average monthly savings on kerosene is INR 109 (US$ 2) and the amount of money saved on charging of cell phones is INR 75 (US$ 1.2).

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Green economy via Decentralised Energy generation and Waste Management by a 60 kg/day Kitchen Waste Biogas Plant at Postal Training Centre, Mysore, India

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Abstract

The 60 kg/day Kitchen waste biogas plant at Postal Training Centre [PTC], Mysore, India implemented by NIE-CREST has solved the problems of waste disposal and created a value chain of waste to energy. The plant at present is partially fulfilling thermal energy demand, has achieved zero waste and low carbon footprint. Analysis of 60 days data shows generation of 251.65 m^3 of biogas (100.66 kg LPG Eq.) from 2600 kg of waste amounting to INR. 9831.97 averaging to biogas generation of 0.097 m^3/kg of waste and an average feed of 43.33 kg/day. The plant in a year saves 611.74 kg of LPG, reduces 1.85 tonnes of CO_2 emission, converts15.82 tonnes of waste to energy & organic manure thus contributing to green economy. Further COD reduction of 74.7 %, BOD reduction of 80.9 % was achieved in outlet slurry.

Keywords: Kitchen Waste, carbon foot print

Introduction

Postal Training Centre [PTC], Mysore is an Indian Government Organisation for training on postal services. Waste was an issue in the campus with pigs, foul odour, nuisance, unhygienic conditions and many problems offered by kitchen waste which was being inevitably dumped in open space. Kitchen waste includes rice starch, wash water of rice, used tea/coffee powder, waste atta, leftout rice, sambar, vegetable/fruit waste, waste edible oil and other cooked waste.

NIE-CREST is a centre of excellence at The National Institute of Engineering for dissemination of Renewable Energy and Sustainable Technologies. Biogas from organic waste is one of the major technologies being promoted by NIE-CREST for energy conservation and waste management. NIE-CREST offered the biogas technology as a solution to problems of PTC.

The biogas plant of capacity 60 kg/day has been implemented by NIE-CREST and is also being maintained by NIE-CREST.

NIE-CREST has implemented more than 100 plants of variable capacities. The installations include household level biogas plants of capacity 2 to 6 kg per day, community level plants of 100 kg/day capacity kitchen waste biogas plants implemented at Administrative Training Institute [ATI]-Mysore, 50 kg/day capacity kitchen waste biogas plant at Chamundeshwari Temple, Chamundi Hills, Mysore and the biogas plant of capacity 1.5 tonnes per day at Mysore Zoo. These plants have resulted in an approach towards sustainable energy supply to the houses and institute and waste management.

Research Objectives

The research was intended to study the aspect of waste management, quality of biogas generated, monitory savings per annum from the biogas plant in terms of savings in LPG, reduction in the COD level of the effluent, estimate the reduction in the CO_2 emission, observe and quantify the performance of the biogas plant and note the benefits that accrued to PTC after installation of biogas plant.

Basic Principle-Biomethanation

The biogas plant works on the principle of biomethanation/anaerobic digestion of waste to generate biogas. The anaerobic digestion occurs in three phases Hydrolysis of organic solids, acetic acid Formation and biogas Production.

Biogas is an output of biomethanation of Organic waste by anaerobic bacteria. The process of biomethanation involves breaking complex organic matter in to simpler molecules thereby releasing biogas. The digested material obtained in the form of slurry is an organic manure to plants. Biogas is a mixture of methane, carbon dioxide, hydrogen sulphide, water and other compounds in traces. The composition is shown in table 1.

Technical specifications of the plant

Floating drum type, water sealed biogas plant of capacity 60 kg/day, designed for a retention time of 30 days. The components include crusher, mixing chamber, inlet chamber, digester, mild steel gas holder, blower, gas meter, outlet chamber and slurry tank. The digester has a water seal (water jacket) to prevent leakage of biogas and house gas holder.

Methods

Quantity of waste fed to the plant and biogas generated on daily basis has been measured and the data has been analyzed for 2 months period. Gas Chromatography was used to determine the composition of biogas, the amount of money saved from Biogas generated is also calculated by finding its equivalent LPG generation and estimating the cost of it. The reduction is CO_2 is estimated. Analyses were also carried out to determine COD at inlet (kitchen waste) and output (Slurry) to find the reduction in COD. Further the output slurry was analyzed for nutrients Nitrates Phosphates & Sulphates to explore the possibilities of utilizing slurry as an organic manure without any treatment.

Data :

Table 1 Composition of biogas obtained from Gas Chromatography.

Sl No.	Constituent	Percentage
1	Methane	49
2	Carbon di-oxide	45
3	Traces [H_2S, NH_3 H_2O, N, H and O]	6

Table 2 Sample Data of waste fed, biogas generated at PTC, Mysore in the month of October 2014

Date	Waste fed (kg)	Biogas Generated (m^3)
01/10/2014	52	5.54
03/10/2014	50	8.99
04/10/2014	60	5.29
05/10/2014	55	4.56

Table 3: The cumulative data of 60days(from 1st Sept to 31st October 2014) is given below:

1	Total quantity of waste fed in 60 days	2600 kg
2	Total quantity of biogas generated in 60 days	251.65 m^3

Table 4: Data of COD & BOD content in waste before and after biogas generation :

Parameter	Inlet feed (Kitchen waste) (mg/L)	Outlet slurry (mg/L)	Reduction (mg/L)	Percentage Reduction
COD	73600	18600	56000	74.72
BOD	30600	5850	24750	80.9

Table 5: Analysis of Outlet Slurry for nutrients

Parameter	Concentration (mg/L)
Nitrate	10.5
Phosphate	39.5
Sulphates	10.0

Calculations :

Calorific value of Biogas (CV_{bg})

CV of methane: 39820 kJ/m^3 (Ref : 8)
Percentage of CH_4 in biogas: 49 %.
CV of biogas = 39820 x 0.49 = 1951 kJ/m^3
Calorific Value of LPG (CV_{lpg}) =49.7 MJ/kg (Ref. 7)
CVbg/ CVlpg = 0.39 (19.51/49.7) **~ 0.4.**
(1 m^3 of biogas is equivalent to 0.4 kg of LPG)

Calculations for savings in LPG

LPG Eq. of Biogas for 60 days generation = 251.65 m 3x0.4
= 100.66kg
Average biogas generation per day = 251.65 m^3/60
= 4.19 m^3
Biogas generated per kg of waste = 251.65/2600
(60 days average) = 0.097 m^3/kg

1 m^3 of biogas costs INR.97.68 x 0.4 = INR 39.07
(*1 kg of LPG costs Rs 97.68*)

Total savings in 60 days = 251.65 x 39.07 INR 9831.97
At the same rate of biogas generation, the annual savings in LPG is 4.19 X365X0.4 = 611.74 kg

Calculations for reduction in CO_2 emission.

CO_2 emission per Litre of LPG =1.665 kg
Density of LPG =0.55 kg/L
Reduction in CO_2 Emission/year = (611.74/0.55) x 1.665=1851.90 kg (1.85 tonnes) of CO_2 emission is reduced (Source: Ecoscore.be)
(*Considering biogas as a carbon neutral fuel and zero emission from Biogas is considered*)

Reduction in COD & BOD = 74.72 % & 80.9 %

Calculation of organic waste managed.

Average quantity of waste fed
=2600/60
=43.33 kg/day
At a feed rate of 43.33 kg per year, the biogas plant converts 43.33 kg/day x 365 days = 15815.45 kg (15.82 tonnes) of waste to energy and organic manure

Table 6: Economics-Investment, savings and payback period

Investment	INR 4.35 Lakh
Total savings through LPG Per annum=611.94 kgX Rs.97.68/kg	INR 0.60 Lakh
Recurring Expenditure per year (for maintenance/repair) of electromechanical accessories like crusher and blower:	INR 0.10 Lakh
Net Savings per annum	INR 0.50 Lakh
Pay back period (4.35/0.5)	8.7 Years

Results and Discussion:

The biogas plant has benefited PTC through waste management, savings in LPG, reduction in BOD, COD, reduction in CO_2 emission, organic manure as a byproduct.

From detailed study and data analysis, the results have been summarized as follows

- The biogas plant has already accomplished savings of 100.66 kg of LPG, at the same rate it can lead to 611.74 kg of LPG per year
- The biogas plant has accounted to reduce COD & BOD by 74.72 % & 80.9 %
- From economic analysis detailed in table 6, the payback period is 8.7 years
- The reduction in CO_2 emission of 1.85 tonne per year is contributing to the green economy
- The presence of nutrients Nitrates (10.5 mg/L), Phosphates(39.5 mg/L) & Sulphates (10 mg/L) in output slurry makes it a good organic manure
- The methane leakage is prevented by water jacket around the main digester; further the working pressure is way below atmospheric pressure (200 millibars), there is no unavoidable leakage due to excess volume either as the biogas is being utilized by PTC daily
- The maintenance of Biogas plant will be handed over to Postal Training Centre in near future, meanwhile PTC will trained well enough to be qualified for O&M

Figure 1: Photograph of 60 kg/day kichen waste biogas plant at Postal Training Centre, Mysore

Conclusions

Although the payback period is 8.7 years, the savings through environmental conservation is intangible. The cost of conventional LPG Cylinders and generation of Solid Waste is likely to increase in future; Savings through reduction in carbon dioxide emission/Carbon foot print and price escalation of LPG have not been considered. The payback period will be less than 8.7 years if both the issues are taken in to account; these facts enable biogas plant to create decentralized microenergy systems sustainable green economy

The reduction in BOD, COD through biomethanation makes biogas plant a feasible option for treatment of biodegradable waste

The biogas plant acts as a model for solid waste management for many institutes.

The slurry from outlet is a byproduct of biomethanation has a good nutrient value for using it as an organic manure.

In contrast to the conventional solid waste management methods where in lot of energy is associated with various stages like collection, segregation, transportation and disposal; the biogas systems generate waste from energy and yield slurry as a manure there by making it possible to achieve zero discharge and adapting these systems in any campus will make the campus compatible for ISO 14001;2004

India being a tropical country has a lot of scope for establishing biogas plants to solve the problem of energy crisis and waste management in a single system.

The biogas plants can be implemented at any place as they are decentralized micro energy systems which create green economy.

The technology can be presented as a business model.

The biogas plants of smaller capacities (1 to 5 kg/day, 6 to 10 kg per day) for households have been fabricated by us out of Locally available PVC Water tanks instead of masonry/concrete construction and 100 such plants have been built.

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Diffusion of Alternative Electricity Supply Solution in Bangalore: The Emergence of a Market for Middle-Income Customers with New Aspirations Case Studies of SELCO and BCIL Promoting Photovoltaic Systems

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Abstract

This article aims to highlight the emergence of urban customers willing to use alternative electricity supplies developed by small yet visionary companies in the context of discontinuous public electricity supply in Bangalore. To illustrate this market evolution, two companies implementing solar photovoltaic systems are studied. The research identifies how these off-grid services initially designed for either very poor rural customers or very rich customers are slowly reaching the urban upper-middle class customers attracted by its practical use and financial incentive. This demonstrated development of a niche market constitutes an early signal of the emergence of a social group willing to change its consumption behavior and contribute to the environment through their day-to-day activity.

Keywords: solar photovoltaic; market development and segmentation; urban customers; India.

Introduction

Bangalore is the fifth most populated city[1] in India with a fast growing population. The domestic users' demand for electricity keeps increasing, and the public electricity supply service is not fully able to meet that demand. In this context, the utilization of off-grid energy source constitutes an intermediate solution to immediately circumvent the incapacity of the grid electricity supply system to answer that growing demand. These off-grid solutions, which complement the electricity shortage of central grid, also find value in terms of energy resilience (O'Brien & Hope, 2010). The cost reduction of renewable energies (especially PV) and of the equipment attached to them has enabled the expansion of the PV market (Bhandari & Stadler, 2009).

To address a segment of this demand, few pioneer companies offer a photovoltaic (PV) system[2] for lighting purpose in urban areas. Consequently, new customers are starting to take advantage of this technology through specific channels that this article will highlight.

This emerging market, which further development is expected, is at present constituted by upper-middle income customers. They use this new technology for different reasons as compared to rural customers.

Research Objectives

This paper highlights a new trend where urban users in India are turning to solar PV solutions for their electricity needs. Using a case study approach this paper tries to explain the innovative business niche in Bangalore.

Based on the definition of diffusion as a process by which an innovation is communicated through certain channels overtime, among the members of a social system (Rogers, 1983), the article aims to answer 3 sets of questions:

1. How do companies define these new segments of urban customers to better expand their business?
2. How are solar photovoltaic (PV) systems, as an off-grid energy supply option diffused within this new category of customers?
3. What are the motivations driving these customers in using off-grid options?

The purpose lies in better understanding the companies' development perspectives to that market, how they mine those potential customers, and the customers' motives to purchase a PV (Sonnberger, 2013).

Methods

To answer these questions, two companies facilitating access to alternative sources of electricity, introducing new technologies (PV) and new service models were identified: SELCO India's[3] PV installation and BCIL's[4] housing development projects. Both these companies propose their service to very distinct customer groups: low-income for SELCO and high-income for BCIL.

To understand the service development and the cultivation of this niche market, an exploratory field study was conducted in Bangalore in June 2014. In both companies we conducted interviews with project managers in charge of implementing the project at the end users' level, but also with the general managers to have a better understanding of the business development. These continuous interactions led us to interact with their customers during few field visits. The choice of customers was done according to the proximity to the SELCO's office. The interviews were generally conducted with a

[1] Population of BBMP (Bruhat Bengaluru Mahanagara Palike: Greater Bangalore Municipal Corporation) in 2011 is 8 425 970. The population of Bangalore district increased a 46.68 % from 2001 to 2011.

[2] The system consists of solar panels, batteries and an invertor.

[3] SELCO India stands for Solar Electric Light Company India. Hereinafter also referred to as "SELCO".

[4] BCIL stands for Biodiversity Conservation India Ltd.

standardized questionnaire however open-ended questions were also mobilized to better understand the reality.
The managers of the companies were interviewed to figure out how they define the new market. Secondly, the project managers and the customers were interviewed to know how the services are brought to them and why they choose the services. Field visits were conducted with the project managers and the customers, whenever possible.

Results

Based on the qualitative survey realized on few customers at the level of the two companies (SELCO & BCIL), few results are presented now. The results of such an exploratory study cannot be generalized yet, but they give first hints regarding a "shift" of customers groups who purchase PV systems.

SELCO India

SELCO India, a private company established in 1995 in Bangalore, mainly provides affordable PV lighting systems for low-income customers in rural underserved communities.
SELCO recently implemented up to ten projects in Bangalore area, involving the use of solar energy systems for urban customers. All of them are connected to the grid system. It should be mentioned that we do not have information about the precise number of customers of SELCO.
The very recent exploration of the urban market corresponds to two goals from a marketing viewpoint.

- It firstly aims to create awareness on environmental friendly systems by installing it at a collective users' scale such as educational institutions or commercial places.
- The second aim is to use these initial projects as a showcase for organizations having their headquarters in Bangalore that can be potential customers of off-grid electricity system. Some of these organizations working in the rural context might also spread this off-grid system in their local offices.

Through these goals, customers become indirect marketing channels for spreading the idea that solar is an alternative for reliable and sustainable power.
The General manager of SELCO classifies this emerging urban market into four categories[5] which are not exclusive :
The first category concerns the customers exposed to acute problems with grid electricity supply and willing to have an alternative source of energy for practical reasons.
The second category deals with high-income customers willing to use eco-friendly energy systems.
The third category gathers savings-minded people willing to save energy so as to save money (financial payback).
And the fourth category is formed by environmentally conscious customers who are willing to sell back the energy they generated to the grid system. This willingness corresponds to the customers' desire, and not to reality, since the PV systems are not connected to the centralized grid due to prohibitive State regulation.
The issue of optimization of the investment by the customers needs to be considered. In our cases, the productivity increase by the introduction of the PV system doesn't appear as a motivation of urban customers, in contrast to rural customers who consider it important. The productivity increase impact would be crucial when implementing PVs because customers invest extra capital on this new technology (Ajit & Dilmus, 1991; Schäfer et al., 2011). However, we observed the increase of "educational productivity" in the case of the school: the continuous electricity supply ensures the student a better learning process of the computer use without interruption caused by power outages.

Case studies of urban collective customers

The following two cases describe the solar panel installation projects for this new urban market.
The two case studies of SELCO consist of an educational institution and a restaurant for vegetarians. In the first case, the customer is facing a grid electricity problem. As a "green-minded" person, the head of the school hopes to sell electricity. The second case deals with a "green-minded" customer who also hopes to save money.

Mahila Seva Samaja, an educational institution

The first case studied was Mahila Seva Samaja (hereinafter also referred to as "the client"), a hundred year old academic institution in Bangalore engaged in education, from nursery to high school. It is a society-oriented school as the founding members worked for helping destitute women.[6]
The project manager of SELCO identified the client through a network of environmental organizations for which he previously worked.
In 2013, the client installed a PV system of SELCO to power a computer room in a new three-story building dedicated to children's education, planned for the 100-year anniversary of the institution.
Three motivations incited the client to install the system:

1. A stable energy source to power the computer room since the intermittent power outages hinder the usage of the computers.
2. An autonomous solar power generating system, to power the room rather than charging the backup batteries with the public grid electricity.
3. A project to sensitize students to the PV system and other environmentally friendly technologies beneficial to the society.

The science teacher, who introduced the PV system to the school, is interested in "green" services because her relatives have an "eco-friendly" house attached with solar panels and are doing garbage composting.
This situation already shows how these innovative models are diffused within the society. In these communities open to innovation, SELCO's PV product found the right niche to get into. The development of the market rather happened by cross-pollination in contrast to traditional marketing approaches, most probably due to the level of

[5] We do not have data or a proper information on the size or the percentage represented by these 4 groups.

[6] The costs of the project were 600,000 INR, equivalent to 9,763 USD.

maturity of the customers, who are convinced by the quality of the product. SELCO just needed to propose them the product to finalize the sale.

Paradigm Shift: a restaurant for vegetarians

The second case studied was “Paradigm Shift” (hereinafter also referred to as “the client”), a restaurant for vegetarians opened on March 2014 attached with an activist center for people who feel concerned by environmental issues.[7]

In 2013, the owner of Paradigm Shift was preparing to open her restaurant. Sensitive to environmental issues, she decided to install a solar power generating system as an alternative energy source for lighting and ventilation by fans. She came to know about the activity of SELCO as one of her friends has a classmate in the company.

The client had three reasons to install the PV system:

- The first reason was its self-sufficiency. As SELCO spent much R&D effort on implementing the PV system in rural areas, the client was convinced of its self-sufficiency and wanted the activist center to be as self-sufficient as possible, in line with its concern for environmental issues.
- The second reason was the social orientation of SELCO India. As it focuses on projects serving in rural communities, the client believed that paying for SELCO’s service indirectly helps underserved communities to have access to electricity.
- The third reason, which is secondary, was commercial. By installing the PV system, the client can save money on electricity costs and recover the initial cost within a few years. So as a commercial entity, they decided to have the PV system.

These two cases of SELCO highlight a multiplicity of factors that drive the potential clients to adopt solar PV products:

- Access for stable energy, “green energy” and spreading awareness among the community;
- Access for self-sufficient energy, helping underserved customers and saving electricity bill

Both the clients are not only motivated by short-term financial benefits but also by long-term environmental and social implications.

BCIL

Biodiversity Conservation India Pvt. Ltd. (BCIL) is a housing developer established in Bangalore that focuses on sustainable methods of creating zero energy emission homes (ZED). BCIL has been creating neighborhoods that appeal to a category of customers who are discerning and see the needs of homes being free of the municipal grid for energy, water and waste management.

BCIL is convinced that developing environmentally friendly residences can be achieved without compromising comfort or convenience. ZED homes have also proven, contrary to industry trend, that such 'green homes' can be created with cost efficiencies that match the regular builder costs and with no additional cost of home purchase, or later on campus upkeep to the home owner or occupants of the building.

BCIL’s mission is to build residences with zero import of water and energy and zero export of waste while reducing the amount of construction materials such as cement and metal, besides avoiding use of other building materials that spell extraction of sand from riverbeds and stone and stone dust from mountains. To pursue this vision, ZED housing developments make the best use of PV systems, wind power generators, solar water heaters, well water and rainwater harvesting to generate their own energy and grow their own water. LED-lights, efficient ACs, aerated showers and aerated water taps are equipped to reduce the consumption of water and energy. ZED homes integrate these services at no extra capital cost to the homeowner. Interestingly, there is a savings of 30–40 per cent to the occupant on energy bills and a drop of 60–70 per cent in fresh water demand.

It provides those services at one-stop building located on a gated community that BCIL owns.

Market expansion toward “affordable” and “low-income”

Since 2000, BCIL has developed seven “green” campuses in Bangalore and Mysore. Until 2004, it only developed stand-alone houses. However from then, it also started to develop apartment residences to expand its business toward lower-income customers.

BCIL defines its potential customers as three groups according to their income levels: *rich*, *affordable* and *low-income*. *Rich* is its initial target customers those earn 400–500 thousand Rs[8]. per month and spend 20–30 million Rs[9]. for its independent houses. *Affordable* consists of customers earning 100 thousand Rs[10]. per month that BCIL is willing to provide flat or independent houses those cost 4–5 million Rs[11]. And *low-income* involves the customer acquiring 20–30 thousand Rs.[12] per month, which would be potential customers for flat residences of 2–3 million Rs[13].

The price reduction of technologies and BCIL’s knowledge in “green” housing domain enabled it to practice apartment projects and make “green” housing available for lower-income group.

Word-of-mouth communication plays a big role in attaining new customers for its residences. In most cases, the existing inhabitants introduce and show their houses to their friends or colleagues, who, in a later stage, become the next customers.

Conclusion and Discussion

These two cases indicate the gradual emergence of new customers willing to have off-grid energy access to

[7] The costs of the project were 330,000 INR, equivalent to 5,370 USD.

[8] Equivalent to 6,510–8,140 USD.
[9] Equivalent to 325,000–488,000 USD.
[10] Equivalent to 1,630 USD.
[11] Equivalent to 65,100–81,400 USD.
[12] Equivalent to 325–488 USD.
[13] Equivalent to 32,500–48,800 USD.

decrease their dependence to the public grid electricity supply service.

Both companies studied are trying to reach this new customer base, aiming to democratize their service to include a wider range of society. These visionary companies are supporting the growth of that slowly emerging niche market by making their service affordable and adoptable.

This diffusion process is followed by three shifts:

- The first shift concerns the development of the urban market: the companies are bringing the service concept initially designed for the rural market into the urban market. Nowadays, the centralized energy supply system prevails in cities but decentralized systems, which have been recognized as a past arrangement, are gaining back its value in some specific contexts.
- The second shift concerns the expansion of the market to new categories of customers. The service initially designed for two very distinct income groups of customers is brought to middle class customers: from low-income to upper-middle income group for SELCO and from higher-income to lower-income group for BCIL.
- The third shift concerns the additional motivation of customers. The new emerging categories of customers also consider the environmental assets of the service as compared to rural customers who are essentially interested by its practical and financial aspects.

Those three significant shifts are observed within the innovation diffusion process happening through communities (a school, a restaurant and gated communities) open to innovations and environmentally oriented solutions (solar PV system). Those communities function as communication channels, which are indispensable for the diffusion, as defined by Rogers (1983): "The essence of the diffusion process is the information exchange by which one individual communicates a new idea to one or several others. At its most elementary form, the process involves: (1) an innovation, (2) an individual or other unit of adoption that has knowledge of, or experience with using, the innovation, (3) another individual or other unit that does not yet have knowledge of the innovation, and (4) a communication channel connecting the two units". The diffusion process of the solar photovoltaic systems we followed in Bangalore sticks to this description.

These cases highlight the emergence of customers ready to change their energy consumption practices for both environmental and financial reasons. These customers are ready to pay for private off-grid energy supply systems (like solar energy) and to use them as an alternative to their conventional energy supply system. They constitute a small niche of customers, marginal in numbers but significant in terms of purchasing power, and visible by their equipment level and their style of consumption. These customers would be the typical "lead users" (Hippel, 1986).

The activities of BCIL indicate early signs of a switch from providing technology to providing energy product service systems in a different context (Schäfer et al., 2011). The next

phase consists of reaching mini-smart-grid systems within the public centralized electricity supply one.

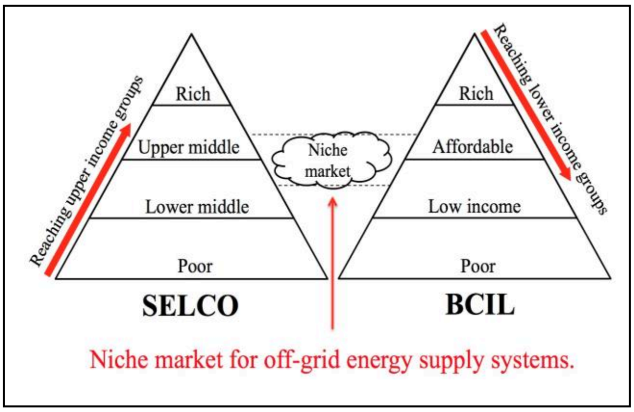

Figure 1: Identification of a niche of potential customers for SELCO and BCIL

The customers we followed represent "archipelagos of population" that are likely to adopt environmentally efficient products and services. Their purchasing power and their willingness to explore alternative solutions to improve daily comforts make them adopt specific lifestyles of communities highly equipped in "green" technologies (Lange & Meier, 2009). Bangalore constitutes a suitable city to study these "archipelagos" as the economic growth and the inclination for innovation allow the development of alternative ways of consumption.

"How to reach the next customers?"

The companies are approaching these "archipelago" on purpose: the category of customers they are addressing is convinced of the necessity of using services that have lower impacts on the environment. Those customers are ready to be convinced by the companies' service. They are also willing to spread the idea to others, at a slow but steady pace.

But how does one convince the customers who are not ready to be convinced? Those customers, who are not naturally exposed to that innovative service, are not easy to reach. However in order to spread the idea to the whole society, the companies must approach those scaled/mass customers who are not confined to the isolated but convinced communities.

Lowering down the price of the service would make it accessible to a larger portion of the society for the service to be more attractive. However, in some developed countries, such as Germany, "to further spread photovoltaic systems, ways of raising people's interest rather than addressing financial motives have to be identified" (Sonnberger, 2013). Hence, taking into consideration frameworks of analysis not strictly confined to economical parameters to explain customers' purchasing motivations needs to be further developed and discussed.

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An inclusive strategy to trigger solar technology market: Case studies of rural distribution models from Ethiopia

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Abstract

The paper is based on study of the distribution chain in Ethiopia. The changes in sale, flow of inputs and the partnerships triggered through incentive-based funding is analyzed over a period of almost one year. The findings show that there has been a growth in sales, an increase in frequency of marketing and promotional activity at the final consumer level through the micro and small enterprise network, a development of customized financial products and also an initiation of new channels and strategies of distribution. The push and pull forces created through incentive at the supplier level and end user activation by the last mile MSE is assisting scale up of commercial dissemination of clean energy products in remote and new geographies and also making the products accessible and affordable to the final consumers.

Keywords: solar light, distribution chain, business model

Introduction

Statistics indicate that only 23 % of the population in Ethiopia had access to electricity in 2012 (IEA, 2014). This is further aggravated due to huge inequality in the rural and urban areas with access at 10 % and 85 % of their respective population. While solar PV is being increasingly used to create access in many countries, this inequality in Ethiopia is also worsened with the under-developed solar market. Even though the solar initiative was initiated in the 1980s, the Ethiopian solar market continues to be in early development stage. The total solar PV market potential is estimated at around 52 MW (GTZ, 2009). In recent years, there has been an annual growth of 15 to 20 % in the dissemination of solar PV solutions (UNIDO, 2010). However, this growth is mainly restricted to the cities with most of the solar equipment dealers being located in and around Addis Ababa (UNIDO, 2010). On the other hand, the major share of the envisaged potential consists of the rural Ethiopian households whose opportunity to have access to solar lighting solutions is constrained by the absence of a proper distribution and after-sales service chain. The creation of a distribution channel is also hindered due to stricter regulations laid down by the Government Regional Energy Bureaus and requirement of approval to initiate dissemination activity in rural areas.

While accessibility to clean lighting solutions seems to be a prominent issue, another key challenge towards scale up of solar lighting technology is also affordability to procure the solar lighting products by the rural households (Lighting Africa, 2012). This issue comes to the fore with more than 30 % of the population below the international poverty line of US$ 1.25 (UNICEF, 2014). The average per capita income in Ethiopia is less than half of the sub-Saharan average (IFAD, 2014). This being the economic status of the households, the study (UNIDO, 2010) mentions that price of the solar PV system in Ethiopia is nearly 2 to 3 times higher than in the Asian countries. The low average per capita income coupled with higher priced systems creates a vicious issue of affordability to majority of the rural Ethiopian households. Further, inadequate technical and financial capacities of rural retailers and distributors and insufficient resources and capacities to carry out promotional and marketing activity to target the rural end-users is also constraining the scaling up of solar lighting products (Lighting Africa, 2012).

Further, rural electrification is not considered a profitable option by the private sector (Yadoo & Cruickshank, 2010) To overcome this, providing output based aids in the form of incentives has proved to be an adept way to mobilize private investment towards rural electrification and decentralized expansion in countries such as Argentina, Chile Panama, Philippines and Bangladesh (Tomkins, 2001). The success behind USA rural electrification is the linking of incentives to targets, in the form of subsidy schemes that triggered decentralized expansion through cooperatives (Pellegrini & Tasciotti, 2012) and it was incentives by the Japanese and German governments that led to market formation of solar market (Johnson & Jacobsson, 2001). The need for linking incentives to output-based targets in Ethiopia with aforementioned barriers in terms of affordability, access and awareness is thus very much needed.

TERI and HoAREC/N, supported by DFID (Department for International Development), Government of UK, have been implementing a project to identify barriers to dissemination of solar lighting solutions in Ethiopia and to demonstrate the techno-social viability of decentralised solar energy applications through innovative business models and financing options. In order to trigger an early development stage market, an incentive of US$ 10.63-15.2 or 40 % of product, whichever is lower, is provided to the national level distributor as an output based aid on reproduction of receipt of sale by the distribution channel partners (suppliers/retailers etc.). This receipt submitted has to be for the transaction between the last mile retailer and end users to ensure that the sale has actually been transacted. Physical verification of the claims is done quarterly on a random basis by HoAREC and TERI. The incentive being provided is being used to expand dissemination through development of last mile MSE[1], creating value addition to the rural end-users and necessary maintenance support systems. The benefits of access to affordable clean lighting technology to end-users are well documented; therefore the objective is to create the necessary market for solar lighting products and also to discourage a pure subsidy based market activation.

This paper discusses the case for incentive based model, supported under the TERI-HoAREC-DFID project, to support the market players for scaling up dissemination of solar lighting products in Ethiopia. This identifies the changes in the supply chain, the translation of the incentive in to various inputs to the multi-level supply chain stakeholders and the value addition to the consumers, which can trigger the dissemination and uptake of solar products in the country.

Research Objectives

The research objective is to evaluate the potential of incentive based strategy in triggering the solar lighting technology market in the early stage of development towards inclusive market activation through development of the rural distribution chain. The study has attempted to address the following research question: In an underdeveloped and non-inclusive market does incentive based sales model at the top and bottom level of the supply chain trigger better market activation?

Methods

A case study based approach has been adopted as we study a context-dependent, complex and understudied phenomenon of incentivizing the distribution channel partners and the activation of last mile MSEs. The study was done to see the changes in sales over a period of one year and changes in terms of the flow of inputs, partnerships developed, marketing and promotion activities undertaken. A primary survey of the end users and MSEs has been done in Arsi Negelle, Ziway and Butajira woredas (i.e. districts). In addition, interviews were also conducted with the national level distributors such as Lydetco PLC, Rensys Engineering PLC, Solar Woman, Sunlight Electrical Engineering and Solar Energy Foundation and the local NGO partners who support the last mile MSEs.

[1] Micro-enterprises and small enterprises are those business enterprises with a paid-up capital of less than Birr 20,000 (in USD) and Birr 500,000 (in USD) respectively

Results

Distribution channels of solar lighting solutions

The Figure 1 illustrates the distribution chain and the different channels used by the suppliers of solar lighting solutions, along with the inputs that are exchanged among the players in the distribution chain. There are four channels of distribution I, II, III and IV. Channel 'I' represents distribution by Unions. Each Union consists of many Cooperatives at Woreda level, which further consist of Primary Cooperatives formed by farmer members. Channel II is the local distributor who further distributes the product to the retailer. Channel III is the agent of the national level distributor who acts as a retailer at the regional and village level. Channel IV is the regional and village level Government Energy Bureaus (GEB) that not only assists in distribution but also in product promotion

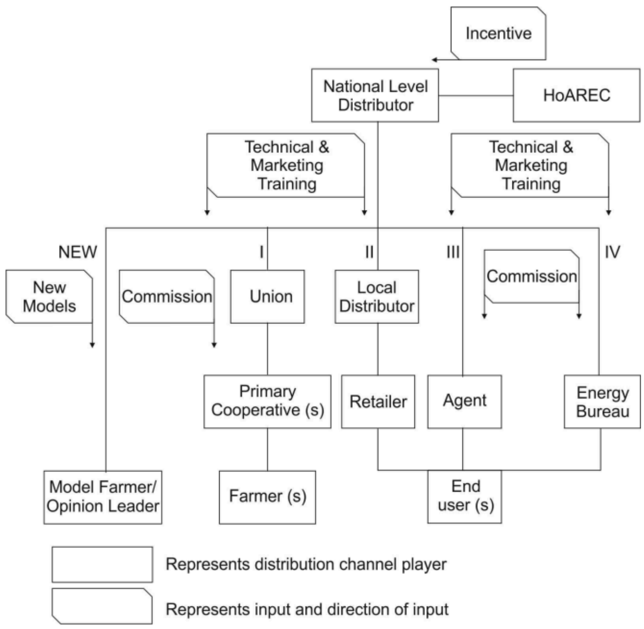

Figure 1: Distribution Chain of Solar Technology

Channel IV was the prevalent distribution chain (before the project intervention) and the inputs put into this channel were supply of solar lighting solutions and technical training. In addition, promotion was also done through GEB officers at the regional level. Promotion was also done by the national level distributor through newspapers and radio channel. The last mile MSE network was non-existent and purchase orders and supply was completely ad-hoc. The promotion activity carried out by the GEB officer was a onetime activity and the promotion carried out by the supplier was not customized to local language or culture. Post-incentive based project agreement with the national level distributor, a new set of inputs started flowing among the distribution channel partners and new channels for distribution also started that created value addition for end-users and last mile MSEs.

