Martina Schäfer, Noara Kebir, Daniel Philipp (editors)

MICRO PERSPECTIVES FOR DECENTRALIZED ENERGY SUPPLY

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Edited by
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Foreword

Access to sustainable energy for everyone remains quite a prominent topic, as current discussions on the international level show.

Especially in some parts of Asia and in sub-Saharan Africa, the dominant question remains one of access: As the current report of the International Energy Agency (IEA 2012) shows, there are still 1.3 billion people worldwide who lack access to electricity and 2.6 billion without access to clean cooking facilities. Over eighty percent of the people without energy access live in rural areas. The report states that these numbers will not change substantially during the next 20 years without new strategies and intensified efforts on the national and international levels. The World Energy Outlook 2011 stresses that the lack of global electrification in rural areas may only be overcome through decentralized structures, such as mini grids and off-grid solutions (IEA 2011).
In the OECD and emerging countries, the question of the transformation towards a sustainable energy system is gaining importance. The IEA report for 2012 clearly shows that the world is still failing to put the global energy system onto a more sustainable path: While some countries have intensified efforts towards increasing their share of renewable energies use, fossil fuels continue to remain dominant in the global energy mix and are supported by subsidies which are six times higher than subsidies for renewables.
Taking up the importance of energy issues for sustainable development, the United Nations General Assembly has declared the decade 2014 to 2024 to be the Decade of Sustainable Energy for All. This resolution stresses the need to improve access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services and resources for sustainable development.

The 2nd International Conference on "Micro Perspectives for Decentralized Energy Supply" (27 February to 1 March 2013 in Berlin) takes up these issues. The special focus of the conference is the role of decentralized energy supply and the integration of user needs into sustainable energy solutions. The starting point for dealing with these questions at the Technische Universität Berlin (TUB) is the interdisciplinary Postgraduate Program "Microenergy Systems for Decentralized, Sustainable Energy Supply in Structurally Weak Areas", which has been funded by the Hans Böckler Foundation since 2007.

The 1st International Conference on these issues, in April 2011, demonstrated the need for intensified exchange incorporating the valuable experiences taking place all over the world. Innovative technical solutions as well as financing, implementation and regulation strategies are being tried out around the globe, but often practitioners and researchers dealing with these topics are unaware of each other. The 2nd International Conference will continue to offer a platform for this intercultural and interdisciplinary dialogue.

We want to thank all of the institutions which have helped us in realizing this conference: First of all, the Hans Böckler Foundation, which has proven to be a partner that is strongly interested in the social and ecological aspects of decentralized energy supply. We also want to thank the German Academic Exchange Service (DAAD), the Heidehof Foundation, the Gesellschaft für Internationale Zusammenarbeit (giz) and the Innovation Center Energy (IZE) at TUB.

We are looking forward to a fruitful exchange on developing sustainable energy solutions worldwide.

The Editors: Martina Schäfer, Noara Kebir and Daniel Philipp

I. Scientific Papers

User Perspective

Examining the experiences of solar home systems in the North Central Mountain Region of Nicaragua: an ex post evaluation of a donor-funded SHS programme

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Abstract

This study evaluated a solar home system (SHS) programme operating in the North Central Mountain Region of Nicaragua. Individuals and households who had adopted SHS four to five years earlier through the programme were traced, and a survey method was used to collect primary data on system use, user experiences, levels of satisfaction and impacts on households. The study found that the majority of users still maintained their SHS despite increased grid electricity penetration; experienced significant 'soft' benefits and reductions in household energy bills. Financial difficulties posed a significant barrier to users in replacing expensive components, such as batteries. While users expressed overall satisfaction with the technology, discontent was expressed with regard to the limited capacity of SHSs.

Keywords: Solar home systems; Nicaragua

Introduction

Recent figures from the United Nations Economic Commission for Latin America and the Caribbean indicate that grid electricity covers just 74.6% of the Nicaraguan population. Furthermore, 86% of households without access to electricity are classified as poor; less than 40% of the rural population have access to grid electricity (CEPAL et al, 2010; CEPAL, 2011). Examining wider energy issues in the Nicaraguan context, the International Energy Agency's *Energy Development Index*[1] - which ranks countries according to progress made on indicators such as the use of modern fuels or increased electricity access - places Nicaragua in 40th place out of 64 of the least energy developed countries, with indices comparable to Sri Lanka and Gabon (IEA, 2011). With the exception of Haiti, Nicaragua demonstrates the lowest level of 'energy development' in Latin America.

In 2004, the government of Nicaragua and the World Bank launched the '*Proyecto de Electrificación Rural para Zonas Aisladas'* (PERZA, Rural electrification for isolated zones project) to address energy access and energy poverty in rural areas. The project aimed to innovate 'private-sector led off grid electricity service provision models…to provide sustainable solutions for off grid users' (World Bank, 2001: 5). A central element of PERZA was the 'Solar PV Market Development Programme' which was designed to achieve the widespread commercial dissemination of solar home systems (SHS) and to 'establish the beginnings of a sustainable local PV industry structure and fill a gap in remote electrification plans' (World Bank, 2003: 32). SHS were considered to be a particularly important technology, as they provided a least cost option to supply basic electricity services to dispersed populations (ibid). Indeed, this is a trend that has been witnessed globally, as Sovacool et al (2011) note; 'SHS represent a vital technology employed by the multilateral financial institutions in their efforts to curb energy poverty' (p. 1534). Since the launch of PERZA, Nicaragua's solar market has grown exponentially, and a variety of actors (including, government ministries, local and international NGOs, multilateral financial institutions, private sector SHS providers and micro financers) and significant amounts of 'energy development' finance have converged to roll out SHS on a large scale. However, there are a multiplicity of governance structures currently operating to make the technology available to users, including both commercial and donor programmes. Although no official data exists detailing the penetration of SHS in Nicaragua, we estimate that around 40,000 systems have been installed in off-grid areas since PERZA was initiated[2].

This paper contributes to an emerging area of scholarship on Nicaragua, which was recently named the second most attractive country in Latin America to invest in renewable energy (IDB, 2012) and heralded the 'ideal laboratory' for a 'renewable energy revolution' (Rogers, 2012). However, despite the rapid expansion of SHS in Nicaragua, relatively little academic attention has focused

[1] The Energy Development Index (EDI) was developed by the International Energy Agency to mirror the UNDP's Human Development Index. The EDI is composed of four indicators: commercial energy consumption (indicating overall economic development); per capita electricity consumption (indicating reliability and consumer's ability to pay for electricity services); share of modern fuels in total residential sector energy use (indicating levels of access to clean cooking facilities) and share of population with access to electricity (IEA, 2010).

[2] Estimation based on SHS import data (Dirección General de Servicios Aduaneros, 2011) and interviews conducted with five major SHS providers in Nicaragua (data collected for author Gent's doctoral fieldwork)

on the political economy of energy in this territory (with the notable exceptions of Corsair and Ley, 2008; Cupples, 2011; Foster et al., 2007; Rebane and Barham, 2011). To address this gap, this paper draws on research conducted on a SHS programme which emerged in the post-2004 era. The programme was implemented by a European development agency, which has facilitated access to over 2,000 SHS across various off-grid areas of Nicaragua since 2006. The research upon which this paper is based focuses specifically on the first phase of the programme, during which 400 subsidised SHS were installed in rural areas of the North Central Mountain Region of Nicaragua between 2006 and 2007.

Research Objectives and Approach

The study conducted an ex-post evaluation of a SHS programme operating in northern Nicaragua, a mountainous region, bordering Honduras. The overall aim of the research was to ascertain what had taken place during the post-implementation period. It did this by tracing and following up with individuals and households who had adopted SHS four to five years earlier. Specific research questions included: were the SHSs still present in people's homes? Did they still function as originally intended? What impacts did users experience as a result of the SHS? How satisfied were users with the technology? And, to what extent were users' energy needs fulfilled by SHS?

Drawing on evaluations of other SHS programmes in Nicaragua, we identified four to five years post-SHS installation as a 'critical moment' for the continued functioning of the technology. Ordinarily, by this stage, the useful life of the battery has been reached and users are required to make a significant capital investment in replacing it. In addition to being able to examine how users responded to replacing key components of the SHS system, this critical moment provided an excellent opportunity to assess the impacts of the technology on users over the medium-term. The survey therefore focused on changes in the lives of beneficiary households through questions targeted at the time prior to and following the use of SHS. There is increasing academic interest in evaluating ex-post the successes and failures of renewable energy technologies in remote rural areas (e.g. see Cherni, 2008), and in the specific case of SHS, to examine the technical performance of systems post-installation (e.g. see Chowdhury et al, 2011) and the impacts of SHS on users (e.g. see Komatsu et al., 2011; Mala et al., 2009; Mondal and Klein, 2011; Wijaytunga and Attalage, 2005) in order to draw lessons for future interventions. At present, there is much emphasis on energy development interventions that provide access to energy, for example to meet objectives such as those set by the United Nations' "sustainable energy for all" initiative. Gaining the perspectives of the users (i.e. those ultimately intended to use, maintain and sustain energy technologies) is therefore of vital importance.

Empirical survey

A total of 152 questionnaire surveys and technical surveys were conducted with households who participated in the original programme. These were carried out across 43 communities within the departments of Estelí, Madriz and Nueva Segovia in the North Central Mountain Region of Nicaragua (see figure 1). This paper draws specifically on the household survey data collected. The questionnaire surveys were conducted from May to November 2011 by a team of researchers[3] with household members who had made the decision to participate in the SHS programme (which in most cases was the male of the household).

Figure 1: Map indicating study areas.

The North Central Mountain Region of Nicaragua

According to census data, this region of Nicaragua has a population of 542,530 inhabitants, of which 58.2% reside in rural areas (INIDE, 2005 a, b, c). The average size of households surveyed was 4.8, which is lower than the national average of 5.8, which can explained by the high incidence of family members working outside of the country. The main economic activity of those surveyed was agriculture (79.7%), mainly cultivating coffee and basic grains. The majority of those surveyed (62.7%) earn between USD $0 and $90 per month, and their economic activities are largely subsistence or temporal work. Of those surveyed, only 17.5% were salaried employees.

The SHS programme

The SHS programme under investigation was executed by a European development agency operating an 'output based aid' approach[4]. This approach involved coordinating

[3] From the Universidad Centroamericana (Nicaragua) and Loughborough University (UK)

[4] According to the Global Partnership on Output Based Aid (GPOBA, 2009), output based aid (OBA) links the payment of aid to the delivery of specific services or "outputs." OBA is used in cases where poor people are being excluded from basic services because they cannot afford to pay the full cost of user fees such as connection fees (e.g. connection of poor households to electricity grids or water and sanitation systems, etc). Service delivery is contracted to a third party (usually a private firm), which receives a subsidy to top-up the user's contribution. The service provider "pre-finances" the project and the subsidy is

local institutions and private sector SHS companies to channel a subsidy to make the technology financially accessible for end users[5]. Organised households belonging to agricultural cooperatives, with the capacity to finance the subsidised SHS (approximately USD $400) were approached by the programme[6]. This programme did not offer micro-finance, rather users found a variety of means to pay for their SHS; 37.9% sold crops or animals (sales of which were often facilitated by the local agricultural cooperatives involved in programme delivery), 38.1% used savings, 11.1% obtained micro-finance (either through a micro-finance institution or agricultural cooperative) and 7% used remittances. In the post-installation period, users assumed the (financial) responsibility for system maintenance and replacement of components. While in some beneficiary communities, a few local technicians received training on the operation and maintenance of SHS, users pointed to a general lack of capacity to deal with technical issues arising (as will be discussed in the 'results' section).

Results

Permanence of systems and use

Despite the increased penetration of the electricity grid in the post-installation period (30.5% of those interviewed became grid connected)[7], 91.4% of systems remained in the original beneficiaries' homes. Users reported that the SHS provided an important back-up for interruptions in service from the national electricity grid. Of the systems still present in users' homes, 75.6% were still in use and functioning technically; 11.1% of systems were reported to have 'partial use' (in most cases, this was due to battery deterioration[8], which meant that the SHS was not performing at its maximum capacity). The remaining 13.3% of systems were not in use largely due to technical issues, most commonly related to battery failure. For those users without full use of their SHS, financial difficulties in acquiring new components (principally the battery) were cited as the main barrier to system functionality.

Impacts: changing energy use and costs

Prior to the installation of the SHS, households had multiple fuel use strategies, typically illuminating their homes with a kerosene lamp, candles and battery-powered torches. The average household energy bill (including illumination, mobile telephone recharges and car battery recharges) totalled USD $7 monthly[9]. We considered this to be a particularly low value, but had not anticipated that an important source of illumination prior to the SHS installation (for 31.5% of those surveyed) was *ocote*, a type of pinewood (figure 2), which can be collected freely in the region, not incurring any financial cost[10].

Figure 2: SHS user demonstrating how an *ocote* wick is burnt for household lighting.

On adopting the SHS, users reported that their basic lighting and connective needs had been satisfied, reducing the monthly energy bill to USD $1.03. This was principally derived from users' needs to continue purchasing disposable batteries to power hand torches for illumination outside of the home. For users with no use or partial use of their SHS, they had reverted to using traditional sources of illumination and powering appliances, spending on average USD $4.85 monthly on their household energy bill.

Other impacts

Aside from reduced household energy bills, users identified other impacts, of those surveyed:

awarded by the donor only once the outputs have been delivered and verified. This approach is considered to improve the effectiveness of aid.

[5] During the programme's first phase, a full SHS kit cost around USD $800; the subsidy provided by the development agency was USD $400, meaning that the user contribution was also USD $400. Declining global prices in photovoltaics mean that the cost of SHSs has declined significantly in the Nicaraguan context. Current costs of a SHS average USD $500; the development agency has therefore been able to reduce its subsidy to USD $100.