Impact of incentive on distribution channel

The incentives to the national level distributors have been transferred partially to the Union, Cooperative, primary cooperative and the sales agent. The incentive (around 30 % of incentive/system) is transferred as commission to cooperatives which also is trickling down to the primary cooperative and is deposited in their common account. The cooperative common fund thus grows proportional to the number of systems bought by its members. Being also the end-users, the value addition through incentive based sales is not only providing clean lighting solution but also strengthening cooperatives in the form of healthier finances. This indirect and direct benefit to the end-users is creating a pull effect to purchase more systems.

Among other tangible inputs, some of the national level distributors are now able to take the risk of introducing products in virgin areas. They use the incentive to identify opinion leaders in the form of model farmers and then the products are given for nominal cost to them for demonstration effect. This is a temporary channel used for product introduction, customization and brand building. Thus, the incentive is also serving to creating better products market that meet consumer expectations, risk coverage to introduce new products and gain feedback, and also building brand image by having opinion leaders as their consumers. Incentive is also taking the shape of intangible input such as marketing and promotion training for different actors in the distribution channel. The tangible commission and intangible inputs such as promotion training is generating a demand for information input to the suppliers. Researchers observe that a major challenge in underdeveloped market is lack of awareness on the benefits of clean energy products to end-users (Rai & Clough, 2012). This challenge was addressed by translating the incentive into marketing and promotion activities such as village level market yard promotion, local language flyers, banners and radio advertisements. These awareness campaigns and value addition in terms of financial and health benefits through solar lighting products has also created the desired pull effect.

MSE channel of distribution

The MSEs, who are primarily producers of improved cookstoves, is a new player added in to the distribution through this project. Their alignment with cleaner energy technology mandate made them a good alternative channel for promotion of the solar lighting products. One of the major challenges in development of last mile MSEs has been absence of credit extended by national level distributors thus requiring cash based purchases by end-users. Since majority of the end-users lack purchasing power, this increases the shelf life of the products and makes this an unattractive option for last mile MSEs. The incentive given to national level distributors is allowing them to sell products on credit to MSEs. The MSEs with better understanding of end-users have developed customized financial products such as: "register and pay in installments[2]" and "two installments"[3]. These products have made the solar lighting solutions. The MSEs are able to place bulk orders at discounted prices and pay in installments by delivering these financial products to cooperatives and employees of private enterprises. Intangible inputs such as technical capacity building, marketing and promotion techniques are also being given to the MSEs. These inputs are translating into localized market yard promotion and village level promotion. The frequency of promotion by the MSEs is weekly unlike the one-time promotion carried out by GEB. These marketing initiatives customized to local setting are bridging the awareness gap in the rural households about the solar lighting products. The awareness to the household on the economic and health benefits of using solar lighting products is creating a value addition by giving the household a cleaner alternative for lighting. Further the profit margin received by the MSEs is creating enabling partnerships between MSE-cooperatives, MSE-village level local representatives and MSE-GEB Officer. The margins on sale are being partially shared by the partners that is triggering additional promotion and marketing activities to create access for more end-users.

Increase in end-user sales

The value addition delivered through last mile MSEs in the form of access, affordability and awareness has created a pull effect from end-users with the incentive acting as push to the national level distributors and last mile MSEs. The exchange of tangible and intangible inputs and formation of new partnerships among MSEs, local agents, GEB officers, NGOs, cooperatives and private enterprises have assisted in increase in the sale of solar lighting products. A total of 4128 systems were disseminated in the last one year (Figure 2)

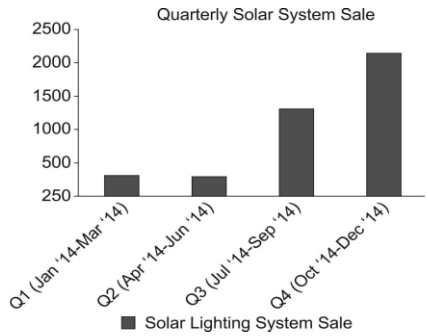

Figure 2: Quarterly Sales of Solar Lighting Products

Post-project sustainability

The incentive-based sales will be active till June 2015, so the suppliers and MSE are investing part of the incentive and margins they respectively receive into activities that may sustain the supply and demand post-project. Some of the suppliers are planning to invest 50–70 % of the incentive into brand building through marketing and

[2] Register and pay refers to an initial registration fee of 10 birr (≈ $ 0.50) in advance to confirm order placement and pay the remaining amount within 3 months of receiving their product.

[3] Two installment purchase: refers to an initial installment payment of 40 % and balance 60 % is paid in a month's duration.

promotion in radio channels, newspaper advertisements, and scaling up current promotion activities in the form of fliers and banners in local language, brand promoting tee shirts for agents and GEB officers and promoting new products using the opinion leader channel.

Discussion

Incentive in the distribution channel

In an early stage market for solar lighting technology, with majority of the target population limited by accessibility and affordability, a strategy that creates both push and pull forces in the extreme ends of the supply chain can trigger the inclusive market activation. These push and pull forces will translate into tangible and intangible inputs such as commisions, promotional product offers, training and capacity building of the distribution channel players on technical and marketing aspects, and custoimized financial products to the final consumers. Currently there are six distribution channels being utilized by the national level distributors including the MSE based channel added throught the project and the temporary channel of model farmers and opinion leaders. The early development stage of the market is a reason for the presence of six different distribution routes to reach out to the rural solar PV potential, some of which may converge and finally the market may have 2–3 channels. While it is early to say which of these channels will be sustainable and converge with the other, there is no denying the fact that the push and pull strategy has able to genertate the interest among all stakeholders, which may finally trigger the development of a commercial market for solar products to enahance electricity access.

Partnership approach

There is a great emphasis laid by large companies on the need for new alliances and cooperation so that commercially viable investments can succeed in poor countries. The association, with the improved biomass cookstoves producing MSEs, acts as the channel of last mile distribution and the local NGO partner handholds these entrepreneurs and acts as a medium to capacitate them. These partnerships are the conduits for flow of inputs across the distribution channel and are creating access to affordable solar lighting products.

Challenge as an opportunity

The limited income of the African consumers is a big challenge towards scaling up of the market and the issue is even more pressing given that the initial acceptable price point is quite low for new buyers. But the case study under discussion, with the evidence of quarterly sales in the rural regions, shows that through direct marketing to the consumers and physical demonstration of the product by the last mile MSEs at the village level meetings and market yard sales is reducing the unfamiliarity of the products. Further, the product is more easily affordable with MSEs also accepting installment based purchase. The availability of the incentives to the MSE is acting as a leverage to cover the costs of installment purchase.

The tangible inputs such as sale of product on credit and at a wholesale price to the MSEs by the supplier are encouraging new MSEs to take up the activity. Further, the supplier is able to take the risk of a credit-based supply, due to the cushion in the form of incentive being given on sale of products. Further the wholesale price is also translating into reduced purchase price to the consumer. The suppliers are also using incentives for localized promotion and translation of user guides in local language. While there is a school of thought that suggests that discounted sales, incentive-based project funding will distort the market and are not ideal for sustainability, however, this pilot project shows development of partnerships and increase in risk taking ability of the MSEs and distribution partners has led to new marketing strategies and increase in the geographic reach of the solar lighting products. This incentive strategy is beyond the promotional pricing strategy that only lasts until the discount in price is offered. This incentive strategy is translating into long-lasting outcomes such as partnerships, brand building, multi stakeholder capacity building and strengthening of the last mile MSEs.

This case study shows that incentivizing sales can trigger the entire distribution channel towards creation of new channels, input flow and partnerships. While it may be premature to fully conclude about the success of the initiative, it is observed that activities are being taken up by the suppliers and MSEs towards sustainability beyond the active project period. New challenges may crop in future, which will more clearly determine the success of the approach adopted.

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Techno-Economic Feasibility of PV Irrigation in Egypt

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Abstract

Egypt's Delta and Valley with the highest population and agriculture density is susceptible to Nile depletion through flood irrigation and inundation attributed to climate change scenarios. To mitigate the risks, the government reclaimed circa 3 million acres for agriculture utilizing the underground water as well as excess solar energy for powering the irrigation. Through a techno-economic model, this paper gages the feasibility trends of PV pumping over dominant subsidized diesel in geographic areas of potential utilizing discounted payback period, and unit water costs of water as an objective function. It was found that PV pumping is feasible at low hydraulic loads and tends to be less attractive with increasing hydraulic loads.

Keywords: PV Irrigation; Solar pumping; Egypt

Introduction

Agriculture in Egypt exhibits the highest employment rate of 55 % indirectly and 30 % directly, also accounts for 17 % of the GDP and 20 % of all foreign exchange earnings (Boers, 2013). 65 % of agriculture along with 99 % of the population are located in the Nile Delta making use of the Nile River which accounts for 76.7 % of Egypt's available water resources through flood irrigation mostly (UNEP, 2010). The immense water consumption pushed Egypt to the water poverty limit and with the current water demand trends, it is projected that Egypt would require twice the current share of the Nile water by the year 2050 (Salim, 2012). The US department of trade report that the Egyptian water pump market is among the largest in the world, and although the delta is connected to a heavily subsidized national grid prices of 0.015 US$/Kwh , the diesel driven pumps dominate the irrigation market (UNEP, 2003). This is attributed to the unreliable grid and subsidized diesel at 65 % burdening the Egyptian government with 21 % of the national budget allocated to energy subsidies (Castel, 2012). Moreover, diesel is among the highest CO_2 emitting fuels that drives climate change. According to (Olba & Saab, 2009), a 1 m sea level rise, would flood 34 % of the Delta displacing about 8.5 % of the population and jeopardizing 12 % of Egypt's agricultural land and hence, the food security. Having realized that, the government reclaimed more than 3 million acres and considering the available underground water aquifers plus treated water; the second available water resource with a 28 % for irrigation (Olba & Saab, 2009). As for powering the irrigation pumps, a huge subsidy was removed and the diesel prices increased by circa 66 % to favor Egypt's solar conditions reaching 3,900 sunshine hours and above 2,600 Kwh/m^2 ("globalpetrolprices," 2014; Salim, 2012).As a preference, farmers tend to purchase the high recurrent cost pumping systems rather than high capital cost ones (Fraenkel, 1986). In addition, with the little published concerning the economic feasibility of PV pumps in Egypt, farmers remain skeptical of the return on such investment in absence of incentives. PV (photovoltaic) driven pumping demonstrated its technical and commercial feasibility elsewhere. Nonetheless, feasibility studies in the literature considered either economic or technical feasibility of PV irrigation, and mostly, the studies were rather system size and/or location specific. A method for sizing a PV irrigation system based on; climate, geographic location, soil quality and crop water requirements was applied near Badajoz, Spain (Gajić et al., 2013) considering only economic indicators. (Kelley et al., 2010) developed a general method to determine the technical and economic feasibility of PV irrigation systems, but exclusive of irrigation application and storage scenarios.

Research Objectives

This paper attempts to devise a generalized approach to assess the feasibility and cost trends of standalone PV underground water pumping against diesel driven pumping. Furthermore, simulate the behavior of both pumping systems under the current Egyptian economic status and various farming sizes within geographical areas of potential. Most importantly, assess the factors with the most impact on the PV pumping feasibility and unit water costs (UWC) as well as highlighting the potential CO_2 emissions reduction through deploying such technology. Thereby, lay out the case for institutions and stakeholders interested in sustainable energy and agriculture.

Methods

The system is feasible when the PV driven pump's unit water costs (UWC) is less than the diesel driven one. A set of technical and economic parameters were identified in a mathematical model with formulas to simulate the PV and diesel pumping configurations. Those simulations are then, combined in an objective function (UWC).

PV pumping is technically feasible when common system configurations are assembled in available land areas accommodating the system size (Kelley et al., 2010). Sizing of the PV and diesel pump is a function of geographical location in Egypt, field area and the crop type storage and irrigation application. The geography entails available solar energy and aquifer depth while the crop type and irrigation application determine the irrigation water requirement and storage. The economical assessment of the pumping systems makes use of the total revenue requirement (TRR) approach to truly reflect the incurred costs over the lifetime of the two pumping systems. This approach is commonly used when comparing a renewable energy system and a conventional one serving the same purpose. Another indicator was the payback period based on a discounted cash flow (DCF). Parameters of major contribution to the lifetime cost of the pumping systems are varied reference to a base case in a sensitivity analysis to assess the trends of the UWCs.

Technical study

Configuration & Operating range

A standalone PV pumping system with a maximum hydraulic load of 4,620 m^4/hr (Figure 1). The Hydraulic load (HL) is simply, the product of the flow rate and the total dynamic head. It is a useful tool since pumps unlike energy systems of (Kwh), have 2 parameters; head and flow. The configuration constitute;

- PV array
- Brushless DC (Direct Current) motor in conjunction with a submersible pump make use of the low maintenance and high efficiency combination and avoid the inverter's capital cost within the hydraulic load range of this paper. Lorentz PS and PSK2 series are the models of choice. The operating ranges as a function of the hourly hydraulic load were derived from Lorentz

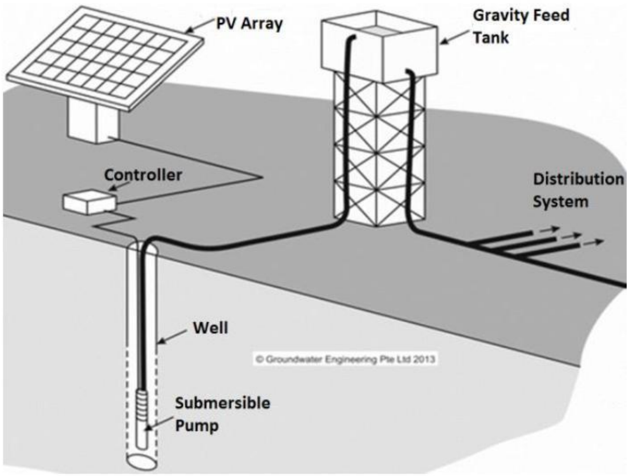

Figure 1: PV pumping schematic

- Gravity feed tank to store water rather than higher investment and maintenance costs of batteries. The storage capacity is dependent on storage at the root zone of the crop which is in turn dependent on many factors (soil, cropping pattern, climate, etc.) outside the scope of this paper (Glasnovic & Margeta, 2007). In this paper, water is pumped from a water source to a gravity tank to equate pressure and account for night pumping hours, if required. Gravity tanks are elevated to overcome friction losses in the distribution system.
- The distribution system in agriculture is the irrigation application. Drip systems complement PV irrigation owing to its high water application efficiency and low heads. Application efficiency is the useful amount of water delivered to the crops on field while, application head is the pressure head required to overcome friction forces. A combination of low efficiency and high head increases significantly the size of the PV system.

Sites Selection

(Salim, 2012) conducted a study to select suitable sites in Egypt for solar pumping of underground water. The suitability was defined based on 4 factors with different weights; solar insolation (40 %), Aquifer depth (30 %), salinity (15 %) and distance from Delta (15 %). Areas of sand dunes or rock faults and susceptible to incidence of flash flooding or seawater intrusion were excluded. The geographical parameters of the three most suitable areas are considered in the base case and sensitivity analysis. The Peak Sunshine Hours (PSH) varied from 6.4 to above 7.1 Kwh/m^2 and aquifer depths varied from a low of 25 to deeper than 350 m.

Daily Water Requirement

The Daily water requirement for irrigation (Q_{PV}) in (m^3/day) depends on the real evapotranspiration (ET_r) in (m/day) of the crop which is the actual water consumption of the crop per unit area (A_f) in (m^2) and application efficiency (η_{app}).

$$Q_{PV} = \frac{ET_r * A_f}{\eta_{app}}$$

The pump design flow rate (Q_{design}) in (m^3/hr) is obtained by dividing (Q_{PV}) by daily (PSH) in case of PV system, and daily pumping hours (H_{DP}) for the diesel system (Kelley et al., 2010). In reality, the crop water requirements vary through the year. Crops need more water in their growing seasons. In that contention, farmers using PV pumping are advised to plant more than one crop per year to smooth the water demand all year (Barlow et al., 1993).

Total Dynamic Head (TDH)

TDH_{PV}=Aquifer depth + Vertical rise + Friction losses

The vertical rise in (m) is the vertical distance from the ground level to the inlet of the storage tank.

$$\text{Vertical rise} = \text{Tank elevation} + h_{Tank}$$

Tank elevation builds sufficient pressure head to overcome friction losses in the distribution system inlet pressure as a function of unit inlet pressure U_{IP} in (m/m^2).

$$Tank\ elevation = drip\ inlet\ pressure = U_{IP} \times A_f$$

An increase in tank height will increase the TDH and ultimately the pumping costs. Height to diameter ratio ($^{h_{Tank}}/_{d}$) of gravity feed tanks should reflect a wide and short design (Barlow et al., 1993).

$$\text{Tank } storage\ capacity = \pi\,(^{d}/_{2})^2 h$$

The TDH of the diesel system is the same as the PV one excluding (h_{Tank}).

Hydraulic Energy and PV array size

The solar field area (A_s) in (m^2) and PV generator peak power (P_{PV}) in (KW_p) are given by (Al-Smairan, 2012) and (Kelley et al., 2010).

$$HE = 0.002725 \times TDH_{PV} \times Q_{PV} = 0.002725 \times HL$$
$$P_{PV} = \frac{HE}{PSH \times \eta_{sub}} \times SF\ ,\&\ A_s = \left(\frac{P_{PV}}{I_{max} \times \eta_{PV}}\right)$$

(HE) is the Hydraulic energy in (Kwh/day), (η_{sub}) is the subsystem efficiency and (SF) is the safety factor, (I_{max}) is the solar radiation used by the manufacturer for the PV panels power rating at standard test condition (STC) in (Kw/m^2), and (η_{PV}) is PV panels efficiency.
The diesel system required pumping power (P_P) in (Kw) is divided by the load factor (L_F) to determine the generator power rating ($P_{Gen,rated}$) in (Kw) (Al-Smairan, 2012; Kelley et al., 2010). (η_p) is the pump set efficiency.

$$P_P = \frac{0.002725 \times HL_{diesel}}{\eta_p}\ ,\&\ P_{Gen,rated} = \frac{P_P}{L_F}$$

Economic study

All non-uniform annual costs are levelized. Levelizing costs is converting the non-uniform annual costs to their present values and summed up to equal annual payments (annuities) over the lifetime of the project. Costs associated with components present in both pumping configurations are not included. Costs of the water distribution system, piping and well drilling are also not included in the analysis, as they are independent of the power source used. The standard cost investments of components listed in Table 3, are levelized by a capital recovery factor (CRF) to find equal amounts; annuities (A_{CI}) equivalent to the present value (P). (i) is the annual discount rate and (n) is the project lifetime.

$$A_{CI} = P \times CRF\ ,\&\ CRF = \frac{i(1+i)^n}{i(1+i)^n - 1}$$

O&M and fuel costs are non-uniform yearly expenses (Table 1) and usually nominal escalation rate is introduced.

$$CELF = \frac{k(1-k^n)}{1-k} \times CRF\ ,\&\ k = \frac{1+r_n}{1+i}$$

($CELF$) is the cost elevation levelization factor relating first year expenditure ($P_{O\&M}$) and an equivalent annuity ($A_{O\&M}$).

Table 1: O&M Schedule and Costs

Maintenance event	Event frequency	Cost/event (US$)
Minor Service	4/year	67
Major Service	2/year	530
Overhaul	10,000 hours	30 % of New
Panels cleaning	1/month	$f(A_s, labor\ cost)$

Results

The base case reflects a hydraulic load of typical small scale farming of 6,000 m^2, (ET) of 0.005 m/day and an aquifer depth of 60 m. The base case inputs listed in Table 2, Table 4 and Table 2 Technical Diesel Inputs yielded UWCs of 0.17 and 0.32 US$/$m^3$ for the PV and diesel pumps respectively as shown in Figure 3and a discounted payback of circa 3.5 years. Last but not least, circa 115 tons of CO_2 could be saved. The cost fraction analysis revealed capital cost dominance in the PV system. Usually, fuel dominate the cost fraction, but within this small hydraulic load, economies of scale and subsidized diesel cost play a role.

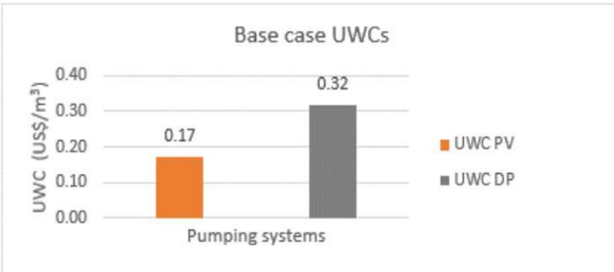

Figure 2: Base case unit costs of water

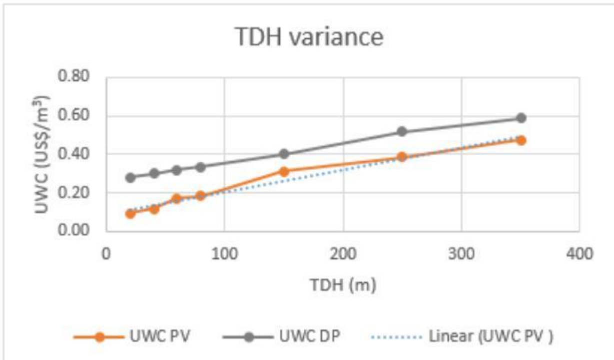

Figure 3: TDH Variance

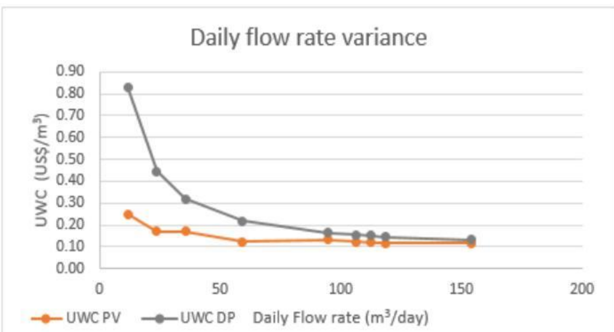

Figure 4: Daily Water Requirement Variance

Increasing the two components of the hydraulic loads illustrated in Figure 4 and Figure 5, decrease the feasibility of the PV system reaching pay back periods of 12 and 15 years. Increase in TDH, increases the UWCs due to increase in capital and fuel annuities. On the other hand the daily water requirement decrease the UWCs because of increase water production though the diesel system shows faster declining pace. The PV system UWCs curve are flattened by increased storage costs. Figure 6 and Figure 7 show the impact of the feasibility main drivers, PV array & diesel costs with significant variance in payback periods. When varying other parameters, UWCs and payback;

- UWCs & payback increase with increasing the storage and night pumping hours.
- PSH increase, decreases UWCS, but at the base case hydraulic load, it is not of anticipated significance as at higher hydraulic loads.
- Increase in the project lifetime decreases the PV pumping UWCs while increasing the diesel pumping ones.

Discussion

This paper accords with literature outcomes of PV irrigation being feasible at lower hydraulic loads and tends to be less feasible as the loads increase. In Egypt, the solar insolation brings PV UWCs down but unfortunately, so does the diesel subsidies to it UWCs.

Thus, interested financing bodies should harmonize high capital investment via loans to be more in pace with negligible recurrent & recovered capital costs of long term PV pumping projects.

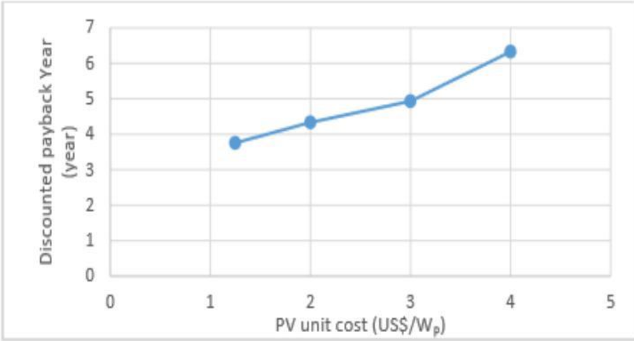

Figure 5: PV unit cost payback variance

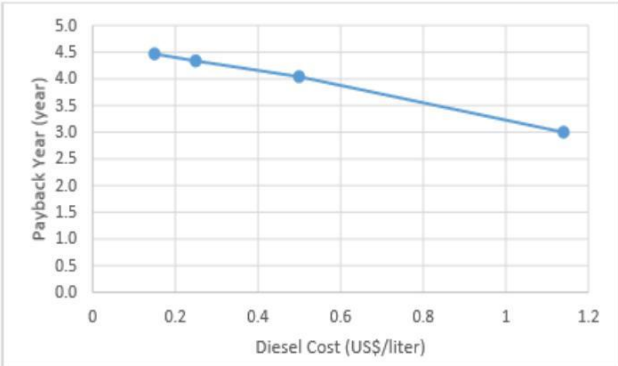

Figure 6: Diesel cost variance payback

Table 2 Technical Diesel Inputs

Inputs	Values
η_P, (%)	0.6
L_F, Load Factor	0.7
$Specific_{fc}$, (liter/KWh)	0.3
CO_2 emissions (Kg/KWh)	1.05
$H_{DP,}$ daily pumping hours (	8

Table 3 Technical PV Inputs

PSH	Night pumping (hours)	Storage (hours)	h_{Tank}/d	Distribution Friction (psi/m^2)	Aquifer Depth (m)	η_{sub} (%)	Safety Factor	I_{max}, (kW/m^2)	η_{PV}, (%)
6.8	0	1	1	0.001	60	60	1.2	1	14

Table 4 Economic Inputs

Project lifetime (years)	PV array (US$/$W_p$)	Gravity tank (US$/$m^3$)	Diesel pump (US$/Kw)	Diesel Generator (US$)	Unskilled labor, ($/hr)	Diesel cost (US$/Liter)	Interest rate (%)	Escalation rate (%)
20	2	200	131	$234P_{Gen} + 3400$	7	0.25	10	3

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Scientific Papers

IV. Financing

Energizing one million rural households in India: A reality check

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Abstract

In India, decentralized renewable energy has emerged as a favorable solution for rural electrification. A cadre of private sector enterprises exists and companies are in a process of scaling up operations. In the context of over 300 million people in India without access to electricity, this paper analyses the ability of decentralized renewable energy enterprises to reach the milestone of one million electrified households. The analysis reveals numerous barriers to scaling up operations, including gaps in financing needs and availability, geographic scale, and lack of implemented standards and quality assurance. Innovative financing initiatives, INFUSE ventures and ADB's 'Mini-grid Fund', are explored and evaluated as potential programs to bridge financing gaps for decentralized renewable energy enterprises.

Keywords: decentralized renewable energy, financing, India, off grid systems, business models

Introduction

At present, over 300 million people in India lack access to electricity (IEA, 2014). Through international efforts focused on energy access, such as the UNSE4ALL initiative, decentralized renewable energy (DRE) has gained global focus and interest for its potential as a reliable energy supply. IRENA (2015a) finds that renewable energy is now the most economic choice in most off-grid areas for electrification and integrating renewables into most fossil-fuel based off-grid systems will lead to a decrease in generation costs.

The Government of India has made a concerted policy push towards nation-wide electrification, with a stated goal of full electricity access in the country by 2019 (Press Information Bureau, 2014). In this context, off-grid renewable energy systems have been emphasized as key solutions. For example, the newly launched Deendayal Upadhyaya Gram Jyoti Yojana rural electrification scheme contains funded mini-grid and off-grid components (MOP, 2015). In addition, the Ministry of New and Renewable Energy (MNRE) has set targets for 2 GW of installed off-grid solar energy by 2022 (Sarangi et al., 2012) and removed excise tax duties on off-grid solar systems.

While traditional electrification programs have been undertaken by public-sector bodies, there has been an increasing shift in focus towards integrating market-driven electrification solutions. This burgeoning DRE sector in India is now going through a transitional phase. Several DRE enterprises have moved from pilots and prototypes to small and medium scale enterprises and raised initial capital, primarily from impact investors or concessional financing from bilateral and development finance institutions. As the volume and growth of enterprises increases, there is a sense of optimism that DRE enterprises like Boond energy, Mera Gao Power, Husk Power, Frontier Markets, ONergy, etc. will scale up and each reach the mark of one million households electrified in coming years.

Donor agencies and development finance institutions have begun to shift the focus of grants, departing from partly or wholly subsidizing off-grid renewable energy systems and instead directing grants towards supporting the creation of a sustainable market (IRENA, 2013). Bilateral and multilateral finance institutions have launched innovative financing mechanisms like Clean Technology Fund's "Renewable Energy Mini-Grids and Distributed Power Generation Program"[1] implemented by the Asian Development Bank (ADB), and the Electrification Financing Initiative (ElectriFI) by the European Commission. These initiatives provide concessional debt, equity and guarantees mechanisms for DRE companies (CIF, 2014; EC, 2014). In addition, a small but growing number of private sector finance sources, such as commercial and impact funds like the Indian Fund for Sustainable Energy (INFUSE) and Bamboo Finance, are already investing in DRE companies.

To strengthen India's business environment in support of market-driven approaches to energy access, a new sector alliance of businesses, NGOs, and government agencies – the Clean Energy Access Network – was launched in 2014. This initiative links relevant DRE organizations, including SELCO foundation, UN Foundation, and Ashden India Sustainable Energy Collective, to collectively work on DRE challenges such as scaling up business models, energy access finance, setting standards and guidelines, promoting skills and training, and supporting incubation centers for entrepreneurs (Climate Group, 2014).

Research Objectives

This paper seeks to evaluate the DRE sector in India and investigate the barriers facing enterprises from reaching the milestone of one million households electrified.

This paper begins to analyze the following questions:

- What are the critical problems and solutions for scaling up DRE enterprises? How can the right solution be applied to the right sector need at the appropriate time?

[1] Referred to henceforth as the "Mini-grid Fund"

- How can economies of scale effects that have driven grid-connected solar costs to fall from $4/W to $1/W be replicated in DRE solar?
- Is there a proven successful commercial business model which can be scaled up to electrify a million households in India?

Methodology

In answering these research aims, a state-of-the-art literature review was conducted to investigate current DRE enterprises and financing initiatives. A funding appetite pipeline for several enterprises including solar home systems, mini-grids, and solar PV pumping systems was prepared along with donor mapping, to identify the scale of funding and innovative financial instruments. Further, several discussions were carried out with DRE enterprises to understand their perspective on financing in the sector. Based on the literature review, financial deal mapping, and enterprise discussions, major barriers to scaling up DRE enterprises in India were identified. Case studies of innovative financing programs by financial institutions and current DRE enterprise business models were selected and analyzed in their ability to address the identified barriers.

Analysis

The following key challenges for scaling up the DRE sector have been identified:

Gaps in Available Capital and Needs

The emerging DRE sector faces a paradoxical situation: a critical mass of projects will only materialize when there is easily accessible investment capital and high interest from DRE enterprises, but investment flow and DRE enterprises entry into the sector will only emerge when a certain critical mass on the ground is reached (Bhatt, 2014). In order to unlock the potential of private sector-led off-grid electrification, significant gaps in DRE enterprises and investor needs require bridging.

DRE enterprises have a need for *high risk, low return capital with long-term tenor* (Bhattacharyya, 2013). Early-stage DRE enterprises face substantial challenges accessing finance as high due diligence and transaction costs for a small-scale investment deters equity and debt providers (Bhatt, 2014). In addition, perceived high risk and relatively low return on investment by lenders increases financing difficulties. Finally, early-stage DRE enterprises also lack a track record of operation, thereby limiting accessibility of debt from commercial lenders. Growth-stage DRE enterprises with an established operating record have an easier time accessing equity investments (Bardouille & Muench, 2014), but face challenges attracting debt to expand operations as they frequently have yet to prove commercial viability for an extended period of time.

On the other hand, commercial banks, multilateral development banks (MDBs) and other development finance institutions have not invested significantly in DRE companies due to their small investment size and high transaction costs. To illustrate, a typical MDB investment costs the institution more than 0.5 million USD for technical and financial due diligence on the prospective company and legal costs. Processing the investment can take up to one year, for debt or equity transactions ranging from $ 2 million to $ 200 million. Further, low returns on investment below 15 % can be a deterrent for MDBs and DFIs. Commercial banks have low appetites for risk and typically require 30–40 % of project costs be covered by the equity by the DRE enterprises, often resulting in an equity gap that prevents lending (GVEP International, 2014).

A few private sector finance sources exist to fill debt and equity financing gaps. Venture debt lender IntelleGrow provides loans between $ 100,000 and $ 600,000 to social ventures operating India, such as mini-grid DRE enterprise Husk Power (Guptu, 2014). Bamboo Finance's "Bamboo Global Energy Fund – Solar For All" is a notable example of a private equity investor, making $ 0.5-$ 4 million equity investments in companies involved in the off-grid solar energy value chain (Bamboo Finance, 2014).

From MDBs and development finance institutions, promising initiatives are undergoing capitalization with ADB's 30 million USD Mini-grid Fund and the European Commission's 75 million euro ElectriFI fund. As the Mini-grid Fund and ElectriFI officially launch, it will be important there is an enterprise appetite to absorb the volume of investments. DRE enterprises such as SELCO have sold over 200,000 solar home systems, while ONergy and Orb energy have sold over 100,000 and 40,000 off-grid lighting products, respectively. Although the scale up of DRE enterprises over the past years has been impressive, there is still a shortage of operating enterprises to absorb large infusions of capital and electrify 300 million remaining people.

Scale

This section evaluates how economies of scale effects that have driven down grid-connected solar costs can be replicated in DRE enterprises. While the DRE sector has benefitted from reduced physical component costs brought on by gains in component efficiency and manufacturing, challenges remain in capitalizing on economies of scale for other business dimensions, such as product distribution and marketing, in the relatively fragmented off-grid market. India consists of 28 states with vastly different physical and socio-economic landscapes. Purchasing power, needs of people, and the political situations on the ground differ in each state. For example, subsidized electricity for agricultural irrigation in Punjab hinders the scaling up of solar PV pumping in unelectrified communities where expectations have been set for highly subsidized electricity.

A business model and enterprise successful in one state will have to adapt to the conditions in other states. For instance, large capacity solar mini-grids of over 100 kW have been deployed in high density locations of Sunderbans and Lakshadweep Islands, while almost all mini-grids implemented in Chhattisgarh are less than 6 kW and deployed in sparsely populated areas (GNESD, 2014). Discussions with DRE companies reveal that every village even within the same state is a challenge for them (IRENA, 2013). They have to convince the village leader, local entrepreneur, bank manager or farmer to believe in the value of a SHS, mini-grid or solar PV pumping system. This struggle goes on with every village, requiring tailored marketing and distribution chains that limit scalability.

Lack of standards and quality assurance

Notable attempts to create standards and monitor quality assurance for the off-grid energy sector have been undertaken by the MNRE, as well as state level governments (MNRE, 2014; Sarangi et al., 2012). Technical standards and guidelines have been put in place for aspects of the off-grid energy sector. For the emerging DC-based mini-grid and electronics market, India recently launched the Low Voltage DC Forum under IEEE Standards Association to create common technical standards for low voltage DC products (IEEE, 2014). In addition, IFC's Lighting Asia program has introduced a quality assurance framework for products in India and supports product testing and verification (Lighting Asia, 2014). However, implementation of these standards and quality assurance still lag behind. For instance, Simpa Networks launched a pre-payment meter product facilitating 'pay-as-you-go' energy services in India and planned to sell this payment system services to mini-grid companies. The business plan faced major challenges as many of the mini-grid companies in India work on different voltages and wattages due to lack of technical standards in place, making the product incompatible with these systems.

Standardization would reduce technological risk and help create a more unified market for products, while increasing investor confidence and access to finance. While minimal licensing requirements for rural energy providers and lack of technical standards has reduced regulatory hurdles and costs, it fragments the market and hinders scalability of enterprises beyond local regions.

Case Studies

To address certain aspects of these challenges presented, innovative financing initiatives and business models have emerged. The following case studies assess nascent programs structured to support market-driven DRE solutions and business models of DRE enterprises currently scaling up operations.

INFUSE Ventures

INFUSE Ventures is a 25 million USD venture capital fund operated from IIM Ahmedabad, India. It includes contributions from commercial, government, and development finance institutions such as IFC, BP, MNRE, and Bank of India (INFUSE, 2013). This collaborative fund brings together an international network of investors and corporates to help fund, advise, and accelerate scale-up of promising Indian clean technology startups, with a focus on DRE enterprises. INFUSE makes investments of 1 million USD, while also providing seed funding of 0.2 million USD. MNRE's contribution is a first loss financial instrument, where MNRE will bear costs of investment losses. This gives much needed comfort to other investors.

To select companies, INFUSE conducts a series of workshops where technical and financial support is provided to prospective companies. For instance, Surya Power, a solar PV pumping company operating in Tamil Nadu and Karnataka, was groomed over two workshops and invested in by INFUSE. They were provided technical and financial support to prepare their business and financial models and were selected for final investment. Surya Power and other companies are constantly under the mentoring and have INFUSE experts for their expansion. This model looks at all the steps of incubating DRE entrepreneurs to move beyond pilot stage to small and medium-sized enterprises. It is yet to be seen if this model can take up the challenge of incubating a DRE company which can electrify one million households.

Asian Development Bank 'Mini-grid Fund'

A novel program under development is the Mini-grid Fund implemented by ADB and co-financed by the Clean Technology Fund Dedicated Private Sector Program. The program plans to finance gaps in project financing or company scaling-up efforts, mitigate credit risks of project sponsors, and provide low-cost loans to mitigate high capital costs of DRE systems in pilot countries of India, Indonesia, and the Philippines (CIF & ADB, 2014). The 34.3 million USD program will deploy 30 million USD in investment capital over three years to private sector companies and impact funds, supported by a 3.5 million USD grant for technical assistance. The program is expected to bring sustainable electricity supply to 150,000 households with up to 30 MW of mini-grids installed.

ADB's mini-grid fund pools resources into a dedicated facility to overcome certain prominent barriers to mini-grid investment. Firstly, the program centralizes resources to streamline investment procedures and lower transaction costs for investments, such as screening potential companies and impact funds and due diligence of projects. Transaction costs are often a large barrier for investment capital for mini-grids due to the small size of projects and equity investment amounts. The grant component of the program will support a dedicated advisory team to evaluate business plans of companies, conduct capacity building with local financial institutions and other financial partners to leverage funds, and establish templates for legal documentation that can be replicated across projects (CIF, 2014). By identifying and guaranteeing a deal flow of mini-grid investments, specialists can be assigned to the project and execute similar due diligence processes, lowering overall transaction costs per an investment.

The program could leverage additional capital into the mini-grid sector from both public and private sector sources. ADB has estimated a 1:2 leverage ratio for CTF finance, where approximately 20 million USD will come from ADB and 40 million USD from other sources (CTF & ADB, 2014). Due to the highly concessional terms of the CTF finance, the program funds blended with other capital sources would play a key role in lowering the overall financing costs for companies. By allowing for more favorable lending terms and higher expected returns, the program bridges a gap by providing the high-risk, low return capital sorely needed by private sector actors in the mini-grid sector.

Lastly, this fund represents the largest proposed investment in mini-grids to date and includes measures towards mini-grid market development, including development of knowledge products from the investments (CTF & ADB, 2014). This is a strong signal to DRE enterprises and investors that opportunities exist in the burgeoning market. The string of projects developed from this fund can help establish the needed track record for mini-grids in the region that give more confidence to commercial investors.

Mera Gao Power

Mera Gao Power is a DRE enterprise providing lighting services with low voltage DC solar mini-grids in Uttar Pradesh, where an estimated 20.5 million households lack access to electricity (Census of India, 2011). Founded in 2010, the enterprise currently serves over 20,000 households. The enterprise follows a micro-utility model, offering specific services of lighting and mobile charging for a weekly fixed service fee. Mera Gao's core offering is 2 LED lights and mobile charging for 7 hours daily for an initial connection fee of 50 INR and a 25 INR weekly fee (IRENA, 2014). The enterprise is vertically integrated and provides mini-grid design, installation, operation and maintenance. Local women's groups and joint liability groups from mini-grid users are engaged for payment collection. To ensure reliable service, Mera Gao has an active team of technicians to respond to service problems within 24 hours.

Low capital and operational costs have made Mera Gao's business model commercially viable. The enterprise typically deploys 240 Wp solar-based systems that serve 40–100 households at an initial capital cost of around $ 900, with a projected return of 30 % and payback period of under three years (GNESD, 2014). Mera Gao focuses on priority services of lighting and mobile charging for households with incomes typically below $ 1/day and low appetite for additional services due primarily to cost restraints (Aklin et al., 2014). With low household energy demand and slow energy use scale up with time from its customers, Mera Gao is able to deploy a "skinny grid" model with a standardized low-cost design optimized to its customers' priority services of lighting and charging. Currently, Mera Gao does not design their mini-grids to be compatible with the national grid (IRENA, 2014). While this lowers costs by eliminating additional design considerations, it presents problems for expansion into other market segments and states where more regulatory cooperation is necessary.

Mera Gao benefitted from an initial 300,000 USD of seed funding from USAID in 2011, and raised 1 million USD in equity financing in 2013. In 2014, the company sought out debt financing and secured limited funding from a variety of sources, including 100,000 USD from angel lenders and 80,000 USD from IntelleGrow. The enterprise identified the following major challenges in accessing debt financing: 1) Indian laws restricting companies from accessing debt from abroad at international rates and 2) preferences by Indian lenders for non-moveable assets as collateral and at least 3 years of a profitable track records (Shaad, 2014). As Mera Gao continues to build up its profitable operational record to unlock commercial debt financing, accessing affordable working capital will be a pivotal challenge.

Looking forward, Mera Gao has identified mobile payments for customers as a priority expansion area to continue to lower costs and streamline payment collection. Developing SHS products for other market segments has also been highlighted, although the focus remains on its core mini-grid offering (IRENA, 2014).

Overall, Mera Gao's business model holds high potential for continued scale-up. It's low-cost, standardized service offering is well-suited to its target customers' priority needs of lighting and charging. With a market of over 20 million households without electricity in Uttar Pradesh, Mera Gao can continue to focus on the state while reaching a threshold of one million households reached. However, identified challenges in accessing working capital for large operation scale-up remain a significant hurdle. In addition, even within Uttar Pradesh, Mera Gao may need to expand its service offering to be able to meet the lighting and energy needs of different off-grid market segments.

Discussion

Private sector interest from developers and investors in the DRE sector in India is beginning to collect, but significant barriers remain for scaling up operations of enterprises. This paper analyzed three key questions on challenges facing DRE enterprises, leveraging economies of scale, and features of scalable DRE enterprise business models that could electrify one million households. Three critical barriers for scaling up DRE enterprises were identified. First, gaps in the financing needs and expectations of different DRE enterprises and financing institutions are creating roadblocks for quick disbursement of capital into the sector. In addition, a fragmented off-grid market with a large range of economic and political realities and a lack of implemented technical standards hinders the DRE sector from majorly scaling up operations.

Moving forward, innovative enterprise incubators and financing programs like INFUSE and the ADB Mini-grid Fund could fill critical funding gaps. If these initiatives are successful, they can serve as pilots to continue scale-up of the Indian DRE sector. In addition, the current scale and funding status of Mera Gao Power was discussed, along with associated challenges to meet the million household challenge.

However, this paper does not propose any single business model as the solution and is of the view that several smaller business models and DRE companies may be required to meet the million household challenge. While uniform technical standards would help create a unified market for products and attract additional investment, a standard delivery model could prove ineffective in meeting the diverse energy needs and political realities of the unelectrified population. To leverage economies of scale and bridge financing gaps, there is a critical need to promote a holistic development approach to expand the sector. Industry alliances such as Clean Energy Access Network that collectively tackle financing barriers, support incubation centers, and promote standards and quality assurance are key to building this conducive environment for DRE sector growth.

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A post-Kyoto CDM bioenergy business model built on systems expansion

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Abstract

This paper proposes a simple market model to strengthen the sustainability of bio microenergy systems. The model is based on a system expansion and proposes an integrated view of climate and development. This implies in the proposed market model that a micro bioelectricity plant project not only is focussed at the plant as such but can include deployment of improved cookstoves in adjacent rural areas thereby providing a sustainable supply of biomass and improved sustainability both through inclusive growth and positive health impacts.

Keywords: bioenergy, CDM, improved cook stoves, climate and development Introduction

Introduction

Due to the difficulties of reaching binding international climate policy agreements there is a growing interest in bottom-up approaches and bilateral climate agreements (see for example the recently published Post-2020 Climate Change Regime Formation (Chung ed., 2013). Since the lack of understanding between developed and developing countries concerning primarily the role of development issues in climate negotiations has been a critical reason for the difficulties at climate negotiations in recent years, and while the future of binding international climate policy agreements is uncertain, the importance of transfer of climate funding from developed to developing countries is gaining importance. Thus, a post-Kyoto Clean Development Mechanism (CDM), or similar, is likely despite that its actual design still is uncertain.

The ancillary effects of climate policies are well known (e.g. Ekins, 1996; Hourcade et al., 2001; Krook-Riekkola et al., 2010) and it has been stressed that these benefits, as improved local air and water quality, etc, are particularly important when addressing the total costs of climate actions in developing countries (e.g. Rive & Aunan, 2010).

CDM should lead to the reduction of greenhouse gas emissions but in addition also to sustainability as defined by the host country, i.e. the country in which the action is implemented. However, the local sustainability of many CDM projects is often questioned (Boyd et al., 2009; Zusman & Miyatsuka, 2013). Despite the requirement of sustainable development being a part of CDM, sustainability issues have not been a central issue of most CDM projects (e.g. Boyd et al., 2009). Further, it is well-known that there are large potential positive co-benefits relating to CDM projects, and that these benefits are of different kinds, e.g. environmental, economic, health, and other social benefits, and that the benefits depend strongly on the type of CDM project (Boyd et al., 2009; Zusman & Miyatsuka, 2013). In any post-Kyoto CDM-like regime it is thus of utmost importance that climate projects with large positive co-benefits can become attractive for investments.

Up to date a large number of CDM projects have been approved and many of these are in operation, particularly in India and China, but CDM is a project based mechanism and the the overall climate outcome of CDM is very far from the levels of intervention that would be required in order to be in line with the 2-degree target. Thus, it is called for a more programmatic and sectorial post-Kyoto CDM (Sterk & Wittneben, 2006; Weiss et al., 2008; Schneider et al., 2009; Bakker et al., 2011).

As already mentioned, the lack of understanding between developing and developed countries regarding how central development issues should be in climate negotiations has been, and still is, a major cause of the difficulties in reaching a new global climate agreement. Particularly in India, the policy emphasize on the term "inclusive growth" demonstrates the need to focus on actions not only targeting sustainability but also aspects of distribution with regards to development. This issue has been dealt with in an increasing number of research publications: e.g. Kok et al. (2008), Halsnæs & Shukla (2008), Winkler et al. (2008), Halsnæs & Garg (2011), Shukla & Dhar (2011), Kaechele et al. (2011), Walsh et al. (2011), Shukla et al. (2012), Pradhan & Ghosh (2012), Weitzel et al. (2012) and Johansson et al. (2014). A general conclusion of these studies is that it can be of great importance to take climate and development into account in an integrated perspective. This may affect climate negotiations in a positive direction since it essential with regards to developing countries' attitudes to climate action and binding targets, and clearly shows that development and climate protection can go hand in hand. This is an area where much more knowledge is needed.

A different way of addressing the coupling between carbon mitigation and development is presented by the model analysis of Shukla & Dhar (2011) showing that there is a large difference between the measures likely resulting of a general climate tax (measures dominated by CCS, carbon capture and storage), and those probably resulting of a more mixed policy package focusing on sustainable development (a mix of emission reduction measures).

In developed countries, interest in so-called green growth is growing. Regarded as a new area for economic growth, it is an area for possible increased exports of products and services related to the very wide concept of green development including climate actions. Many of the products and services, which are denoted *green* have been developed as a response to environmental constraints of different kinds. However, within the green growth sector it is still only a limited interest in targeting the fast-growing developing economies (possibly except China), where most of the next half-century growth will occur.

Due to variations in environmental policies, technical competence and experience, green growth focus varies between countries. Here, Sweden will be used as an example. In Sweden there are large forest resources and a large forest and pulp and paper industry. There has also been more than two decades with an active climate policy with a rather high carbon taxation in selected sectors. Together this has led to bioenergy becoming the largest primary energy supply where the biomass is used primary in the process industry and for heat generation and increasingly for combined heat and power. Naturally, this development has sparked an interest in bioenergy technology exports, e.g. small to medium sized bioelectricity plants. This has so far resulted in a few bioenergy CDM projects.

In rural areas of most developing countries, bioenergy is also the most important energy supply. Primary biomass and forest and agricultural residues are primarily used for cooking, most often in simple, inefficient devices. The combustion emissions are a major cause of respiratory illness and deaths (Bruce et al., 2000; Torres-Duque et al., 2008) mostly affecting women, responsible for cooking, and children. Further, collection of fuel wood is time consuming and back breaking and is also a task of women and children (Rehfuess et al., 2006). Recently, black carbon emissions due to biomass combustion have also become an issue in the global warming debate (Ramanathan & Carmichael, 2008).

There are several technology options available offering options of a more efficient combustion resulting in better resource utilization and reduced negative health and environmental impacts. Such options include cooking devices but also systems solutions including mini and micro grids based on electricity generation based on direct biomass combustion or biomass gasification. However, neither the modern cooking devices nor the more advance systems solutions have reach a dominating market share and deployment is slow.

Efficient fuelwood cooking devices, often referred to as improved cook stoves (ICS), come in a variety of designs with very different performance in terms of primary fuel to useful heat conversion efficiency. They also differ with regards to emissions. They range from very simple models to more advanced ones based on biomass gasification. Gasifier stoves are the most advanced and superior both with regards to resource efficiency and emission reductions but also the most costly. Adoption of ICS will not only imply a better utilization of the cooking fuel but also reduced negative health impacts due to reduced emissions and, when the fuel is gathered, to considerable time savings.

Globally, there has been a large number of ICS programs carried out but unfortunately the long-term success is far below expectations. A critical factor seems to be related to the households´ possibilities for economic gains (Barnes et al., 1994). Thus, ICS success increases with the share of the fuel wood that is purchased. This share is generally increasing with fuel scarcity, and is highest in urban and semi-urban areas.

CDM provides possibilities for financing of climate mitigation projects. Since an ICS project could lead both to reduction of fuelwood use and reduced methane and BC emissions in addition to the health benefits due to a more efficient combustion, CDM financing could certainly be an interesting option for ICS financing. However, in consideration of the above mentioned difficulties encountered by many past ICS programs in rural areas where biomass is collected rather than purchased coupled with the difficulty of accommodating an ICS program in the CDM framework due to that BC is not included among the Kyoto GHGs, the uncertainties relating to the climate impact of the use of woodfuels for cooking, and the large transaction cost relating to small-scale CDM projects, there are major barriers to overcome for a more large-scale ICS dissemination through CDM; as also evidenced by the very few on-going CDM ICS projects.

Objectives

This paper takes a departure in these three different topics; climate and CDM, green growth and technology transfer, and sustainable use of biomass, closely related to each other but not always dealt with in an integrated way.

The aim of the present work is to present a model based on small-scale bioelectricity generation, which in a post-Kyoto CDM framework could enable the inclusion of a wider sustainability perspective by addressing the bioelectricity plants in a systems expansion market model and focussing not only on the bioelectricity plant as such but also on a sustainable biomass supply including deployment of improved cookstoves.

Method and model

The study is based upon a recently proposed market model for energy efficiency at the base of the pyramid based on systems expansion (Vahlne & Ahlgren, 2014). The starting point for that study is the above described slow deployment of improved cookstoves. When fuel wood for cooking is collected ICS adoption is often very slow and there are even many cases when already paid-off cookstoves are abandoned while in urban or semi-urban settings, when all or a large share of the used cooking fuels are purchased, the ICS deployment seems much faster. This indicates that successful ICS deployment programs could try to mimic urban conditions and create local fuel wood markets to get a price, or a higher price, of the fuel wood. In (Vahlne & Ahlgren, 2014) such a fuel wood market model is suggested. The key principle is to create a demand for fuel wood, which in turn would lead to a price and a market provided that there is someone willing to pay for the wood. If the wood would be used for power generation climate funding could contribute to the fuelwood purchasing power. Actually, under a future climate regime climate funding could be obtained both due to carbon emission reduction in electricity generation (in line with bioenergy CDM projects) and due to substantial reduction of black carbon due to reduced emission when ICSs are adopted. In (Vahlne & Ahlgren, 2014), the fuel wood purchasing entity is assumed to be a coal condensing power plant where the biomass could be co-combusted with coal up to a share of about ten percent without any major power plant refurbishing. Therefore, this model would only work in countries with a

substantial share of coal power like China, Vietnam or India.
Here, the point of departure is instead a CDM bioenergy project. Up to now most CDM bioelectricity (condensing or combined heat and power) projects are of limited scale. There are several reasons for this scale limitation. First of all, even with substantial carbon funding there are profitability difficulties in most major grids supplied by power from fossil fuel or hydro power plants. One reason to this is the lack of mature biomass markets. In rural areas however, the grid is normally weaker and there are fossil fuel supply limitations. Thus, there are relative advantages for bioelectricity plants. Then, these plants can utilize locally available biomass, either agricultural or forest residues.

Results and Conclusions

The model proposed in (Vahlne & Ahlgren, 2014) discusses two major concerns topics related to implementation of the proposed model. One is the payment for the biomass. Since the model is assuming that ICS adoption would not alter the amount of collected fuelwood and that the excess fuelwood, saved due to the higher energy efficiency of the ICS, would be sold for use in a power plant, it is essential that the amount of compensation for purchased biomass should neither be too small (would not result in sufficient incentives for ICS adoption) nor too large (could result in increased deforestation). The other topic is deforestation. With increasing biomass payments there is an increased risk of deforestation and thus the model should be limited to areas not currently experiencing deforestation.
The model presented in the present model, would instead be centered on a small to medium-sized bioelectricity plant as part of a CDM project. The inclusion of the biomass market model ideas from (Vahlne & Ahlgren, 2014) would expand the bioelectricity system to also include a local biomass supply market where fuelwood could be traded for ICS. This would increase biomass supplies without increasing deforestation and would provide ICSs as part of a market based solution. The biomass stream not required any longer for household cooking due to the ICS adoption (and its higher energy conversion efficiency) would be purchased by the bioelectricity plant. Thus, without increased biomass payment this would result in a revenue stream for the household, which could be regarded as a payment for the labor of collecting fuelwood and would provide the economic means for household to purchase an ICS. In this way, the saved fuelwood due to ICS adoption would lead to economic gains for the households. Thus, the model mimic more urban environments where fuelwood is a market commodity and ICS adoption better. In this way, the proposed model would possibly overcome some of the socio-cultural obstacles associated with ICS dissemination in rural areas. In this way, the sustainability of the CDM bioelectricity project could be enhanced both due to a more sustainable biomass supply, through benefits associated with ICS adoption and through inclusive growth since wood gatherers would become part of the monetary economy.

While the model proposed in (Vahlne & Ahlgren, 2014) is addressing ICS adoption, the model proposed here is rather addressing a combined CDM bioelectricity and ICS project. The model proposed in (Vahlne & Ahlgren, 2014) is quantitatively evaluated through a calculation of the project economy. The outcome of the calculation, which includes the compensation to the biomass collectors, the distribution costs and revenues for substituted coal, shows that under most conditions there is a positive project economy as long as there is carbon funding available. This also indicates that this kind of project would be additional in the sense that it would not be occurring in absence of carbon funding (disregarding all other barriers). Calculations of the present, bioelectricity centred, model economy is still to be carried out.
Finally, the key message of this paper is that by addressing local energy systems development and actions (most ICS deployment programs are development rather than climate driven) in an integrated climate and development context (resembling the landscape approach as advocated by e.g. CIFOR, cifor.org) there could be several important sustainability benefits, which in turn can be essential for the long-term success of the microenergy system.

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The role of microfinance in energy access – changing roles, changing paradigms and future potential

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Abstract

This paper provides a concise theoretical overview of projects linking microfinance and energy access and tracks both sectors for signals of a transition process where roles and paradigms appear to be changing from both sides of the equation; a shift away from solar home systems to both smaller portable systems as well as more elaborate service offers through different mini-grid schemes from both international donors, as well as the demands of the end-users themselves. The paper concludes with an estimation of future potential, and microfinance's dynamic role in addressing energy poverty.

Keywords: Microfinance, energy access, minigrid, solar lantern

Introduction

With the final negotiations on the Sustainable Development Goals (SDGs) rapidly approaching, chances are high that, unlike in 2000 during the formulation of the Millennium Development Goals (MDGs), universal energy access for all will play an explicit role (UN, 2015). Voices are calling out for microfinance as the key link to make energy affordable for those living at the Base of the Pyramid (BOP). In fact, delivering energy services through end-user financing schemes offered by microfinance institutions has already become a widely cited and discussed topic (Mohiuddin, 2005; Morris et al. 2007; Rao et al. 2009; Rippey, 2012; Groh & Taylor, 2014; Sadeque et al. 2014; Allet, 2014), particularly brought to the forefront by Grameen Shakti, and the notoriety of it's founder, Nobel Prize Winner Muhammad Yunus (Wimmer, 2012). However, it must be acknowledged that despite the academic research and numerous pilot projects employing various business models, many microfinanced energy services have not reached the scale that many had anticipated and still lack evidence of evolving beyond the "project" phase. With the exception of Bangladesh, scaled-up and financially sustainable energy lending programs with national prevalence in increasing energy access rates are scarce to find. Academic literature, however, seems to continue to contend that there is in fact an important role for microfinance to play in the energy access field (e.g. Morris, 2007; Huybrechts & Mertens, 2014; Allet, 2014; Almeida & Roberts, 2014). Furthermore, there appears to be a gap in the analysis of a globally orientated assessment why so few initiatives seem to manage a larger up-take. While there are many barriers to implementation, it comes at a surprise that energy microloans have in practice not met the expectations of academics and experts alike.

Research Objectives

This paper analyses the link between end-user finance and energy access technologies and aims to discuss the question in how far MFIs are (still) an appropriate actor to participate in financing energy access for the BoP? And to what extent their role can potentially be strengthened through adaptation? It seeks to address the existing gap in literature by analyzing why microfinance, despite its theoretical synergy potential, has not managed to churn scaled results in achieving energy access for millions living at the BoP in the developing world. Furthermore, the paper utilizes the understanding of the progressive nature of energy needs of poor populations, to offer insight into the changing energy needs of end-users at the BoP. It further looks into the dynamic role microfinance can play in leveraging their unique position to avail the opportunity to help their clients access modern energy services.

Methods

A review of current literature on the subject of microfinance's role in energy access as well as an overview of current and past project reports is employed to identify gaps between practice and theory. A thorough analysis of the technological and financial nature of the relationship between microfinance and energy reveals a justification for the slow take up of microfinance energy access projects. An analysis of the progressive nature of energy needs for those at the BoP is conducted in order to identify new opportunities for microfinance institutions (MFIs) to engage in the energy access market. Moreover, both of the authors' professional experiences administering energy access programs through a focus on financial solutions is used to formulate critical analyses, and recommendations for future project formulation.

Results

It comes at a surprise that even after 10 years since the conception of energy lending through MFIs, the practice has not managed to reach scale. While some MFIs and energy service providers (ESCOs) have managed to incorporate energy lending permanently into their financial portfolio, successfully scaled-up energy lending programs are scarce and in most cases, debated over their efficacy. Bangladesh is among the few examples to date to achieve nationally measurable improvements of energy access through the energy lending approach, and in many instances is cited to be a result of significant government support and program management.

A review of major MFIs engaged in energy lending presents a technological dimension to the relationship between microfinance and energy access technologies. Microfinance generally only is applied to distributed stand-alone systems (Morris et al., 2007) to overcome the affordability barrier of the upfront payments for purchase of the system. In other terms, microfinanced energy technologies are generally for a single household or business, and are an independent generator of energy, not connected to any national or community electricity grid systems, and once the repayment is made, are fully owned and operated by the client. Moreover, typically these systems are within USD 250 to 500 and therefore clients must qualify for a loan of such a size, repayable in generally 2–5 years (Allderdice, 2007). Although loans of this nature are generally longer than the typical cash-loan disbursed by MFIs, they generally do not overwhelm the established procedures within the MFI, with the help of technical assistance, or oversight from management.

However, within the energy access industry, one can notice a shift from focus on stand-alone systems, to systems with both more and less capacity. This shift, is argued is a result of a dual divergence of energy needs away from standalone systems in opposing directions, as well as a shift in the donor community's expectations of the energy access ladder. These diverging trends as a result, have opposing pressures on MFIs from both the client base as well as the donor community.

Shift from Donor Community

Perhaps this shift is a response due to the fact that energy is no longer conceived in a binary "electrified vs. non-electrified" paradigm. Rather, a spectrum of access to energy that considers both quality and quantity has emerged to the forefront of the energy access debate (IEA/WB, 2014). The energy ladder has emerged as a concept in recent years, with the understanding that "populations can increase their access to energy services as incomes and energy provision expand" (Craine, 2014). The use of the term "ladder" is to evoke the implicit understanding that the goal is to climb the ladder to achieve uninterrupted, affordable and quality modern energy, underlining the progressive nature of energy needs.

The Sustainable Energy for All (SE4ALL) tracking network, as proposed by ESMAP employs such a categorization, using "tiers" ranking from 0 (referring to no access to modern energy) to 5 (referring to uninterrupted and access to large quantities of electricity supply, for example for productive machinery and uses). The specifications of the tiers for households can be found in Figure 1 in the appendix.

This concept of progression in energy access can therefore be linked to the current phenomenon of a shift away from stand-alone systems to minigrids on the one hand, and solar lanterns on the other. Solar lanterns, while having very limited uses (lighting and mobile charging), and generation capacity, allow end-users make the initial step onto the energy ladder, and are particularly relevant for the very poor populations who in some cases do not qualify for even a microloan. While stand-alone systems generally fall into the tier 1/2 category, minigrids can bring the end-users into tier 3 depending on the size, capacity, and reliability. They present the opportunity to use the energy for productive purposes due to higher overall capacity. These two technologies stand in contrast to, the typically microfinanced stand-alone systems, which are a considerable investment for many BoP households, however, generally do not yield enough energy for productive uses, and therefore many times result in an improvement in wellbeing in the household, but do not generate significant livelihood improvements and income generation increases (Groh, 2014). Therefore, to invest in bringing populations on to tier 2 of the energy ladder, lies in a peculiar "middle ground" that perhaps, in light of this new energy access framework, lacks justification for considerable investment from donors.

Changing Needs from End-Users

This shift is not just perpetuated through the international donor community, but also through the demand for energy services from the end-users themselves. For example, in Bangladesh, one of the few markets wherein stand-alone systems have successfully penetrated the market at a national level, SHS users are expressing a demand for more generation capacity that exceeds the possibilities of SHS offered through the MFIs' energy lending program (Groh et al., 2015). This is the case that is being reported elsewhere as well; in a recent study in Pakistan, 15 % of SHS users cited dissatisfaction with their system citing insufficient generation capacity to meet their needs (Ajaz & Taylor, 2014). It is for this reason, that many are turning to minigrids to access energy that is within a tier 3–4 categorization that can also be used for productive uses.

However, minigrids present much more technical and operational intricacies, which can be argued, are beyond the potential capacity of MFIs. They require significant investment in generation technologies and distribution infrastructure, while collection of tariffs, operation and maintenance of the grid, are arguably beyond the technical capabilities and scope of the MFI. On the other hand, Pico PV Solar Lanterns are also receiving considerable donor support, particularly through the IFC with its "Lighting Africa" and "Lighting Asia" initiatives with the intention to get the poorest of the poor simply on to the energy ladder to experience the benefits that lighting in the home or business after dark can render. Many argue for donor's preference for solar lantern programs due to the ability to reach significant numbers of households that constitute the poorest of the BoP, and therefore are able to satisfy institutional impact requirements. However, solar lights generally are sold for between 15–100 USD (CITE, 2015) and therefore are affordable to many more than the upfront costs associated with a stand-alone system. This presents a challenge to MFIs, as a 15 USD loan is not attractive to MFIs, as the administrative costs associated with administering the loan and collecting payments most likely outweigh the potential return from the interest rate.

Role of Microfinance in Question

MFIs therefore find themselves in a perplexing position in addressing energy access. While in the literature they continue to be hailed as indispensible actors in achieving universal energy access, due to the ability to bear risk to overcome the affordability barrier and unique relationship to the client, in practice the energy solutions that are being increasingly promoted by international donors, as well as demanded by consumers do not lend well to their financing models.

Particularly in the face of emerging pay-as-you-go or prepayment or leasing of systems gain prominence in the distribution of energy access technologies across developing world markets (such as energy-hubs in Africa, or pay-as-you go models from East Africa as well as India), it seems appropriate to question if MFIs continue to hold a unique value proposition to bridge the financial barriers of energy access for many BoP households through microloans.

While for minigrids and solar lanterns end-user finance may not appear as appropriate, this is not to claim that these energy technologies are without financing needs. On the contrary, their low penetration into off-grid markets is largely cited due to a need for financing (DFID, 2002). However, financing needs for solar lamps and minigrids differ significantly from stand-alone systems in that the financing needs are not coming from the end users, which some have argued may threaten MFIs' unique value proposition in the market.

Solar Lantern Opportunities for MFIs

For solar lanterns, affordability from the end-user is not the main issue, but rather distributional actors along the value chain have been cited as the stakeholders with the most need for financial support to reach rural off-grid customers (Lighting Africa, 2013). Evidence can be derived from Burkina Faso, where Total, a major petrol retailer, is the predominant retailer of solar lanterns in its shops, conducted as a corporate social responsibility initiative. The lanterns are sold at full cost, with Total subsidizing distribution by putting them in trucks with other products to be transported to their shops, wherein the infrastructure is already established across the country in even some of the most remote regions (Lighting Africa, 2013).

Therefore, it is argued that the solar lighting market is not out of reach of MFIs due to the financing needs in the solar lantern value chain, which if solved, as experience from Total shows, can successfully distribute solar lanterns to BoP households. From the experience in Burkina Faso, it can be derived distribution and last-mile retailers are the actors that require financing to reach remote customers. Yet, although many reports cite value chain financing as a major barrier to bringing the distribution of solar lanterns to scale, the connection to energy microlending is rarely made. Rather, it is argued that microfinance banks must again leverage their unique position, to fund loans below the threshold of many formal banks, to finance last-mile retailers to acquire stock and bear costs of traveling to remote regions to sell the lamps. While this does deviate from their comfortable role in financing the end-users, last-mile retailers are generally not beyond their typical client in their portfolio, and a loan needed to restock their business practice is considered generally within their financial capabilities, and small business loan service offerings. Moreover, what cannot be underestimated, is the market potential solar lanterns present; by 2030, the solar lantern market is expected to be valued at 125 million per year, all of which needs to bypass through a last-mile retailer.

While there have been some instances of MFIs financing last-mile retailers, generally this has been more often offered reluctantly by the solar light manufacturer themselves as technology suppliers are often reluctant to bear risk of non-repayment. Therefore, this presents a market opportunity for MFIs, however, must be recognized by the international community to support this process of training MFIs to cater to the last-mile retailer rather than to the end-user to whom they are more familiar with lending practices.

Minigrid Opportunities for MFIs

On the opposing side, minigrids present a very different challenge to the role of MFIs in energy service provision. The challenges are however very much dependent on the operational and ownership model of the minigrid, and can require upfront payments for the installed technology for either a community entrepreneur or a village association, as well as ongoing operational and maintenance costs, in addition to the monthly tariff that end-users must pay. The multiple sources and kinds of funding required to successfully operate a sustainable minigrid therefore complicate the MFIs position, as well as can overwhelm low-income household's and small businesses energy budgets. It is for this reason that many minigrids have opted for a pre-paid energy credits system, to ensure affordability from the end-user, and solvency for the minigrid owners.

Yet, the inability of minigrids to penetrate solar markets, without significant government support and donor back-up are attributed to many operational challenges that have been widely cited in research, in attempts to analyze a successful operational model that can be scaled up to reach the off-grid market. Firstly, while minigrids are hailed to offer more generation capacity than an SHS in order to spur economic activity, it has been found that productive uses within minigrid end-users remains very limited due to a progressive increase in complexity (Rahman et al., 2013). Moreover the initial costs for installation are in many cases so high, that the problem persists in most operational and ownership models; investors see the break-even point as too far in the future and therefore too risky, and local entrepreneurs cannot access such capital upfront. Finally, in many cases where minigrids have been successful, it has been primarily based in business districts – or local markets, which thus continue to exclude the poorest segments of the population due to affordability barriers with connection costs (Samad et al., 2013).