[6] This approach to SHS dissemination is similar to other SHS programmes operated in Nicaragua (for example the PERZA programme, outlined in the introduction), although the authors observe increasing numbers of 'aid-style' programmes, where SHS kits are completely donated and users are encouraged to pay into savings schemes for future maintenance costs.

[7] The government of Nicaragua is currently pursuing aggressive grid electrification activities to reach off-grid households.

[8] Typical batteries installed were 12V, 105 Ah deep cycle lead acid batteries, maintained with demineralised water, with a one year warranty and life span of approximately two to three years (dependent on maintenance and proper use).

[9] The values collected in household surveys were in the national currency, the Córdoba (C$), which was converted into USD, using the average exchange rate in 2006 (C$ 17.57 = USD $1) (Banco Central de Nicaragua). This figure was standardised according to the average price of fuels and services available in 2006, also taking into account that families in remote areas often purchase fuels in smaller, which implies higher costs.

[10] While *ocote* does not incur a financial cost, we recognise that collecting *ocote* does require time and metabolic energy (usually of females) (e.g. see Batliwala and Reddy, 2003; Clancy et al, 2007; Mathee and de Wet, 2001; UNDP, 2004). *Ocote* produces more smoke than a typical kerosene lamp and provides lower quality lighting.

- 95.2% recognised that air quality had improved in their home
- 67.5% reported that the number of hours that children study had increased as a result of lighting provided by using the SHS
- 86% affirmed that they felt more connected and informed by the television that they were able to power using the SHS
- 96% reported that household tasks were made easier
- 16% reported using the SHS to sell mobile telephone battery recharges[11]
- 20% stated that illumination had made their economic activities more productive and easy; in the case of small businesses, e.g. *pulperías*[12], those surveyed stated that lighting enabled them to stay open later, making their business more attractive
- 56.8% reported that they had been unable to use the SHS to improve household income

In addition to these impacts, users acknowledged that SHS transformed their daily routines; on average, users' day length was extended by two hours. Participants reported that extra time was dedicated to relaxation, entertainment, talking with neighbours, household tasks and participation in religious activities. Very few of those surveyed reported engaging in additional productive activities due to the extended day length provided by the SHS.

User satisfaction and perspectives

Not one user reported a negative experience with the SHS, and 99.2% of those surveyed said that they would recommend a SHS to another family. The majority of those surveyed did however express some discontent with the limited capacity of the SHS. Users expressed desires to power refrigerators and workshop-style equipment (which were perceived to enable engagement with income generating activities) or to pump water, in order to address perceived problems in their communities (e.g. 25% of those surveyed identified the lack of potable water in their community as a key issue). In addition to this, users discussed financial difficulties in replacing components (such as batteries), stating that limited financial mechanisms existed to support them in this regard. Limited programme training and follow-up was also identified as an issue; users stated that private SHS companies would often not travel to remote areas to provide technical assistance, and that local technical knowledge of the systems was often limited, potentially inhibiting the future functioning of systems.

Discussion

One of the surprises of this research was the financial difficulties users expressed in replacing components. Users were specifically approached for involvement in the programme based on their capacity to pay for the SHS; many users financed the kit upfront at a cost of around USD $400 in 2006-7. Four to five years later however, some users manifested difficulties in replacing components, such as batteries (which cost approximately USD $130), compromising system functionality. Increasing impoverishment in the region could be one of the factors explaining this; a representative from of one Nicaragua's largest micro-finance institutes explained that the global financial crisis had impacted negatively on the incomes of agricultural producers in the north of the country[13]. Drawing on the technical surveys of SHS conducted, we project that if by the end of 2012, the users who have not already replaced batteries, have not done so, approximately 58% of the kits installed will be out of service. An implication of this finding is that SHS programmes should consider finance issues (particularly for expensive components) beyond the initial financing of access to the technology.

One of the pervasive views presented about SHS in the literature is that 'solar home systems are… a reliable technology which is able to satisfy basic energy needs, easy to operate and maintain, and a means of promoting small-scale income generating activities' (Mala et al., 2009: 361). Users were satisfied with SHS, alluded to the fulfilment of their basic energy needs and the significant 'soft' benefits provided by SHS (outlined in 'other impacts') (e.g. Wamukonya, 2007), however they often expressed desires for greater quantities of energy to enable them to generate incomes or to address key poverty or development concerns in their communities. The majority of users expressed that SHS make limited contributions to income generation (e.g. Mondal and Klein, 2011). A key question arising therefore is how can solar energy programmes be designed and scaled in line with local priorities, aspirations and needs?

In addressing operation and maintenance issues, users demonstrated limited technical knowledge and pointed to a lack of local capacity within their communities to resolve technical issues. A critique of similar 'energy development' style assistance programmes, is their often limited focus on 'hardware' and 'finance' aspects (Byrne et al, 2012), rather than stressing the local capabilities and conditions that need to be nurtured in order to sustain technologies in the long term (e.g. Sesan et al, 2010).

This paper has summarised results from one case study SHS programme in Nicaragua, a fascinating context where decentralised solar energy applications have become an established alternative to grid connectivity. Ex-post evaluation studies provide valuable insights into what occurs beyond initial access to electricity, such as the technical performance of SHS and the impacts experienced by users. These insights are crucial for ensuring long-term longevity of SHS and the programmes promoting them, which is particularly vital for achieving and sustaining targets such as those advocated by the UN 'sustainable energy for all' initiative.

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[11] A symbolic payment of between C$3 and C$10 (approximately 0.13-0.42 USD $ cents) is made per battery recharge, which we deduce does not make a significant contribution to household income.

[12] A small shop, usually based in the home of the proprietor

[13] Interview conducted during author Gent's doctoral field research

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Analysis of the Potential for Energy Products and Services in Rural Areas of Tanzania

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Abstract

This paper analyses the market potential for micro energy products and services in rural areas of Tanzania. It is based on a field study that was conducted in four villages across Tanzania, which investigated energy consumption in individual households and businesses as well as the villages in which they were located. The results of this study illuminate the diversity of the households' energy consumption. Plus we are given an insight into the technical details about the energy consumption of local businesses. Through this study, a tool was developed to estimate the energy remoteness of a village without the need for local investigation.

Keywords: Energy Demand, Tanzania, Productive Use, Village Context, Micro Energy

Introduction

In Tanzania only 12 % of the population are connected to the national grid (National Bureau of Statistics Tanzania 2009). This setting gives the country a huge potential for micro energy products and services which aim at providing energy on a local level from local sources. In order to improve the cost efficiency of energy appliances as well as the general living standards, micro energy can be of great use. Furthermore, environmental impacts like deforestation can be reduced by fuel switches and more efficient technologies. The major household energy demands are cooking, lighting, electricity for powering radios and charging cell phones. Businesses use energy for various purposes like powering mills, fridges, TVs but also for cell phone charging, haircutting machines and cooking.

The overall energy situation in Tanzania is well documented in statistics and publications mainly by the Tanzanian government, TaTEDO (Tanzanian Traditional Energy Development Organization) as well as the World Bank. However, these statistics mainly give average values and they do not represent the situation for individual households and businesses. The village setting is usually not taken into account.

This thesis is set up as a case study to provide the necessary setting for detailed information and analysis on an individual level. Providers of micro energy related products and services seek for detailed information about their potential customers and the villages they are situated in, in order to develop their product and better their marketing strategies. This study developed a tool that makes it easier to estimate the potential for micro energy related products and services in a certain setting without the need for local investigation.

Research Objectives

(1) To demonstrate the diversity of energy needs and expenditure of households and businesses in rural areas of Tanzania by:

(a) providing a detailed picture of the energy sources, energy demands and energy expenditure of individual households.

(b) identifying financial sustainable business models and analyzing their energy consumption.

(2) To demonstrate the relationship between the general village living conditions and energy usage on a household and business level.

Methods

This work is based on a field study using qualitative research methods. The study is a collective case study with two stages; the first being the analysis of a selection of 12 households and 18 businesses and the second being the examination of four villages. The data was gathered through interviews and observations; further analysis was made through the use of technical, statistical and geographical data.

The interviews offer the perspectives of three stakeholder groups: interviews with members of individual households, with owners or employees of businesses and interviews with village officials. Interviews were always open-ended but guided by a set of topics for each type of interview. From 77 individual households and businesses 29 cases were selected according to their similarity with other cases but also to demonstrate specific differences which are outlined in the analysis.

The four interpreters, students from the University of Dar Es Salaam played a central role in the field research. Every interpreter was in one village only. They were not just interpreters but also chose a village where they had family connections to enable better access to the culture and people of the village. It was upon their judgment to select the village as the only ex-ante criteria was a certain level of remoteness to the next town.

Results

Households

Households are grouped according to the number of energy consuming devices that they use: *low* means less than four devices, *medium* between four and eight, *high* is anything above eight.

Regardless of which group the household comes under, some general results can be outlined: a low cooking efficiency, low luminous efficiency for lighting and high prices for electricity. All of these are areas where micro energy products and services have a market potential. The potentials differ according to the groups profile; *low*, *medium* or *high*.

By far the largest amount of energy is used for cooking which has an impact on local and regional climate through smoke and deforestation.

The spending on energy increases with the number of energy sources used to satisfy the demand. Figure 1 gives an overview on the energy expenditure by type of energy usage.

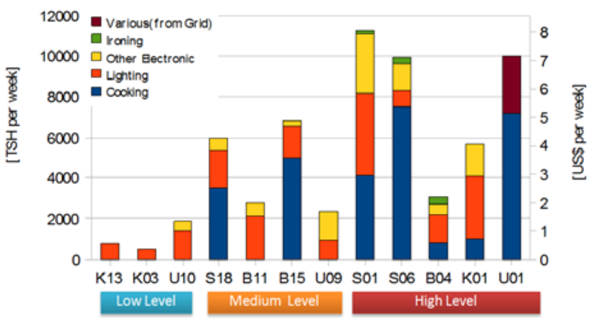

Figure 1: Weekly spending on energy per household[1].

Cooking

Low level households do not pay for their cooking fuel; therefore they have no direct financial interest in improved stoves. *Medium* cases however who pay around 1.50 US$ per week on firewood could lower their spending on energy by 50 % with improved stoves. One case showed that these devices which cost 3.60 US$ for one pot and 7.15 US$ for two pots are available to buy within the village. *High* level households already have a large variety of cooking fuels and use kerosene or gas stoves for heating water. Nevertheless, especially in regard to cooking with charcoal, more efficient devices would reduce consumption and costs with short payback times.

Lighting

For *medium* and *high* level households lighting devices with a lumen output of 50 lm or more could enter the market, when the costs for one hour of light were below 2.5 cUS$ to replace kerosene lamps (see figure 2). *Medium* and *low* level households mainly use wick lamps (*koroboi)* and torches with lumen outputs of 10 lm or less. To replace wick lamps, the costs per hour of light must be below 1.5 cUS$ to be financially attractive.

[1] x-axis indicates the household cases: the letter stands for the village, the number for the individual household.

Investment costs are crucial and should consider the current costs for torches and kerosene lamps which are 1.43 US$ and 2.50 US$. LED based torches play a key role in the development of low cost light. Furthermore, broken or old LED torches can be modified to run on recycled batteries, as observed in two villages. Such a device can only be a source for dim light but is used to help one get around the house at night. Through this modified lighting source spending on kerosene can be reduced and also the capacity of dry cells would be used by at least 8 % more.

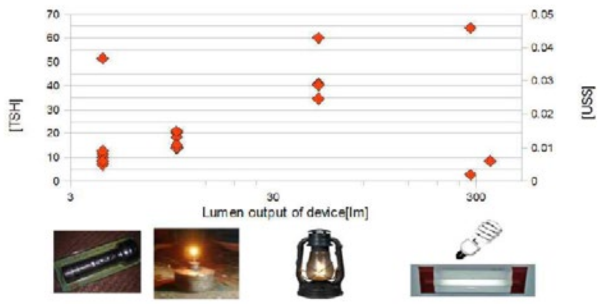

Figure 2: Costs for one hour of light per device[2].

All these measures take place with no additional technological input. In order for such ideas to develop and spread, skill development and knowledge transfer are required on a local level.

Electricity

There is a wide deviation in costs for electricity. While AA-sized batteries are by far the most expensive energy carrier, D-Cell dry cells are relatively cheap and less expensive than the energy for charging a cell phone (AC from diesel generators or vendors' Solar Home System).

The service of providing electricity is currently in a very oligopolistic situation in the villages with prices being set by agreements between the few businesses that offer the service. For all villages, but especially the more remote ones, the price for electricity offered by businesses (up to 90 US$ per kWh) is much higher than costs for electricity in dry cells (around 30 US$ per kWh). As charging cell phones with dry cells is technically possible, it could be that these alternative charging services develop. One such service could be to charge cell phones with a certain number of *old* batteries (those that do *not* give enough light anymore in torches). This could then been an option for very remote homes but also a business idea for a village with a certain turnover of batteries.[3]

However, prices for charging should be reduced and drop below the current value of 30 US$ per kWh of D-Cell dry cells which means a price of 9cUS$ per charge. Not only cell phone charging itself will then become less expensive but also the usage of rechargeable lighting devices would develop more rapidly.

[2] Technical data from (Jacobsen 2009; REEEP 2009; Rotenwänder 2009; Schwarz, Dimpl und Bandlamudi 2005)

[3] It is however critical if this were done using *new* dry cells as then more batteries are disposed with all possible negative impacts associated.

AA-cells should be totally avoided in any appliance due to the high energy costs of 145 US$ per kWh and only be used where their small size is crucial.

Businesses

There is a long list of energy related businesses that have proven to be financially sustainable in a certain village setting. These include workshops, labour intensive stone crushing or firewood splitting but also radio repairmen, cooling facilities for medical or refreshment purposes and also energy providing businesses like charcoal and fossil fuel retailing.

The highest energy consumption per customer is found in restaurants. Even though they only depend on locally available energy sources, they could improve financially as well as ecologically through the use of more efficient charcoal cooking devices.