Therefore, while many have noted that the complexities or minigrids and operational models are beyond the capacity and reach of MFIs in their traditional role financing energy access, a closer analysis into their current challenges presents opportunities for MFIs to engage, again leveraging their unique position to finance energy access in the context of minigrids. Firstly, the design of both technical components as well as operational model of a minigrid requires an intricate assessment of both energy demand from the end-users, as well as their ability to afford and finance access. Therefore, there is a unique role for MFIs, due to their unmatched relationship to their clients and intricate knowledge of their financial situations, to work with the minigrid energy supplier company to assess the financial capability of communities.

As stated previously, while the financial needs of the community in respect to financing a minigrid differ depending on the operational model, Moreover, MFI's present a unique opportunity, for a "piggybacking" on their existing payment collection processes and infrastructure to additionally collect payments for energy use, alongside normal repayments for cash and business loans.

Increasingly, minigrid experts and practitioners are calling for a need for community ownership, or the employment of a local entrepreneur to invest in a stake in the minigrid, to ensure continued usage, repayment and interest in the grid's success. For the business models that employ such a community ownership component, MFIs can have a central role in supervising the pooling of the community's financial resources and overseeing the community's contribution to the minigrid's installation, operation and/or maintenance. Moreover, the MFI can act as a guarantor to a local entrepreneur or community council in acquiring a larger loan to cover the local investment into the capital costs of the generation and distribution equipment. Finally, the MFI may engage with the minigrid service provider, by agreeing to provide preferential loan rates to encourage clients to invest in productive use equipment or processes utilizing the energy source, thereby securing a significant "base load" for the minigrid, which will not only ease financial recoverability, but also system reliability for the minigrid.

While minigrids may be too technically sophisticated for an MFI to engage in a "one hand model[1]" without expanding their technical capacity significantly, there are many opportunities, as have been presented above, for the MFI to play a collaborative role with he energy service provider, and therefore mitigate and overcome barriers that have been identified in the successful promotion of minigrids to meet energy needs at the BoP. Any involvement of an MFI with a minigrid energy service provider will depend, as it does with the "two-hand model"[2] for stand-alone systems, on incentives and a careful balance of respective risk and responsibilities for such a composition to succeed. Moreover, the MFIs willingness to participate with a minigrid provider will depend on their ability to see a clear value proposition in terms of new customer acquisition, additional funding sources or fulfill an environmental or "green" mandate (Allet, 2014).

Finally, it should be noted, that in many cases MFIs have already considerably expanded their internal capacities in setting up processes and organizational structures to service loans for stand-alone systems, and therefore can be utilized in progressing to the financing of more technically sophisticated minigrids. For example, MFIs engaged in energy lending two-hand models for stand alone systems, such as is the case in Peru and Philippines, have created positions for engineers to address the technical aspects of their energy loans within the MFI to link financial and technical concerns and adequately oversee the program (Realpe, 2014). These employees therefore possess the technical capabilities that can be fostered to extend into more technically sophisticated technologies, and bridge the gap to bring MFIs into lending for minigrids.

Discussion

MFIs continue to be called upon to overcome the affordability barrier for the poor in accessing distributed energy technologies in the face of stagnant national grid extension. This assessment in the literature to date, however, is very much limited to stand-alone systems. This is not in line however, with the trends seen from both the international community as well as the demand from the people and small businesses at the BoP, actualized in a dual divergence from stand alone systems to both solar lanterns, and minigrids. It is expected that future financial support by the donor community for energy interventions will be earmarked on its ability to increase a household's or microbusinesses' respective tier assignment based on the multi-tier framework to measuring energy access.

While MFIs' involvement in financing the supply chain for solar lanterns, or entering into a two-hand model relationship with a minigrid energy service provider, as have been outlined are rarely seen in practice, the opportunities for MFIs to continue to engage in energy access, as the market changes are far from limited. This phenomenon must be met further research to analyze in depth, the role of microfinance in responding to the changing environment in the energy access discussion. An initial overview of the challenges to scale-up of solar lanterns and minigrids however have shown that financing gaps and opportunities for MFIs to leverage their unmatched relationship to the client exist in bringing these energy access technologies to scale. Therefore, it is believed that equipped with further feasibility studies and research, the proper technical assistance, appropriate incentives and division of responsibilities, that MFIs have an opportunity to address energy poverty while fulfilling their mission of extending access to financial services to a market that is believed to be 1.6 billion people (Groh et

[1] In the one hand model, championed by Grameen Shakti in Bangladesh, the MFI or technology supplier becomes the sole entity in the sale and credit disbursement to the end-user. In such an approach, one organization will procure the technologies and provide the credits to the end user, while themselves providing installation and after-sales services.

[2] The most commonly practiced model in energy microlending is the two-hand model, wherein an MFI will team up with a specific technology supplier in a contractual agreement. The MFI provides the loans, and the technology supplier provides the clients with quality systems and offer proper installation and after-sales services.

al., 2013). MFIs can remain an invaluable stakeholder in the energy access industry; however they must be willing to break from end-user financing to engage in other roles to remain a catalyst to universal energy access for all.

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Appendix

MULTI-TIER FRAMEWORK

ACCESS TO HOUSEHOLD ELECTRICITY

Attributes	Tier-0	Tier-1	Tier-2	Tier-3	Tier-4	Tier-5
1. Capacity	No Electricity	Very Low 1-50 W	Low 50-500W	Medium 500-2kW	High >2kW	
2. Total Duration Evening Supply	<4 hrs <2 hrs	4-8 hrs 2-4 hrs		8-16 hrs 2-4 hrs	16-22 hrs >4 hrs	>22 hrs >4 hrs
3. Reliability	No				Yes	
4. Quality	No			Yes		
5. Affordability	>5%		<5%			
6. Legality/Formality	No			Yes		
7. Health & Safety	No				Yes	

1. ***Capacity***: Amount of energy required to support different levels of power load
2. ***Duration***: (i) Total hours of supply during the day, and (ii) Hours of Evening Supply
3. ***Reliability***: No more than 3 unscheduled outages or breakdowns per week of less than 30 min each
4. ***Quality***: Drops or fluctuations in voltage are only minor and rare with little or no impact on use
5. ***Affordability***: Ratio of expense for a specific consumption package to monthly household income
6. ***Legality/Formality***: Electricity supply is obtained through legal means
7. ***Health & Safety*** : Harm from burning, injury, electrocution, air pollution or drudgery is unlikely.

Tier-rating for the household is calculated by applying the lowest of the tier-ratings across all attributes.

Figure 1: ESMAP Household Energy Access Tiers *(Source: IEA/WB, 2014)*

Scientific Papers

V. Evaluation and Assessment

A comparative study of electricity supply and benefits from microgrids, solar home systems and the grid in rural South Asia

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Abstract

We collect for the first time data on electricity supply conditions and benefits from three types of systems – solar home systems (SHS), microgrid and grid – in proximate villages in 3 districts in Bihar and Nepal. Based on 859 household surveys and 75 small business interviews, we quantify income differences and benefits to women and children, and qualitatively assess the role of electricity in rural development. Electricity service is highly differentiated across the systems, particularly with regard to availability and cost. We find electricity discernibly increases women's leisure, but find no discernable income differences. Kerosene use is noticeably reduced only with solar systems. Small businesses rarely locate themselves based on electricity availability, but suffer high opportunity costs from poor supply.

Keywords: Energy access; poverty; electrification; microgrid; solar home systems, village grid, grid extension, rural electrification.

Introduction

There are over 600 million people in South Asia who lack electricity access. According to the Global Energy Assessment (2012), investments of over $ 2.5 billion a year will be required to provide universal access in South Asia. Both national and private sector investments, as well as national policies and private entrepreneurship, will be required to meet this goal. In order to make effective investments, however, we need to better understand peoples' needs, and better exploit the range of benefits that different energy systems provide.

Electricity offers numerous well-known benefits for poverty alleviation, including improving education, health, and quality of life, and enabling more productive use of technology and time. Small-scale rural systems have the potential to additionally involve women, generate local employment, and provide more reliable supply.

Quantitative studies on the benefits of rural electrification are growing (Barnes et al., 2003; Peters et al., 2011; Khandker et al., 2012; Rao, 2013). Recently, an increasing number of assessments of minigrids and microgrids (Frearson & Tuckwell, 2013; Schnitzer et al., 2014; Yadoo & Cruickshank, 2012) and of solar home systems (Samad et al., 2014) has emerged. However, systematic and rigorous quantifications of benefits are few, and comparative studies of different systems are non-existent. This study begins to fill this gap.

To address this research gap, this research looks at the societal impacts of small-scale energy entrepreneurs in India and Nepal. It focuses on entrepreneurs that provide electricity to homes through integrated systems, either at a household level (e.g., solar home systems (SHS)) or at a village or community level with mini-grids, including bio-mass powered plants and micro-hydro power plants. This study uses a comparative approach, comparing these systems to surrounding villages with access to grid electricity and with no access to any form of electricity.

Research Objectives

This project is motivated by the following overarching questions: How has the recent proliferation of small-scale electricity systems in South Asia improved the lives of communities that they serve? How does supply from different types of solar offgrid systems (SHS and village grids), and corresponding benefits, compare to each other and to those from electrification by way of grid extension? We focus the analysis on the following benefits: livelihoods and income, as measured in households and small businesses; women and children's health, as reflected in kerosene-related injuries[1]; women's time; and children's education.

Supply Conditions

Electricity supply in developing countries is far from homogeneous. Prior to evaluating benefits, it is important to establish what product is being compared. First, we compare service conditions, in terms of hours of availability, unit cost and any other peculiarities in supply conditions.

Livelihoods/Income

Income benefits manifest through many channels. Direct income benefits result from increased livelihood opportunities, and productivity benefits. For instance, lighting allows longer working hours.

However, there are also indirect benefits from small-scale systems, as they are sometimes community-run (in the

[1] Note that there are other salient health effects of kerosene use we do not measure, particularly from inhaling fumes.

case of Nepal micro-hydro) or provide jobs in the community where power plants are deployed (e.g., biomass microgrids and SHS). Biomass based plants also employ labor for processing the biomass residue (for instance, rice husk residues can be used residues to create incense sticks).

In addition, with the growing volume of these small-scale systems (WRI estimates the mini-grid market at about USD 2 billion and the SHS market at about USD 27 million on annual basis for India alone), the suppliers themselves are growing in size, employing more people in management, marketing, distribution and sales. We attempt to quantify or at least comment on, all these avenues of employment. For instance, the experience of Husk Power suggests that 2–3 people gain employment for every plant serving one minigrid catchment area. Note that this estimate would not necessarily be a net addition to employment – it is possible that these suppliers crowd out other suppliers, such diesel generation or retailers of candles and wick lamps or.

Impact on Women

One contribution of this study is to provide a new estimate of women's time spent on daily activities, including leisure and daily chores, and compare these among electrified and unelectrified households. Having access to electricity and consequently to mechanical power may reduce the time women spend on housework.

Impact on Health

By reducing the usage of kerosene for lighting, electricity provision will also reduce the incidence of fatal and non-fatal kerosene-related accidents.

Children's Education

Studies that find measurable benefits of electricity to children's education usually examine proxies, such as study time, since it is difficult to relate school performance to electricity. We add to this literature by assessing *the perception* survey respondents have of education benefits, which is a reflection in part of the quality of supply, and their observation of children's behavior.

Methods

We conduct surveys of households and small businesses, and assess benefits both quantitatively, where possible, and qualitatively.

Sampling and Identification

Electricity benefits manifest over time (Khandker et al., 2009), and the proliferation of energy entrepreneurs is a recent phenomenon. We therefore selected sites that were served by the oldest microgrid systems we could find, and where grid access and unelectrified villages are in relatively close proximity, so as to ensure similar external conditions as far as possible. This search resulted in a selection of two districts in the Indian state of Bihar, and 1 district in Nepal, comprising a target sample of 300 households per district, and 75 small businesses. Note that this choice of proximate sites doesn't ensure that there aren't any differences in conditions that may influence electricity uptake or its benefits – the inclusion of some contextual variables in the Propensity Score Matching (PSM) analysis does attempt to put these sites on a level playing field, but it is a limitation of this study that one can't know for sure.

All districts have a diversity of income and infrastructure conditions, and contain households with and without access to electricity from these systems. Twenty five households were selected from each village at random, and villages within districts were selected at random. This allowed us to sample several villages across the district. The resulting responses are shown in Table 1.

Table 1: Household Surveys

Household Surveys						
	No Elec	Grid	Small-scale Energy System			To-tal
			Bio-mass	Micro-hydro	SHS	
Nepal	14	81		90	53	238
W. Bihar	77	99	94		45	315
E. Bihar	134	95	77		0	306
Total	225	275	171	90	98	859

Small businesses were selected so as to evenly draw from five categories of business (Table 2).

Table 2:. Small Business Interviews

Small Business Interviews						
	To-tal	Re-tail	Mecha-nical (Mills)	Elec-trical	Hotel / Rest.	Other Mfg
Nepal	42	12	10	3	7	10
Bihar	33	15	2	4	5	7

Quantification of Benefits

Where possible, the benefits were compared across groups using Propensity Score Matching (PSM), to account for possible selection bias.

Qualitative Analysis

Small business interviews have been coded to determine patterns in responses with respect to the following issues linking electricity to profitability:

1. Whether businesses migrated or located due to electricity conditions
2. The income impact of poor reliability and its variation by business type
3. The market opportunity costs of limited supply

Results

The following preliminary results emerge from the data:

Service Conditions:

- Microgrid systems tend to supply homes in the evening and commercial entities during the day. Evening supply varies, but is usually between 7pm-11 pm (the project scope didn't allow for monitoring devices to measure actual hours of supply. This question was not included in the survey. Actual supply is erratic.)
- Electricity supply for households is worse in Bihar than in Nepal due to technology and institutional challenges (See Table 3). In both the Indian cases, suppliers admitted that households were a second priority to commercial customers, without whom the plants were not viable. Husk Power indicated that household supply was cross-subsidized by commercial customers for a large part of the microgrid history. In Nepal, due to government subsidies and the lack of commercial customers, household supply was better.
- While grid services in the target region tend to provide higher availability than microgrids, their reliability is lower (Table 3).
- Market-driven SHS penetration is high in the target regions in both Nepal and India, as reflected in the fact that almost a third (98 out of ~325) households that were surveyed in unelectrified areas has SHS.
- Service costs are highly differentiated by type of customer and type of system (in preparation).

Table 3. Electricity Supply – Hrs/Day

Electricity Supply – Hrs/Day		
Mean (std dev)	Grid	Microgrid
Nepal	18 (2)	15 (5)
W. Bihar	6 (5)	4 (2)
E. Bihar	4 (4)	3 (2)

Kerosene accidents/use:

- Kerosene-related accidents are a minor issue as they were only reported in 29 of the 859 HH interviewed. Since this is a cross-sectional study, it is not possible to know whether there has been any trend.
- Kerosene use for lighting is widespread among grid and microgrid connected customers, reflecting high unpredictability and low reliability (80 %).
- Kerosene use for lighting was far less common among households that have solar home systems (25 % of households). While this is obviously a highly interesting finding (for example, it might imply that the reliability or service quality of SHS influences kerosene use more than (intermittent) grid power), further research would be needed to better understand and substantiate it.

Children's education:

- The perception of lighting benefits seems to be influenced by supply conditions. A lower (statistically significant) share of grid customers compared to shares of other systems' customers perceived lighting as beneficial for children's studying habits. One hypothesis for this is that household supply *in the evenings* may be more erratic/unreliable with grid supply, since many non-local conditions influence evening load shedding. Power from microgrids in the cases we studied is supplied only in the evenings, so despite some unreliability in starting times, supply seemed more reliable than in the mains grid.
- The perception of schooling benefits is not distinguishable, expect for solar customers who perceive the benefits to be higher.

Income/Small-scale businesses:

Among households, after correcting for selection bias through PSM, no discernable differences in household expenditure (proxy for income) were found across systems, including unelectrified. This is most likely due to the high standard deviation and relatively small sample size of the study. Without these adjustments, grid customers did have higher average incomes up to twenty percent. More than the household income differences, though, the small business surveys (which are still being analyzed) seem to reveal greater insights on the income impacts of electricity. The following preliminary insights emerge:

- Electricity is not the primary determinant of business choice or location. In Nepal, the primary determinant is road access; in Bihar family and businesses that are a supplement to farming dominates.
- Reliability of electricity supply is essential to small-scale businesses, where cost for reliable electricity supply is not an important factor.
- Electricity is perceived as a service that enhances the customer base of small businesses.
- Businesses report (but can't quantify) high opportunity costs of poor reliability, primarily due to a loss of market/customers, and a disincentive to expand their business.

Discussion

This study extends previous knowledge by characterizing systematically the characteristics of electricity supply from microgrids compared to grid supply. The poor supply conditions and high unit cost of power (not shown here, because these are still very preliminary) are important insights from this study. The diminished use of kerosene among SHS owners is a significant indicator of system reliability with a battery-based system.

The absence of discernable income differences, and the fact that businesses do not base their decisions on electric supply, despite losing money from its poor reliability, are intuitive and corroborate many previous studies.

These results aren't generalizable since they are case studies of specific locations. This analysis is a cross-sectional study. The absence of time series data limits the extent to which differences in benefits across systems can be attributed to electricity conditions.

Since analysis is still underway, further results will be developed and presented in the conference.

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Multi criteria selection of RETs sites using Simple Additive Weighting (SAW)

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Abstract

One of the critical steps in developing a Renewable Energy Technologies (RETs) project is to find a suitable site and assess its feasibility for development.
This paper uses the Simple Additive Weighting (SAW) scoring method to determine various renewable energy sites for development under the Millennium Science Initiative (MSI) project for rural electrification, sponsored by Uganda National Council for Science and Technology (UNCST). SAW is one of the most linear multi criteria decision analysis techniques that uses regular arithmetical operations. In this research, a desk study of possible sites was done as a first step and 20 sites were visited for primary data collection using designed questionnaires for group meetings and target persons in the second step. The SAW technique adequately checks site suitability for different RETs and in this research, the tool successfully ranked the top six sites which were consequently developed. The results present the scores for all the sites based on attributes including demand, fuel or source of energy, technology, application of electricity and the human factors. The RETs installed include a solar PV energy kiosk, a solar PV mini grid, a pico-hydro mini grid, and three gasification plants.

Keywords: Site selection, SAW, Mini grids, Rural electrification, MSI.

Introduction

The Ugandan energy sector is dominated by biomass, accounting for 92 % of the energy use, followed by petroleum (6 %) and electricity (2 %). The national access to electricity is currently at just 14 % while rural access is about 7 %. Energy generation in Uganda is very centralized: large hydropower plants near Jinja town and thermal power plants around Kampala. This, together with the dispersed housing patterns of Ugandan rural households, results in high distribution costs and explains the low electrification rates in rural areas (Mackay, 2009).

The Government of Uganda places highest preference and priority on extension of the existing electricity grid. However, it is also clear that grid extension is not possible everywhere and thus small-scale, independent grid systems are promoted by the government as the next step in rural electrification through the Rural Electrification Strategy and Plan (RESP) for the period 2013 to 2022 (MEMD, 2012). Where these so-called mini and micro-grid systems are not feasible, stand-alone systems such as solar PV home systems or even the smallest solutions, pico-solar PV, in the form of lanterns or kits are the last steps towards providing electricity in rural areas.

However, one of the biggest challenges of the projects is the question: where to place them?”. There has to be scientific means to choose a location based on relevant factors. Some examples of these factors can include but are not limited to: Distance to the nearest point of the national grid. The farther the better; Number of potential consumers. A critical mass of customers is needed for any business model. This parameter can also be calculated by obtaining potential and actual demand for the area; Interest from the local community. The business model and uptake of services rely heavily on the acceptance of the local community (Rasmus, 2014).
These factors are not necessarily of the same importance weight in all projects, as they depend on the overall success criteria. They have to be analysed by conducting baseline studies and using multi criteria decision methods in order to select the most appropriate sites at a given time.

Background

Different multi-criteria methods have been applied to energy and environmental problems. The main approaches can be classified based on the type of decision model they apply to. In many situations, the alternatives to be considered are very many. The use of multi-objective programming methods to tackle these cases is well known (Pokharel & Chandrashekar, 1998; Ramanathan & Ganesh, 1995). Nevertheless, these approaches face a considerable drawback as they sometimes end up with an infeasible alternative. It is for this reason that we recommend discrete multi criteria decision aid (MCDA) techniques for tackling energy planning issues. A concise overview of discrete multi-criteria analysis methods is described in the next paragraphs.The main families of methodologies include: the Elimination Et Coix Traduisant la Realite (ELECTRE) family (Vincke, 1992), the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) I and II methods and Regime Method Analysis (Nijkamp et al., 1990). In ELECTRE IV an option of no weighting is provided while in PROMETHEE weights can be seen more as trade-offs between criteria and not as coefficients of importance (Munda, 2004).
The value or utility function-based methods, include the Multi-Attribute Utility Theory (MAUT), the Simple Multi Attribute Rated Technique (SMART), the Analytic Hierarchy Process (AHP) and the most elementary multicriteria technique, the Simple Additive Weighting (SAW); other methods include the Novel Approach to

Imprecise Assessment and Decision Environment (NAIADE) (Munda, 1995), Flag Model and the Stochastic Multi-objective Acceptability Analysis (SMAA).

The SAW method is also known as a weighted linear combination or scoring method. It is simple and the most often used MCDA. In this method, an evaluation score can be calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision makers or experts, followed by summing of the products for all attributes. The advantage of the SAW method is that it is a proportional linear transformation of the raw data. This means the relative order of magnitude of the standardized scores remains equal.
SAW is the basis of most MCDA techniques such as AHP and PROMETHEE that benefit from the additive property for calculating the final score of alternatives.

Research Objectives

1. Selection of an appropriate MCDA method
2. Pre-selection of sites to be visited by desk work using referenced data, renewable energy country resource maps and national zones
3. Field visits to preselected sites for primary data collection
4. Selection of the appropriate sites by ranking using the chosen MCDA method and the data collected

Methods

We used the SAW technique and the final score of each alternative is obtained as follows;

1) A set of decision makers or experts are selected depending on the technology considered;
2) A set of possible alternatives,
$$A = (A_1, A_2, \ldots, A_m) \;;$$
3) A set of attributes to measure the performance of the alternatives,
$$C = (C_1, C_2, \ldots, C_j) \;;$$
4) The performance rating of alternative, A_i, with respect to attribute, C_j , provided by the experts is denoted by, r_{ij} ,
$$j = 1, 2, \ldots, n \quad i = 1, \ldots, k \;;$$
5) The importance weight of attributes, C_j , provided by the experts is denoted by, w_j ,
6) The score for each alternative , V_i , is obtained by summing the product of the importance weight of each attribute, w_j, and the performance rating, r_{ij}, of each alternative site as stated in the equation below;
$$V_i = \sum_{j=1}^{n} w_j r_{ij} \qquad (1)$$

20 potential sites were pre-selected from the desk study using referenced data and resource maps. 5 sites for each of the technologies scoped for the study including, gasification, solar PV, Pico-hydro and biogas. Survey questions were designed to collect actual quantifiable data from each site on demand for electricity, fuel or energy source available for conversion to electricity, adaptable technology options, the existing applications and the human factors. The attributes listed were selected by a team of experts with diverse experience in planning, training and implementation of renewable energy systems. The experts included persons from engineering, computer and information technology, social sciences, business, private sector, civil society, financiers and target beneficiaries. The attributes are presented in figure 1 below.

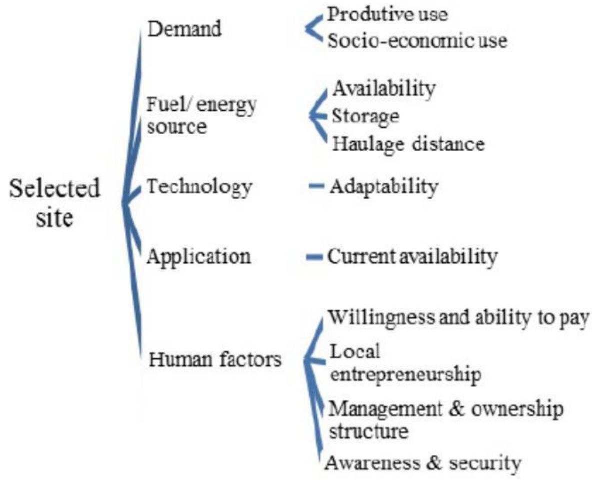

Figure 1: Attributes

Results

The importance weights, w_j , are assigned to each attribute by a group of experts based on their experience with RETs implementation and perspective on local context. The average weights obtained from experts are as detailed in figure 2 below.

From the data collected, the performance ratings of each of the 20 potential sites visited with respect to each attribute were presented as ratios.
Using the ratings, r_{ij}, for the five alternative gasification sites, G1, G2, G3, G4 & G5 and the importance weights, w_j, from table 1, the scores for each site are computed using equation 1 above. The results of the scores are presented in table 2 below. Tables 3, 4, and 5 present the scores of the other 15 sites.

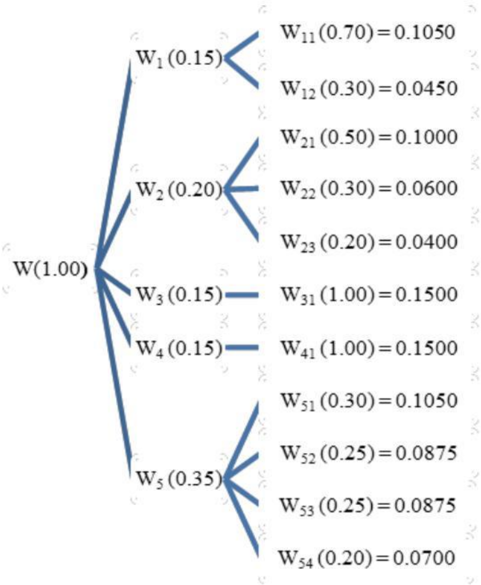

Figure 2: Importance weights of attributes

Table 2: Scores for gasification sites

Site location	Alternative	Score
Muduma – Mpigi	G1	0.53
Opit – Gulu	G2	0.85
Sekanyonyi – Mityana	G3	0.68
Bussunju – Wakiso	G4	0.50
Doctina – Jinja	G5	0.52

Table 3: Scores for solar PV sites

Site location	Alternative	Score
Kabanga – Mukono	S1	0.65
Mayuge – Iganga DSS1	S2	0.28
Mayuge – Iganga DSS1	S3	0.37
Mayuge – Iganga DSS1	S4	0.32
Nakasengere – Kiboga	S5	0.76

Table 4: Scores for Pico hydro sites

Site location	Alternative	Score
Haven – Jinja	H1	0.78
RMS – Kasese	H2	0.89
Arlington - Mbale	H3	0.60
Wild waters – Jinja	H4	0.82
KSB site 3 – Jinja	H5	0.75

Table 5: Scores for biogas sites

Site location	Alternative	Score
Flora poultry – Mukono	B1	0.65
Softpower – Jinja	B2	0.73
Jesa – Mityana	B3	0.91
Meat packers – Kampala	B4	0.70
Arlington – Mbale	B5	0.76

Table 1: Data for evaluation of gasification sites

Attribute	Weight	G1	G2	G3	G4	G5
1.0 Demand						
1.1 Productive use	0.0105	0.72	1.00	0.83	0.74	0.80
1.2 Socio-econ use	0.0450	1.00	1.00	1.00	0.80	0.75
2.0 Fuel/Source						
2.1 Availability	0.1000	0.74	1.00	0.91	0.72	0.85
2.2 Storage	0.0600	0.10	1.00	0.50	0.10	0.40
2.3 Haulage distance	0.0400	1.00	1.00	0.17	0.20	0.30
3.0 Technology						
3.1 Adaptability	0.1500	1.0	0.80	0.90	1.00	0.70
4.0 Application						
4.1 Availability	0.1500	0.06	1.00	0.90	0.07	0.08
5.0 Human factors						
5.1 Ability to pay	0.1050	0.48	1.00	0.45	0.52	0.60
5.2 Local entr.	0.0875	0.61	1.00	0.32	0.66	0.70
5.3 Mgt& ownership	0.0875	0.66	0.91	1.00	0.62	0.77
5.4 Awareness & sec.	**0.0700**	**0.57**	**0.71**	**1.00**	**0.57**	**0.69**

From the rankings, the top six sites were selected for actual installations with overall consideration on the available funds and project objectives. The details are in table 6 below.

Table 6: Installed sites

Site	Alternative	Technology	kW	Funds
Opit	G2	Gasification	10	MSI
Sekanyonyi	G3	Gasification	10	MSI
Muduma	G1	Gasification	32	Norgesvel
Kabanga	S1	Solar PV kiosk	01	MSI
Nakasengere	S5	Solar PV grid	01	MSI
RMS – Kasese	H2	Pico hydro	05	WB

Discussion

The study shows that the SAW scoring method is simple but effective in guiding decision makers and experts during site selection for renewable energy systems. It was observed that other financiers and investors besides MSI were attracted much more easily. It should be noted that this method was used at the preliminary stage of the project for site selection but in the next step, the study will consider other MCDAs operationalized in fuzzy environments to reduce on the subjectivity of the decision makers, the complexity with the weighting process and the possible limitations in computational reliability and applications of the SAW method.

Acknowledgement

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Introducing Solar LED Lanterns to Rural Kenya: Sustainability Assessment of Environmental, Economic, and Social Impacts

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Abstract

This paper examines the impacts of the introduction of solar LED lanterns on in rural Kenya on environmental, economic, and social dimensions of sustainability. A survey was conducted on the use of the solar lanterns in households, compared with these households without solar lanterns. It shows that the solar lanterns had made some positive impacts with regard to reducing kerosene consumptions, thereby expenditures for purchasing it and CO2 emissions, improving health conditions, and increasing time for doing homework for children at home, therefore contributing to moving towards sustainability. There remain many challenges, however, including provision of necessary finance, robust business models, viability of local cooperatives, and the establishment of supply chains for product delivery and maintenance from a long-term perspective.

Keywords: solar lantern, sustainability, rural area, Kenya

Introduction

Modern energy services are crucial to human well-being and to a country's economic development (International Energy Agency, 2011). In developing countries, access to affordable and reliable energy services is fundamental to reducing poverty and improving health, increasing productivity, enhancing competitiveness and promoting economic growth. It is estimated, however, that approximately 1.3 billion people still do not have access to electricity, around 20 % of the global population, with more than 95 % of the people lacking access to modern energy services living in either sub-Saharan Africa or developing Asia and 84 % in rural areas (International Energy Agency, 2011).

Solar lanterns that use light-emitting diodes (LEDs) powered by batteries, which are in turn charged by small solar panels, have emerged as a cost-competitive alternative to kerosene and other fuel-based lighting technologies, offering brighter light for longer duration at equal or lower cost over time (Adkins et al., 2010; Zahnd & Kimber, 2009). LED lanterns have already started to be introduced in developing countries. The World Bank Group's Lighting Africa initiative aims to support the global lighting industry in developing new technologies for off-grid regions through a variety of mechanisms (World Bank Group, 2014).

Research Objectives

While previous attempts have been made by small-scale enterprises and organizations to introduce solar lanterns that are relatively inexpensive and easy to use, recently multinational electronic companies have also started to enter into this business. Sanyo Electric, which has later been merged to Panasonic, is one of the largest electronics companies in Japan, with production and sales operations worldwide. With core business activities on photovoltaics and batteries, the company has developed various types of pro-poor products targeted to the African market, including long-lasting and chargeable solar LED lanterns. As one of the leading manufacturers of electronic products, the company has been struggling to establish a robust business model of supplying relatively high-quality solar LED lanterns that would provide safe, clean, and convenient lighting.

To assess the impact of solar LED lanterns, it is crucial to examine whether they really contribute to sustainability, which involves environmental, economic, and social dimensions. With regard to environmental impacts, the solar LED lanterns are expected to replace the use of kerosene and candles so that emissions of carbon dioxide decline, which contributes to coping with the climate change. This will have a significant implication for world-wide application of this technology. At the same time, by replacing kerosene and candles with the solar LED lanterns, emissions of hazardous substances such as soot and carbon monoxide are expected to be reduced, with positive impacts on health conditions of the local people. The solar LED lanterns are also expected to induce changes in lighting patterns for buyer households. By switching to using a solar LED lantern, although bearing the initial cost of purchasing it, the households which have been relying on traditional lighting sources can reduce expenditures on fuels in the long run. It is also expected that the light provided by solar LED lanterns will make it possible for children to study at home at night, which will increase the amount of time spent for their study with a potential positive effect on school performance. And women would be able to perform routine household work at night and during power outages, generating considerable social benefits. The solar LED lanterns could also create new business opportunities for local entrepreneurs by utilizing them for various purposes.

In this paper, we attempt to make a comprehensive assessment of the sustainability of solar LED lanterns provided by a large electronic manufacturer to people without access to electricity in a rural area in Kenya. A field survey was conducted to examine what impacts solar LED lanterns made on households with regard to environmental, economic, and social aspects. Then we explore the possibilities and challenges in promoting a broader dissemination of solar LED lanterns in rural areas in developing countries.

Methods

A household survey was conducted to assess the environmental, economic, and social impacts of the solar LED lanterns produced by Sanyo Electric. For environmental impacts, the amount of CO_2 emissions reduced by replacing fuels (e.g. kerosene) used for lighting was examined. For economic impacts, it was examined how much amount of the expenditures which had been spent for buying fuels (kerosene) was reduced by using the solar LED lanterns. For social impacts, we examined how much time the children in the households which have received solar LED lanterns increased the time they spend for study in the evening.

Solar lanterns were donated by Sanyo Electric through the local non-governmental organization (NGO) African Children Education Fund (ACEF) in Embu to promote education in the area. The lanterns were provided in March 2010 to 250 households through Kanyonga and Ngecha Primary Schools in Makima in the Mbeere district, one of the districts that form Eastern Province in Kenya. The district's population is generally young, with those aged below 15 years accounting for almost 40 % of the total population. The youth population has also given rise to a high level of unemployment in the district. Approximately 60 % of the population in Mbeere live below the poverty line, which means that they earn less than one US Dollar or 90 Kenyan Shilling per day.

The study involved a survey conducted for a total of 209 households. Over half of the households sampled, 105, had received a solar lantern per household for free from ACEF. Another 26 households had bought their lanterns, either from ACEF or independent salespeople. There were 78 households without solar lanterns. This is the group that acted as a control group in the survey, given that it was not possible to conduct a baseline study prior to the introduction of the solar lanterns in the community. In addition to the survey, focus group discussions and key informant interviews were conducted for obtaining detailed information. Three focus group discussions were conducted, involving local leaders, such as NGO representatives, teachers, women groups, and health workers, while key informant interviews were conducted with the head teachers of Kanyonga and Ngecha Primary Schools, the local Chief and the Director of ACEF.

Results

Distribution and Use of Solar Lanterns

This section summarizes data from households with and those without the solar lanterns in order to make comparative observations on how the lantern has impacted on the community. Table 1 suggests that the distribution of household's head by the level of schooling is very similar for both types of households with and those without the solar lanterns.

Table 1: Level of Schooling of Household's Head

Households' head by level of schooling	Without solar lantern		With solar Lantern	
	N	%	N	%
Before schooling age	32	29.1	57	32.9
Primary	54	49.1	75	43.4
Day secondary	13	11.8	22	12.7
Boarding secondary	5	4.5	9	5.2
Local college	3	2.7	5	2.9
University	3	2.7	5	2.9

The two types of households with and without solar lanterns basically exhibited very similar socio-economic characteristics, as shown in Table 2. This could be mainly attributed to the fact that the lanterns were not distributed on a needs basis, and we can basically assume that it is simply that the households got the lanterns because they had children in the two primary school where solar lanterns were distributed.

Table 2: Main Sources of Livelihood/Occupation of Households

Main sources of livelihood	Without solar lantern		With solar lantern	
	N	%	N	%
Farmer	54	67.6	88	69.3
Salaried/employed	8	10.0	11	8.7
Businessman/self employed	7	8.8	17	13.4
Mason	0	0.0	1	0.8
Other	11	13.8	10	7.9
Total	80	100.0	127	100.0

Table 3 gives the distribution of the use of the lighting equipment in households with and without solar lanterns. The households without solar lanterns basically used tin lamps or hurricane lamps, or both of them, with almost a half of the households using tin lamps only and a little less than the other half of the households combining the use of tin and hurricane lamps. For the households with solar lanterns, on the other hand, only less than 10 % of the households used solar lanterns exclusively, while a majority of the households used solar lanterns in combination with tin or hurricane lamps, or both of them. That result would be in agreement with an earlier observation of the average number of 4.9 rooms per household, which would require extra lighting equipment.

Table 3: Use of Lighting Equipment in Households

Use of equipment	Without solar lantern		With solar lantern	
	N	%	N	%
Tin lamps only	36	47.4	0	0
Hurricane lamps only	7	9.2	0	0
Tin and hurricane lamps	33	43.4	0	0
Solar lanterns only	0	0	8	6.3
Tin and hurricane lamps and solar lanterns	0	0	53	44.4
Tin lamps and solar lanterns	0	0	34	26.6
Hurricane lamps and solar lanterns	0	0	33	25.8
Total	76	100	138	100

According to Table 4, which shows where the lanterns were used, the lanterns were mainly used in the sitting/table room (61 %), while 20 % of the households also used their lanterns in the bedrooms, probably due to unavailability of space. Less than 10 % of the households used their lanterns in the kitchen.

Table 4: Location of the Use of Lanterns in Households

Main Location of Lantern Use	N	%
Sitting/ table room	81	61
Bedrooms	27	20
Kitchen	10	8
Other places	15	11
Total	133	100

The purposes for which the lanterns were used are given in Table 5. A majority of the households (85 %) used their lanterns for reading or doing homework. Approximately 10 % of the households used the lanterns for the general lighting of the household, whereas 3 % of the households used them for lighting their business premises at night.

Table 5: Purposes of the Use of Lanterns in Households

Purpose of Lantern Use	N	%
Reading/doing homework	105	85
General lighting of the household	13	11
Lighting shop/business premises	4	3
Other	2	1
Total	124	100

Lanterns' Impact on Kerosene Consumption and Expenditures

With regard to whether the use of the solar lanterns had led to a reduction in kerosene consumption, Table 6 shows that the amount of kerosene consumed per week per household had overall decreased with the use of the solar lanterns. Before the introduction of the solar lanterns, almost a half of the households consumed less than one liter of kerosene per week, whereas more than three fourths of the households consumed less than one liter per week after having adopted the solar lanterns.

Table 6: Amount of kerosene used before and after the introduction of lanterns

Kerosene used by household in liters/week	Before introduction of lanterns		After introduction of lanterns	
	N	%	N	%
0-1.0	56	47.9	87	76.3
1.1-2.0	33	28.2	17	14.9
2.1-3.0	9	7.7	2	1.8
3.1-4.0	7	6.0	5	4.4
4.1-5.0	4	3.4	1.0	0.9
5.1-	8	6.8	2	1.8
Total	117	100	114	100

The average amount of kerosene consumed per household dropped from 2.1 l to 1.4 l per household per week after the acquisition of a solar lantern. That means that the use of the solar lantern helped households cut the consumption of kerosene for lighting by 0.7 l per week, which translates to a saving of 3.0 l per month and 36.5 l per year per household. This contributes to reducing emissions of carbon dioxide (CO_2), the main source of greenhouse effect, as well as reducing household expenditures by about 300 Kenyan shillings per month, which means an annual saving of 3,650 Kenyan shillings, almost equivalent to 40 US dollars. That implies that the households would be able to recover the cost of one solar lantern within the first year from the savings on kerosene alone.

Lanterns' Impact on Health

The study found that over three-quarters (77 %) of the households thought the fire/light, smoke and other gases given out by the lighting equipment of tin and hurricane lamps they used caused health problems. To reduce these negative effects on health, some of the households mentioned that they were trying to cut the time for using these lamps per day.

Many of the households thought that the tin lamp had harmful effects on their health, as indicated in Table 7. Almost a half of the households (46.5 %) reported their children suffered from eye problems caused by the gases emitted by tin lamps. Approximately 40 % of the households associated the tin lamp with causing coughing problems among children, while 35 % of the households blamed the tin lamp for causing breathing problems in children, and 23 % of the households considered that tin lamps caused burns among children. This means that children are the main casualties of the tin lamp's health hazards in the household, closely followed by their mothers. On the other hand, the emissions from the tin lamp had little effect on fathers and other members of the households.

Table 7: Effects of the Gases Emitted by Tim Lamps on Health Conditions

Children		Mother		Father		Other	
Yes	No	Yes	No	Yes	No	Yes	No
Eye problems							
46.5	53.5	46.5	53.5	10.5	89.5	2.0	98.0
Coughing							
41.8	58.2	32.9	67.1	11.8	88.2	1.3	98.7
Difficulties in breathing							
35.4	64.6	35.5	64.5	11.1	88.9	1.3	98.7
Burns							
23.2	76.8	20.1	79.9	11.8	88.2	0.7	99.3
Headache							
7.7	92.3	7.2	92.8	3.2	96.8	0.7	99.3
Ear problems							
1.9	98.1	1.9	98.1	2.0	98.0	0.7	99.3

The study indicates that the use of solar lanterns basically had an impact on improving health conditions in the households. Table 8 suggests that the households which adopted solar lanterns could reduce cases of coughing among children and mothers, compared with the households without solar lanterns.

Table 8: Effects of Tin Lamps on Coughing in Households with and without Solar Lanterns

Children	Without		With		Mother	Without		With	
	N	%	N	%		N	%	N	%
Yes	33	54	24	40	Yes	24	40	27	28
No	28	46	36	60	No	36	60	68	72
Total	61	100	60	100	Total	60	100	95	100

Lanterns' Impact on Study Hours

The study also attempted to examine whether there was any impact on the amount of time that children spent doing homework for households that received solar lanterns, compared with those households without them. With solar lanterns, children would be able to do homework for longer hours as the supply of light is of a higher quality and the lighting time is not limited to availability of financial resources for buying kerosene as is the case with tin and hurricane lamps. Table 9 shows that approximately 20 % of the children in the households without solar lanterns spent one hour or less, while only a little over 10 % of the children spend more than four hours doing homework. On the other hand, a majority (96 %) of the children in the households using solar lanterns spend at least two hours for homework, with about one third of them spending more than four hours.

Table 9: Time Children Spend on Homework in Households

Time children spend on homework per day	Without lanterns		With lanterns	
	N	%	N	%
Less than 1 hour	3	4.5	1	0.9
1 hour	11	16.4	3	2.8
2 hours	23	34.3	33	30.8
3 hours	21	31.3	35	32.7
4 hours	5	7.5	21	19.6
5 hours	3	4.5	13	12.1
6 hours	1	1.5	1	0.9
Total	67	100	107	100

Discussion

This paper examines the impacts of the introduction of solar LED lanterns on in rural Kenya on environmental, economic, and social dimensions of sustainability. A survey was conducted on the use of the solar lanterns in households, compared with these households without solar lanterns. It shows that the solar lanterns had made some positive impacts with regard to reducing kerosene consumptions, thereby expenditures for purchasing it and CO_2 emissions, improving health conditions, and increasing time for doing homework for children at home, therefore contributing to moving towards sustainability.

There remain many challenges, however, including provision of necessary finance, robust business models, viability of local cooperatives, and the establishment of supply chains for product delivery and maintenance. Although it was found that it would be possible to gain a financial saving comparable to the price of solar LED lanterns in one year, that would still constitute a significant hurdle for many of the populations with a limited amount of incomes, suggesting a critical need for establishing financing options to facilitate adoption among poorer populations in rural areas. For market-based models of the dissemination of solar LED lanterns to have a real potential to be implemented and scaled up in off-grid regions in developing countries, it would be crucial to assess and improve the viability of local cooperatives and the establishment of supply chains for delivering and repairing products from a long-term perspective.

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You are what you measure! But are we measuring it right? An empiric analysis of energy access metrics based on a multi-tier approach in Bangladesh

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Abstract

Measuring energy access through binary indicators is insufficient, and often, even misleading. In this work, the SE4ALL global tracking framework, and the recently introduced ESMAP multi-tier approach, is critically discussed analyzing questionnaire based primary data from rural Bangladesh. The performance of different energy interventions is evaluated using the new tier framework. The challenges in its application lie in reliable data collection, adequate gradation of indicators, and an effective algorithm for the tier assignment based on the specified set of attributes. The study showcases very high sensitivities to parameter changes, different algorithms, and data requirements. The results reveal a clear trade-off between capturing the multi-dimensionality of energy access and the simplicity of an easy to use global framework. Suggestions to improve the measuring approach are made and conclusions are drawn for possible implications of the tier framework for different energy service offers in the market. Strengths and weaknesses of the present measurement scheme are discussed and country specific results interpreted through targeted gap analysis for future policy advice.

Keywords: energy poverty; Bangladesh; energy access; electrification; multi-tier approach

Introduction

Despite increasing rhetoric and action in support of the 2030 sustainable energy for all (SE4ALL) goal of achieving “universal access to modern energy services by 2030” (Ki-moon, 2011), there are still at least three issues that remain, at best, vague. First, what does universal energy access actually mean? Second, how do we actually get there? And third, if we don’t have an answer for the first question, how will we even know at what point we got there? Only what gets measured is what gets done.

Counting connections to the grid is insufficient as a measurement of energy poverty (AGECC, 2010; Practical Action, 2013; IEA/WB, 2014). In fact, it can even be highly misleading. As an example, Bangladesh just celebrated its accomplishment of installing more than 3.5 million solar home systems (SHS) representing by far the highest penetration of SHS in the world (IDCOL, 2014). Ignoring for a moment the number of SHS that are in areas officially counted as electrified and assuming an average family size of five, this number represents 25 % of Bangladesh’s off-grid population that are equipped with some form of electricity. Yet, not a single one of these systems is reflected in the national energy poverty statistics. Meaning that today they represent zero progress towards the SE4ALL goal, because the baseline of the global tracking framework is still the binary indicator determined by the percentage of people living on- and off the grid, respectively. The reason behind this is that currently available global databases only support a binary global tracking of energy access. The good news is that the World Bank’s Energy Sector Management Assistance Program (ESMAP) has come up with a new “milestone” for measuring energy access: the multi-tier framework (Bensch, 2013). A multi-tier framework consists of several attributes (e.g. durability, affordability, etc.) measured either by binary indicators or by gradations. A combination of these individual attribute’s performances determine the assignment to a specific tier which in turn reflects the level of electricity access of the object of investigation. But does the candidate framework uphold its promise of measuring a “continuum of improvement, based on the performance of the energy (service) supply” (ESMAP, 2014)? It should now be up to the scientific community to support the operationalization of the ambitious energy access for all by 2030 goal through rigorous evaluation of the new measurement framework. In 2015 the Sustainable Development Goals (SDGs) will be agreed upon in September in New York (UN, 2015). This time, unlike in 2000 during the formulation of the Millennium Development Goals (MDGs), chances are high that energy for all will be an explicit goal. Its inclusion makes it even more important to have a robust set of measurement tools to track progress towards its achievement. This paper adopts the recommended ESMAP framework for the case of Bangladesh, assessing access for a sample of 230 households and microbusinesses[1]. It is the objective of this analysis to provide feedback on the multi-tier frameworks design, and potential improvements, as well as to discuss its wider implications against the framework of energy access intervention programs in Bangladesh.

[1] Henceforth, all survey objects are only referred to as households.

Measuring energy access

The process so far

The predominant criterion for measuring energy access/ poverty is still the binary indicator estimated as the ratio of people lacking access to the national electricity grid, and the people being dependent on traditional biomass for cooking, respectively, to the total population (IEA, 2010). At times these figures are supplemented by estimates of the number of people who suffer from an intermittent electricity supply, although "intermittency" lacks a clear definition (AGECC, 2010). Several attempts for a new criterion applying a uni-dimensional approach have been put forward ranging from minimum energy consumption thresholds (Modi et al. 2005) to income-invariant energy demand measures (Barnes et al., 2011). At the same time, a group of multi-dimensional approaches have also been put forward, such as the Multidimensional Energy Poverty Index (MEPI) (Nussbaumer et al., 2012), or the Total Energy Standard (TEA) (Practical Action, 2012). Recent reviews and comparative studies on different energy poverty indices include those by Pachauri (2011), Kandker et al. (2012) and Bensch (2013). Many of the current indicators measure electricity as an output (e.g. lack of access) rather than an outcome, which better reflects service needs and welfare gains (Pachauri & Spreng, 2011). This is mainly due to the fact that an accurate measurement seems very challenging given the diverse nature of energy in terms of different forms of generation sources, technologies, a wide spectrum of applications, phenomena such as fuel stacking, and heterogeneous target groups (household, micro-businesses and hybrid forms). Nonetheless, despite high data requirements, "there is a growing consensus that measurements of energy access should be able to reflect a continuum of improvement" (IEA/WB, 2014). It is generally believed that electricity is "the preferred choice for lighting and running appliances" (Pachauri et al., 2013). From a user perspective, it should not matter where the electricity is coming from unless social status symbols and connotations are at play (e.g. perception of SHS as second class electrification vs. the image of the grid as full power access) (Schützeichel, 2015). What should really matter is the quality of the electricity service[2] provided and this is also what should be measured. Quality can here be defined as "the characteristics of a product or service that bear on its ability to satisfy stated or implied needs" (ASQ, 2015). If we look at poverty as an "absence of sufficient choice" (Sen, 1999), according to the capability approach, we need to pin down individual welfare components and assess how they interact as multidimensional causes of development and deprivation. For instance, using the concept of an energy poverty penalty, Groh (2014) shows how a lack of access to affordable energy services, a deprivation, can lead to a situation where people are trapped – or at least delayed – in their capability to achieve welfare improvements. The candidate multi-tier metric put forward by ESMAP reflects a multitude of the research cited above and promises to set a new benchmark, while being flexible to country specific targeting. Nonetheless, in order to reach consensus on the candidate composite index, a thorough testing of it is required.

The ESMAP multi-tier framework

"Defining energy poverty metrics and respective targets is a complex task" (Bazilian et al., 2010). It should be designed in a technology neutral way in order to allow a just energy assessment of all sources, and it should further reflect the impact of all energy interventions. The most complicated part though may very well be to find an effective algorithm for the combination of individual indicators that adequately reflects an energy service offer quality. This quality is determined by the service's ability to satisfy stated or implied needs. And this is the point where things get complex. Based on assumptions of these needs, without giving into the "we know what the poor people need" trap (Schützeichel, 2015), an effective combination of indicators needs to be designed. In the multi-tier framework these needs have been defined for seven attributes, namely capacity, duration, reliability, (technical) quality, affordability, legality and health/safety (appendix). Indicators to determine these attributes are either binary or gradations. ESMAP is suggesting here to use the simplest possible decision rule for a household's tier assignment: to assess the household's performances for each attribute and then assign it according to the lowest performance across all attributes.[3] An in-depth discussion on the (dis-) advantage of this approach is done in the analysis section based on field testing of the results. Weighting the tiers leads to a composite index of energy access: $\sum(P_i \times k)$, where P_i is the proportion of households in the k^{th} tier. This index can be aggregated across villages, districts, provinces, countries and regions. It allows countries to set their own specific targets, which can be tracked over time. At the same time, a dashboard approach can be adopted, with a separate in-depth analysis of individual energy poverty indicators. This flexibility allows for a hybrid approach reconciling the "advantages of a single easy-to-understand and -interpret composite metric with the legitimate concerns related to aggregating information of various kinds" (Bazilian et al., 2010).

Applying the multi-tier framework in rural Bangladesh

Country Study Bangladesh

Recent data suggests that the electrification access deficit, globally, is about 17 % of the world population or 1.166

[2] The term service is used herein throughout the text in order to emphasize on the intangible nature of electricity and the on-going relationship between electricity service provider and end-user, contrary to a potentially one-time over the counter relationship of a product.

[3] Beyond the simple algorithm, at ESMAP another more complex version was also under discussion but then discarded again. Within this paper both versions, the simple and the complex algorithm, are analyzed.

billion people. Most of this population resides in Sub-Saharan Africa and South Asia (87 %), and in rural areas (85 %) (IEA/WB, 2014). With its 66.6 million off-grid people, Bangladesh ranks third among the countries with the highest electrification deficit and has been considered a high impact country to reach the SE4ALL goals. In 1971, the year of independence, a mere 3 % of the population of Bangladesh had access to grid electricity, but today, the share has increased to almost 60 %. In the last couple of years Bangladesh's GDP has been growing at a rate between 6 % and 7 % (World Bank, 2013). In its development plan, titled *Vision 2021*, dated half a century after its struggle for independence, the Government of Bangladesh (GoB) has made the provision of access to electricity and achieving economic and social well-being of all citizens through a low carbon strategy a central goal (GoB, 2012). Universal access to electricity by the year 2020, with improved reliability and quality, is the declared goal of the GoB. But again, there is no concept as such as to what universal access actually means. Should every Bangladeshi be at least tier 2, tier 3 or 4, as defined in the ESMAP framework? To highlight the complexity of measuring access, many of the on-grid population of Bangladesh outside the capital may not fulfil the duration attribute for an assignment to a tier 3 level due to frequent load shedding, and a lack of access to back-up power supply. In extreme cases, such households might even by assigned to a tier 0 level, meaning no access at all, despite statistically being on-grid. At the same time, the question arises how the globally acclaimed SHS program[4], with its 3.5+ million installations to date perform against the candidate framework? The same question applies to the Rural Electrification Board's (REB) grid electrification program through its electrical cooperatives, the so called Palli Bidyut Samity (PBS) that for the most part is considered an equally great success (Kandker et al., 2009).

Methods and Sample

For testing the multi-tier framework, a sample of 231 households were surveyed and data was collected based on the generic underlying questionnaire of the multi-tier framework provided by ESMAP, with slight country specific adaptations and extensions.

A stratified random sample was drawn based on electrification status. Of the total interviewed households, 69 (30 %) are connected to the national grid, 107 (46 %) have a solar home system[5], and 55 (24 %) reported no primary electricity source. Another 5 % referred to using diesel generators and other sources. 5 % of the sample reported using multiple primary energy sources. Field selection was performed in a top down way, aiming to reflect diversity in terms of geographical location, weather conditions, remoteness, and culture. One random district was drawn from the Northern (Lalmonirhat), Central (Manikganj) and Southern (Bhola) part of the country. Within the respective division, an area was chosen where the Rural Service Foundation[6] has a regional office (Rangpur, Manikganj and Bhola). Within the customer base of the regional offices, the sample was ordered based on the following criteria in order to have a diverse set of users: 1st order: past repayment performance, 2nd order: system size, 3rd order: income activity. From the stratified groups a random selection was drawn. The remaining sample was randomly chosen on-site based on vicinity criteria. The data was then analyzed based on three different algorithms (two for electricity supply and one for electricity appliances) in order to determine the respective tier assignments for each household. A comparative study and sensitivity analysis of the results was performed through descriptive statistics. Further gap analysis was undertaken to draw insights on the performance of different past and potentially upcoming energy interventions in the country.

Analysis and Discussion of Results

Sample tier performance: Descriptive statistics and gap analysis

The stratified sample contains 44 % SHS, 29 % national grid access and 23 % with no option for electricity. The tier assignment for different electricity generation sources exhibits an exclusive assignment to tier 0 for those without any form of primary energy source, 98 % of the SHS users are assigned to either tier 1 or 2. A fairly diverse set of assignments is obtained from using the simple supply algorithm for grid-connected households ranging from tier 0 (16 observations) to tier 4 (1 observation). The latter result clearly showcases the limitations of the binary assessment of physical grid access. In terms of *capacity* a detailed analysis is undermined by the fact that the gradation variable on the total electricity capacity was not sufficiently distinguished. The great majority of observations fall into the range of 51–500 W. For further research, it is therefore recommended to have an intermediate option of 200 W included. The *duration* of supply out of 24 h, seems to be less of an issue as the majority of the households (about 90 %) fall into the range of having at least 8 h of electricity supply. Evening supply, in contrast, seems to be far more relevant, as almost 20 % have less than 2 h of supply and about 43 % are just at the border stating to have 2 h of evening supply. The grid seems to have capacity problems, especially at peak usage times. It should be noted though that data reliability may differ among the two questions. An estimation of evening supply seems to be easier than estimating the amount of hours over an entire day. Additionally, electricity is mostly used in the evening hours, so the question

[4] The systems consist of a 10–130 Wp panel, battery, charge controller and LED lights. System cost range from BDT 8,100 to BDT 46,100, approximately, where about 10 % is paid upfront and the remaining balance in up to 36 monthly installments with an interest rate of less than 12 % (depending on the respective institution).

[5] They all form part of the before mentioned IDCOL program,

[6] The Rural Service Foundation is a non-profit organization of Rahimafrooz Group and a partnering organization (PO) of IDCOL's SHS program. To date, RSF has installed more than 500,000 SHS. Further information can be found under: http://rsf-bd.org/solar.html (Accessed on 16th February 2015).

regarding hours of supply in the evening is likely to be easier to handle for the respondents always provided that evening hours are clearly defined as it is the case in the questionnaire. Also, a further distinction in the tier decision rule is recommended to distinguish between tier 1, 2 and 3, for e.g. to establish a minimum of 3 h for tier 3 (compare appendix for status quo). In terms of *reliability,* 69 % of the households suffer from more than three interruptions per week, and about 93 % of the households undergo regular outages, stating these last more than half an hour. On the *quality* dimension, 19 % of the people with a connection to the national grid report appliance breakage due to voltage drops. *Affordability* is measured here based on relative electricity expenditure, as it is considered adverse if a high share of income is spent on it (Bazilian et al., 2010). On average, households spend 6 % of their total income on electricity. 64 % spend up to 5 % of their income (17 % spend nothing at all) and another 17 % spend from 5 % to 10 % of their income on electricity. This leaves about 19 % that spend more than 10 % of their total income on electricity. Concerning *legality*, there is not a single household officially stating that it is paying no electricity bills. On the other hand, only 61 households state they have a meter, whereas 69 are considered grid connected. There seems to be a good tracking of the electricity users affiliated to the PBS scheme. Furthermore, all SHS users indicate they pay their bill to the respective partnering organization of the IDCOL program, making legality a minor issue in this case. *Health & Safety* is only reflected in the productive use section of the questionnaire, and thus only received 34 responses from the microbusinesses in the dataset. Based on this data it seems a negligible factor, as only one observation states an incidence in the past. In a nutshell, the gap analysis suggests that health & safety, as well as legality seem to be less of an issue. Affordability, measured here as energy expenditure as a share of income,[7] seems to be a potential field for intervention. If we are to rely on existing statistics that consider income poverty to be far less than energy poverty (WBI, 2010; Barnes et al., 2011), the unaffordability incidence of 19 % is fairly high. People with access to the grid spend on average 3 %, people with SHS 8 %, and 'completely off-grid' people 7 % of their total income on electricity services reflected in the questionnaire.[8] Even though these results require careful interpretation, it seems fair to say that the end-user cost of the widely adopted SHS scheme are too high. The average cost for a SHS is 3.5 times higher than kerosene and 1.4 times than the equivalent service from the national grid. This strongly contradicts the widely cited claim that the SHS financing schemes work, as its monthly installments set off the current kerosene expenditures, among others (Mondal, 2010; Chakrabarty & Islam, 2011; Komatsu et al., 2011). SHS owners, on average, have twice as much income as people using kerosene as their primary source of electricity, and have a similar income to people connected to the national grid. Rahman and Ahmad (2013) came to similar conclusions referring to solar home system as often adding to a household's 'social status'. It needs to be carefully noted though that the service options of a SHS, in the given sample range up to 85 Wp, allowing for a range of advanced appliances, such as color TV (22 in the sample), are no comparison to what kerosene can provide. Still, the average expenditure for a 20 Wp system is Tk. 380 (still twice as much as for kerosene). As a result, the market seems to lack an electricity package that lifts people at least to tier 1, which is accessible and more affordable than the current portfolio of SHS. However, for the SHS program as well, affordability needs to be improved in order for more SHS users to reach a tier 2 or tier 3 level, respectively (under the complex algorithm). Reliability and quality only affect the ability to reach at least a tier 3 level. Here, for the on-grid customers, a better load management and transformer improvement may have the potential to move up to 93 % of the on-grid households (under the simple algorithm) to a higher tier level, provided that the second most pressing issue of evening hour supply is also tackled. Further analysis is needed here.

Comparative analysis of tier algorithms

This part of the analysis is dedicated to the evaluation of the underlying decision rules as well as differences and sensitivities of applying the simple and the complex version of the algorithm. It is important to note that the majority of the decision rules do not apply for solar home systems and solar lantern interventions, but only for national grid, mini-grid and diesel generators due to the skipping pattern proposed in the underlying questionnaire. It is strongly recommended to change that, and also collect data on capacity, duration, quality and reliability for these systems. In the present dataset this has only been done for a minority of the SHS owners (8 %). Nonetheless, a lot can be learned from the little data. The simple algorithm undermines the SE4ALL goal of energy efficiency (this may even apply for households connected to national or minigrids). With higher efficiency appliances a lower peak generation and storage capacity is needed to provide sufficient duration of service supply. Through the simple algorithm, however, a lower score in peak capacity, rules out a higher possible overall score supported by sufficient daily and evening supply hours in connection with a good performance in electricity appliances available. The key difference here is that with an autonomous system, like a SHS, the peak capacity sets the ground rules for the needed efficiency for a certain amount of electricity service hours, as generation and storage capacity is capped individually. In a centralized scheme, in turn, overall generation capacity is usually assigned based on pricing mechanisms, appliance efficiency being only indirectly affected. . But even in a DC minigrid, as an example of centralized generation the utilization of highly efficient appliances is not adequately reflected in the simple algorithm, and if no longer excluded by the skipping pattern, individual solar based systems are not either. This line of argument finds support

[7] Appendix 1 – figure 1 shows the application of a different criterion than the 5 % and 10 % thresholds of relative energy expenditure, which is discussed later.

[8] Note that these statistics suffer from a lot of noise, and standard deviations are extremely high.

by Craine et al. 2014. This has further implications for the calculated investment needed, as done by the IEA, for universal energy access. Pachauri et al. (2013) estimate that globally US$ 2005 65–86 billion per year would be required to achieve near universal access to electricity and clean cooking by 2030. They also state, however, that taking into consideration feasible decentralized options, investments are likely to be lower compared to their estimates where all access is achieved via grid extension alone. Craine et al. (2014) argue that the investment estimations could potentially decline from a level of USD 640 billion over the next 20 years to as low as USD 200 billion, mainly based on revised efficiency values in decentralized energy options. This, in turn, has been heavily criticized by Trembath (2014) as being far too low. The importance of including the latest trends in energy efficient appliances remains, however.

As much as the new tier framework wants to capture the multiple dimension of energy poverty, it loses part of its power by the simplified decision rule it recommends to always choose the lowest performing attribute as the final tier score. This explains to a large extent why, as already stated, the simple tier score is significantly lower than the score estimated when using the complex algorithm (1 % level). The other factor explaining this difference is a different interpretation of the affordability attribute. The analysis presented here uses the 5 %/10 % relative energy expenditure criterion that is also used in the complex algorithm. This indicator seems rather arbitrary and is therefore far from perfect. It also suffers from the same drawbacks as methods based on physical measures of energy (Khandker, 2012), and additionally, it depends on income, which causes high sensitivities to the income level. However, this criterion is, nonetheless, more suitable than the rule that the cost of a standard consumption package of 365 kWh per annum or 1 kWh per day be less than 10 % of household income. Such a criterion is still based on income. But on top of that, considering advances in appliance efficiencies, 1 kWh per day seems to be far beyond that necessary for a tier 2 electrification level. The root of the problem here lies in the comparison of different units. If Unilever offers packages of 10 g washing powder in remote areas, there is no talk of why this package is more expensive per unit than if you buy 'a standard consumption package' of one kg of washing powder. The same applies for microfinance. In this case, the interest rate on small loans is in no relation to the interest rates for loans for a significantly higher amount. Beyond that, it is recommended to add another layer to the affordability attribute, namely flexibility in repayment. Collins et al. (2010) explain the complexities of the portfolios of the poor requiring an array of sophisticated methods to sooth various liquidity traps. Pay-As-You-Go (PAYG) solutions have revolutionized the SHS market in East Africa allowing its customers increased flexibility in their payment plans both in terms of up-front payment as well as amount and frequency of monthly installments (Moreno & Bareisaite, 2015). These technology innovations, that are expected to be implemented in Bangladesh shortly, must be reflected in the tier framework. This could be done through a flexibility indicator feeding into the affordability attribute. At the end of the day, it should be the goal to get closer to a comparative analysis of what an hour of TV, light or fan costs a household instead of comparing peak capacities and kWh prices always taking into consideration economies of scale. The complex algorithm, in turn, is very prone to errors as it is more complicated to calculate. It should further be modified so as to change the condition for allocation to tier 1, 2, and 3, where certain appliances are checked for tripping or non-allowance by the provider. Reflected in Q. B3 of the questionnaire, elicitation of information on this item caused confusion among the respondents. It is recommended that the question be rephrased to only refer to tripping. Not recommended use of appliances come from the supplier and should be asked instead. The criterion, however, also undermines the performance of SHS in the given case, as the POs only allow a very limited selection of appliances to be used with their systems, in order to be in a better position once it comes to warranty claims regarding the battery. The main recommendation is to modify this condition in a way that it is a positive condition and integrates the service algorithm into the complex supply algorithm. This can be easily done. By taking the list of appliances that cause tripping or are not recommended to use from the service algorithm, and modifying the rule in a way that it say that these appliances are usable without causing any form of tripping. This turns it into a positive statement and will allow households with limited generation capacity but sufficient access to 'higher tier' appliances, to be assigned to a higher overall tier performance. Furthermore, the complex algorithm contains a default condition in tier 2 that inhibits a SHS to perform better than tier 2, and in tier 3 for a minigrid. Both conditions should be abolished. Both supply algorithms depend on income, whereas the service algorithm does not contain this variable. The service algorithm does not show any significant correlation with income, whereas the simple and complex supply algorithm are both positively correlated with income (1 % level). Here the higher value of the complex algorithm (0.41) over the simple rule (0.26) stands out. These results confirm the outcome of the sensitivity analysis, that reveal that excluding income from the decision rules or setting its level to 0, results in a much lower tier performance, reflected in a major shift from tier 2 to tier 1. It also suggests that the complex algorithm places more value on income than the simple one, as it appears more often in its decision rules, which is considered a weakness of this algorithm.

Conclusions & Recommendations

The authors recommend revising the algorithms aiming at a compound algorithm that combines the supply and the appliance analysis. This will substantially support an adequate reflection of a household's available hours of electricity dependent on the use of more advanced appliances (efficient or inefficient). This adds, however, another layer of complexity to the algorithm in comparison to the simple version. A trade-off between "methodological sophistication and theoretical accuracy on the one hand, and applicability and transparency on the other" is unavoidable here (Bazilian et al., 2010). Recognizing the urgent need of a theoretical underpinning for the measurement of progress towards the first SE4ALL goal, this paper strongly advocates in favor of the multi-tier framework. It also values the need for pragmatism in light of the urgent need of an indicator that is fairly easily computable. Nonetheless, it concludes that the presently favored simple version of the algorithm for tier assignment does not give sufficient justice to the multi-faceted and multi-tier nature of energy access, especially in the current times of rapid technology innovation (e.g. DC appliance efficiency; PAYG). The paper, therefore, recommends the algorithm can potentially be improved. Although there will always remain a trade-off between an approach that is more reflective of reality but is fairly complex, and hence prone to errors, and an approach that is simpler, easily computable, but also has several shortcomings. It should be noted though that the approaches discussed here require the same amount of data and that the debate in this paper is simply based on calculation methods and alternative algorithms. In light of a likely inclusion of energy access in the upcoming SDGs, the authors advocate for a fast review of the present method and a quick adoption in the field through systematic integration in existing surveys or, which may work out quicker, to put it high on the agenda of the multilateral national offices of the SE4ALL member countries.