Being able to provide cold drinks attracts customers and so does entertainment through TV or radio. Electricity helps businesses by having lights and being able to open for longer, but especially through cell phone charging which is a highly profitable business. Technically however this service is mostly provided in a very inefficient way. As shown in figure 3, avoiding the conversion from DC to AC and back to DC is a main potential for energy saving. If DC to DC chargers with efficiency of about 80 %[4] and a DC fan were used, the demand for this case would be reduced by 18 % from 147 kWh to 120 kWh and the system size could be smaller.

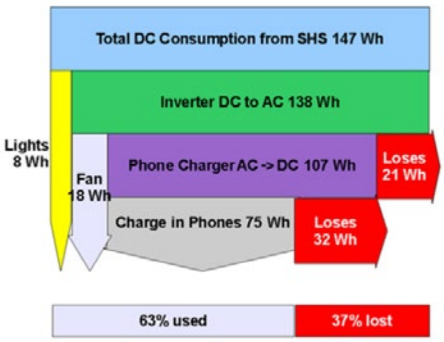

Figure 3: Energy losses in a business using a SHS[5].

The required technology (DC-DC charger, as used in cars) is already available at low costs in Tanzanian towns but currently not used in rural areas. Considering that petrol generators also have a DC outlet, these chargers work in both available electricity sources- SHS and generators. Thus, all cell phone charging businesses in non electrified villages should use DC to DC chargers.

Saloons and video / TV shows are profitable businesses with high electricity consumption which is usually provided with generators. A well used solar home system has only about half the costs per kWh than a generator. Hence, it is an example for a micro energy investment which could reduce energy costs with a short payback time. This switch may however require capital from (micro) financial institutions.

In all villages, mills are part of the village picture, with high potential of lowering the energy costs when a grid connection is possible, as illustrated in figure 4. A possible business expansion, depending on the cultural and traditional setting, is that of a grinding-only mill to one that also offers hulling.

	Diesel Mill			Electric Mill		
Average load per day[kg]	560			804.3		
Average number of customers per day	40			35		
Running Time[h per day]	0.72			1.3		
Energy Consumption[$kWh_{fuel/electric}$]						
per day	24.9			21.67		
per kg load	0.04			0.03		
per customer	0.62			0.62		
	TSH	**€**	**US$**	**TSH**	**€**	**US$**
Costs per kWh_{mech}	**502.01**	**0.27**	**0.36**	**147.09**	**0.08**	**0.11**

Figure 4: Basic data for a diesel mill and an electric mill.

Village Setting and Remoteness

The general village setting is the key variable when looking at the business or household energy situation. The general economic situation, education possibilities but mainly infrastructure and institutions have a large impact on how easily or hard different energy sources, devices and services are available. The term remoteness refers not only to the geographical distance to economic centres but also to *energy remoteness* which slows down the development of energy related developments made towards the improvement of living standards.

Comparing the four investigated villages, Kanyezi is by far the most remotely located and energy remote village. Followed by Bunduki and then Salawe. Umbwe is very close to an economic centre and even has connection to the national grid. This can also be seen when looking at data that was available without local investigation as presented in figure 5.[6] These factors for remoteness serve as an easily available tool to estimate to which degree a certain village is *energy remote*. The factors are normalized and relative numbers following the formulas given in table 1.

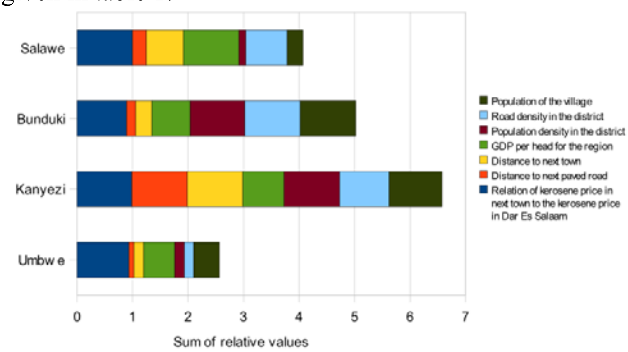

Figure 5: Factors of remoteness based on statistical data.

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[4] (Conrad Electronics 2012; Quaschning 2009, 201)

[5] Technical data from (Quaschning 2009; Rotenwänder 2009)

[6] (EWURA 2010; National Bureau of Statistics Tanzania und Kilimanjaro Regional Comissioner's Office 2002; National Bureau of Statistics Tanzania und Morogoro Regional Comissioner's Office 2007; National Bureau of Statistics Tanzania und Rukwa Regional Comissioner's Office 2007; National Bureau of Statistics Tanzania und Shinyanga Regional Comissioner's Office 2007; National Bureau of Statistics Tanzania 2010a, 2010b, 2010c, 2010d)

Table 1: Formulas for relative Remoteness Values.

High value associated with higher remoteness
$$Value_{Rel} = \frac{Value}{Max}$$
○ Distance to next town ○ Distance to next paved road ○ Fare to next town ○ Price for charging a cell phone ○ Price for a "500TSH" voucher ○ Kerosene price ○ Relation of kerosene price to the price in next town ○ Relation of kerosene price in next town to the kerosene price in Dar Es Salaam
Low value associated with higher remoteness
$$Value_{Rel} = \frac{Max - Value}{Max}$$
○ Population of the village ○ Population density in the district ○ Road density in the district ○ GDP per head for the region
Max = Highest Value of all villages

Discussion

This work has indicated potentials for micro energy products and services in rural areas. Both in a household as well as a business environment, large improvements in regard to energy and money saving can be made. Strategies are yet to be developed on how to do this best. Some cases that were included in this study show that many solutions, which only require locally available personnel and material resources, have already been found. If these solutions and ideas are further developed and promoted, many people in rural areas would benefit from them. Many villages show a human capacity for technology modification, installation and repair which should be used to its full potential. Further research needs to be done in order to show how this can be done in detail.

For many business appliances like SHSs, engines or fridges and TVs technology needs to be brought in from towns and abroad. Hence, the approach for sustainable technology development should focus closer on the user perspective. Electricity conversion losses are a key topic to be addressed and should be followed up further by for example the expansion of direct DC usage for charging.

Furthermore, this thesis has shown how the energy situation of a village correlates with statistical and geographical data that is easily available. Factors are developed that measure energy remoteness. Further research needs to be conducted on these remoteness factors to see if they are suitable for measuring micro energy potential. The examined villages of this study could serve as the first four reference models as a start of a bigger database.

These references can then be used to estimate the micro energy potential for any given village when the data to calculate the remoteness factors is available. Also the factors themselves should be tested in other regions and modified to be a reliable source in illustrating the real village setting.

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An Objectives Analysis for Improved Holistic Design of a Rural Electrification System

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Abstract

Universal energy access remains a challenge despite it being essential in enabling human development. Existing approaches to rural electrification are oftentimes fragmented and leads to poorly designed systems. Integrating the rural electrification system's social, technical and financial aspects calls for a more holistic design process. This paper presents a representation of a rural electrification system's objectives and high-level requirements in an effort to incorporate various perspectives and needs in the initial stages of an improved design process. This approach is invaluable as it enables the formulation of a design that emphasizes human development as the ultimate objective.

Keywords: Energy access; Rural electrification; Objectives analysis; Human development; SysML.

Introduction

Social, economic human development and poverty reduction have repeatedly been linked to improving energy access through electrification. Modern energy access plays a key role in driving sustainable human development through enabling education, improved water, healthcare and sanitation services, lighting and the creation of local small and medium enterprises.

The focus of conventional rural electrification programs has usually been on understanding energy access barriers and creating institutional approaches and top-down mechanisms to address them. However, energy access programs, which are primarily aimed at providing or extending electricity services to all, may eventually prove to achieve limited improvements in human development. The ultimate challenge of an energy access program should not be to merely deliver electricity services, but to focus on delivering human development impacts.

A renewable energy micro-grid system is an attractive and viable option given advances in renewable energy technologies and the ability to use available local resources. The off-grid energy system in a rural setting creates a whole host of issues, ranging from meeting energy needs while ensuring cost-effectiveness, to the technical design that generates safe electricity and incorporates appropriate technology. The success of any decentralized activity is also highly dependent on local empowerment and participation (CORE International, 2003) and thus identifying the community as the main stakeholder in defining their needs and roles will lead to more effective implementation of electrification. Improving the technical design of an electrification system has traditionally been the role of engineers, who typically design technology to meet customer needs. There is a tendency for engineers to emphasize the technical aspect of the system and overlook the issues that may arise from how the technology is eventually installed and used. Installed technologies that fail to consider the particular needs and preferences of community end users may eventually lead to problems such as difficulty in operating and maintaining the system, electricity theft, power capacity issues in meeting long-term demand, and the associated financial burdens of these problems.

A strong understanding of community needs and goals, the technical design of an electrification system, and how the components interact to facilitate socio-economic development all need to be incorporated into a single design process. This calls for a modification in engineering approaches and demand for new tools and methodologies to address multiple stakeholders and the unique requirements of a rural energy system.

A systems engineering design process generally begins with a requirements analysis that clearly articulates customers' needs and defines proper engineering design processes (Buede, 2009). However, a rural community oftentimes lacks the skills and experience needed to formulate working engineering requirements. A needs-driven approach preceding the requirements engineering is an objectives analysis in the form of a decomposition, aimed at developing and refining a set of objectives for the system (Kossiakoff, Sweet, Biemer & Seymour, 2011). These objectives establish the requirements for the system design. The main benefit of this objectives analysis is twofold, allowing community participation in the design process by communicating their high-level objectives, and enabling an expansion of the system boundary to incorporate social and financial aspects in the earlier stages of the system design. The technical component or the technology used (also referred to as technical 'artifacts') does not exist in isolation and must be engineered to integrate into an expanded view of the system (de Weck, Roos & Magee, 2011).

The set of requirements that are eventually constructed from this objectives analysis is necessary to define the design problem, and is used as inputs into the functional definition and allocation of the system's architecture. The requirements formulation and subsequent functional modeling is beyond the scope of this work. The systems engineering modeling language, Systems Modeling Language or SysML is employed in this paper for graphical modeling purposes, due to its ease of use.

The case study of Kampung Buayan, Malaysia is used as the basis for understanding a rural energy system in this paper. Kampung Buayan is a community of approximately 150 people or 25 households, and operates a 10kW, community-based, micro-hydro system. The village is located in a remote, mountainous area of the Crocker Range rainforest.

Research Objectives

The main objective of this work is to incorporate human development goals in the earlier stages of a rural energy system design process. This work will apply SysML in developing an objectives analysis using a decomposition of a rural electrification system's objectives. The decomposition is the first step to engineering the requirements needed for the design of a community-based, rural energy system and is essential in ensuring that the system architecture that follows these requirements achieves the main human development targets.

Methods

Field work at a case study site was carried out, largely as participant observers, in order to achieve an understanding of a rural community's energy needs, local institutions, financial, socio-cultural and technical barriers, and other issues pertaining to energy access. Data and information from field notes, direct observations, structured questionnaires and focused group discussions were utilized in developing this work's objectives decomposition.

SysML is used to represent an analysis of the objectives decomposition of a rural electrification system. The term 'objectives' is used instead of 'requirements' as this exercise represents an earlier stage of the design process, aimed at eventually eliciting clear, technically appropriate system requirements from lower-level, decomposed objectives (Kossiakoff, Sweet, Biemer & Seymour, 2011). High-level objectives of the system are graphically represented as components in rectangular boxes. The highest-level component is decomposed into lower-level components and the connection between them is abstracted using the 'generalization' link. The 'generalization' link is represented by an arrow with the arrowhead pointing towards the higher-level component or target component. This connection typically denotes that the lower components are more specific in nature and inherit the target component's more generally stated features (OMG, 2012). In this representation, the connection indicates that the lower-level components (combined) fulfill the objective stated in the higher-level component by satisfying its own stated objective.

The diagram begins with the highest-level objective component, Human capability enhancement, which represents the main need or value to be delivered by the system. The objective is then decomposed into lower-level objectives that are conceived to be more specific objectives or requirements that achieve the higher-level Human capability enhancement. For example, Human capability enhancement can be broken down into the objectives, Improving energy access, Improving community's financial means, and Capacity building. In other words, in the context of a rural electrification system, the goals Improving energy access, Improving community's financial means and Capacity building all fulfill the higher level objective of Human capability enhancement.

The diagram also depicts components connected using a 'dependency' link, which is represented by an arrow with a dashed line. These links indicate that the beginning objective depends on the target objective in order to be satisfied. The condition under which this dependency operates is described in writing on the dashed portion of the arrow.

The objectives are decomposed until a sufficient level of detail is revealed. This level of detail is defined by when the objectives have been decomposed to a verifiable objective (Kossiakoff, Sweet Biemer, & Seymour, 2011) that can be translated into system requirements. Once a verifiable objective has been defined, functional and non-functional requirements (constraints) can be formulated using lower-level objectives. Any further decomposition would begin to reveal the architecture (functions and form) of the system and could restrict optimal design options. SysML is also used to reorganize the components based on its connections, following a hierarchy of levels.

The red colored component in the diagram represents comments while the yellow colored components are outside the scope of this work.

Results

Figure 1 on the following page shows the resulting objectives analysis of a rural electrification system aimed at enhancing human capabilities. It can be seen that the technical components of the system were able to be decomposed or conceived from the high-level objective of human capability enhancement.

The following Table 1 shows the lower-level objectives that the system must fulfill in order to achieve human capability enhancement through energy access.

Table 1: A list of lower-level objectives of the system.