As the new framework allows for a reflection on country specific energy interventions, this paper for the first time evaluates the widely acclaimed solar home system program of Bangladesh. Currently, SHS are not reflected at all in (inter-) national statistics on energy access. According to the multi-tier framework, the sample households with SHS score at the tier 1 and 2 levels. A major challenge, despite opposing rhetoric, remains the issue of affordability, including higher flexibility in repayment plans. Monthly installments of the microcredit based scheme are still too high compared to expenditures for kerosene and on-grid access, as well as in relation to total household income. The latest trends in energy efficient appliances that are already available locally, however, are presently paving the way for higher tier performances provided a more sophisticated tier assessment, as suggested herein, is adopted. There is also a need for actions that address households at lower income levels, as present schemes address largely higher income rural customers. It should be carefully noted that the tier assignments are highly sensitive to parameter changes, different algorithms, and data requirements. The performance evaluation of country specific energy interventions can differ significantly, depending on the type of algorithm that is used, which may lead to conflicts when it comes to a consensus building process for a universal measurement framework among the SE4ALL member countries. Once this is achieved, pro-poor policies that influence energy access in terms of having households climbing up tier levels can be designed and implemented more effectively. Still, only what gets measured, also gets done, so immediate action is needed here.

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Appendix

			Tier-0	Tier-1	Tier-2	Tier-3	Tier-4	Tier-5
Attributes	1. Peak capacity	Power	No Electricity	V. Low Power Min 1 W	Low Power Min 50 W	Medium Power Min 200 W	High Power Min 2 kW	
		Daily capacity		Min 4 Wh	Min 200 Wh	Min 1.6 KWh	Min 4 KWh	
	2. Duration	Hours per day	< 4 hrs	Min 4 hrs		Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening	< 2 hrs	Min 2 hrs		Min 2 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability					Max 3 disruptions **per day**	Max 7 disruptions per week	Max 3 disruptions **per week** of total duration < 2 hours
	4. Quality					Voltage problems do not prevent the use of desired appliances		
	5. Affordability				Cost of a standard consumption package of 365 kWh per annum is less than 10% of household income			
	6. Legality					Bill is paid to the utility / pre-paid card seller / authorized representative		
	7. Health and Safety					Absence of past accidents and perception of high risk in the future		

Figure 1: Multi-tier Framework according to ESMAP 2014

Scientific Papers

VI. Planning and Governance

Is a grid connection the best solution? Frequently overlooked arguments assessing centralized electrification pathways

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Abstract

Providing reliable electricity access is still a major challenge in many regions of the Global South. This study discusses indicators characterizing grid power supply and provides various measures next to the electricity access rate to show the linkages between electricity access pathways for doing business. The results of the analysis, done for six selected countries in Sub-Saharan Africa and Asia, indicate that a grid connection, often perceived as cheaper, is characterized by its own challenges. These challenges should also be considered and evaluated when assessing different electrification strategies. The quality of grid supply in terms of length and frequency of power outage, T&D losses, and connection charges are assessed. A trend towards decentralized independent power generation can be observed as one of the consequences.

Keywords: decentralized electricity supply, T&D infrastructure, quality of electricity supply

Introduction

Providing electricity to everyone is still an unsolved challenge from a global perspective. Central electricity generation with transmission and distribution (T&D) is still considered as the most cost-competitive way of providing electricity (Deichmann et al., 2011). Though this might be true for most urban and densely populated areas, the situation in rural areas is different. In absolute numbers, a very large share of humanity is living in rural areas, with rising population growth projected for the future (UN, 2012).

This paper presents a framework for understanding the limitations of electricity supply by T&D grids in developing countries with limited or no access to electricity. Combining this with the current state of infrastructure in the most affected regions in the Global South leads to a chicken-egg dilemma:

Does the state of a country's T&D infrastructure influence the sufficiency of its electricity supply and, in particular, will investment in its infrastructure lead to universal access to electricity? Or, should we instead be asking if a decentralized power scheme is in fact the best approach for some rural areas?

Very often the analysis of electrification pathways is carried out using only levelized cost of electricity (Short et al., 1995) for decentralized options in comparison with the cost of grid electricity per kWh. Certainly, more aspects should be included.

Electricity access is a combined measurement of a nation's power sector status, available infrastructure, and economic development. However, today there is much more data available to draw a more comprehensive picture of energy access and infrastructure.

The SE4All Global Tracking Framework (World Bank, IEA, 2014) applies a multi-tier approach to describe the current access of electricity, developed by Bhatia et al., 2013. One measure is the amount of energy consumed by a country, and other factors such as the timely availability of power and the possibility of productive use also play a key role.

The frequently cited statistic of 1.3 billion people without access to electricity (IEA, 2013) is not very precise nor does it take into account local characteristics, which might offer the key to developing approaches to providing access.

Opportunities for providing access to electricity

Two main options for providing access to electricity can be differentiated (Tenenbaum et al., 2014):

1. Decentralized options like mini-grid and off-grid systems, where energy technology (renewable or fossil-fueled are installed locally to provide electricity to households or communities connected within a micro-grid), and
2. Centralized systems where a national or international T&D system is connected to central electricity generation plants to distribute electricity to the consumers.

As both approaches are based on two different principles the desired path needs to be clearly defined[1]. All available relevant information should be included in a prior assessment. Here it is crucial to take an intensive look at existing infrastructure, as well as the society's perception and reaction to the current state of electricity availability.

Most countries in the Global South have at least a small national electric network installed. This varies greatly in size, capacity, state, and age of the system across countries and regions (Foster & Briceño-Garmendia, 2010). The number of people served by a given infrastructure also varies. A grid is generally divided into transmission and distribution systems whereas the largest share (in relation to length) is made up of distribution lines. The absolute length of transmission lines is generally higher in geographically large countries, where the population is more scattered. Certain parameters can

[1] The differentiation of these two approaches is necessary to define objectives for each possibility, although in the end a combination of both pathways might be the optimal solution in most cases. In this case an integration of both schemes needs to be developed.

be derived depending on the characteristics of the energy infrastructure. The International Energy Agency provides data about both technical and non-technical losses (IEA, 2011). Data is also collected on power outages, their length, their frequency, and their negative economic consequences (Enterprise surveys). Another tracked indicator describes on which level electricity is perceived as a barrier to doing business. Reliable access to electricity is ranked higher in importance than corruption (IEA, 2014), for example.

Research Objectives

This paper aims at focusing on important, often neglected aspects regarding the electrification pathway with T&D grids in rural areas. The objective is to

1. Gain an understanding of challenges related to existing installed T&D infrastructure, and
2. Provide an overview of the impacts of grid-based electricity supply for productive use in six selected countries.

Methods

The results of this paper are drawn from a comprehensive data analysis. A combination of various sources yields a clear visualization of relations between the given data parameters. Today, a large amount of data is publicly available and helps to narrow the gap between understanding local conditions and the application of appropriate measures for providing electricity (AEEP, 2014). The Results section summarizes findings for the six selected countries Republic of Congo, Ghana, India, Myanmar, Nepal, and Tanzania (Fig. 1). They were chosen to account for a wide geographic variety in South and South-East Asia as well as Central, West and East Africa.

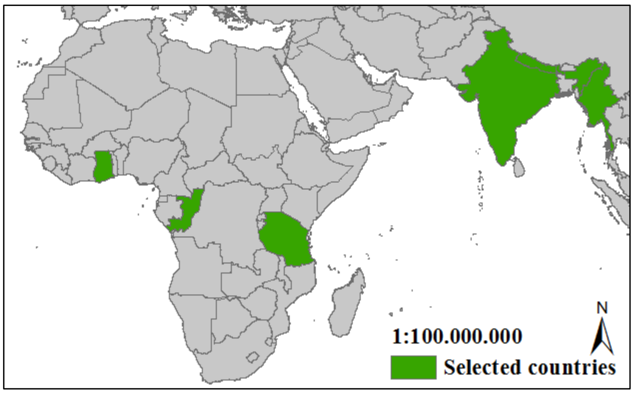

Figure 1: Selected countries for the study.

Table 1 lists the total national electrification rates and the rural electrification access as well as the respective Human Development Index to create a linking to the socio-economic situation of the countries. Here it is important to consider that characteristics vary greatly, which means that a transfer of results to neighboring countries is not advisable because the situation can change dramatically over borders. In the selected countries, electrification rates are generally much lower in rural areas than on a total national level (IEA, 2013). Only in the least developed country, Tanzania, is the overall access to electricity almost as low as the access in rural areas. India has the highest values of electrification access. However, looking at absolute numbers of people lacking access to electricity, this country would lead the list.

Table 1: Electrification rate as defined within the World Energy Outlook 2013 (IEA) and HDI 2013 (UNDP).

Country	El. rate total (%)	El. rate rural (%)	HDI[2] Rank
Congo (Rep.)	37	9	140
Ghana	61	38	138
India	75	67	135
Myanmar	49	28	150
Nepal	76	72	145
Tanzania	5	4	159

Results

Poor electricity provision as a barrier to business development

Electricity is recognized as major factor in economic development. Apart from health and educational benefits, it is the major area benefitting from a reliable affordable access to electricity (Kanagawa & Nakata, 2008).

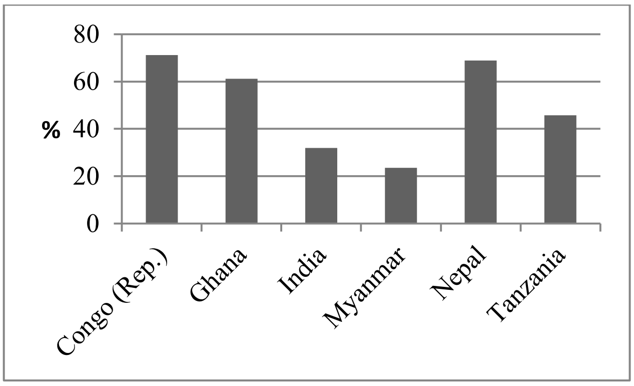

Figure 2: Percent of firms identifying the lack of electricity as a major constraint[3]

Access to electricity is identified as a more important factor in doing business than other hindering aspects, such as access to capital and corruption (IEA, 2014). Figure 2 illustrates the percentage of business enterprises in each country which identify electricity as a crucial factor, starting with about 20 % in Myanmar up to more than 70 % in the Republic of Congo.
This also indicates that in all sectors electricity is needed as a basic service, as the shares of agriculture, service sector and IT vary across the countries. The perception of the lack of power as a barrier mainly results from frequent power outages. Figure 3 shows why the grid electricity supply is inadequate in the six countries. Long power outages occur frequently. Of course, non-electrified

[2] HDI refers to the Human Development Index 2013. http://hdr.undp.org/en/data. Accessed on 12th February 2015.

regions also perceive the absence of electricity as a barrier to certain business opportunities.

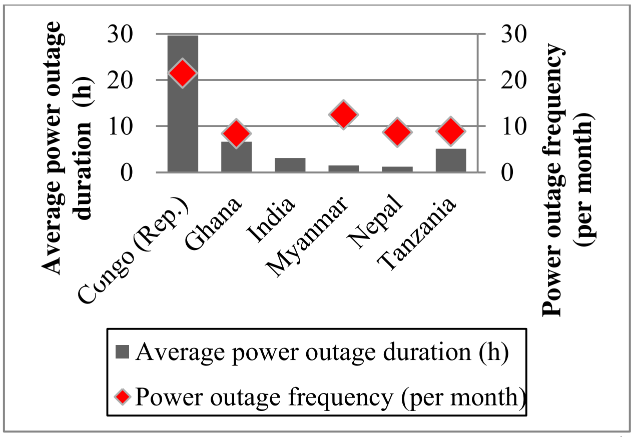

Figure 3: Average power outage duration and frequency.[4]

The Republic of Congo has both the longest and most frequent power outages. Values show the unreliability of the existing grid infrastructure. The discrepancy between duration of outage and frequency is the highest in Myanmar. Here, frequent outages occur for short durations. For India, only data about the average duration of power outages is available from the source. When interpreting these values it is important to bear in mind that the number of people affected by outages changes from country to country depending on the number of connected customers.

Independent self-generation of electricity

With the above presented unreliability of certain infrastructure systems, a rising share of privately generated electricity for business purposes can be observed.

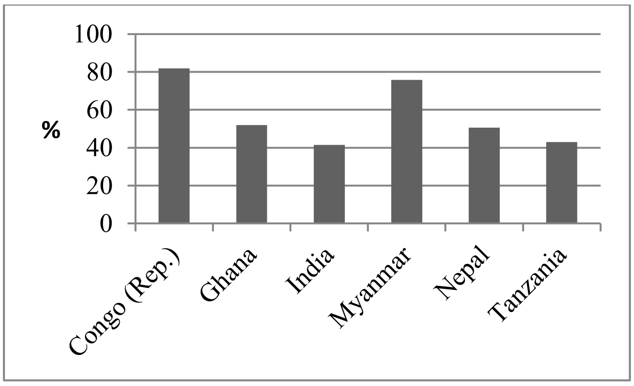

Figure 4: Companies using grid independent electricity generators[6].

The level of ownership or sharing of independent power generation infrastructure is shown in Figure 4. About 40 % to 80 % of the businesses surveyed in all six countries rely on independent electricity generation with generators.[5] This may lead to varying power supply costs due to different fuel prices. Also, the overall non-availability of access to electricity together with the comparably quick and easy installation of small generators can be the reason for self-generation, which is already a decentralized solution established in many regions.

Transmission and distribution losses

The analysis shows that high losses of up to almost half of the electricity production occur in the six countries (Fig. 5.). Comparing these values to countries with advanced grid systems where losses are usually less than 10 %, these levels are very high. T&D losses are a combination of technical and non-technical losses. Technical losses mainly depend on the length of the T&D network lines from power generation to consumer, as well as their respective voltage and currents. Non-technical losses include inadequate or non-existing metering, unrecovered billing and theft.

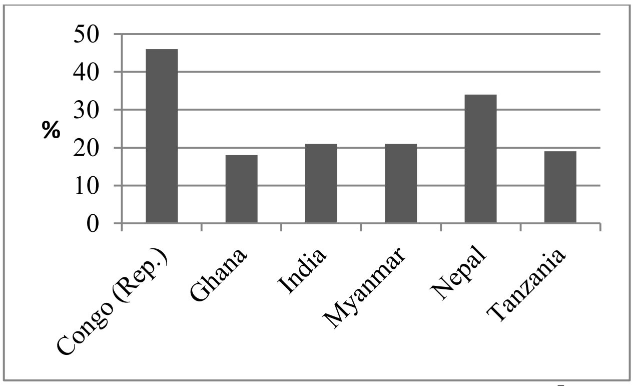

Figure 5: T&D losses of electricity production[7].

High upfront connection fee

Decentralized systems are often characterized by high up-front costs which exclude people who do not possess the requisite financial resources. In these countries, this is a high proportion of the total population (Ahlborg & Hammar, 2011). Yet in many countries, connection to the national grid requires an up-front fee for the cost of connection from the household to the distribution grid, as well as for metering technology. These costs vary across countries but tend to be high in comparison with the populations' ability to pay. For example, the fee can be up to 400 US$ which is higher than an average monthly income (Golumbeanu & Barnes, 2013).

As a consequence, many people, especially in rural areas, live near the grid but cannot obtain electricity. In these cases new tariffs or subsidy schemes or micro-financing opportunities need to be developed to allow the payment of these fees (Palit & Chaurey, 2011).

Tanzania provided a positive example in 2013 when it lowered connection charges significantly, for rural areas in particular (United Republic of Tanzania, 2014).

[3,4,5,6] Data based on http://www.enterprisesurveys.org/data/exploreTopics/Infrastructure. (Accessed on 12th February 2015). Depending on the country different base line years are available (Congo (Rep.) 2009, Ghana 2013, India 2014, Myanmar 2014, Nepal 2013, and Tanzania 2013)

[7] International Energy Agency (IEA) 2011–2014 Energy Statistics and Balances of Non-OECD Countries and Energy.

Tenenbaum et al. (2014) state that the connection charges in Asia are generally lower than in Sub-Saharan Africa.

Discussion

The major aspects which are commonly included when looking at electrification pathways are generation costs based on levelized cost of electricity and grid extension cost per kilometer or current costs per kWh. Within this framework a centralized approach for providing access to electricity is often the chosen pathway (Zvoleff et al., 2009).

From the analysis of the provided indicators it can be concluded that access to electricity can have many facets which are not reflected in global data sets (e.g. World Energy Outlook, IEA, 2014). This should be taken into consideration when planning the extension of electricity access.

Power outage frequency and length indicate the reliability and quality of the existing electrical infrastructure. Existing infrastructural shortcomings need to be accounted for and the definition of access to electricity should be carefully applied. Having access to an unreliable grid might not in fact count automatically as being electrified. The same applies for populations which theoretically live in the electrified regions but cannot afford the connection charge.

With these aspects in mind in certain regions the choice for the electrification pathway might shift towards decentralized approaches. In all six countries more than 20 % of surveyed firms identify the lack of electricity as a major constraint. The absence or lack of reliability of grid electricity leads to a higher share of private generation (more than 40 % of surveyed firms rely on independent power generation). This occurs even without respective policies in place, which can be interpreted as a clear readiness for decentralized structures.

A more detailed look at T&D losses leads to a better understanding of the state of the electricity systems in the six countries considered in this paper. The upgrade of an already faulty network is a much larger challenge than a total new development of infrastructure. In addition, with reference to the grid connection charges it is shown that electricity is often within physical reach of rural populations but there are no financial means of meeting the costs. Even significant investment in new grid infrastructure cannot solve this problem (Lee et al. 2014).

To account for some limitations of the parameter set discussed here, some complex indicators like the Energy Development Index (EDI) and the Multidimensional Energy Poverty Index (MEPI) have been developed (IEA, 2012; Nussbaumer, 2012). An inclusion of these can further deepen an understanding of the electricity access situation within different countries in order to establish the most suitable electrification pathway.

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Institution as the catalyst for productive use of electricity in livelihood cluster: A Case for energy plus approach from Andhra Pradesh, India

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Abstract

This study in the Pochampally handloom cluster in the state of Andhra Pradesh, India examines the role and impact of institutions in channelizing non-energy inputs to rural handloom households and their ability to trigger income augmentation via productive use of electricity. Economically weaker weaver households from two sites in the handloom cluster were compared based on their income, change in income and productive usage of electricity. The findings indicate that households receiving non-energy inputs channelized by a formal institution perform better in each of the identified comparison variable than the households that were not linked to any such formal institution. The study recommends inclusion of institutions as channels for facilitating non-energy inputs in programs/projects designed using energy plus approach of the United Nations.

Keywords: Energy plus approach; Rural electrification, Community based organization, Livelihoods.

Introduction

Over 300 million people in India do not have access to electricity (IEA, 2013). Among households having an electricity connection, many have access to only sporadic supply networks. Further, financial inability of a rural household to afford electricity service restricts its usage for basic as well as productive purposes. However, Access to modern energy service including electricity is a facilitator for Millennium Development Goals (Modi et al., 2010). Hence, rural electrification has been a priority of the government for decades.

However, governed by supply-centric approach, rural electrification has largely been measured only in terms of physical access to the grid infrastructure (Patil, 2010; Rehman, et al., 2012). In addition, for below poverty line families, traditionally, rural electrification initiatives of the government have focused on providing only one light point connection (Patil, 2010).

While importance of basic lighting cannot be overemphasized, it does not often directly translate into income augmentation opportunities for the poor (UNDP, 2011). Many studies suggest that electrification is a necessity but not a sufficient condition for enterprise success. Researchers have attributed this to market saturation by presence of similar local enterprises (Dijk & Clancy, 2010), supply of low quality raw materials, lack of sufficient scale of production capacity of local enterprises and low electricity usage beyond lighting (Dijk, 2012). This restrains opportunities for the poor households to escape from poverty. Hence, researchers suggest that without significant productive use of electricity, the goal of unleashing economic growth in rural areas of India would require following an energy plus approach. The energy plus approach emphasizes the amalgamation of energy (providing quality and reliable electricity services) as well as non-energy[1] inputs to enhance prospects of sustained usage of the electricity service by the poor. This is also corroborated by various researchers who reported positive impacts of electricity for enterprise income generation (Bose et al. 2013; Kirubi et al., 2009; Imai & Palit, 2013).

This paper discusses the case for energy plus approach from Pochamapally handloom weaving cluster in Nalgonda district of Andhra Pradesh. We have identified non-energy inputs that account for productive use[2] of electricity by households. In addition, the paper also looks into the role of institutions for channelizing these inputs. Further, we have analyzed the impact of energy plus approach on income augmentation. Based on the study, the paper shares some best practices to design projects incorporating energy plus approach in a livelihood cluster.

Research Objectives

This study has attempted to address the following research question: What catalyzes the productive use of electricity for income augmentation in a livelihood cluster?

The research objective(s) are as follows:

- To identify complementary inputs over and above electricity that has encouraged productive use of electricity among households
- To determine agents that facilitated amalgamation of energy and non-energy inputs.

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[1] As per UNDP (2011) non-energy inputs may include among others; access to credit, access to raw material, market linkages, infrastructure such as roads and communications, availability of information and skills training and social services

[2] This study only looked into non-farm and home-based activities that lead to income generation/augmentation.

Methods

The study has attempted to identify the impact of institutions in channelizing different non-energy inputs[3] that may trigger productive usage of energy input[4] and measures their impact on household income. The definition of non-energy inputs was adapted from the National Rural Livelihood Mission (NRLM) of India (Figure 1).

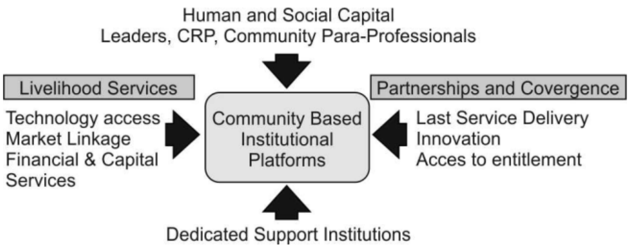

Figure 1 Non-energy Inputs Broad Categories

The Pochamapally handloom weaving cluster in the state of Andhra Pradesh[5] (AP) has been selected for the study. This cluster had access to electricity since many[6] years; however, the households have minimum adoption of mechanization for weaving. Further, weaving seems to be an unattractive livelihood option as there has been reduction in number of households involved in weaving.

For this survey, only households involved in weaving activity were considered. Only Self-help Group (SHG) members receive the non-energy inputs from SERP[7]. The quality and quantity of these inputs is proportional to the Village Organization (VO) grade[8] varying from A to F (A being the highest grade). In addition to SERP inputs, specific inputs for weaving activity have also been given through KRuSHE (a project by an NGO called Chetana Society) and Chenetha Color Weavers (a private entity) in partnership with SERP in this cluster. Thus, Grade A or B households (involved in weaving), receiving non-energy inputs from SHG, SERP and its partners, is referred to as 'SITE A' households. On the other hand, non-SHG member households (involved in weaving), with no connection to SERP projects, receiving relatively lesser non-energy inputs are referred to as 'SITE B' households. Further, SITE 'A' and SITE 'B' are similar in terms of availability of electricity supply, scheduled power cuts and voltage fluctuations.

The cluster was selected based on occupation and electricity access , followed by stratification based on SITE 'A' and SITE 'B'. Final households for sample survey were selected randomly, and in case the respondent was not available or reluctant, a proper replacement was done. Sample size considered was 60 households, with 40 households from SITE 'A' and 20 households from SITE 'B'. For this survey households for SITE 'A' and SITE 'B' were selected in the ratio of 2:1, which is similar to the ratio of SHGs with Grade 'A' and 'B' to that of other Grades in the Nalgonda district (Department of Rural Development, 2014).

Structured questionnaires were administered and focus group discussions were conducted at SITE 'A' and SITE 'B' were conducted. The current income (as of August 2014) and change in income were captured from the survey. For simplicity of analysis, income change was grouped as increase, no change and decrease, taking baseline year as 2000 when SERP operations had not begun. To recognize the non-energy inputs that played a role in income augmentation, each household was asked to rank fifteen different non-energy inputs based on their perceived impact on their income. The non-energy inputs consisted of institutionally channelized non-energy inputs[9] and other[9] non-energy inputs. Further, questions were directed to map the level of usage of electricity in the weaving activity from basic to productive.

Results

Average Monthly Income

Figure 2 and Figure 3 indicate that the households from SITE 'A' have higher average monthly income than that of SITE 'B'. Further, SITE 'A' also has higher percentage of households (47 %) with increased income in last ten years as compared to SITE 'B' which has only 6 % of households with increased income.

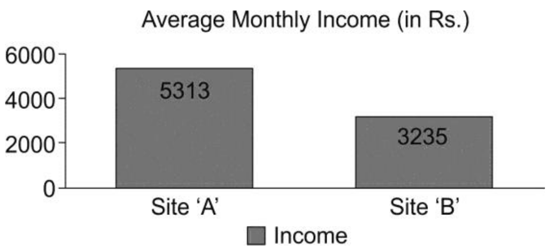

Figure 2: Average Monthly Income

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[3] Refers to startup finance, supply of raw material, training, government support, external institution support, plant & machinery (infrastructure) and mid-term finance

[4] Access to electricity is considered as the energy input.

[5] Andhra Pradesh for this study refers to the region including the newly formed state of Telangana in India.

[6] Many: a period of 30–40 years that is sizable in comparison to start of activities of SERP in 2000.

[7] The Society for Elimination of Rural Poverty (SERP), established by the Government of AP, acts as a resource cell for the development of NRLM. The SERP acts as support structure to facilitate the social mobilization of rural poor women in 22 rural districts in AP. SERP works on a comprehensive multi-dimensional poverty alleviation strategy by focusing on building strong/sustainable institutions of the poor and their federations.

[8] Grade is the performance of the SHGs under the VO (village level federation of SHGs) in terms of loan repayment, savings, regular SHG meetings and internal lending. Grade of VO determines the quality and quantity of benefits transferred.

[9] Refers to personal rapport in the market, support from family and friends, market proximity, road and public transport, access to skilled manpower or unskilled labor and experience of entrepreneur and competition.

Productive Use of Electricity

Figure 4 shows higher percentage of SITE ‘A’ households in comparison to the SITE ‘B’ in terms of extended working hours and usage of electricity for activities beyond lighting such as use of motor driven machines to improve productivity to save time. The machine saves 2–3 man-days of work for the enterprise, which is INR 274 to INR 411 (taking MGNREGA rate as INR 137[10]). This shows that households receiving the non-energy inputs in addition to electricity are able to augment their income through productive use of electricity access. While SITE ‘A’ and SITE ‘B’ had access to electricity since last 30-40 years, however, post injection of non-energy inputs and development of community organisations has seen enterprises taking up productive use of electricity.

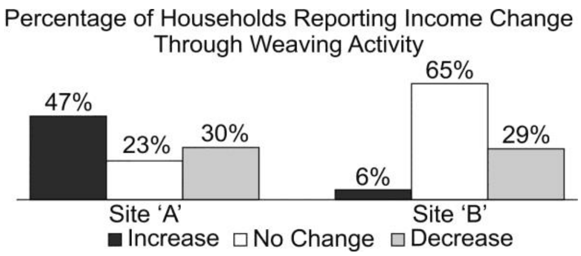

Figure 3: Households reporting change in monthly income

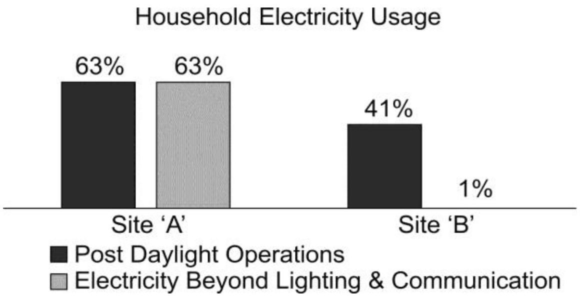

Figure 4: Electricity use for weaving activity

Non-Energy Inputs

The households at SITE ‘A’ have access to low cost of credit: 0 %, 3 % per annum, and 12 % per annum through the SHGs, while SITE ‘B’ households rely on informal lending streams that have higher cost of credit. The time saved (2 to 3 days) by households from SITE 'A' using the warping machine can translate in to an indirect benefit in terms of potential earnings of INR 274 to INR 411 (through MNREGA[10] payment). Further, the training by Chetana Society, access to good quality raw material, market access[11] and branding of weaver products of SITE 'A' households has resulted in a 20 % increase in market price for the dress material in comparison to the Pochamapally local market.

The two pentagons represent the two categories of households (SITE ‘A’ and SITE ‘B’) and their reported perception of top five non-energy inputs received that has led to income augmentation. Figure 5 shows market access, startup finance, institution support, supply of raw materials and training as valuable inputs for the SITE ‘A’ enterprises. These inputs were channelized through institutions at various levels and of varying strengths such as SHG, NGO and private partnership. The weavers have leveraged on the three forms of loan available to the SHG members such as bank linkages, Community Investment Fund and 0 % interest. Supply of raw materials and market access were provided by Chenetha Color Weaves and training by Chetana Society.

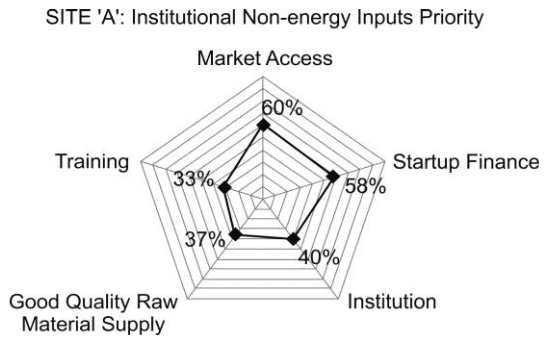

Figure 5: Top five Non-energy inputs for Site A

Figure 6 shows valuable inputs identified by SITE ‘B’ enterprises, these inputs are independent of any institutional or project support and are mainly personal ties and rapport in the market. Further, market access and supply is related to proximity of Pochampally weaving cluster, which is not an external input as in the case with SITE ‘A’ enterprises. Some other inputs were also reported by the SITE 'B' households such as training by cooperative Society. However, this was a one-time training unlike the the continuous upgradation training received by SITE ‘A’ households on meeting market expectations for better designs, colors and tools.

It is notable that average monthly income of SITE ‘A’ is higher than that of SITE ‘B’. While access to electricity is a common input across both the sites (~ 16 hours of average daily supply), it is the presence of community based institutions that distinguish the SITE ‘A’ households from SITE ’B’. Motor-driven appliances that improve productivity are now accessible and affordable due to the continuous support in the form of timely, affordable and sufficient credit, external market tie-up, training and capacitation on designs, techniques, quality and market acceptable standards, and access to good quality raw material.

[10] Mahatma Gandhi National Rural Employment Guarantee Act http://nrega.nic.in/nerega_statewise.pdf Accessed on 25th January 2015.

[11] Market access includes activities by Chenetha Colour Weavers such as opening a store and providing an e-commerce portal for the products under the brand name Karghaa.

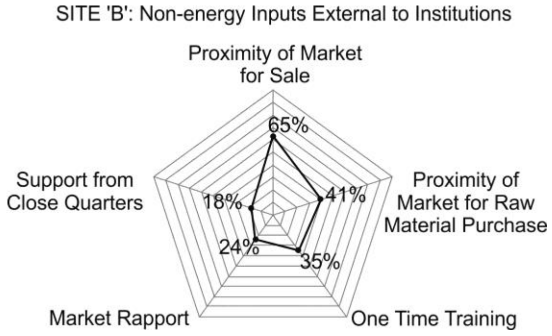

Figure 6: Top 5 non-energy inputs for Site B

Discussion

Access to electricity is essential for economic growth in rural areas. Productive usage of electricity in livelihood activity will magnify the opportunites for poor. To realize this, chanelizing both electricity and non-energy inputs through synergistically alligned development programs is essential. Based on the study, the following conclusions can be drwan:

Coupling of livelihood opportunity and electricity access: In order to facilitate sustained use of electricity by the poor, livelihood augmentation is essential. The success of Township and Village Enterprises (TVE) model in China (Bhattacharyya & Ohiare, 2012) substantiates this fact. TVE introduced institutionalization of local enterprises that led to job opportunities for the village inhabitants and subsequently augmented rural electricity demand and adoption of electrical appliances by them. In India, existing livelihood clusters such as the handloom and weaving clusters present significant opportunity. The cluster development scheme for handloom sector and National Productivity Council's recommendation for use of machines in handloom industry reflect on above (NPC, 2012).

Effective institution for channelizing inputs and building synergetic partnerships: Lack of institution dilutes the impact of development program which is otherwise attainable. Efforts via medium of effective community based organisations will lend collective voice and increase earning capacity of entrepreneurs/individuals. These institutions create/facilitate access to an enabling environment for livelihood augmentation. Further, they foster value chain based approach that allows for integration of goals and roles of participating agents in the interest of the poor.

Knowledge management and new metrics for measurement of success: To replicate successful projects, it is essential to capture and document challenges faced by the stakeholders and the steps undertaken to address these challenges. In order to identify successful projects, a prior step would be measurement of impacts and outputs. However, conventional methodologies will not suffice projects incorporating energy plus approach. Multi-dimensional metrics are essential to monitor and report the role of participating institutions, degree of synergy and integrated achievements on the lines of larger goals such as Sustainable Energy for All.

In final conclusion, mere access to electricity and non-energy inputs will only have limited impact on household income. This study highlights that channelizing non-energy inputs through effective institutions and institutional partnership accelerates the process of income augmentation through productive use of electricity.

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Decentralized Energy Generation, Rural Electrification and Smart Grid Solutions at the Brazilian Power Sector: An Overview of the Improvements, Bottleneck and Incentives Established through New Regulatory Framework (2009–2013)

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Abstract

During the last 4 years Brazil has been trying to build a solid foundation and create a promising environment for the development of smart grid arrangements and decentralized energy supply. A number of actions have been taken by the government and the regulatory agency to promote it, from the improvement and creation of regulation framework until the promotion of a strategic research and development projects. From 2002 until 2009, sparse regulation was built to stimulate and contribute to both rural and urban decentralized energy supply. But after 2009, governmental institutions changed the track taken and started to build a road map to improve, not just remote areas rural electrification but also urban decentralized energy generation, allowing different payment methods and smart grid solutions. Therefore, the article main intention is to present the regulatory framework enhancements for the promotion of decentralized energy supply and correlated issues, and also through that analysis identify the possible impacts and bottlenecks to its development.

Keywords: Regulatory framework, Rural Electrification, power supply, smart grid, distributed generation.

Introduction

Since 2001 Brazil has faced three big challenges and bottlenecks in the electricity industry, and now is towards facing another one. The first one was the 2001 power shortage, the second the "Electricity for All Program" implementation and the third one, which is an ongoing experience represents the establishment of a new electricity era. The cyclical challenge that Brazil is facing since 2013 and that will probably persist also during 2015 is the possibility of another electricity shortage, and decentralized energy supply might come as one of the strategies applied to mitigate this problem.