Lower-level Objectives
Economic activity creation
Enhancing local governance/institutions
Building local management skills
Enhancing environmental resource management
Building local technical skills
Encouraging knowledge transfer
Designing and implementing an appropriate tariff system
Lowering cost of system's installation
Lowering cost of system's operations
Choosing cost-effective technical design
Providing reliable electricity supply
Providing electricity using a robust system
Providing electricity using an efficient, safe system
Providing adequate electricity supply
Providing electricity using a flexible, scalable system

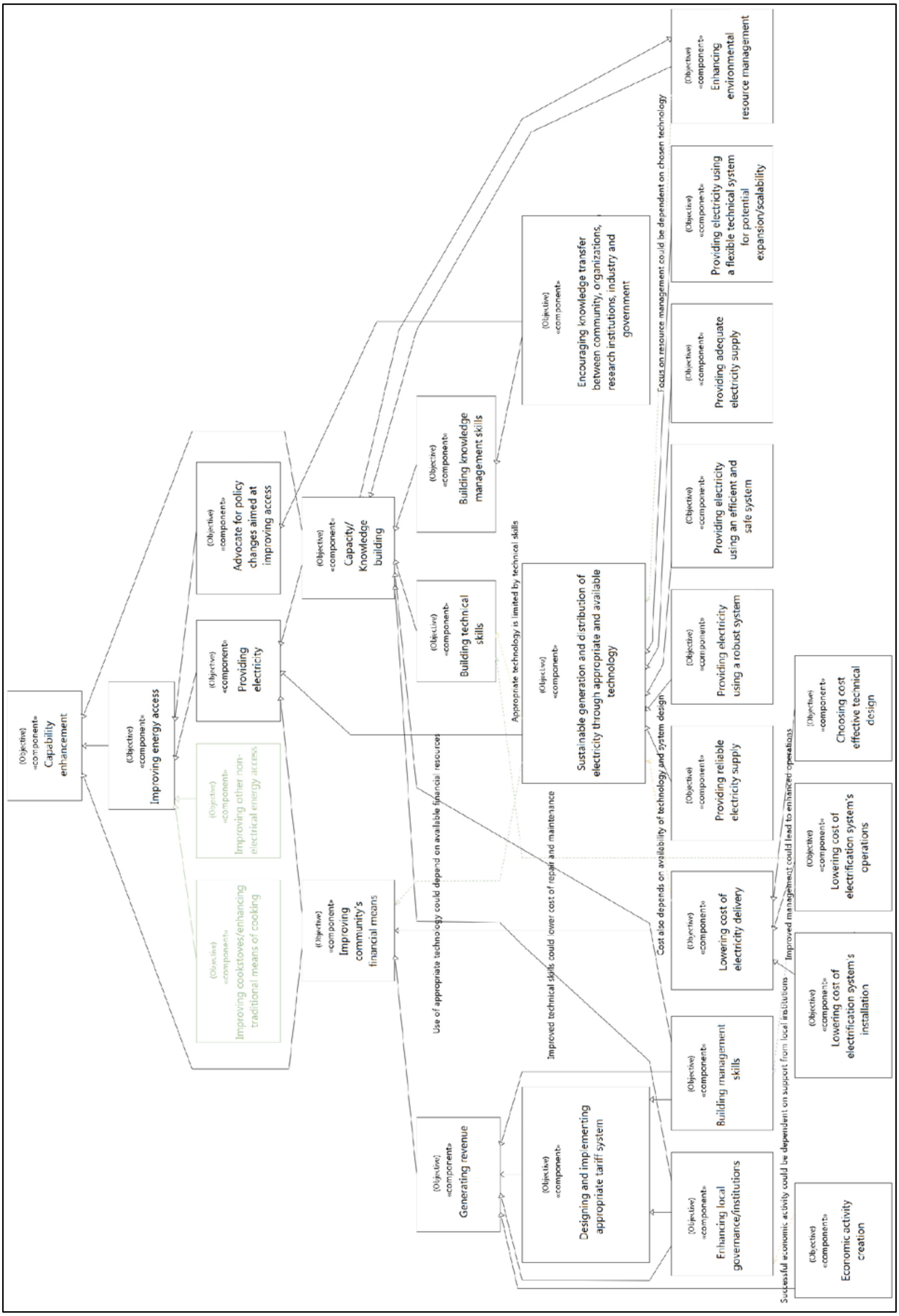

Figure 1: SysML objectives decomposition of a rural electrification system.

Discussion

An objectives analysis was used in order to understand the system's objectives and the relationships between objectives. Using an objectives decomposition diagram is useful in being able to begin with abstract customer needs, and translate them into systems requirements for energy access projects with an emphasis on capability enhancement. Table 1 provides a list of potential preliminary systems requirements that have been conceived to achieve capability enhancement.

The system in its entirety must be engineered to meet the high-level goal from the onset. Instead of conventionally focusing the design of the system on generating electricity efficiently, the system boundary of the electrification system is expanded beyond its technical components to include community needs, and developed to accomplish capability enhancement first and foremost. While providing electricity at first glance appears to be the apparent high-level objective of an electrification system, real-world goals of community-level electrification are aimed at enabling the improvement and creation of human development-oriented activities. It appears as a rather straightforward and simplistic approach, especially to the multi-faceted challenge of human development. However, the inclusion of human capability enhancement as the main value of a system will dictate the lower-level system requirements, functional allocation and the mapping to the eventual form the system will take.

Note that even with the emphasis placed on capability enhancement, the technical electrification components were still conceived and become an instrument in accomplishing improved human capabilities, but do not constitute the main component of the system. Other components such as capacity building and increasing income become fundamental objectives to attain in the process of rural electrification. This analysis shows that electrification is not an end, but a means to achieving higher-level objectives and system requirements.

The diagram also provides some insight into how the different objectives of the system interact or are interrelated with one another. For example, the technical components, which are insufficient in providing electricity, must be coupled with an appropriate tariff system that generates enough revenue for the community, as well as the development of local technical and management skills in operating the system. Local institutions and participation are also crucial in the formal organizing and empowerment of the community to help realize common goals.

Another advantage of this graphical representation is the ease in which the hierarchical nature of the different objectives can be viewed and appreciated. Objectives that were initially thought to be of a particular level could in fact (based on connections formulated), be higher or lower. For example, Revenue generation, which was initially perceived to be of the same rank as the technical components, was shown to be a higher-level objective instead, implying that Revenue generation could be a higher-ranking objective. Considering this as a higher-ranking objective could be valid as cost recovery is an important factor in ensuring sustainability of the system. If the community is unable to at least recover the cost of the system, they will be left dependent on external sources of funding (Barnes & Foley, 2004) and may face system shutdowns due to the inability to finance the system's operations.

Knowledge and resource management must also be designed into the system if energy access is to be achieved. Knowledge transfer between the community, organizations and government entities is vital to improving rural energy policy and providing a positive environment for community systems. Proper resource management is also a main part of community capacity building and also helps to maintain sustainability of the renewable resource.

The requirements that are engineered from this objectives analysis can be employed to complete the design of an energy access program. However, the objectives analysis conducted in this work is used to develop a sound understanding of the needs and requirements of a sustainable community electrification system. This understanding provides the groundwork for the creation of a technical tool that can be used by a community to design its own community-based energy system. The tool as an artifact is intended to provide different energy system options mapped from the requirements of a rural electrification system (as conceived from this analysis). Intended for use by the community in order to guarantee community participation, the tool will be applied through a process aimed at achieving human development goals.

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Home is where the hearth is? Focal points of heat, low carbon heating and domestic thermal experience

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Abstract

This paper reports preliminary findings of an interdisciplinary research project investigating the thermal experiences of older adults living in diverse domestic contexts following the installation of low carbon heating technologies (e.g. biomass boilers). Using a grounded theory approach on a qualitative dataset comprising interviews with occupants and managers in diverse domestic contexts (e.g. care homes, urban rented and rural owned homes), the research revealed that hearth-like focal points of heat continue to be a valued attribute of the 'cosy' home, evidenced by the use of both mock and real devices to provide a psycho-physical experience that efficient heating systems (e.g. heat pumps with under floor heating) fail to provide. The implications of the findings for policy and industry are discussed.

Key words: hearth; glow; low carbon heating technologies; older adults; thermal experience

Introduction

This paper reports findings from an interdisciplinary research project involving researchers from sociology, architecture, urban planning, engineering, science and technology studies, geography, and environmental psychology that share certain ontological and epistemological positions about the socio-technical nature of the energy challenges facing society (Berkhout et al., 2004). Patterns of consumption are not simply the result of rational economic decisions and value choices but constrained, facilitated, pre-structured, configured, or conditioned by complex networks of technological, social, cultural, and institutional factors (Shove, 2003). From this conceptual perspective, the way people use, 'misuse' and interact with technologies depends not only on technical performance and cost but also on risk, reputation, habit compliance, aesthetics, meaning, usability, affective impact on users, maintenance requirements, professional support networks, compatibility with pre-existing routines, and so on (Southerton et al., 2004). These parameters are of crucial importance to the diffusion of technologies and – by recursive implication – to the (non-) diffusion of new consumption patterns, intended as well as unintended ones.

Thermal experience is conceived as arising from 'the intersection of technical comfort provisions and the psychological and social realms of experience, movement (mobility) and interaction' (Cole et al., 2008: 324). With a particular interest in these psychological and social realms, and particularly meanings of 'home' (Moore, 2000; Tuan, 2001), this paper aims to explore to what extent hearth-like focal points of heat and glow (defined as concentrated points of radiated heat and visual sources of light suggesting such concentrated heat sources) continue to be psychologically and socially significant across diverse domestic spaces heated by low carbon thermal technologies and occupied by older adults.

Our interest in researching older adults stems from the expectation that by 2025, more than one third of the UK population will be over 55[1] with similar trends occurring in France and other parts of Europe. Older people will therefore become increasingly significant in the profile of domestic energy demand since they reportedly spend 70 to 90% of their time in domestic space.[2] The implications for housing policy have been recognised (DCLG 2008) including those related to 'empty nesters', people who 'downsize' their homes, poor quality institutional accommodation, and so forth. Whilst the challenges of an ageing society have been addressed by some recent energy research – particularly focused on issues of fuel poverty (e.g. Day and Hitchings 2009) – the studies have only just begun to acknowledge the heterogeneity of 'the elderly' and their ways of living in a wide variety of spaces. We therefore propose to unpack this demographic category and the related domestic settings. For example, the 35 years that most 55 year olds can still expect to live[3] are typically characterised by very different phases of activity and health (Metz and Underwood, 2005), financial power (living in fuel poverty vs. maintaining second homes), and domestic living situation (home owning, private renting, sheltered housing, retirement homes, and so on).

Another key aspect driving the research is the expectation that low carbon heating technologies (e.g. solar hot water panels, ground source heat pumps, air source heat pumps, biomass boilers) will lead to a reduction in carbon emissions. Research has already suggested that older people are less likely to adopt low carbon technologies (e.g. Mahapatra and Gustavsson, 2008). Our interest is to investigate how older occupants actually engage with and use these technologies post-installation. We are particularly interested in how such technologies become assimilated into the 'home'. How hearth-like focal points of heat and 'glow' are achieved may have important environmental implications, for example previous research has identified significant negative impacts on urban air pollution derived from the seeking of a 'cosy glow' from burning wood (Petersen,

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[1] http://news.bbc.co.uk/1/hi/uk/4012797.stm. We have chosen the 55+ population as our definition of older people because this straddles the boundary between actively working and retired individuals and enables us to explore key phases of lifecourse change.

[2] Centre for Policy on Ageing. See http://www.guardian.co.uk/society/2009/dec/02/pensioners-golden-girls-retirement

[3] http://www.retireearlyhomepage.com/lesafe.html

2008). Furthermore, it may be that adequately functioning thermal technologies such as under floor heating that are characterized as low in 'exergy' (Tweed and Dixon, 2012) fail to provide the energy services – i.e. a hearth like focal point – that occupants may desire. In such contexts, the provision of 'extra' heating technologies that supplement adequately functioning low carbon heating systems may counter the expected emissions savings from low carbon thermal technologies. Thus, we expect the analysis to have important policy and industry relevance.

Research Questions

To what extent does a 'hearth' retain importance in contemporary living for providing valued thermal experiences and for wider practices of home-making?

How is it manifest in diverse residential contexts?

What are the implications of these practices for low carbon policies in an Ageing Society?

Methods

A qualitative method was employed in the study. Standardised interview schedules with open ended questions were devised and implemented by each partner with the aim of investigating how occupants in diverse domestic contexts engaged with low carbon heating technologies. The material from these interviews was transcribed and coded using Atlas.ti software, using a coding template shared across the project team. Focal points of heat and glow were not explicitly raised by interviewers, but instead arose from the conversations that ensued. Using a grounded theoretical approach (Glaser and Strauss, 1967), any section of text that referred to 'focal points of heat', 'glow' and 'hearth' was identified, coded and then systematically compared across diverse living contexts.

Sample

Each University partner in the project focused on a distinct domestic context to research older people, thermal experiences and low carbon technologies.

Table 1: Characteristics of the sample.

Partner	Socio-economic category and domestic living arrangement	Number of cases/interviews
Manchester	Lower income, living indepen-dently, urban rented housing	23 households
Cardiff	Lower/middle income, living semi-indepen-dently, sheltered and social housing	18 households
Lancaster	Mixed income, living institu-tionally, care homes	6 care homes, 39 interviews
Exeter	Middle/high income, living independently, rural home owners	17 households, interviewed over three seasons (total of 51 interviews)

Results and Discussion

Our analysis is not yet complete, but has already indicated some interesting preliminary findings. First, analysis of the interview data has revealed the continued importance of hearth-like focal points of heat in rural homes. For example, in one household with a ground source heat pump and underfloor heating, the occupants were asked about the presence of a wood-burning stove in the living room:

Wife: But I mean I can see that we will run the wood burning stove really because they're nice to sit round, it's nice to sit round a fire.

Interviewer: So even if you were warm you would still want to have a fire to sit around.

Wife: Yeah.

Husband: And at Christmas I mean when you're sitting round the table in there with the other woodburner you've got the smell of the ... you know put some nice logs on and you get the smell of a wood burning stove and so it is lovely.

The quotation reveals the important sensory and affective aspects to hearth-like focal points of heat, providing appreciated smells to the occupants.

Interviewee: … because in the lounge as a feature we put in a woodburner so if it's a really really cold night in the winter we do put the woodburner on because it just - I think just looking at something warm means you feel that bit warmer doesn't it, so I've got that as a back up but that doesn't take a lot to warm the place 'till it's too hot and you've got to try to gasp for breath like you know it gets so hot.

Interviewer: So would you do that even if you were here on your own for example?

Interviewee: No, it's when we're all sitting around together and you think well perhaps on a Saturday night or Sunday night or something when everybody's in we might decide to put the woodburner on in there, yeah. (P2)

This quotation, from another household with a ground source heat pump and woodburner also reveals important non-functional aspects to the provision of thermal experience. The stove is regarded as a 'feature' in the lounge, a piece of furniture that visually fits with the occupants' expectations of how their living space should appear. The actual use of the stove makes clear that it has an explicit social function, only used when family members collect together on weekend occasions. It is clearly not required to provide thermal comfort, however, as the quote suggests that the combination of the existing heating system (ground source heat pump) with the wood burning stove produces an excess of heat and leaves occupants uncomfortable.

Preliminary analysis of interview data from the institutionalized settings has revealed tensions between the care homes' aim to provide safety and security to the older occupants and the provision of focal points of heat. In fact, heating systems were selected to avoid focal points of heat (e.g. stoves, radiators) and underfloor systems of provision were preferred for this reason. However, to continue to provide a visual sense of 'cosiness' to occupants, the care homes employed technologies that suggested a hearth without comprising safety – 'dummy' glowing devices were installed to mimic a hearth that did not provide heat and were not required to ensure thermal comfort. In this way, both hearth-like focal points were provided without compromising the safety of the occupants.

'Now we've got that. It's a new addition. That's literally just the lights on. That is not working as a source of heat because obviously we can't, it's far too dangerous' (Care Home 3 Tour/R = CH3 Activities Coordinator).

In conclusion, this preliminary analysis of a qualitative study of thermal experiences of older adults in diverse residential environments suggests that hearth-like focal points of heat and glow continue to be valued as an important element of thermal comfort experiences and that efforts to secure such experiences play out in diverse ways depending upon contextual demands. The installation of 'dummy' devices in institutional settings suggest ways that concerns over safety can be accommodated without compromising perceived homeliness. Given the durability of these values, and their potentially negative implications for carbon emissions involving supplementary heating practices, the results suggest important lessons for technology designers and policy makers. Nevertheless, as preliminary research using a small sample and a qualitative method, further research is required to replicate and extend these findings.

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Reflection by Breaking - Understanding Transitions to Decentralised Energy Supply through Power Cuts

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Abstract

This paper provides a qualitative interview study to discontinuities and disruptions in domestic heating practices during long blackouts. It is discussed whether failures could serve as an entry point to the change dynamics of the practice. Results implicate that failures in practice open up the reflexivity of the practitioner; that blackouts activate unused skills and resources, activate uncommon meanings to electricity and heat, and regenerate dormant elements of practice. In particular pursuits for decentralized energy supply benefit of acknowledging more openly that sustainable solutions derive from practitioners' everyday experiences, and therefore understanding of the myriad practice of energy use is important.

Keywords: User experience, learning, disruption

Introduction

Energy resilience is amongst the policy-relevant topics related to energy system developments. Resilience of the system refers to how systems are able to respond to disruptive challenges; it stands out as measure of adaptive capacity and ability to learn how to cope and adjust. Resilience building can be seen as a process of co-evolution where actors and technologies interact within a system to minimize vulnerabilities and maximize opportunities (O'Brien & Hope, 2010).

However, resilience building in centralized energy systems faces a bumpy road ahead. Aging energy grids, increasing load on supply and distribution networks, political claims for energy autonomy and, especially, threats caused by changing climate and extreme weathers arouse doubts and concrete problems on the reliance for centralised production. The size, complexity, pattern, and control structure of the centralised, large-scale supply make it inherently vulnerable to large-scale failures (Lovins & Lovins, 1982). For instance, in recent years India, the US, Mexico and Cuba have witnessed extensive blackouts, not to mention the mundane inconveniences caused by brief, localized power outages that regularly hit the grid around the world.

As centralised energy system is facing challenges in terms of resilience, discussions concerning the development of decentralised energy supply run on actively. In Finland the field has merely taken baby steps and many actors admit that Finland is lacking behind many countries in terms of coherent guidelines, regulation and support (see Sitra, 2012). Decentralised provision is seen promising in tackling issues of climate change and decoupling from non-renewable sources of energy, but it has been less discussed from the point of view of resilience building.

This paper argues that resilience building and the capability to adjust bring new perspectives to the discussions of 'pros' and 'cons' in centralised and decentralised energy supply. It is suggested that distributed organising of energy provision pushes forward new forms of social relations and new engagements between users and technologies (Walker & Cass, 2007; Spaargaren, 2011; Juntunen, 2012) but still the understanding of how these new engagements arise is limited.

Disruptions and instabilities in energy supply in everyday life context are chosen as the focus of interest for two main reasons. Firstly, it is suggested that failures could be seen as justifications for policy intervention (Weber & Rohracher, 2012; Strengers & Maller, 2011). There are examples where disruptions as such are used as a platform for intervention. In Juneau, Alaska, an electricity supply disruption lead to persistent reduction – 8% of historic consumption – in energy demand through a combination of new habits and technical improvements (Leighty & Meier, 2011). The liberation from the constraints of current practices is seen as a key driver for attaining higher order learning (Davies et al., 2012), and thus disruptions are of relevance in discussing the transition of one form of provision to another.

Secondly, disruptions bring about questions on what is perceived as normal, and they provide a useful perspective to examine connections between practices, politics and socio-technical systems (Shove, 2012). Therefore disruption is important in understanding the norms, practices and technologies that construct the socially accepted definition of normality (Trentmann, 2009).

As energy resilience is amongst the policy-relevant topics related to energy system developments, research hasn't yet acknowledged its embedded role in everyday systems of energy provision. In the following, I clarify how blackouts are approached in this paper to discuss the resilience building and reflectivity towards distributed and centralised systems of provision.

Research Objectives

This paper contributes to the discussions on transition from centralised energy supply to decentralised forms of provision by discussing disruptions in domestic heating practices. Analytically I explore continuities and ruptures in everyday life practices during multiple-day power outages. I provide a qualitative study of domestic space heating practices and their interruption in the context of detached houses.

This study asks how energy consumers (households) change or 'negotiate' their practices when faced with extensive power cuts (of up-to five days) *in situ* and subsequently. Specifically, this paper discusses the following question: What kind of 'reflective space' does power supply disruptions offer for energy consumers to renegotiate energy use and supply?

I adopt a practice-based approach to study practices (Schatzki, 2001; Reckwitz, 2002; Warde, 2005; Shove et al., 2012) of energy use (Gram-Hanssen, 2011). Previous practice-theoretical approaches suggest that disruptions and failures have a central role in reflection and change (Trentmann, 2009; Shove, 2012). It is argued that the breaking and shifting of structure takes place in everyday crises of routines and of the inadequacy of knowledge with which the agent, carrying out a practice, is confronted in the face of a 'situation' (Reckwitz, 2002).

Practice theory would seem to suggest that critical and cultivating reflection is about reconsidering the conditions of one's action and the historical, material and social making of ones taken-for-granted routines. Routines, practices and networks of practices are seen to provide a concrete way of tracing the social associations through which situated learning occurs (see Roberts, 2006; Antonacopoulou, 2008).

Devine-Wright and Devine-Wright (2007) have shown that blackouts evoke both positive and negative associations, and that they have past and future temporal referents. I aim to take this notion further, and discuss the reflexivity provoked by the power cut. Reflexivity goes beyond reflecting cognitively on an event to solve a problem because it is dialogical and relational activity that unsettles practices and can lead to learning in experience (Keevers & Treleaven, 2011). Reflexivity provides a basis for examining taken for granted assumptions.

Thus, if we seek to understand the unmaking of unsustainability, it calls for rapid development of the 'flip-side' of innovation studies and for methods of conceptualizing processes of social and infrastructural destabilization, collapse and repair (Shove, 2012) – in this respect, disruptions, failures and crises are welcomed to the research agenda.

Methods

Practice approach has important methodological implications. Firstly, activities of social life continuously have to be carried out and carried through, and this mundane performativity is organized through a multiplicity of collectively shared practices. Practices take several forms: linguistic, non-representational, social, material, corporeal and sensual, and they involve both human and non-human entities (Reckwitz, 2002; see also Valtonen, 2012). Simplified, practices consist of both doings and sayings (Warde, 2005), which suggests that analysis must be concerned with both practical activity and its representations. Secondly, the locus of interest is not on the individual, but on the practice: individual is seen as a carrier of practices and as a place for intersection of a plurality of practices (Reckwitz, 2002; Warde, 2005).

Empirical material

The data for this study has been collected by interviewing households, business actors and municipal governance in a small Finnish municipality. This region faced power cuts of up to one week in January 2011, followed by power cuts in December 2011. The area is easily subject to harsh weather conditions due to its geographical location; in 2011 the power cuts were caused by heavy snow that toppled the trees onto the on-ground cable network. The repair work was especially slow and difficult due to the severe weather with frost and high snow banks.

Interviews were conducted in 2011 and 2012 with households as well as local governmental and business actors. Five interviews with households, 6 semi-structured interviews with other actors (local council chairman, house managing agency, home and rescue services) affected by the power cut have been made. The focus of analysis is on the interviews with households; interviews with other actors are used as interviews with households were in situ interviews in order to grasp the surroundings and material environment of the practice. This set of data is supported by news articles dealing with the power cut.

The interviewed households were dwellers in rural discrete areas. None of the households had implemented 'new' energy technologies, i.e. air-heat pumps, solar panels, PVs nor wind turbine. However, they had a varied set of other heating technologies such as wood-chips and log boilers, and supplementary wood-burning stoves. Thus, the provision of heat was arranged by direct electricity which was either supported by occasional wood-burning or more systematically by central heating with wood chips or logs. They all relied on centralised electricity provision.

Interview data is of relevance here because in interview situations, people are brought to talk and reflect upon their practices with the help of an outsider (see Hitchings, 2011). Acknowledging that the significance of the experimental performance prompted by disruptions can only be understood in the context of stabilised practices and social relations (McMeekin & Southerton, 2012), both questions concerning the 'normal' heating practice and the disrupted situation were included in the interviews.

In the analysis phase, the interviews with households were thematically coded and analysed. In the heart of the analysis lied practices, systems, relationships and artefacts that were influential in shaping the disrupted trajectory of the practice.

Results

In this result section, I start by discussing our findings on the disrupted practice by focusing on the material side of the disruption, control of practice and the meanings the disruption evoked. I conclude with an analysis on the 'reflective space' blackouts prompted for the practitioners.

Disrupted practice

Dormant materials and re-arrangements

In the face of disruption, households reassessed the materiality related to heat provision and electricity use. The central boilers stopped working, radiators got cold, house got colder, lights didn't turn on, mobiles turned numb and appliances for cooking didn't work. Consequently, in most cases a variety of dormant materials for back up were brought in to the practice. Unused fire-burning stoves, garden-wells, different lighting apparatuses, blankets, wood-stoves and gas boilers were used to bring back the normality of outputs. In most cases, these backup technologies were found inside the home, and some were bought from the local stores or provided by friends or relatives.

For those people who had a forcing need to access electricity, acquisition of new backup device (aggregates) turned out as a sensible option. Some households with live-stock had already an aggregate ready to be used. Aggregates were also circulated within the community, amongst neighbors.

Thus, many of our interviewees possessed homes that carry elements of decentralised energy provision, hybrid systems. In most cases distributed forms of provision co-exist with electric heating: cheap electric heaters offer back-up and were acquired to enable flexibility and increase convenience.

Control

In general, heating was a relatively visible and present in the everyday life of interviewees due to intense wood heating in the colder periods. However, disruption evoked a set of physical, social and mental skills to carry out through the power cut. Disrupted practice required increased manual control of heat provision that was more time-consuming.

The media assumed that the households' capacity to adapt was weak than it was; for instance elder people proved more competent than assumed.

For those people, who didn't have backup devices, adjusting indoor habits was likely. Adjustment, loss of control, meant for example allowing the lowering of the room temperature from normal comfort levels. When yielding comfort at home was not enough, seeking comfort outside own properties was an option for some. We didn't have many of these dwellers in our small sample but respondents reported of neighbors, relatives and acquaintances that left their homes because of the blackout.

Circulated meanings

Some households reported on a culture for energy conservation before the disruption. Those people valued self-sufficiency in their heating and reported achieving it by using wood as a source of heat. The failure was consistent with their normal orientation as they reported business-as-usual feelings.

Coping in face of the power cut evoked many meanings attached to the power cut. Feelings of insecurity, unpredictability, non-autonomy were overcome with achievements of managing:

So it [realisation that the mobile phones didn't operate] was a scary feeling, a feeling that you have to manage on your own. … And then we really started to think that sure we had anticipated that it's the weather, that this looks bad. That we had run cold drinking water in advance… (Interview 5).

Coping was especially highlighted in the stories concerning older people. For example, the national media reported of older people who coped in unsafe conditions with very low indoor temperature and with weak physical skills, who still refused to leave their homes. They shared certain pride of managing on their own and readiness to bear varying levels of comfort.

Coping with the power cut meant also renegotiating the concepts of privacy. Interviewees reported sleeping in the same room, sleeping with the door open and showering in more inconvenient places (in the barn).

Reflective space

To a large extent we could see a recommencing of 'old', dormant habits. Dormancy here refers to materials, meanings and skills that had once been active, but that had been unused due to new arrangements. Thus, rather than seeking change towards the future, past arrangements were given value.