The 2001 power shortage forced the Brazilian government to make changes on the electricity industry model and one of those changes was the implementation of the Energy for All Program – LpT Program in 2002. Before 2002 most of the electricity supply was done just by extending the electricity transmission and distribution network. However, there were still a number of small communities and households located in isolated and remote areas where it was not economically viable to extend the net so the Distribution Service Operators – DSO did not provided that part of population. The LpT Program came as a way to solve this problem; hence the main purpose of the program was to provide electricity to all the Brazilian inhabitants. Most part of this goal was achieved just by extending the network, but to a number of areas this approach was too expensive (almost prohibitive). On those cases, at first, it was necessary to install individual generation systems either using diesel generators or renewable resources (in most cases solar energy) to provide the minimum power supply, around 13 kWh/month.

During the first seven years of the program stakeholders and DSO´s main complaint was the lack of a solid regulation framework and equipment and systems standardization. The only resolution with some basic standardization for individual system was the normative resolution nº 83/2004.

Along with that, another stimulating factor to study new regulatory indicatives for decentralized energy supply was induced by actual focus given on distributed electricity, smart metering and net balance. So the electricity industry roadmap puts pressure on Brazilian electricity sector to start dealing with another challenge which is to prepare the entire regulatory framework necessary for a new electricity industry era, where decentralized energy supply, smart metering and different payment methods will prevail and play an important role.

Following this trend, four years ago the Brazilian Electricity Regulatory Agency – ANEEL started to study the best way to build a whole new regulatory framework, which comprised not just rural electrification regulation, but also issues related with decentralized energy supply as well as issues directly or indirectly associated to it. Topics like payment methods, smart grid meters and systems and possible incentives schemes for distributed generation with renewable resources were put on the table for discussion.

During the whole process, the regulatory agency, the Ministry of Mines and Energy – MME, Energy Research Company – EPE, stakeholders (DSO, TSO and electricity generators) and community, as well, participated broadly through public hearings and consultations and also elaborating of studies on the matter. All and any new regulation implemented passes through the public endorsement process.

Also investments on decentralized energy supply using solar energy was promoted and stimulated through research and development projects, and this represent effort done to improve the use of those arrangements.

Research Objectives

Based on all the written on the introduction, the article objectives is to present the regulatory framework improvements since 2009 on issues like decentralized energy supply, rural electrification, smart grid solutions and prepayment methods. Those regulatory enhancements will be considered together with other incentives to identify how it could affect positively the dissemination of smart grid solutions and decentralized energy supply.

The article will be divided in five parts. The first part presents the methodology applied to carry out the overview. The second part will take a closer look and study the evolution of the rural electrification regulatory framework from 2009 until 2013. Especial attention will be devoted to the Law nº 12.111 because it represents the starting point of all other regulatory improvements. At this part it will also be presented technical notes and resolutions approved on distributed generation, smart grid, payment systems and electronic meters, and it will be done a brief but consistent overview of public consultations and hearings occurred between 2009 and 2013. The fourth part will present some investments and R&D programs leveraged within the LpT program, the World Cup Projects and the Strategic R&D promoted by ANEEL. The fifth and last part of the article will present final analysis, conclusions and highlights.

Methods

The method used to develop the study works as presented on Figure 1. The scope of the work is divided in three parts, which deal with different moments from the technology dissemination. Public hearing and consultations represents the first step towards a framework implementation because is the moment where government, stakeholders and society have the opportunity to discuss and expose opinions and concerns about the matter. The result of public hearings and consultations are usually directives, laws or resolutions. With all the framework and foundation established, the next step of the process is to promote and invest on research and development projects and also pilot projects as a way to disseminate and test a new technology, possible arrangements and equipment.

And the article will follow that lead. The idea is to connect the public consultation and hearings with the resulting law and/or resolution. And also present examples of initiatives taken to use decentralize energy supply both on Brazilian rural and urban areas.

The regulatory framework improvements will be studied considering all the resolutions, technical notes and laws that ANEEL has opened for consultation from 2009 until 2013. In Brazil, all new resolution and technical notes, before its ratification, pass through a process of public audiences, so the community and stakeholders can give their inputs, opinions and add-ons to the process and be part of its development. Usually there are two types of public audiences, the public consultation and hearing. The difference between the two is essentially associated with bureaucratic procedures. On public hearings, stakeholders and community have the opportunity to express their opinions verbally to the regulatory agency and/or government on public meetings, not just by sending a contribution report. And on the public consultation, there are no public meetings, just the possibility of sending contribution report. Sometimes public consultation comes before public hearing, so ANEEL can take stakeholders and community opinion into account even before the development of any technical notes or resolution´s draft.

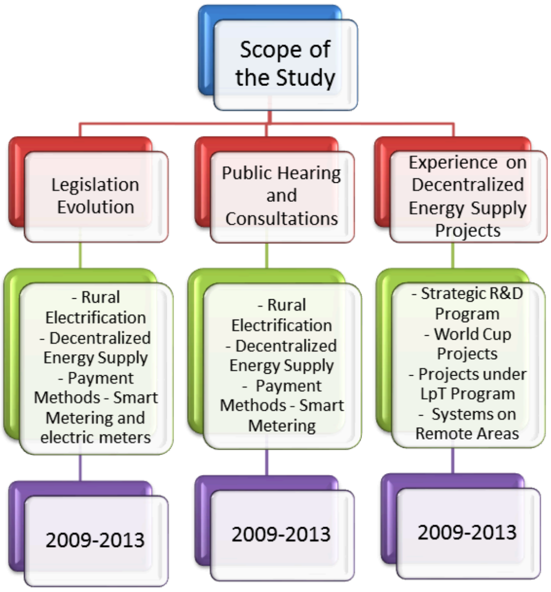

Figure 1: Scope of the Analysis

Regulatory Framework Evolution since the Act nº 12.111

The act nº 12.111 and all the regulation that comes after it is part of a series of improvements made on the regulatory framework that treats specifically about rural electrification and determines changes on the service and management model applied so far. Until then, the electricity supplied on remote or isolated areas was provided just by implementing projects authorized by ANEEL under the LpT Program investments. But since the act´s ratification, this procedure changed and all the projects must pass through an auction, executed by the distribution company, to define which company will be responsible for the generation project and the system management. So by doing this, power supply to remote and isolated areas started to be treated on the same *modus operandi* already used for providing electricity supply on non-isolated areas.

Moreover, other change caused by the Law nº 12.111was related with the operational costs of decentralized off grid systems. Since the approval of law nº 12.111, the "Fuel Consumption Account" – CCC[1] could be used to reimburse the off grid systems 'maintenance and operational (O&M) costs. The amount to be reimbursed was the difference between on grid and off grid system´s O&M costs. This procedure is specific for rural

[1] A CCC is an account whose levy is used to cover the fossil fuel use´s costs (use of diesel, for instance) applied to generate thermal electricity on isolated systems. This account is shared between all Brazilian´s electricity consumers, and the DSOs are responsible for collecting theirs share monthly.

electrification purposes, especially implemented to provide support for the DSO to cope with high level of operational costs. And also only applies for decentralized systems located on remote or isolated areas using renewable resources and represents the first effort made by the government to promote the use of those technologies. Any power supply project to remote areas before being auctioned have to be designed by the DSO, analyzed and approved by EPE. And the auctions only occur after ANEEL authorization.

To have the environment favorable to develop decentralized systems projects as the act nº 12.111 defined, ANEEL opened several audiences to discuss and create a robust regulation. The audiences focused on issues like decentralized generation with and without network associated, smart grids, net metering and payment systems. Almost all the regulation framework associated to decentralized energy supply and correlated matters was constructed between 2009 and 2011.

Together with the evolution of the basis to promote decentralized energy supply, ANEEL decided, on 2012, to extend the Electricity for All Program – LPT until 2014 and now was extended again until 2018. And the main purpose of the program continuation was to make possible the electricity universalization on areas where the costs to provide the service were three times higher than the price of attending usual isolated rural areas[2].

To a better understanding of the regulatory framework evolution, from Table 1 on the Annex I show the picture of all the public consultation and hearings occurred from 2009 until 2013 and the subject discussed.

Besides of that, a number of acts, ordinance and decrees from the Ministry of Mines and Energy were promulgated during this period of time. More than explain each one, the idea is to show priority level rural electrification and distributed generation issues have gained over the last years (Fig.2).

On some "Reference Projects"[3] auctioned by DSOs the idea was to provide electricity using renewable resources or hybrid systems but some projects still were conceived to use diesel only. Despite of that, it is possible to see through the issues discussed on public audiences and also through the next chapter that, a substantial number of projects are pointing out towards a more intensive use of cleaner fuels (photovoltaic and wind) than fossil fuels.

Concerning the evolution of distributed generation, smart grid and net metering regulatory framework, all the activities on the matter between the years 2009–2012 were conceived as a way to take the first steps towards the development of a new network system, which can be called the new electricity industry era. That is the reason why, ANEEL started to discuss and formulate a concise and objective regulation for those issues. This process has started with public consultations and public hearing´s openings, making available technical notes describing international experiences on the theme, and putting critical points on the table to get feedback from the community and stakeholders. At the end, the discussions end up proposing the promotion of some incentives to micro and mini distributed generation, especially the ones with solar energy.

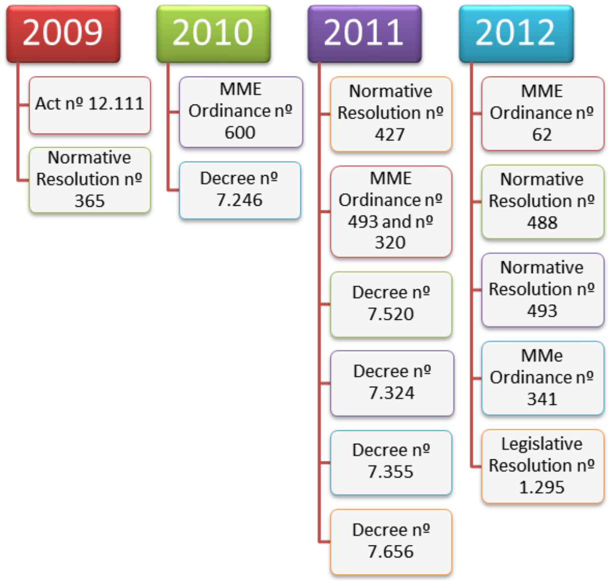

Figure 2: Regulatory Framework Evolution.

The main incentive proposed was to give discounts ranged from 80 % until 100 % on transmission and distribution charges for mini and micro distributed generation facilities.

This chapter attempted to demonstrate how much effort has been done through the regulatory point of view to universalize the electrification and also to promote, not just for rural but also for urban areas, the decentralized energy supply. On the next chapter, the initial results of decentralized energy supply and rural electrification programs will be presented.

Decentralized Energy Supply Investments in Brazil

Most of the initiatives to promote the use of decentralized electricity generation came from strategic research and development projects leveraged by ANEEL, from the LpT projects and also resulted from the world cup stadium solar plants studies. Some of the world cup stadium solar plants projects to become a reality, entered into ANEEL´s Strategic R&D program.

The recent projects developed by the DSOs to provide electricity on remote areas uses renewable resources and decentralized energy supply. Amazonas Energia DSO has a 12 mini distributed generation facilities on 12 communities located on six cities in Amazonas State, using prepayment systems and solar energy arrangements. The electricity availability per household was estimated around 45 kWh/month. EPE also approved CELPA reference project named RESEX, to provide electricity supply to 10 communities with decentralized energy supply (149 households) and 1.202 households with individual systems. The collective systems were conceived as hybrid system (solar + diesel) with an average 45 kWh/month per household consumption, and

[2] Areas where the investment costs represent three times the costs of the usual rural areas not included on the LpT Program.

[3] Reference Projects are the name given by EPE to the decentralized energy supply´s projects after the act nº 12.111.

the individual systems with a 30 kWh/month average consumption.

Another two initiatives for urban decentralized energy supply was developed during the last years. The first one is the R&D Strategic Program developed by ANEEL, which enable generation and distribution companies to build solar energy facilities all over the country. And the second one is the Solar World Cup Stadium projects, where all the world cup stadiums should have constructed rooftop solar generation. Despite of the entire project evaluation and study, only Macaranã (in Rio de Janeiro), Mineirão (Belo Horizonte City), Fonte Nova (Salvador City) and Castelão (Fortaleza City) have concluded the construction of the roof top solar generation. Under the Strategic R&D Program, ANEEL authorized 18 projects with an installed capacity ranging from 0.5 MWp until 3 MWp and total amount invested of around 400 million BRL. One of those 18 projects was the Castelão Stadium Project, Itaquera Stadium Project (São Paulo City) and Capibaribe Stadium Project.

From this brief and concise analysis it is possible to see that even though Brazil still have a lot to do to improve decentralized energy supply investments and penetration, great advance has been made.

Discussion

Through the analysis of the recent regulatory framework evolution and also the investments made during the last 4 years on specially decentralized energy supply, it is possible to see good perspectives lining up for dissemination of smart grid and decentralized energy generation. Furthermore, Brazil is now facing a period of adverse hydrology, lacking of water to generate electricity and using all thermal capacity. In this environment, decentralized energy supply on urban areas and energy efficiency projects tend to gain space. Also the continuation of LpT Program until 2014 and now postponed until 2018 opens space for the penetration of new “reference projects”. But most of the effects and consequences of all the regulatory framework evolution will only be visualized some years ahead. Another initiative that could be used to promote the use of decentralized energy supply could be the application of feed-in tariffs. The penetration of decentralized energy supply on remote and non-remote areas could lead to a more sustainable development for the electricity industry, and on the best case scenario can postpone building hydro and thermal plants.

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ANNEX I

Table 1: Public Consultation and Hearing 2009-2

Topic	Audience Number	Issue	Observations
LpT Program	AP009/2009	Definition of new goals for LpT Program - period 2010	Normative Resolution ANEEL nº 365, 19/05/09
	AP044/2009	Definition of new penalties for not achieving LpT Program goals	Change on Article 14 of the Resolution nº 223/2003
	AP115/2010	Definition of new goals for LpT Program - atendance of consumers units with investmens costs 3 times higher than the LpT Program unitary cost	Based on the contributions recieved, a public hearing was open for further discussions
	AP061/2011	Definition of Condition for LpT Program Attendance from 2011 until 2014	Normative Resolution ANEEL nº 488, 15/05/2012
Distributed Generation and Smart Metering	CP115/2010	Discuss and present the regulatory instruments used in Brazil and abroad to encourage grid connected Micro and Mini Distributed Generation with Renewable Resources	Based on the contributions recieved, a public hearing was open for further discussions
	AP042/2011	Discuss actions to reduce the barriers and give incentives to install micro and mini distributed generation and give discounts on transmission and distribution charges for solar energy facilities	Normative Resolution ANEEL nº 481 and Normative Resolution ANEEL nº 482, 17/04/2012.
	CP015/2009	Discuss the development of electronic metering on low voltage custumers	Based on the contributions recieved, a public hearing was open for further discussions
	AP0432010	Definition of the minimum requirements for electronic metering on low voltage consumers	Normative Resolution ANEEL nº 502, 07/08/2012.
	AP48/2012	Regulation of electronic prepayment and postpayment methods	Normative Resolution ANEEL Nº 610, 01/04/2014
	AP100/2012	Definition of the taxes discounts on mini and micro distributed generation	Retify Normative Resolution ANEEL nº 482
Reference Project´s Auction	AP020/2011	Stablishment of procedures to provide electricity thourgh colective or individual systems to remote or isolated comunities	Normative Resolution ANEEL nº 493, de 5 de junho de 2012.
	CP008/2011	Auction Contract Model and Tender Model	Based on the contributions recieved, a public hearing was open for further discussions
	AP005/2012	Discuss the First Draft of the Auction Contract Model and Tender Model	Resolution ANEEL nº 1.295, 05/06/2012

*The acronym AP represents public hearing and the acronym CP represents public consultation.

Decentralized renewable energy interventions in India as eco-innovations: forms and drivers

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Abstract

Decarbonizing the electricity sector has received heightened attention worldwide amidst growing concerns of climate change. Towards reaching this end, numerous clean energy innovations have been attempted across countries that increasingly emphasized on various renewable energy technologies. Of late decentralised renewable energy interventions have caught the attention of policy makers and private sector players in significant ways due to multiple benefits associated with these systems, importantly as a form of eco-innovation. In this backdrop, the paper lays thrust on mapping and analyzing key driving forces for the promotion of decentralsied energy systems as eco-innovation and how these systems have led further innovations in the form of eco-behavioural changes in India The analytical contours of the paper draws from secondary data sources as well as from case study analysis.

Keywords: decentralized energy; India, eco-innovation

Introduction

At the current juncture where environmental and climate related concerns have received heightened attention, ecologically sustainable growth paths are assigned top priority in the development agenda and have become the most desirable state of economic development. However, charting out a development trajectory, where both economic development and environmental considerations compete to be equally prioritized, is not an easy task (Dower, 2012). Environmental innovations, often reckoned as eco-innovations, have emerged as a systematic response to break this Gordian knot. Of late, innovations in the field of renewable energy have attracted wider attention in all circles. Within the field of renewable energy, decentralised energy interventions have emerged as a major window of opportunity for environmental innovations in many countries across the globe. Emergence of decentralised energy systems have brought about the resurgence of innovations in the field of energy. Though, internationally it is convincingly argued that regulation and environmental awareness are crucial drivers of decentralized energy systems (Chmutina et al, 2014), there has been inadequate scholarly attention in India to understand what the key drivers are and trigger factors promoting decentralized renewable energy interventions as a form of eco-innovation.

Research Objectives

In this backdrop the paper aims at exploring the following set of research questions;

- How have government policies and incentives, regulations, and market forces etc. played as drivers of decentralised renewable energy development in India as an important form of environmental innovation?
- How have environmental innovations through decentralised energy interventions led further innovations through environmental behavioral changes of users?

Research Design

The paper applies a systematic methodology for the analysis of gathered information. Qualitative analytical tools are employed for the analysis of the gathered information. Two different methodological approaches are followed. Extensive desktop based survey research was conducted to understand the existing challenges of the sector with specific thrust on decentralised energy systems as a niche territory for environmental innovations. To get the ground level perspectives, two case studies are strategically selected which capture the prevalent variants of decentralized renewable energy interventions in India. Case studies were conducted as part of the on-going OASYS project[1]. Projects studied in one of the case studies are run by private investors known as Husk Power Systems (HPS) and use biomass gasification technology for power. The other project is supported through the research grant of OASYS project and exploits solar PV energy for producing electricity locally in a cluster of four villages in the Dhenkanal district of the state of Odisha. Information gathering at the field sites constituted administration of semi-structured interviews to key stakeholders such as state level and local agencies associated in the sector, technology suppliers, NGOs, officials, village energy committee members, plant operators and project beneficiaries.

Conceptualization of eco-innovation

The process of innovation is characterized as fluid and non-linear and is largely shaped by human ingenuity, private sector efforts, codified and tacit knowledge networks, and networks of financial resources. Eco-innovations or environmental innovations in the last two decades have generated wider interests among environmentalists, academia, policy makers, and planners.

[1] http://www.oasyssouthasia.info/ Accessed on 19th January 2015.

Environmental innovation is interpreted in terms of innovations in the form of new or modified processes, practices, systems, products which contribute to the environmental sustainability (Rennings, 2000). Theoretical discourses on environmental innovations offer varying rationales explaining the key trigger factors for environmental innovations. The approach propounded by scholars of environmental economics advocates that it is essentially the well designed and well executed regulation which propels environmental innovations (Rennings, 2000). The belief is drawn from theoretical foundation of externalities and the societal imperative to internalize the externalities through various modalities including regulation. Theoretical propositions of evolutionary economics on environmental innovations are built around the notion of biological evolution (Variation, selection and retention). It argues that the selection environment characterised by sum of external factors such as factor prices, market competition, customer demand plays important role in shaping the environmental innovations (Green et al., 1994). On the other hand resource based theory of the firm espouses role of internal factors as key drivers of environmental innovations (Green et al., 1994). It is argued that, there is a need to broaden the scope of general theories of innovation to incorporate environmental policies and institutional consideration in order to better explain the environmental innovations (Horbach, 2008). Environmental innovations are often linked to the theoretical conception of lock-in, in particular lock into dominant technologies which are unsustainable (Unruh, 2000). Since the notion of lock-in is not only associated with technological lock-in, but also closely determined by the prevailing institutional, social and cultural ethos and systems, sustainable innovations are also motivated by the above mentioned determinants (Rennings 2000; Smith et al, 2010). Rennings (2000) further argues that the conventional notion of innovation characterised as process, product and organisation innovation is inadequate to explain the current phenomenon where innovations are directed to meet the sustainable development goals (Rennings, 2000). Drawing from these theoretical ideas of innovations propunded by Rennings (2000), the paper examines and assesses the promotion of decentralised renewable energy interventions in India as a form of environmental innovation as driven by policy, regulatory and market elements and manifested through change in environmental behaviour of the beneficiaries.

Drivers and forms of eco-innovations in the sector

This section discusses major driving forces of decentralized renewable energy interventions and their impact on the change in the environmental behaviour of beneficiaries. As detailed out in the methodology section, the analysis is heavily relied on both the secondary literature as well as on the case studies. The discussion is structured around three major headings as drivers and forms of eco-innovations in the field of decentralized energy systems in India.

1) Influence of policies and regulation

Though, it is recognised that policies and regulations play instrumental role in diffusion of environmental innovations, it is contended that policy instruments acting as a catalyst for environmental innovations have not received adequate scholarly attention (Bergek & Berggren, 2014). Effectiveness of policy and regulatory instruments in driving environmental innovations has often been linked to the present or absent of certain conditions. Studies argue that policies and regulations become more effective in driving green innovations in countries with liberal energy markets (Nesta et al., 2014). Policies, either in the form of broad policies, or programmes or specific incentive structures such as fiscal, financial, information or other incentives do influence environment innovations. Review of policy and regulatory statements and legislative announcements reveal that decentralised energy sector in India has received a renewed thrust with the enactment of the electricity Act 2003. The Act by withdrawing the licensing requirements for setting up of decentralised renewable energy projects, has ushered a new regime for the sector by allowing private sector to act as a key player in the field. The Act followed by several other policies again reiterated the emphasis on decentralised energy interventions as catalyst for introducing new and alternative ways of generating electricity. In addition several other policies also have specific thrust on promotion of decentralsied energy systems. For example, Integrated Energy Policy 2006 lays thrust on biomass based interventions for rural areas. Rural Electrification Policy 2006 gives emphasis on promoting renewable energy based stand alone energy systems for electrifying remote rural villages. Besides, a set of specific decentralised energy programmes are under implementation.

Decentralised renewable energy interventions during pre-2003 Act era were limited in their scope and largely bundled with other rural electrification programmes (Siddiqui & Upadhyay, 2011). However, post 2003 Act era experienced a regime where emphasis was laid on designing and implementation of dedicated programmes for decentralised energy systems in the country. Four major programmes require specific mention i.e. Remote Village Electrification (RVE) programme, Village Energy Security Project (VESP) programme, Decentralised Distributed Generation (DDG) programme, and off-grid component of Jawaharlal Nehru National Solar Mission (JNNSM). Implementation of these programmes over time has brought out two key lessons for the policy makers. One key policy learning is that without making provision of some amount financial assistance as operational subsidies, sustainability of these projects is threatened. Second, policy makers over time have understood the need and importance of mobilizing additional source of funding such as carbon financing for making these interventions financially viable. Therefore, the recent thrust is to recognize these sources of funding as an additional source of financing for these projects.

2) Market based drivers

Market based instruments are found have influenced environmental innovations in significant ways (Stavins, 2001). One of these market forces gets manifested through the prevailing CDM mechanism. Introduction of CDM mechanism and recognition of small scale clean energy projects through the scheme of programme of activities (POA) has instilled a sense of business among private companies to look forward to decentralised energy systems as new business ventures. We present here some key insights from our case studies to understand how market driven mechanisms have acted as stimulants for environmental innovations. Decentralised energy projects run by the Husk Power System Company have availed the CDM benefits. It was revealed from the discussion with company officials that several of Husk Power Projects have been registered under the programme of activities (PoA) scheme of UNFCCC to get CDM benefits. Similar benefits have also been accrued by other decentralised energy projects in India. For instance, DESI Power System also have bundled 100 small scaled decentralised projects to get CDM funding through the UNFCCC process. However, given the small size of the projects, the challenge is to combine these projects in meaningful ways in order to avail the CDM benefits.

Another interesting dimension of these market based environmental innovation is related to the smart grid systems introduced by several private companies operating in the space of decentralised energy systems. Smart grid systems generate efficiency gains through smarter management of energy generation, energy transmissions and energy use. In both the case studies, we found that introduction of smart systems have resulted optimal use of energy and hence conservation of energy. In case of Dhenkanal projects, smart systems have been applied to optimise the use of available energy by energising livelihood activities in the day time and use of domestic use in the night time. In case of HPS, smart grid systems have been deployed, though in select cases, to monitor the performance of plants. Another important technology innovation is remote monitoring systems. Remote monitoring systems have been deployed to manage the systems remotely and take immediate actions in case of any technical snags. This has enhanced the performance of the projects and hence better environmental outcomes. HPS has also deployed smart meters in all their mini-grid type interventions. This has been able to reduce the wastage of energy use.

3) Behavioral eco-innovations through decentralized energy interventions

Environmental innovations also get manifested through environmentally benign behavioural changes. These behavioural changes bring about positive transformations in the environment (Beretti et al., 2013) and could be grouped under demand side considerations of environmental innovations. It was revealed from our case studies that decentralised energy projects installed in villages have led transformation in the energy behaviour, though in different degrees. Discussions with the beneficiaries of two projects revealed that people have become energy conscious with introduction of these new energy interventions. Since, management structures of the projects studied are different; it also generated varying impacts on the environmental behaviour of users. In case of solar based intervention, the projects are managed by village energy committees, and beneficiaries are deeply engaged in the project activities. Whereas in case of Husk Power System projects, the management is with the private company and beneficiaries are not directly engaged in the project management. Literature on behaviour studies suggests that community management of resources generates better environmental behaviours, than available other options (Heiskanen et al., 2010). In case of solar based projects in Dhenkanal,Odisha, which are managed by VECs, were found to have generated better environmental behaviour compared to the other project which is managed by a private company. VECs formed to manage this small energy interventions act as energy communities which provide new context for behaviour change. In case of solar based projects, beneficiaries are not only users, but also engaged in their capacity as members of the VEC in day to day management affair of the projects. This has led them to understand the importance of energy and the need to conserve it. It was revealed from the focused group discussions (FGDs) that there has been a greater sense environmental consciousness among the users. Most of the villages now understand the importance of conserving energy. However, in case of Husk Power Systems, there has been less sense of environmental consciousness as people feel they have right to switch on lights and other electrical equipment as they are paying for it. Though, literature suggests that motivation for environmental behaviour could be either due to financial gains associated or due to general consciousness about environment. However, it was found from the field study in case of solar projects that these behavioural changes are largely due to growing environmental awareness and consciousness among the beneficiaries. Since, beneficiaries are charged on flat rate, there has been little incentive left for them to be motivated by financial gains.

Conclusion

Renewable energy based decentralised energy intervention, of late, have caught the attention of policy makers and private sector players as a window of opportunity for introducing clean energy innovations. The paper lays a thrust on mapping the processes of environmental innovations and their drivers in the field of decentralised renewable energy interventions in India. It emerged from the analysis that renewable energy based decentralised energy systems as forms of environmental innovation have been spurred by several legislative, policy, regulatory and programme initiatives undertaken from time to time in the country over last decade. These policy and legislative landscapes also have opened new vistas for private sector to become an important stakeholder in the sector. In addition, market forces such as CDM mechanism also have become an important stimulant to drive the sector by providing additional funding route. More importantly, insights from the case studies reveal that in order to make the sector commercially viable, private sector players have laid emphasis on introducing new technologies and mobilizing additional sources of financing. Comparative analysis of the two case studies shows that environmental behavioural changes are largely associated with the change in environmental consciousness, as experienced with the solar projects in Dhenkanal, Odisha, rather than financial gains accrued through energy savings. However, several challenges continue to act as roadblocks. There exist multiple structural barriers in the form of market distortions, lack of level playing field of private investors, financial constraints, institutional weaknesses making it impossible for large-scale diffusion of these interventions without appropriate government interventions. Therefore, it is important to continue with the financial assistance scheme as long as the sector itself is not commercially sustainable. Second, there is also need to introduce additional financial mechanism like 'sustainability certificates' which would provide private sector players an additional source of funding for scale up these interventions. Policies and programme designs are to be context sensitive and require presence of necessary complementary measures such as human resource development, institutional and infrastructure development, boosting of companies innovative awareness and establishment of networks.

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Electrification in Tanzania from a Historical Perspective – Discourses of Development and the Marginalization of the Rural Poor

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Abstract

While rural electrification has attracted much scholarly attention in the last years, few attempts have been made to conceptualize electrification as an embedded and contingent process. A historical approach can contribute to understanding the roots of the current urban-rural disparities of rural electrification. Using the example of Tanzania, this paper takes a historical perspective on electricity supply in sub-Sahara Africa, focusing on the discourses associated with the provision of electricity and the shared terms and concepts they produced. It argues that the rural poor's energy needs were marginalized in most of these discourses, leading to the fact that only recently, 100 years after electricity has become commercially available, efforts for an extensive rural electrification are slowly bearing fruit.

Keywords: Rural Electrification, History.

Introduction

In the current research literature, rural electrification has been largely conceptualized as technical and economic problem. Consequently, much research has been invested in assessing the most cost-effective ways to promote access to electricity. In scenarios for universal access to electricity in 2030, a key role is attributed to decentralized solutions such as mini-grids or small, stand-alone off-grid systems (SE4ALL, 2013; OECD/IEA, 2011). Recent works have therefore advocated the integration of a "decentralized track" in the national electrification strategies and have looked into ways of creating regulatory frameworks conditions to promote demand-driven approaches for rural areas through small power producers and mini-grids (Tenenbaum & Greacen et al., 2014). These approaches are supposed to fill a gap which results from the fact that rural private houses are usually unattractive to large power utilities from a commercial point of view.

It seems striking, however, that despite the model-based assumptions of their technical and economic advantages, decentralized solutions have not taken off in most countries yet. Except for the widely cited example of Bangladesh with its 3.8 million solar home systems[1], decentralized solutions do not significantly contribute to rural electrification in any other country of the Global South. In his PhD thesis on the "marginalization of 'small is beautiful'", Chris Greacen has investigated why in Thailand most community micro-hydro projects, allegedly the superior electrification option for remote mountainous communities, failed while the national grid has been extended to over 69,000 villages (Greacen, 2004).

These examples show that technical and economic analyses of rural electrification fail to grasp the complexity of the problem. Recently, scholars have advocated a (re-)politicization of energy policy at all scales. Smits argues, that it "should not be the sole responsibility of engineers and economists, but instead be conceived by a broad coalition of actors that are informed by multi-disciplinary studies" (Smits, 2013). Dismissing universalistic and linear assumptions underpinning macro-level conceptions of "energy transitions" he stresses the embeddedness, the contingency and multiplicity of energy systems.

Taking this into account, the absence of historians in the debate seems particularly noteworthy. Although the need for a historical perspective in the Global South is widely emphasized in the research community working on energy transitions, few if any historians have turned their attention to this topic. They have left it to scholars from other disciplines, who include a historiographical part in their studies, usually based on secondary literature. In doing so, they run danger of reproducing the currently prevailing paradigms, categories and terms. Historians working on electricity in Europe and the United States have demonstrated the constructed quality of these paradigms. They have shown for example, how in Germany in the first half of the 20th century a pressure group from political institutions, electro-industry and finance played an essential role in establishing a "dogma of the economic superiority" of centralized power model in academia (Gilson, 1994) and have convincingly questioned inherent superiority of this model (Stier, 1999). Some have even radically deconstructed structuralist approaches, arguing that electrification was essentially a result of societal discourses (Gugerli, 1996).

Works that treat the history of electricity in Africa are rare and except for one or two laudable exceptions (e.g. Chikowero, 2007) studies that look into the distribution and use of electricity are nearly non-existent. To date, the majority of scholars have focused on the large dams for hydropower generation, which have become iconic for the African power sector but are only part of the story.

Research Objectives

Using the example of Tanzania, this paper takes a historical perspective on electricity supply in sub-Sahara Africa, focusing on the discourses associated with the provision of electricity and the shared terms and concepts they produced. This included for examples ideas about who was to benefit from electricity services at all, how electricity could contribute to social and economic development and what role the state should play in leading its citizens into what was imagined to be an

[1] www.idcol.org

energy-modernity (Smits, 2013). The paper furthermore looks into the political economy of the energy sector, asking how these ideas of electricity materialized (or didn't materialize) in the interplay between the public and private, local and international actors.

It therefore also offers a perspective on rural electrification which goes beyond purely structural and technical or economic arguments. This perspective helps to explain why in its 100 year long history of electricity supply in which access in urban areas was considerably deepened, less than 1 % of rural households in Tanzania were electrified. It is not about writing a history of failure. "Energy has never been a "success" or "failure", but rather a negotiated and contingent project" (Ghanadan, 2008). The paper describes how energy policy was embedded in the different political projects for development and modernization of the 20th century in Tanzania: The constructive imperialist imperative of extracting value the British colonial "estates", the post-war "Colonial Welfare and Development" agenda, the "high modernist" (Scott, 1998) visions of state-led development in the late colonial and post-independence era as well as the structural adjustment programs of the 1980ies which turned into far-reaching market reforms in the 1990ies. The paper identifies the shared terms and concepts in the discourses on electrification which led to a marginalization of the rural poor's energy needs throughout all these periods.

Methods

The paper is based on preliminary results of an ongoing research project on the history of electrification in Tanzania. The project makes use of written sources from the British mandated Tanganyika Territory and post-independence Tanzania, planning documents and reports from the state utility, the ministries, international consultants and organizations associated with early development funding and assistance, newspaper articles as well as contemporary academic literature. Archival work will be supplemented by expert interviews. At the methodological level the project seeks to explore ways of writing a history of electrification in Sub-Saharan Africa, given that written sources are scarce and dispersed amongst the archives of a multitude of national and international actors – a research challenge that Tanzania generally shares with other former colonies in Africa.