Reflectivity was prompted through pursuits of carrying out the practice, i.e. 'work' and 'non-work'. Thus the respondents didn't report on conscious reflection of whether they should change the material arrangements of the practice but rather the elements of the practice started to be renegotiated – i.e. notions of autonomy, security and reliance were brought on to the open.

Reflexivity was directed both towards the home and outside home. In other words, the repairing acts were expected from both decentralised and centralised systems of provision. Consequently, the web of practitioners (neighbours, community, energy companies) became more visible.

In terms of convenience and self-reliance, the households found development of hybrid systems important. Reflection of the relation towards the electricity company was prompted on the level of dependence. What I did not find was any explicit intention to change the provision of heat because of the power cuts.

Discussion

In this paper I discuss the plasticity of consuming practices, focusing in particular on the dynamic and 'hard-to-catch' energy use practices. Through a case on indoor heating practices and their disruption during a power cut, I have shown how the practice of heating carries dormant elements of practice that are regenerated and enacted during an instable event.

The exploration of user practices during long power cuts has shown that power cuts serve as limited spaces for reflexivity on the heating practice. Only little evidence that the disturbance in power supply brought about reflexive take on energy use in a more general level was found. Thus, blackouts do not prompt changes in practices in the short run but can cause changes in the long run.

However, I found that blackouts activate unused skills, resources and technologies that are overcome by other elements but have been dormant for one reason or another. Moreover, technical systems have further implications apart from the temporal ordering of human action. One aspect of the cultural rooting of heating systems is that they enable and/or imply social relations.

In this paper domestic space heating is addressed as a deeply ingrained, flexible and routinized behaviour. As the repairing act was found to move temporally backwards rather than forwards, our findings are in line with Chappells et al. (2011) suggestion that the orientation towards the practice is relevant when discussing the change dynamics of the practice.

Our approach suggests interest in the shades of the dominant discussion on sustainable configurations of socio-technical arrangements, namely in the complexity of the space heating practice in terms of co-existence and dormancy of multiple arrangements. Indeed, vulnerability of energy systems is multi-dimensional, not only including technical failure, accidents and errors, but also resource availabilities, constraints, diversity of energy supply and political disruptions.

Distinctive in this research design was that heating was conducted through embedded and localized systems of provision. These systems supply more resilient energy services than non-autonomous systems (see O'Brien & Hope 2010). This opens up further necessary discussions on resilience as an argument supporting development of small-scale renewable energy production and, for instance, community-led energy initiatives. Further longitudinal investigations on the role of disruptions and resilience-building in varying institutional contexts are needed to better understand the change dynamics of energy practices.

Broadly, different social situations such as home buying, moving, and aging, prompt disruptions and offer 'hot spots' for interventions. In this paper I have discussed upon merely one of such event, and suggest further research for new investigations.

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Consumers' perception of photovoltaic systems

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Abstract

So far, studies on the adoption of photovoltaic systems were almost exclusively drawing on survey methods focusing on the common variables used in socio-psychological studies (environmental consciousness, willingness-to-pay, peer-group influence) combined with socio-demographic variables (age, income, education). Other purchase motives, which are more cultural in nature and quantitatively hard to grasp, like e.g. conspicuous consumption or identity expression, have been left aside. Therefore, a comprehensive and open exploration of factors and personal motivations of the decision to purchase a photovoltaic system is still missing. In this study, in order to elicit personal motives relevant for the purchase decision the laddering technique has been applied during problem centered interviews. Two exemplary mental models of the decision to purchase a photovoltaic system are presented as preliminary findings.

Keywords: Photovoltaic; Laddering; Means-End Chains

Introduction

In the face of declining natural resources, anthropogenic climate change, and no least the societal project of the “Energiewende”, the urgency of switching to renewable energy sources is rapidly increasing. Hence, the German government has put a lot of effort into establishing photovoltaic systems among German households thereby mainly relying on the financial incentive of feed-in tariffs. Because of the growing associated costs (see for example Frondel et al., 2010), the feed-in tariff for solar electricity has been more and more called into question resulting in a number of cutbacks of the feed-in tariff, thus reducing financial incentives for the adoption of domestic photovoltaic systems. If the aim is to further spread photovoltaic systems across Germany, ways of raising people’ interest in adopting photovoltaic systems other than addressing financial motives have to be identified. A comprehensive exploration of the decision to purchase a photovoltaic system is necessary in order to fully understand people’s decision making. Then, effective communication strategies can be developed for spreading photovoltaic systems more widely.

Research Objectives

In this paper, two exemplary mental models of the decision to purchase a photovoltaic system based on 17 problem-centered interviews are presented as preliminary findings of this study.

Here, mental models are understood as individual’s cognitive representations of specific concepts and their relationships about a particular domain (e.g. the decision to purchase a photovoltaic system) (Huff, 1990: 15-16). Such concepts can be attitudes, emotions, symbols, actions, goals, values, images, experiences, memories and so on (Christensen & Olson, 2002: 478). Mental models guide people in everyday decisions, help them to make predictions of future developments and conditions and therefore can be regarded as some kind of folk theories (Binder & Schöll, 2010: 3). Since people make decisions on the basis of such mental models, their elicitation can provide explanations for individual behavior.

On the basis of empirically identified mental models, this article addresses the following questions:

- What kinds of motives are significant for the decision to purchase a photovoltaic system?
- How are these motives represented in individual mental models and how are they related to each other?

The theoretical framework of the study is provided by the Means-End Chain Theory. In order to elicit personal motives relevant for the purchase decision, the laddering technique has been applied during the problem-centered interviews.

Current State of Research

Over the last years, a large number of studies has been published on the adoption of solar collectors, these studies almost exclusively draw on quantitative methods (e.g. Jager, 2006; Labay & Kinnear, 1981; Welsch & Kühling, 2009; Haas et al., 1999; Keirstead, 2006; Erge et al., 2001; Faiers & Neame, 2006). The reasons for purchasing a photovoltaic system revealed by these quantitative studies are restricted to the common variables used in socio-psychological studies applying the Theory of Planned Behavior (environmental consciousness, influence of friends and relatives etc.) or to socio-demographic variables, like age, income, education etc. Furthermore, the results of these studies are vague and sometimes inconsistent.

To the author’s knowledge there has never been a comprehensive and thorough qualitative study of factors and personal motives of the decision to purchase a photovoltaic system. Motives, which are more cultural in nature and quantitatively hard to grasp, like social prestige (respectively conspicuous consumption (Veblen, 1899)) or expression of self-identity (Belk, 1988), have so far been left aside.

Theoretical Concept

The Means-End Chain Theory (Gutman, 1997; Gutman, 1982; Olson, 1989; Pieters et al., 1995; Walker & Olson, 1991) captures value related issues influencing a purchase decision. Its basic assumption is that people purchase products because of their ability to satisfy abstract personal values. Thus, people create mental relations between the attributes of a specific product and their personal values (Gutman, 1997: 545).

According to Olson and Reynolds, the attributes of a specific product and the personal values are related as follows (Olson & Reynolds, 2001: 13 f.):

- The first level is composed of concrete attributes (e.g. color, price etc.) as well as abstract attributes (e.g. sustainability, reputation) of a product.
- From these attributes functional consequences (e.g. promising high earnings) and psycho-social consequences (e.g. social prestige) are derived by the consumer on the next level.
- These consequences are again related to instrumental values (e.g. moral) and terminal values (e.g. peace, freedom, sense of belonging) (Rokeach, 1973: 8-10).

Each level (attributes, consequences, values) can be investigated empirically. The appropriate interview technique that is usually applied in connection with the Means-End Chain Theory is the laddering technique.

Methods

By applying the laddering technique (Balderjahn, 1998; Grunert et al., 2001; Grunert & Grunert, 1995; Miles & Rowe, 2004; Reynolds et al., 2001; Reynolds & Gutman, 1988), mental models of the decision to purchase a photovoltaic system were developed based on 17 interviews with owners of photovoltaic systems. The laddering technique was embedded in a problem-centered interview (Witzel, 2000) in order to ensure a comprehensive depiction of the purchase decision. Thus, enabling and inhibiting factors influencing the purchase decision could be adequately investigated (Olson & Reynolds, 2001: 16).

When trying to identify mental models in a qualitative interview, the researcher has to rely on the respondent's verbal statements about his thoughts on a specific issue or subject. However, these verbalizations of cognitive representations may be error-prone in a twofold way: On the one hand, the researcher could misinterpret the respondent's statements; on the other hand, the respondent could be unwilling or unable to provide correct information about his thoughts and their interrelationships. "Communicative validation" (Kvale, 1995: 429; Mayring, 2002: 147) is one way of at least avoiding the problem of misinterpretation and thus of increasing validity. Therefore, the mental models identified during the interviews were discussed with the respondents afterwards.

The problem-centered interviews were analyzed content analytically (Mayring, 2008). Thus, the relevant aspects, which have been revealed by the laddering technique, as well as other important aspects could be isolated in order to compile a mental model of the purchase decision.

Results

With help of the laddering interviews, two typical contrasting mental models of the decision to purchase a photovoltaic system have been identified. One model is mainly ecologically dominated, the other one economically. Two of the 17 interviews have been chosen as examples and are discussed here, since they represent the aforementioned typical mental models particularly well. Figure 1 and 2 show these exemplary mental models.

Within the ecologically dominated mental model depicted in figure 1, several relevant linkages from the product attributes to the costumer's values can be distinguished. The main decision path results in altruistic and ecological values: "protection against climate change", "intergenerational justice", "protecting the environment" as well as "acting effectively and responsibly". Besides this ecological path, there are two other important decision paths leading to the value level: One is resulting in the value of "social recognition", the other one in the value of "being self-sufficient". Compared to the economically dominated mental model depicted in figure 2, figure 1 shows more linkages to the value level as well as a higher diversity of values. The economic model is exclusively dominated by the values of "financial security" and "making economically sound decisions". Here, the photovoltaic system is perceived as a means to realize profit and thereby gaining "financial security". In the ecological model, economic considerations are only of minor importance, resulting in the absence of economic values. However, economic issues are not completely neglected. On the level of functional consequences, the amortization of the photovoltaic system is mentioned (see figure 1, lower right corner) with the comment of the interviewee that she cannot afford to lose too much money by purchasing a photovoltaic system. Gaining money through the feed-in tariff, however, does not play a significant role.

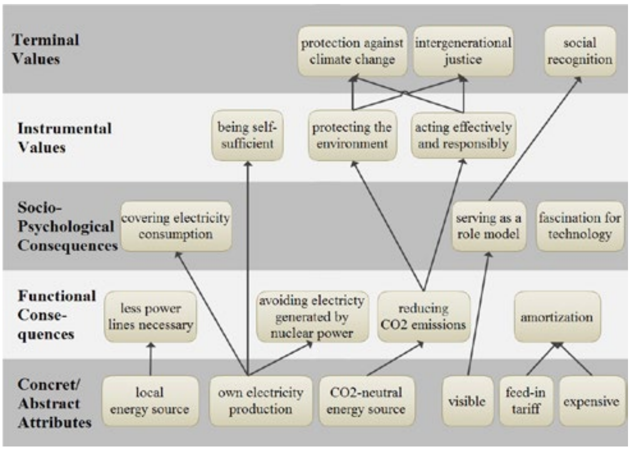

Figure 1: Ecologically dominated mental model.

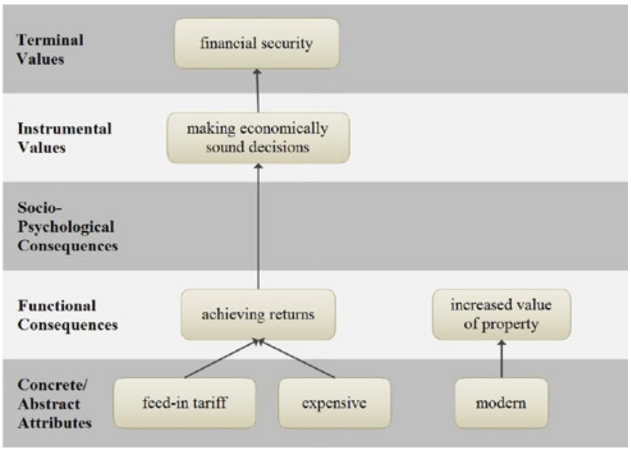

Figure 2: Economically dominated mental model.

Discussion

The results show a complexity of motives that has not been considered adequately in previous studies on the adoption of photovoltaic systems. E.g. there seem to be different paths in which environmental aspects motivate people to purchase photovoltaic systems. Furthermore, environmental consciousness as such may not be a motive but rather its different sub-aspects like "intergenerational justice" or "protection against climate chance". Therefore, it may be pointless to call upon consumers' environmental consciousness, in order to motivate them to purchase a photovoltaic system. It would rather be more fruitful to refer to the complex structure of motivation by emphasizing different aspects of environmental consciousness.

There also seem to be no overarching economic motives but different perceptions of desired consequences of the feed-in tariff. Consumers can perceive them as a means of both ensuring amortization of their investment and gaining profit.

"Social recognition" derived from being a "role model" for sustainable behavior seems to be a particular aspect of the conspicuousness of photovoltaic systems. For such a motive to become relevant, photovoltaic system must be considered as a significant symbol that identifies its owner as being sustainable. However, the symbolic meaning of goods is socially constructed, which points to the cultural formation of purchase decisions.

This study has shown that there are at least two different decision models regarding the adoption of photovoltaic systems. It may be assumed that with decreasing feed-in tariffs, the economically dominated decisions models will become less significant. Therefore, other values have to be activated in order to further spread photovoltaic systems. For examples, motives like "taking an active role in the Energiewende" and "being a responsible citizen" could come to the forefront. Furthermore, with innovation and progress in the field of energy storage technology, photovoltaic systems will provide better and better means for achieving the value of "being self-sufficient". This decision path could therefore also gain importance in the future.

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II. Scientific Papers

Implementation

Designing a Sustainable Model for Financial Viability of Decentralized Bio-fuel based Power Projects

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Abstract

This paper made an attempt to design sustainable model for financial viability of Straight Vegetable Oil (SVO) based power projects for enhancing rural electricity access. For long term sustainability of decentralised power projects in rural areas, viability from both implementing agency and the end-users need to be ensured. The minimum desired electricity price from both these stakeholder' perspective thus have been estimated. While for implementing agency the cost recovery is the key for viability, the affordability to pay is crucial for the end users. Analysis carried out here on the basis of data obtained from operational projects implemented in India reveal that, it is essential to not only operate the system at higher capacity utilization factor, but an integrated approach will also be required for ensuring sustainability of SVO based decentralised project.

Keywords: Off-grid electrification; biofuel

Introduction

India is one of the fastest growing economies in the world. However, the country continues to face huge rural electrification challenge with more than 289 million people without access to electricity. Over the years, a number of programs supported by the Indian government such as *Kutir Jyoti*, Minimum Needs Program and Accelerated Rural Electrification Program attempted to enhance electricity access either as part of overall rural development or specifically targeting rural electrification. In 2001, the Ministry of Power, Government of India declared the objective of 'Power for All by 2012' under the Rural Electricity Supply Technology (REST) Mission and continued it with the launch of the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), in April 2005 to accelerate rural electrification and provide access to electricity to all households. Under RGGVY, grid extension is fully subsidized to all but to the most remote areas. For the 'remote' off-grid locations, the Ministry of New and Renewable Energy (MNRE) has been implementing the Remote Village Electrification (RVE) Program since 2001 and test phase of Village Energy Security Program (VESP) from 2004 respectively. MNRE designed the VESP test phase holistically to provide total energy security at the village level, through locally available resources especially biomass, with full participation and ownership of the community. Further, since early part of 2009, Decentralized Distributed Generation (DDG) scheme under RGGVY has also been launched to cover such remote areas, where grid extension is economically daunting.

India initiated biofuel production nearly a decade ago to reduce its dependence on foreign oil and improve energy security and also launched a National Mission on Biodiesel in 2003. The program was mainly directed towards using the fuel as a transport fuel. While the country is facing the rural electrification challenges, Straight vegetable oils (SVO) or biofuel are also promising candidates for small scale power generation in rural areas. In this context, the VESP attempted to use SVO for power generation in the remote villages (MNRE, 2008), but met with limited success due to low load factor and financial un-viability in spite of high subsidy amount of 90 % of the total project cost (TERI, 2009a). Kumar et al. (2012) also observes that biodiesel development by itself could become a major poverty alleviation programme for the rural poor apart from providing energy security to the country in general and to the rural areas in particular and upgrading the rural non-farming sector. At the same time, they also voice concerns that land availability for bio fuel production may be a major constraint as additional 67 Mha land may be required by 2020 for meeting the food needs only in the country.

Research Objectives

While there are studies on bio-fuel and production and use including their environmental risks and benefits (Achten et al, 2008; Gmunder et al., 2010; Wang et al., 2011, Yusuf et al., 2011), there is almost no recent literature on use of bio-fuel for electricity generation and their financial viability. Very few attempts have also been made to estimate the breakeven price of electricity for SVO based power projects vis-à-vis the consumer's capacity to pay, both for domestic and small commercial load, in rural areas and the optimum operating conditions of a SVO based power project for ensuring project viability. This paper attempts to design a sustainable model for financial viability of SVO based power projects, based on a field study of the SVO projects implemented under VESP (TERI 2009a), for enhancing rural electricity access in India and other developing countries, particularly the Sub-Saharan Africa.

For large scale dissemination of such systems to meet the electricity demand, it is necessary that delivered cost of electricity is within the paying capacity of the consumers. Hence, choice between pricing of electricity from a project implementation agency (PIA) perspective or user's payment capacity requires analysis from the perspective of all key stakeholders:

- The PIA – would like to evaluate the techno-economic viability of SVO system based mini-grids to provide electricity services to rural communities;
- The government – would like to assess the financial burden of subsidies for making electricity available from SVO system affordable as compared to extending the central grid for rural electrification and/or developmental programmes.

- The beneficiary community i.e. consumers – would like the tariff to be within their payment capacity for availing the electricity services.

Methods

In an attempt to address the issues highlighted in previous section, this paper suggests integration of financial sustainability from both PIA's and consumers' perspectives as per following:

- This paper estimates the Minimum Desired Price (MDP) of electricity (Palit et al, 2011) under different operating conditions and thereby the minimum desired price of electricity for ensuring viability or financial sustainability of the SVO systems from a PIA's perspective. The estimation is based on actual field performance data collected from a number of projects implemented under VESP (TERI, 2009b).
- The paper then attempts to see the MDP under a given scenario from a consumer's perspective and attempts viability gap analysis to estimate any gap between actual payment performance prevalent in the projects implemented under VESP and the cost of electricity and viability from a user's perspective.
- Thereafter, the paper attempts possible mechanisms to bridge the gap and suggest breakeven price under different scenarios to develop a sustainable financial model for small capacity SVO systems.
- Finally, the paper suggests an integrated approach for ensuring long term 'sustainable electrification' with SVO systems as an option in the remote rural areas.

Financial Viability from PIA Perspective

From the PIA perspective, a SVO system will be financially viable if the present value of cost (C_{PV}) of the project is less than or at least equal to the present value of benefits accrued to the PIA from the sale of electricity (B_{PV}) over the entire useful lifetime of the project. Mathematically, it can be expressed as:

$$\mathbf{C_{PV} \le B_{PV}} \qquad 1$$

The present value of cost component in equation 1 for a SVO system can be defined as sum present values of capital cost, operation & maintenance (O&M) costs and fuel costs incurred during the entire useful lifetime of the project. Mathematically, it can be expressed as:

$$C_{PV} = C_o + \sum_t \frac{C_{a,t}}{(1+d)^t} + \sum_t \frac{C_{f,t}}{(1+d)^t} \qquad 2$$

Where,

- Capital cost (C0) includes cost of capital equipments in the form of SVO system, housing shed and power distribution network (PDN).
- Annual O&M cost (Ca,t) includes annual operator salary, annual maintenance cost, annual cost of ignition fuel, annual contingency cost interest expenses (if any).
- Annual fuel cost (Cf,t) is calculated by multiplying price of oil seed with annual power generation and specific fuel consumption and
- "d" is the discount rate

The present value of benefits component of equation 1 is essentially of the present value of revenue generated from sale of electricity from SVO system. Mathematically, it can be expressed as:

$$B_{PV} = \sum_t \frac{P_{e,t} \times E_t}{(1+d)^t} \qquad 3$$

Where Pe,t is price of electricity, and Et is the net annual electricity generated SVO system.

The amount of net annual electricity generated from the SVO system depends on rated power of the system (P), CUF and fraction of gross generated power consumed by auxiliaries (a) in SVO system. Mathematically, it can be expressed as:

$$E_t = 8760 \times \text{CUF} \times P \times (1 - a) \qquad 4$$

From equations 3 and 1 it is evident that price of electricity play an important role in determining the financial viability of a SVO system from the PIA perspective. Therefore, using equations 1-4 the MDP of electricity (P_{ed}) of a SVO system (a breakeven condition for financial viability) can be estimated as

$$P_{ed} = \frac{C_o + \sum_t \frac{C_{a,t}}{(1+d)^t} + \sum_t \frac{C_{f,t}}{(1+d)^t}}{\sum_t \frac{E_t}{(1+d)^t}} \qquad 5$$

Input parameters and assumptions

The minimum desired price of electricity has been estimated for various possible cases considering input parameters and information gathered from various SVO systems based field project implemented under VESP.

Capacity Utilization Factor (CUF): During field assessment, it was observed that projects operate at a load of 40–50 % of their rated capacity for 3-5 hours daily to meet lighting requirement. Considering these aspects, a capacity utilization factor of 7% has been considered for estimating the MDP for SVO system without any productive load. For best-case scenario, a 33% CUF has been considered for the analysis.

Useful Life of System: Very little information has been reported in the literature on operating experiences of SVO systems and consequently on the values of parameters such as useful engine, life of distribution network etc. Thus, for the present study, the useful life of a SVO system and distribution network has been considered as 10 years based on discussions with the system suppliers.

Specific Fuel Consumption (SFC): The SFC is taken as 350-ml/kWh as observed during the assessment of the SVO systems. It was also observed during field assessment that SFC significantly varies with load.

Financing: As mentioned in the approach, MDP has been estimated here for both 'with' and 'without subsidy' scenario. For the 'without subsidy' scenario, 70% of the capital expenditure has been considered as long term loan from the financial institutions and remaining has been considered as the community or PIAs contribution towards capital expenditure. In VESP and DDG projects supported under MNRE schemes, 90% subsidy is available. Thus, under the 'with subsidy' scenario it is considered that the community or the PIA contributes the remaining capital. No return on capital employed by the community or PIA is assumed here, because the consumers are themselves owners of the asset and any return on capital employed by them will only increase the MDP. For 'with subsidy' scenario, no interest expense has been considered as the capital expenditure is in the form of PIA's contribution and subsidy.

O&M Cost: Monthly O&M cost of a SVO system is the recurring expenditure incurred over the whole life cycle of project. This includes the operators' salary, preventive and breakdown maintenance cost of the complete system and any other operational cost (except fuel). Based on the field assessment and interactions with the operators and VECs, the following O&M cost has been assumed:

- Monthly operator salary: INR 3000 per month
- Monthly maintenance cost of expeller at INR 300/- for an expeller with a capacity of 30 litres per hour and monthly maintenance cost of engine generator at INR 200/- for a 10 kWe system

Table 1: Values of input parameters.

Particulars	Unit	SVO system
Capacity of engine generator	kWe	10
Capacity of oil expeller	Litres/hour	10
Life of distribution network	Years	30
Average load (of rated capacity)	%	40
Hours of operation per day	hours	4
Distribution line network (average)	Km	2
Specific Fuel Consumption	Litres/kWh	0.35
Auxiliary consumption and technical loss	%	5
System cost (in thousands)	INR	375
Civil Shed (in thousands)	INR	200
Cost of PDN (in thousands)	INR/km	150
Interest rate on loan	%	11.25
Fuel (seed) cost	INR/kg	6.00
Annual O&M cost (1st year)	INR	42000
Annual escalation in O&M	%	5
Annual escalation in fuel cost	%	5
Discount rate	%	12

Note: 1US$ = INR50

Results and Discussion

The financial analysis indicates that the MDP for a 10-kWe SVO system 'without any subsidy' is INR 17.89/kWh at a CUF of 33% (Table 2). Considering a capital subsidy of 90% and 10%contribution by the community or PIA, the MDP for 10-kWe systems is INR 11.31/kWh at a CUF of 33%. However, based on the field assessment of the VESP test projects, it was found that most of the projects operate at a CUF of only 7 % (Palit el al 2011). In such case, with the above mentioned assumptions (with subsidy), the MDP for a 10kWe SVO systems was found to be substantially higher at INR 19.79/kWh making its operation unviable vis-à-vis paying capacity. MDP is estimated for 10kWe SVO system (with 90% subsidy) at different values of CUFs (Table 3). As expected, MDP decreases with increase in CUF.

Table 2: MDP of electricity of SVO system[1].

	Without subsidy	With 90% subsidy
Rated capacity (kWe)	10.00	10.00
MDP (INR/kWh)	17.89	11.31
MDP (INR/kWh)	12.53	10.77

Table 3: Minimum desired price of electricity for SVO system (with 90% subsidy).

CUF	MDP (INR/kWh) for 10 kWe SVO system
7% (Av 40% load)	19.79
13% (Av 40% load)	14.82
20% (Av 80% load)	12.79
25% (Av 80% load)	12.04
33% (Av 80% load)	11.31

Since CUF depends upon hours of operation and average load of the rated capacity, sensitivity analysis of MDP with respect to both the parameters was carried to assess their impact. It is observed from Figure 1 that if load increases from 40 to 50 % at 4 hours of operation the MDP decreases by approximately 11%. However, it decreases by only 7% in case of 10 hours of operation indicating that MDP is more sensitive to percentage connected load of rated capacity at lesser hours of operation. It is also observed from the sensitivity analysis for oil seed pricing that for every 1 Rupee increase in the oil seed price per kg, MDP increases by about INR 1.5/kWh.

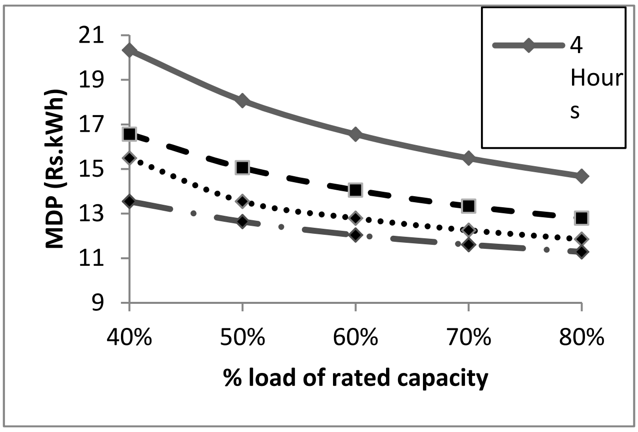

Figure 1: Sensitivity analysis of MDP w.r.t daily hours of operation and percentage load of rated capacity.

[1]Figures are based on 33% CUF; capital cost considered for 'without subsidy' case is based on VESP guidelines.