Results

For Europeans Only – Colonial Power Policy

In 1908, a railway company installed the first power generator in Germany's East African colony, in Dar es Salaam. About 40 years later, at a time when universal electrification was nearly completed in Europe and the US, electricity in now British-mandated Tanganyika was only available for a few hundred European and Indian customers in the capital and in a handful of upcountry towns. An examination of the debates among German and British colonial officials and investors in the electricity sector show the difficult colonial legacy of the Tanzanian power sector. Electricity supply was embedded in the "deeply racialized structure of colonial urban society" (Brennan & Burton, 2007), reflecting and in some cases even supporting the urban racial segregation policies in colonial cities, as Chikowero (2007) has shown for colonial Zimbabwe.

Most colonial administrators and utility company officials adopted the racial stereotypes of Africans being "traditional" or "primitive" and therefore uninterested in electricity (Hoag, 2013). As a consequence, the local utilities limited their efforts to meeting the demand of the small European communities in the city and of the colonial plantation agriculture, instead of developing new markets among Africans. In Tanganyika, this tendency increased after the power sector was privatized in 1931. With a view on the interests of their British shareholders, the utilities delayed any investments outside the small profitable market in the capital Dar es Salaam and the sisal plantation area in the north of the country.

Generally, in the first two decades of the 20th century colonial officials had attributed little attention to the development of electricity supplies in the British Empire (Clark & Gibson, 1922). Unlike railways or telecommunication, electricity was not a "tool of empire" (Headrick, 1981), associated with the penetration, conquest and consolidation of the colonies. It was not before the 1920ies, that a debate on the utilization of the Empire's vast hydropower resources started in Britain. Especially colonial engineers promoted an "alchemist dream" of systematically investigating and developing the Empire's rivers for electricity generation (Spencer, 1927). This "constructive imperialist" vision however, was not aimed at improving the living conditions of the local population but was rather rooted in the Chamberlainite idea of extracting value from the Empires "great estates" for the British metropolis. Tanganyika's first large hydropower station at Pangani Falls, by far the biggest generation unit in the colony at the time of its completion in 1936, produced electricity for European owned sisal plantations and later also for its export to the Kenyan harbor town of Mombasa, leaving the local African population in the dark.

For the "Productive" Only – Electricity and the Colonial Development and Welfare Policy

In the late 1930ies, Britain started to reform its market and export-oriented colonial development policy. The most lauded outcome of this reform was the Colonial Development and Welfare (CD&W) Act of 1940, in which Great Britain committed itself to spending metropolitan resources to raise the living standards of the entire population in the colonies. The motivation behind the social reforms were not primality philanthropic ones. In their consequence they were aimed at producing a healthier and more efficient workforce and, above all, a less erratic and rebellious one. Instead of the racial categories, implicitly guiding colonial infrastructure policy previously, a new dichotomy became more important. It differentiated between the "productive" part of the native population, the African wageworker, generating monetary values on cash-crops plantations and the secondary industries under "proper supervision" of

Europeans, and the "unproductive" subsistence farmers in rural areas (Central Development Committee, 1940).

During World War II, electricity and its associated services were discussed among British colonial officials as a social welfare for the native African working class. They pressured local administrations to include electricity in the new social housing programs for Africans (Lyons, 1943) as well as government institutions such as schools and hospitals (Electrical Engineer, 1942). However, domestic supply for African remained a distant vision. The utilities were rather struggling to keep pace with the growing electricity demand in the cities in the war and post-war years. East African governments commissioned studies, which criticized the utilities for their "piecemeal approach" (Westlake, 1946) and recommended to nationalize the power sector. This suggestion was taken up by the Ugandan administration only, the sector in Kenya and Tanganyika remained private.

In the late 1940ies, early 1950 the utility opened a number of new branches in smaller upcountry towns in Tanganyika. Cinemas and clubs with electric light, which were opened in nearly every electrified town (Moffett, 1955), were increasingly perceived as a central feature of urban social life – by Europeans as well by a small privileged class of educated Africans with an urban employment. In an account from an African resident for a 1955 on Dar es Salaam, the "conquering hero" returning to his village asks "what you live in a village without electricity? No cinemas? No dance hall? No bands? What a dump?" (Cited in Brennan and Burton, 44). English language newspapers in Tanganyika were boasting with advertisements for electrical appliances, some of them illustrated by happy white housewives. The energy modernity in the newspapers was a drastic contrast to the overall picture. The average per capita consumption of 4 KhW was extraordinary low, even when compared with other colonies of the British Empire: In British Malaya the yearly use per capita was at 120 units. In the United Kingdom it was at 800 units and in the US at 2000 units (Egerton, 1954).

For "economic development" only – Dammed progress

In the global discourse on development of the 1950ies and 1960ies, electricity's symbolic meaning as a modernizing and developmental force for Africa gained momentum. Referring to the success of the Tennessee Valley Authority (TVA), "the granddaddy of all regional development projects" (Scott, 1998), the UN promoted the construction of large dams for hydropower generation (along with other purposes such as irrigation and flood control) as an essential feature of economic development. As calls for political independence became louder in many colonies, hydropower projects offered concrete examples for the benefits British rule had bestowed upon Africa. In Tanganyika the British Colonial Development Fund financed two dams, the (run-on-the-river) Hale hydropower plant and a dam at Nyumba ya Mungu, which materialized after independence and were celebrated in the English language press of Tanganyika" (Tanganyika Standard, 1960).

The euphoria for large hydropower dams coincided with the rise of development economics – a combination which had profound consequences for power sector policies in Africa for the next three decades. Abstract economic growth models focusing on macroeconomic indicators, which had been developed in the industrialized West, became the lens through which planners, politicians as well as academics regarded electricity. This perspective created a bias for capital-intensive hydropower generation and large-scale energy consumers, "labeling a broad range of domestic and rural electricity benefits and beneficiaries as 'uneconomic' or expensive social welfare" (Showers, 2011). After independence, the leaders of the new African nation states adopted this perspective and readily implemented the colonial plans and feasibility studies for hydropower dams with international aid money and technical assistance.

In Tanzania this seems particularly noteworthy as its post-independence government under Julius Nyerere had adopted a policy of "African socialism" promoting local small-scale development and increased productivity in rural areas. It nationalized the country's natural, industrial, and communications resources in the Arusha Declaration in 1967. From 1964 on the government subsequently purchased all shares of the national electricity utility Tanesco. Power sector policy however remained top-down and expert driven, emphasizing macro-level objectives, focusing on large-scale generation and the establishment and consolidation of a centralized transmission grid. With a credit from the World Bank and technical assistance from the Swedish Institute for Development Assistance (SIDA) Tanzania developed the hydropower resources of the Great Ruaha River. The Kidatu dam which was completed in 1975 became the first large-scale hydropower project in Tanzania, paving the way for the beginning of the big dam era. It was followed by the Mtera dam further upstream in 1980 (Öhman, 2007). While in 1960 the country's total installed capacity, had been below 50 MW (Amann 1969), Tanesco added 380 MW of hydropower to the grid until 1990. By then, hydropower accounted for 95 % of the total generation capacity. Access to electricity was deepened urban areas and by 2000, coverage had expanded to 59 % of Dar es Salaam residents and around 30 % in other urban areas (Ghanadan, 2008).

For the rural areas, however, the picture looked different. A study on the East African power sector from 1969 found that rural electrification in Tanzania "remains in a very early stage of development which must be characterized as being just a wish or hope, formulated as a consequence of a rural-production-oriented development policy of "self-reliance" (Amann, 1969). In 1981, a Tanzanian expert summarized that "Rural Electrification has hitherto (1981) not been an integral part of Socio-economic development planning process in Tanzania, and in fact there has not been any coordinated rural energy planning" (Nkokoni, 1983/2). In 1990 less than 1 % of the rural population had access to electricity. About half of 66 small and medium size provincial towns were either connected to the national grid or supplied isolated diesel generators, with 34 towns remaining completely without electricity. Even in the electrified towns more than 80 %

of all households had no grid connection. Tanesco's rural electrification program had reached a mere 14 of the 8600 villages of the country. All isolated grids run by a diesel generator were operating at a loss (Kjellström, 1992).

For payers only –From Public service to Commodity

Prospects for rural people to be connected to the grid did not rise during the 1990ies when electricity provision in Tanzania was to be rewritten along market lines and electricity in Tanzania was increasingly reconceptualized as a commodity rather than a public service. The story of power sector privatization began in 1992 when electricity generation at the Mtera dam dramatically decreased due to shortcomings in the projects design, mismanagement and a natural drought. For two years power had to be rationed in Dar es Salaam. The massive power crisis coincided with a new phase of liberalization of Tanzania's economy. The shock treatment of the structural adjustment programs of the late 1980ies turned into a long term narrative of private capital-led development and the energy sector was a major field of intervention. With the first free multi-party elections ahead, the government hastily lifted the monopoly of Tanesco and started to search for independent power producers (IPPs), who were supposed to be contracted to generate and sell "emergency power" to the state utility (Cooksey, 2002; Degani, 2013; Ghanadan, 2009).

The story of Tanzania's first IPP, Independent Power Tanzania Ltd. (IPTL), turned into a 20 year-long nightmare, which has been well-researched by now. Legal disputes over alleged systematic bribery led to more than half a decade of expensive delays and when the IPTL plant came online in 2001 it was one the of most expensive of its kind on the continent. Up to date, a large share of Tanesco's revenues, up to 69 % in 2005, are shuffled back to IPTL and another IPP fuel and capacity charges, money which is missing of course for the improvement and extension of services. In 2002 the Tanzanian government hired a South African consulting company to manage Tanesco and commercialize utility operations in order to make it fit for privatization. Their efforts to increase revenue collection included an increase in tariffs, a cut of the "lifeline" subsidy for poor customers and started a disconnection campaign of customers with payment who failed or delayed their payments leading to a massive decrease of Tanesco's customer base (Ghanadan, 2009). For most rural dwellers, electricity became even further out of reach.

Since mid 2000ies, however, the ideological trenches between supporters of private and public sector-led development in the electricity sector are slowly being overcome. The privatization of Tanesco was successively taken back. The exploitation of Tanzania's natural gas reserves and a number of new generation and transmission projects which are financed either by public investments or by public-private-partnerships have raised hopes that the countries power crisis can be overcome. In 2005 a Rural Energy Agency and Rural Energy Fund (REA/REF) were founded to separate out off-grid operations from the utility and channel international funds for rural electrification. As a consequence, rural electrification rates increased to about 6 % in 2014 and the trend is rising. In November 2014 the Deputy Minister for Energy and Minerals claimed that total electrification rate had gone up to 36 % from 10 % in 2010.[2]

Discussion

Since electricity became commercially available around 1880 disparities and asynchronicities between urban and rural areas have been part of every national electrification story. For grid-based electricity supply they are inherent to the business rationale of power utilities, as rural private households are an unattractive or at least less attractive market. In the United States 90 % of urban dwellers but only 10 % of rural private households had access to electricity in 1930. Overcoming these disparity was a heavily subsidized political project with Rural Electrification Administration (REA) at its forefront, which took around thirty years to be completed. In Europe, many countries relied heavily upon their public utilities to provide universal access by the middle of the 20th century (Pellegrini & Tascotti, 2012).

This paper shows that in Tanzania, the political project of rural electrification has just recently begun on a more extensive scale and helps to explain why rural electrification has been the step-child of power policy for more than a hundred years. It remains, however, be an attempt to sketch the "full story". More case studies on different levels are needed to compare and relate the different electrification histories. One of the most pressing questions is the question at scale. Current attempts to provide a nuanced understanding of scale and scalar interactions (e.g. Smits, 2013) of energy problems deserve particular attention and should be grounded historically. Other promising approaches which investigate how the "politics of the kilowatts" of local distribution and the "politics of the megawatts" on the national political arena interact.[3] A historical perspective here would add much value to the analysis.

This perspective, however, needs to reflect upon its limitations, in particular in regard to written sources. While there is an abundance of documentation of colonial and post-colonial international activities in the Tanzanian power sector, few records have been kept for first the two decades after independence at the ministries and the public utility. There are furthermore very few historical accounts of users' perceptions of electricity and reactions to changes. Recent anthropological scholarship has argued for a more relational perspective on electricity supply, suggesting that users take a far more active role in the local governance of electricity than has been assumed in the past (Winther, 2012). Focusing on public electricity supply, this paper has left out the countries long history of isolated generation for private use. These ranged from large generators for the power supply of mines to small generators in government buildings or on private farms, as

[2] http://www.busiweek.com/index1.php?Ctp=2&pI=2240&pLv=3&srI=53&spI=20 Accessed on 24th February 2015.

[3] See e.g. the ongoing dissertation project of Ivan Cuesta: https://africanstates.wordpress.com/ Accessed on 24th February 2015.

well as informal diesel-minigrids in rural areas. It is argued here, that these forms of generation can be considered marginal in terms of domestic supply but might have had a significant impact on the perception of electricity in rural areas. At present, the increasing distribution of solar home system in Tanzania bears the potential of taking private generation to a new level.

Historia est Magistra Vitae – is history life's teacher as Pellegrini and Tascotti (2012) suggest? There is a great temptation to draw recommendations from the successful electrification program in the US for the developing countries today. These recommendations, however, always run danger of creating a new "Tennessee Valley Authority" – a model which was praised as the silver-bullet for economic development in Africa but let to some fatal attempts by authoritarian governments engineer their social and natural environments by construction of large dams. This paper shows the electrification as a highly embedded and contingent process. Historiography of electricity can inform current political debates and help to situate them in the specific history of the country. In these debates, historical narratives are too often politically instrumentalized: In Tanzania proponents of the power sector reforms repeat the salvation promise of liberalization while their opponents evoke the legacy African Socialism. A history of electricity which unveils different historical narratives and gives a well-funded and balanced account on how they have shaped the power sector can inform and mediate in these debates.

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Applying Postcolonial Technoscience to domestic Biogas. Reflections on the genesis of a German-Tanzanian biogas project

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Abstract

The paper first characterises the postcolonial approach in Science and Technology Studies and in the History of Technology. With that theoretical background the genesis of a recent development cooperation project between a German NGO and a Tanzanian farmers association is analysed. The empirical data result from ethnographic field research and literature on the history of biogas. Results are twofold: The analysis of the case study reveals a multilevel and ambiguous translation process that led from the articulated need for firewood by subsistence farmers to a joint research project on domestic biogas. The historical view shows how domestic biogas was 'bypassing' Europe but likewise spread in Tanzania mainly as a 'South–North–South' technology transfer: It thus points to the developmentalist character of the relations between Europe and Africa. The results show that there is no pure origin of ideas or technologies but a long and complex history of interwovenness that can better be captured with the help of a postcolonial perspective on technology.

Keywords: Postcolonial Technoscience, History of Technology, Domestic Biogas, Tanzania

Introduction

Departing from the analytical perspective of postcolonial theory as it evolved in literature studies and subsequently has been adopted in various fields of the social sciences, some authors debate the "transfer" of the analytical strategies of postcolonial theory to Science and Technology Studies (Anderson, 2002, 2009; Abraham, 2006) and History of Technology (Arnold, 2005; Moon, 2010). This led to new research questions regarding long term patterns as well as for more recent phenomena of technological development outside Europe. The paper shows how a postcolonial approach, by posing different questions and applying certain analytic strategies, contributes to the shift of perspectives and to question well known categories. This enables to better capture and explain research results, in this case for the history of domestic biogas and a small North–South research and development project of a new digester type that is currently taking place.

The paper analyses the genesis of a conjoint research project between a Tanzanian grass roots farmers association and a German NGO which is promoting small scale technical development cooperation between countries of the global North and South. In 2008 the association of mainly subsistence farmers, based on principles of direct democracy in north-west Tanzania approached the German NGO with the request for a joint biogas program. With this paper I want to shed light on the question how this request came about and how it lead to a cooperative research project. In order to do that I will introduce the meaning of postcolonial technoscience according to literature in a first step. I want to connect it to the analysis of technology development in the context of current North–South relations as well as to the specifics of the topic of renewable and decentralised energy supply. Secondly I will present some results of ethnographic field research which was conducted in the context of the already mentioned project during the last three years. Subsequently I will reflect the case study from a postcolonial technoscience perspective to finally discuss scopes and limits of this perspective for research on renewable and decentralised energy supply.

A Postcolonial perspective on technology

David Arnold (2005) provides a literature overview of the History of Technology (HoT) outside Europe regarding colonialism, decolonization and 'development' and identifies changing perspectives and emerging research issues that enable to overcome the early and mainstream ´diffusionist` arguments of HoT as well as the polarisation between "Western" and "indigenous" technology. He identifies this dichotomization as part of the self-legitimizing mechanisms of colonial regimes to disqualify indigenous technologies as primitive (because not validated by modern science) and sanctioned by the imperatives of productivity and profitability (ibid. 96). Subsequently diffusionist arguments – equating technology with industrial technology as evolved in Europe and North America – saw the establishment of modern technology in Africa and Asia primarily as a legacy of colonial intervention. Following this paradigm, "such technologies were diffused to the rest of the world almost entirely through European agency and without significant local input" (ibid. 86f). Apart from the diffusionist approach, Arnold identifies a second distinct HoT approach in the age of Third World nationalism. It was pointed out then that non-European societies had long histories of technology on their own, that were superceded forcibly by colonialism and international capitalism (ibid.). European technological intervention was seen as physical and epistemological violence, against past practices and via military technologies, land appropriation, mineral extraction, intrusive medicine, etc. Indigenous technologies thus served as a site for resistance against colonialism (ibid.). Thirdly he identifies a postcolonial approach in the History of Technology, though few and analytically weak. The Postcolonial approach is looking temporarily after the colonialist period and gains inspiration from the postcolonial criticism as it evolved in other diciplines. It is guided by distrust in regard to generalisations across space and time, and simplicistic dichotomies. It uses the terms “space” and “travel” instead of “dissemination” and technology is seen as an instrument of power relations (ibid.: 87). HoT in this sense would be more research about the use of technologies, its meaning, and effects, rather than analysing their origins and inventions.[1] Arnold identifies possible modes of ‘decentering’ Europe in regard to HoT: First, reversing the paradigm to show that and how the technology of Europe cannot be understood without reference to the rest of the world. Secondly he refers to researchers that favour a sinocentric model of world HoT (as Ronan, 1978). Third, the colonies themselves have to be seen as places of technological inventions which often are based on indigenous practices and knowlegde and fourth he suggests to adopt a model of complex exchanges and interconnectedness, including inter- and intraregional movements, also between different colonies and bypassing Europe.

While HoT focuses on the past due to the disciplinary scope, the integration of a postcolonial perspective in science and technology studies focuses on a critical analysis of effects of colonialism on *current* science – technology nexus. Based on the programmatic text of Warwick Anderson (2002) a lot of similarities to the Postcolonial approach in HoT can be identified: 1. finding out how science and technology ‘travel’, not whether they belong to a culture, 2. revealing and complicating durable dichotomies, produced under colonial regimes, 3. taking up the idea of provincialising Europe, but more in the sense of questioning ‘universal’ reason, with the description of ‘alternative modernities’, and the “recognition of hybridities, borderlands and in-between conditions.” (Anderson, 2002). Anderson refuses to draw a definite boundary what Postcolonial Studies of Science and Technology would deal with, but lists some core features: First the emphasis on the situatedness of technoscience; secondly the focus on contact zones as sites of “multivocality; of negotiation, borrowing, and exchange; and of redeployment and reversal” (651)[2] and third, that the situated production of globality, transnational processes of reconfiguration, fragmentation and hybridity of technoscience have to be illustrated in multi-site studies. He refers to Escobar (1995)

“Instead of searching for grand alternative models or strategies, what is needed is the investigation of alternative representations and practices in concrete local settings, particularly so as they exist in contexts of hybridization, collective action, and political mobilization.” (Escobar, 1995)

One aspect I want to point out, that was mentioned in texts of Arnold and Anderson, is the connection between technology and dominance: Modern technology and science has been qualified as accomplice of colonial regimes and legitimizing factor for modernist theories of development, which sometimes led to the rejection of “modern” technology as innately violent (Arnold, 2005), especially because of various phenomena as the displacement of people through big dams in the name of development. Deriving from that there was a call for intermediate, appropriate and convivial technologies in the 1970s (Schumacher, 1973; Illich, 1975; Ullrich, 1979 and others) promising a high potential for self determination, redistribution of power and local control over resources in combination with the integration of indigenous knowledge. While it seemed to be forgotten with the end of the Cold War a small revival of these thoughts can be noticed in the context of renewable energies (e.g. Wilhite, 2005; Sachs, 2006).

Renewable energies are associated with more democracy, local autonomy and self-determination in certain discussion strands due to their decentralised character (in the sense of the spatial link between energy production and consumption). This potential is especially mentioned by civil society movements in the Global North but not often a focus of research, although especially in regard to the historical background of the role of technology in North-South relations it is of particular importance. Subsequently I add it for a postcolonial perspective on decentralised energies in the Global South.

Research Objectives and Methods

Coming back to the already mentioned case study of a North South cooperation in the field of domestic biogas as a renewable energy source, the research question would then be: Despite the inherently unequal ‘partnerships’ of the Global North and South: To what extent projects and practices are possible which support the self-determined pursuit of user interests and needs and generate energy technologies that are suitable for their everyday practices? To answer this question different aspects and dimensions have to be looked at: How are decisions taken between the partner organisations, who is perceived to have which kind of competencies, how does the (re)distribution of technoscientific and “local” knowlegde shape and influence the decision taking processes and the course of the project, how is the division of labour and what is the role of the users, how are they able to articulate their interests? The research presented in this paper is part of a PhD-Project where all these aspects are included. Here only one aspect will be discussed: The question who had the ability to define the problem and who was developing the solution. This is seen as one important aspect to understand how self determined actors of the Global South are able to perform in the context of „development“ projects.[3]

Following the perspective of anthropological research of recognising local grass roots organisations as main actors for societal change and focusing on hybridities, contact zones, and places of negotiation, I did ethnographic

[1] Edgerton (2007) is also voting for a focus on technologies in use to overcome the innovation centric bias in HoT. He points out that a story of inventions inside and outside Europe also still has to be written, but this story necessarily would have to focus on in the derivateness rather than on the originality of engineers in general. It would also imply to write a history of failures instead of focusing on some technologies that were successful later on.

[2] Citing Gilbert Joseph (1998).

[3] In reference to a postcolonial perspective on development cooperation offered by Glokal e.V.: http://www.glokal.org/. Accessed on 24th February 2015.

research for three years in this case study that showed some interesting features for the analysis with a Post Development and Postcolonial Perspective.

Empirical data collection for the case study is based mainly on active participant observation in various formal and informal settings. Observation was combined with semi-structured interviews to obtain background information and to integrate the perspectives of all the actors involved.[4] I accompanied the German group of engineers and the Tanzanian Farmers Association for three years, joining meetings and field trips, sharing mailing lists and becoming involved, as far as possible. Additionally some documentary research on project documents, E-Mails, reports and literature about energy and biogas was necessary. This typical form of methodological triangulation proved to be very useful to understand the decision taking as well as the innovation processes as these aspects often cannot be captured through explicit questions in interviews.

Results: From the need for firewood to a "conjoint" biogas research project

The farmers association was founded in 1993 by 22 farmer families with the main purpose of mutual support in learning about agricultural practices. Over the years it grew in numbers and in 1998 the members decided to change it from a Community Based Organisation (CBO) to a Non Governmental Organisation (NGO) to be able to work in more communities and to be recognised internationally. Meanwhile 350 households are members in the association, pay fees and decide in a general assembly and other participatory structures what they need and what to spend the money for. The board is also elected by the general assembly. One of the staff members explains the current structure:

"We use a bottom up approach […] The community, they can discuss, share experience and initiate several programs and projects according to their wishes and according to their needs. After that, when it comes to the management also we need to discuss to find the way forward from there. As staff, we are here like a link, to link the community, to link the other people who need support, to link technologies and whatever. So when it comes and is discussed with the groups, discussed with management, discussed with the general meeting, finally it's decided in which way you have to take. … yes at the end the general assembly has to decide." (Int. 20.08.2014)

How did the biogas project come up in this constellation? One of the founders explained that the farmers of the community noticed a growing scarcity of firewood for cooking and asked the staff of the association what to do. Based on this articulated need, the organisation came up with the idea of biogas as a solution and put this as a request to one of their partner organisations specialised on technologies – the German NGO of engineers and engineering students. How did it come about that they saw this technology as a solution and what meaning has it for them? One of the staff members explained that little reforestation as well as population growth are the main reasons for the scarcity of firewood. But also he connects the problem of deforestation with the risk of climate change which would be a serious problem for the farmers because of sinking rates of rainfall and increasing soil erosion. Thus, they saw biogas as "appropriate" technical solution to confront scarcity of firewood as well as climate change.

The fact that they voted for biogas as an alternative cooking energy can also be understood as a result of a long history of biogas in Tanzania and in this region. Due to the fact that the technology of domestic biogas was brought from India and China to Tanzania since the 1970s with the help of international development organisations from Europe (Netherlands, Denmark and Germany), it likewise can be characterized as a history of development cooperation. In the context of one of these programs the initiator of the farmers association and his family (some of them are now working as staff of the association) got a domestic biogas digester that was in use for many years.

So the request for a Biogas programme can be characterised as a translation process, in which a professionalized Tanzanian NGO representing a community translated the need for firewood against the background of their own experience into a certain technology already known in the region by some (though not by the majority of the farmers of the association) and articulated a request to an international development organisation focused on technical solutions.

The idea was positively taken up by the German NGO and as a reaction an engineering student conducted a so called feasibility study on behalf of them, which declared a high potential for biogas in the region. However he observed very unequal property structure of cows in this region since only few people own big herds. This was a problem because the common digester type is working mainly with cow dung and most of the members of the farmers association would not have enough cows for running this type of digesters. So he concluded that it would be necessary to develop a new type of digester that is only working with plant residues.

The necessity of having enough cows is the reason why domestic biogas is said to be a technology for comparable rich people. In a feasibilty study for a domestic biogas programme the German development agency GTZ mentioned the risk that it "may increase the gap within society" (GTZ, 2007). In contrast to that, the new type of digester was characterised as "equalising" technology by one staff member as it would allow the usage of biogas also for households without cows. Finally, the idea of a new type of digester that works with plant residues only – particularly with the residues of banana plants which is the staple food in this region and is cultivated by all the farmers households - was agreed to be a common goal and the starting point of what was said to be a conjoint project.

[4] Interviews were conducted with staff members of the farmers association, with farmers, with the German group of engineers and engineering students, with Carmatec and other NGOs that work about renewable energies in Tanzania.

Rethinking the case from a postcolonial perspective

The interesting aspects from a postcolonial perspective on Technology and North – South relations could be manifold. In this paper I will highlight two aspects, the first being the longterm-history of the technology as a mode of ‘provincialising’ Europe.

Biogas can certainly be understood as one of the technologies that transcend the dichotomies of ‘Western’ or ‘indigenous’, ‘modern’ or ‘traditional’ technology if one considers how it was and is traveling through space and time. Bond and Templeton (2011), referring to He (2010), note that the first deliberate use of biogas might have been in Assyria and ancient China in the 10th century B.C. while the first well documented usages can be found in the 19th century in India and New Zealand. In the 1890s a sewage slugde digester was built in Exeter (UK) to fuel street lamps, while the first attempt to commercialize a 8 m digester for household waste took place in the 1920s in China (ibid.: 348). The first large agricultural plants started operating in the 1950s in Germany. While in the 1980s application in waste management can also be found in China, the main type of use in China and India and Nepal was domestic biogas. In China about 30.5 million household digesters have been buildt by December 2008, in India about 4.1 million by March 2009 (SNV, 2009). The use of domestic biogas was never of bigger importance in Europe, also due to inappropriate climate conditions. Thus the technology of using biogas for domestic purposes can be seen as one example of technology bypassing Europe. In a long term perspective biogas could be seen as a candidate for the sinocentric model of the History of Technology (although the various places of research and use worldwide would suggest to speak of a global history). This background leads to the question, why this technology spread in Tanzania predominantly via an European agency?[5] Why is this technology not implemented by Chinese actors? Why do German engineering students take it for granted that they should and are able to develop this kind of digester? This fact surely cannot be understood without taking into account the long lasting developmentalist character of the relations between Europe and Africa as it was not the case with China.[6] This can be illustrated in the following description of it as “South-North-South transfer”:

“Following its launching in 1980, GTZ-GATE chose biogas technology as a focal point of its activities. […] Industrialized countries neither had sufficient experience nor appropriate technologies to build on in developing countries. Rather, this experience was identified in India and China and transmitted by a South–North–South transfer.” (ISAT, 1998)

[5] Although the first 120 digesters have been implemented by SIDO, the Tanzanian Small Industries Development Agency in 1975 before in 1982 the GTZ/GATE – CARMATEC-cooperation started. Further research on the role of SIDO would be necessary.

[6] Although there are long lasting relations between China and Tanzania and in the recent years this certainly changed with regard to Chinas growing activities in Sub-Sahara Africa.

The second aspect that is important to discuss is the interpretation of the translation of needs. How can the constellation in this case study be assessed in regard to one of the central questions of postcolonial thinking and criticism, the question if the subaltern speak (Spivak, 1988)? In this case: Can the translation process from wood scarcity to a biogas technology research project be seen as a process where the voices of the local population were heard? With regard to the question of political representation I would say, that through the membership based association of the subsistence farmers and the principles of direct democracy they form a collective subject to a certain extent. On the other hand it became obvious in the first users workshops (that took place in 2012), that neither the technology was really known to the farmers nor the difference between gas and electricity. They were skeptical about the high price of the digester, because until then it was not clear how the project would be financed.

It might be interesting to take a closer look at the NGO “linking” and representing them. On the one hand, the staff members see themselves as part of the community, encouraging self organisation and representation of their members. On the other hand, it can be noted that the family that forms the main part of the employed staff, as well as the manager, belong to the better situated part of the local community. The organisation notably developed a logic on its own that cannot be equated completely with the interests of the members. They requested a biogas program and they saw themselves as the potential users.

I have been told three slightly different versions of the request to the German NGO: The manager of the farmers association told me that they themselves already in the first request to the German NGO asked for a digester that would work with plant residues only. The Tanzanian employee for the biogas project (and younger brother) told us, that the original question was how the farmers could feed the digester if they would lose their cows, which implies that they thought about the farmers who already had digesters but also were thinking about alternative substrates. Following the version of the German engineer it was him who raised the problem, that many of the members of the association are not having enough cows and thus substrate and introduced the possibility of developing a new digester type that would fit to the living conditions of the majority of the community and members of the organisation. He wanted to start it as a research project.

To consider the multivocality of different perspectives reveals the ambiguity inherent to the situation with various interests and positions and moreover complicates a clear assessment of it. In contrast to most Tanzanian NGOs who are said to be having no ‘organic‘ link to the people that they claim to represent and basically represent themselves (Dietz, 2011), this NGO staff lives in the same village as their community, they speak the same language and are to a certain degree bound to the decisions of the community. And they have attained the ability to make the community internationally visible to donors. Although rooted in the community, the association also represents and maintains itself, as well when acting in the frame of ‘development’ and fitting in the predominant form of

NGOs in Tanzania that are focused on providing services but not acting politically (Shivji, 2006; Dietz, 2011).

Conclusions

With a tiny example it was possible to show the fruitfulness and necessity of applying a postcolonial perspective on decentralized energy supply. The genesis of the research & development project of the new digester was influenced and shaped through different ideas and interests of the farmers, the farmers association, the German development organisation, the donor and the long history of technical development assistance between North and South, especially also between Germany and Tanzania.

A multilevel translation process led to a certain technical solution to approach a multifaceted problem: The articulated problem of wood scarcity, framed also with climate change as a way of a local appropriation of an international discourse, was transformed into a technical solution of this problem by a farmers association. The story also points to the question of social inequalities, which takes shape in the question of having enough cows to be able to profit from that technology, a question which was again met with a technological solution of a new digester type of the German engineers. The search for the origins of the project reveals that there is no pure origin of ideas or technologies but a long history of intervowenness that goes beyond the categories of Western or indigenous technologies.

What are the limits of this work? First, as Anderson (2002) puts it: The structural features of the network became clear, but often it is hard to discern the relations and the politics engendered through it. Different perspectives ideas and interests to the same situation produce a fuzzy reality where the version of the story that I tell here is also constructed through my own perspective on the events. Secondly as already mentioned, the genesis is only one important aspect that is necessary to look at for a better evaluation of this project. In order to get the full picture also the division of labour, the further decision taking process, knowledge exchange and integration of the users have to be taken into account. And third, as all case studies are local stories, the limitations lay in the boundedness of certain historical socio-political contexts and cannot easily be generalised. But they surely can unfold their power when they are connected.

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Posters

An Induction Generator Controller for Mihunga Pico Hydropower Scheme in Kasese, Western Uganda

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Abstract

The poster presents an Electronic Load Controller (ELC) model design for a 3 kW Pico hydropower scheme, Mihunga in Kasese, western Uganda. Mihunga pico hydropower has a poor power quality and voltage regulation because of the induction generator (IG) which is connected to a manual load controller. The site which is running on a manual control demonstrated a need for an ELC shown by the voltage fluctuations. A model was designed and simulated using Matlab as a step towards future local fabrication within Uganda. The presented model is simple and performs effectively. The model comprises of logic gates and an IGBT switch as the main components.

Benefits and Challenges of Off-grid Rural Electrification: Case of mini-hydropower in Bulongwa-Tanzania

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Abstract

This paper is based on a case study of a mini-hydro power plant operated by Bulongwa Lutheran Hospital in the southern highlands of Tanzania. The study applies qualitative and quantitative methods. The analysis shows that some entrepreneurial activities emerged; whereas others were improved such as grain milling machines that shifted from diesel to electricity. The major challenges include lack of enough technical resources, environmental problems; tariff setting; and restriction on usage to some of the energy intensive machines which could assist as a generating income to meet operational and maintenance cost. The electricity from BLH benefited both the owner (hospital) and villagers.

Micro Energy Harvesting

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Abstract

Energy harvesting, a physical process and a new technology play an important role when it comes to self sustaining systems. Sources include the way collected energy is stored used to accumulate the same, so the basic source includes all the electro-chemical elements those like batteries or fuel cells or even electrical storage systems such as capacitors. Doing this it is feasible and attractive for many of the smaller electronic systems. Energy collecting capabilities enable totally released operation of universal systems for extended ages of time without requiring battery-operated replacement. However it seems simple in theory but needs immense knowledge to design a harvesting system. This paper examines technical issues mainly with solar energy harvesting and also the considerations.

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