Viability from a Consumer Perspective

For estimating the viability from consumer's perspective, the average prevalent tariff being paid by consumers as observed from the existing VESP test projects has been considered as the benchmark for computing the tariff under different scenarios. The prevalent tariff being paid by consumers, found during the field assessment ranges between INR 30 – INR 60 per month per household, for 4 hours of electricity daily, depending on the socio economic condition of villages (TERI, 2009b). However, the above analysis indicates that the MDP is much higher than the prevalent tariff. The real challenge is to bring down the price of electricity in line with the rural consumer's payment capacity. It was observed during the assessment of VESP test projects, that lighting load accounts for about 40% of the rated capacity of the system. Thus, one way to enhance the CUF and bring down the cost of generation is introduction of productive load or creating convergence with economic activity based on electricity.

Table 4: Required tariffs at different load for domestic and commercial load.

Scenario (load in kW)	Av Load kW	MDP INR/kWh	Consumption Dom (kWh/month)	Consumption Com (kWh/month)	Required tariff Dom (INR/month)	Income from Oil cakes (INR)	Required tariff (Com) (INR/kWh)
Dom - 3 Com - 5	8	14.67	360	600	50.00	960	15.21

Note: Considering 4 hours of operation; 80% collection efficiency considered for 100 domestic consumers (30 W per household load); Sale price of oilcakes considered @Re 1/kg.

Integrated oil expeller - biogas system

From the above analysis, it is observed that a SVO based project will be economically viable if proposed commercial tariff is set at around INR15/kWh. However, commercial micro-enterprises such as rice hauler/*atta chakki* etc. may be reluctant to pay such high tariff, as it won't reduce their current expenses as compared to diesel. In such case, the viability can be enhanced through an integrated SVO oil expeller-biogas system for projects where domestic load is below 4 kW, which is typical in most cases. In the integrated oil expeller–bio gas system, oil extracted using mechanical oil expeller will be sold at market prices in the market and the residual oil cakes are used as a fuel in biogas digester. Considering de-oiled cake price @ INR 1per kg, gas production of 0.5m^3 per kg de-oiled cake, and power generation of 1 kWh per m^3, unit fuel cost of electricity generation would work out to around INR 3-4/kWh, thus improving economic viability of the project substantially. However, the viability of such system depends on the availability of sufficient quantity of oil seeds in the village for producing enough de-oiled cake to generate gas for the entire village. Further, local and regional level impact of biofuels plantation on food crops and land use also have to be assessed before embarking on large scale implementation of such projects.

Acknowledgement

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A Pricing Strategy for Micro Enterprises in Decentralized Electricity Generation Projects based on Renewable Energy

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Abstract

This paper analyses a Solar-PV based 'Multi Utility Business Centre' (MUBC) which provides electricity for productive applications. The analysis is of three components of this system, the Solar-PV power plant, the MUBC which owns the appliances, and the customers who obtain services from the centre. The objective is to develop a model for how different business activities can be priced, cross-subsidized and what effect the ratio of equity to grant has at various points in the system; for use in the design of sustainable business models for off-grid power.

Keywords: Solar Photovoltaic, LUCE, pricing strategy, decentralized electricity.

Introduction

There are numerous publications closely examining the vital role of electrification for facilitating sustainable development especially in rural areas. They all point out how both human and economic development relies on the access to reliable, affordable and socially acceptable energy services. (DFID, 2002; IEA, 2002).

According to these studies, one problem many previous off-grid electrification projects encountered that ultimately led to their failure is the focus only on technology rather than on the business sustainability of the project as well (Kumar et al., 2009). Other issues often faced in the past are the financial, technical and regulatory obstacles in developing countries that has led to few off-grid projects having been carried out so far (Chaurey et al., 2004). Further, there is limited information available on successful business models for decentralized off-grid electricity projects in the developing countries (Bhattacharyya et al., 2010). This is one reason why project developers and investors are cautious while investing in off-grid RE projects in rural areas.

So far, most projects have focused on providing lighting loads to households and it has been shown that such narrow provisioning leads to a low Capacity Utilization Factor (CUF) of the power plant, making it unviable (Palit et al., 2011). Hence the introduction of productive loads linked to certain livelihood generation activities such as grinding, sewing, fruit processing and so on has been proposed as a solution for increasing the CUF and therefore the economic viability of the plant.

In addition to this, integration of energy and local livelihoods increases community participation in the project and brings a variety of sources of income to the power plant business unit. Rather than directly paying for the unit cost of electricity, consumers instead pay for the services offered by the business unit, such as grinding of wheat in kilograms, or TV viewing on an hourly basis or purified water bought in liters. Hence, the pricing of these services becomes crucial to recovering costs, making a profit, and setting aside funds for operation and maintenance.

This paper aims to develop a pricing strategy for renewable energy powered business units which provide such services, taking into consideration the cost of electricity generation from the Solar Photovoltaic Power Plant (SPVPP) as well as other processing costs. The following sub-sections include: description of the SPVPP and the Multi Utility Business Centre (MUBC) considered for this paper; the key research questions; the methodology employed; followed by results and three key points for discussion.

Description of the Multi Utility Business Centre

Using electricity from a solar power plant, a variety of different appliances and machines are operated, such as water purifiers, grinders, driers, etc. Each machine or appliance forms the technology input for a pre-identified livelihood generation activity or intervention in the area, such as provision of clean drinking water, grinding of wheat, mixing of manure and so on. The business unit charges a certain fee for each service provided. The unit itself is common property of the village, managed and owned by community members and not restricted to any one household. This forms the MUBC used as a model for research in this paper.

Case Study: NFA – project site in Odisha

For the purpose of this paper, a model MUBC installed in Patapolasahi village in the State of Odisha by The Energy and Resources Institute has been used. Surveys were conducted by the authors to estimate user demands, possible technical interventions for productive activities and ability to pay, among other factors, for the implementation of this MUBC. This pricing strategy has been developed for this MUBC in Odisha and is being implemented on site.

Patapolsahi is a hamlet of Kochila Nuagaon village with 35 households and a population of 180. The project is expected to impact a larger group of people, although the operators have been selected from this village. All households except 1 belong to the Munda community (Scheduled Tribe). Agriculture is the primary livelihood (39%) followed by non-agricultural labour (21%) and other regular employment (18%). Those dependent solely on agriculture earn around INR 6000 (USD 110*) per month and those engaged in non-agricultural labour earn as much as 18000-22000 (USD 325 – 400) a month.

*All conversions in this paper: 1 USD = INR 55.

Research Objectives

The key research questions, assuming certain equity to grant ratio for the capital cost of the power plant and other equipment, are as follows:

1. The economics behind livelihood generation activities is complex. How should services from the MUBC be strategically priced to ensure that the MUBC recovers capital cost while ensuring long-term sustainability through savings for O&M and replacements and can also make a profit?

2. Which types of productive activities are most likely to bring in high and sustained profits? As compared to this, which activities need to be initially subsidized? Since many productive activities are new, time, training and market development may be required for them to yield profit. During this period, which other activities can support the MUBC?

3. How does the unit cost of electricity from the power plant impact the service charge of each activity? How high or low is this service charge and how does it impact the economics of the project as a whole?

Methods

The project considered here is divided into three functional units. The first unit is the decentralized solar photovoltaic power plant (SPVPP), which has been installed with a significant grant component and a minor equity component. The second is the Multi Utility Business Centre (MUBC), which has both the grant and equity component in fair proportions. The SPVPP comprises of solar panels, power electronic equipment and construction and the MUBC of machines and appliances. The grant equity ratio for the case study is given in table 1 below.

Table 1: Grant to equity ratio in case of the SPVPP & MUBC.

	Units	Share of Grant/ Funding	Share of Equity	Total
SPVPP Unit	%	95.70%	4.30%	100%
	INR (USD)	2180179.98 (39639)	97960.02 (1781)	2278140 (41420)
MUBC Unit	%	36.55%	63.45%	100%
	INR (USD)	144007 (2618)	249993 (4545)	394000 (7163)

In the first functional unit of the SPVPP, the Levelised Unit Cost of Electricity (LUCE) has been calculated based on the equity component, since this is the only component which needs to be recovered by the implementer. The implementer in this pilot case is the partner NGO with contributions from the community, who therefore hold the equity. However, in other cases the equity may be contributed by a private developer or a group of entrepreneurs from the villages. It is also assumed that, at this time, large subsidies are required for setting up solar power plants and this component has been excluded from calculations. The LUCE has been calculated from the annualized equity cost which was calculated using the formula for capital recovery factor and lifetime of project and discount rate. To arrive at the final value of LUCE, the analysis has considered outflows of annualized capital cost, operation and maintenance (O&M) of SPVPP and battery-inverter replacement costs. For the cash inflows, the 8 kWp plant produces 30 kilo-Watt-hours per day for 350 days of the year and the price of electricity sold per unit is INR 7 (USD 0.127). These figures have been arrived at from data collection from the installed power plant and from the current grid electricity rate which is INR 7(USD 0.127). A sensitivity analysis is conducted for LUCE versus grant to equity ratio to determine the effects of the ratio on the LUCE and at what ratio the LUCE is equal to the current market price of grid electricity.

For the second functional unit of the MUBC, the calculations lead us to the price per unit charged for each service provided. The components taken into consideration for calculating this service charge include annualized appliance capital cost, cost for units of electricity consumed for each service (on a per kilogram, hour or liter basis), appliance O&M including operator salary, logistics, inflation, taxes and profit margins. Overall management of the services is carried out by a committee comprising of members from the SHGs, partner NGO and local governing bodies, which meets regularly to take critical decisions, therefore excluding the need to hire managers, restricting the employees to operators with specific skills and reducing costs. The percentage or money value of each of these components has been derived from the field survey conducted in 2012 in the same site and inputs from subject experts. Table 2 and 3 provides a break up of costs and their respective quantities. The service charge is either on kilogram, litre or hourly basis depending on which service is being considered. This service charge is capped by an upper limit of the Ability To Pay (ATP) of customers, which depends either on prevailing market rates for the same service in nearby towns or on findings from the survey of potential customers.

In some cases it might be found that the service price obtained is lower than the ATP, in which case it is proposed that the same service charge be levied initially to attract customers, with future plans for increasing it to the ATP. In case the service charge is higher than the ATP, the service charge is brought down to ATP levels. The third functional unit is generally members of the local Self-Help Groups (SHGs), Farmer's Associations or individuals, who are customers to the MUBC. The customers either directly use the service (TV-DVD, Water) or take the final product to the market to sell at a sale price that includes raw material cost, service charge from the MUBC, logistics, inflation, taxes and profit margins as per the requirement of the business and activity. This is capped by the upper limit of prevailing market rates of such products. This sale price is directly affected by the service charge from the MUBC which is further affected by the LUCE from the SPVPP.

Results

Solar Photovoltaic Plant

As seen in Figure 1 the total equity contribution towards the power plant in this case has been about 4.3%. At this percentage, the LUCE for the power plant is found to be INR 3.4 (USD 0.06) per unit, below the current market rate of electricity. In order for the LUCE from the power plant to be at least similar to if not greater than the current market rate of electricity, it is essential that the equity percentage at least be increased to around 21%. This is one of the key reasons why private developers are still unwilling to participate in the off-grid market, where the contribution from the community is very low and in this case, only 4.3%. In addition to this, if the community is unable to pay the high cost of solar electricity, the developer must reduce his price to equal grid tariffs and this negatively impacts his payback period. Lastly, although a 30% subsidy is available in India, the application process is tenuous and the time taken to receive the subsidy amount is uncertain. Hence, a contribution from the community can significantly hasten the installation process.

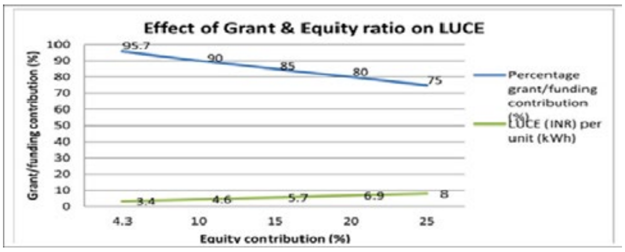

Figure 1: The graph above shows how the LUCE changes with change in the grant to equity ratio.

For the MU Business Centre and customers

Table 2: Details of the MUBC & SHG Customers/Entrepreneur/Third Party Micro-business units for Manure Mixer & Sattu Grinding activities.

MU Business Unit			Customers/Third Party Micro-business units		
	Manure Mixer	*Sattu* Grin-der		Manure Mixer	*Sattu* Grinder
	(INR[USD]/kg)			(INR[USD]/kg)	
Annualize-d Equity for setting up of unit	0.75 [0.013]	0.43 [0.007]	Raw Material Cost	2 [0.036]	5 [0.09]
Buying cost of Electricity	0.21 [0.004]	0.21 [0.004]	Processi ng Cost	5 [0.09]	2.5 [0.045]
O&M cost	0.5 [0.09]	0.5 0.09]	Logistic s Cost	1 [0.018]	1 [0.018]
Logistics Cost	1 [0.018]	1 [0.018]	Inflation	8%	8%
Value Apprecia-tion of service	5%	5%	Business Risk	5%	5%
Risk	10%	10%	% profit	25%	25%
Inflation	8%	8%	Taxes	12.50%	12.50%
% of profit	25%	25%	Sale Price	12.71 [0.23]	13.51 [0.24]
Service Tax	7%	7%	Current Market Cost	14 [0.25]	12 [0.21]
Proces-sing Cost	4.04 [0.07]	3.48 [0.06]	Profit/ Loss	1.29 [0.023]	-1.51 [0.02]
ATP	5 [0.09]	2.5 [0.045]	Final Sale Price	14 [0.25]	12 [0.21]
Profit/ Loss	0.96 [0.017]	-0.98 [0.017]			
Final Service/ Proces-sing Cost	5 [0.09]	2.5 [0.045]			

At the MUBC, four different activities have been taken up for evaluation. Of these, two activities, the manure mixer and the *sattu* (ground wheat, lentils, almonds and sugar used as a supplement food in government funded school mid-day meal programmes) grinder have been evaluated for all three stakeholders, the power plant, the MUBC and the customers. This is because the customers (who are Farmer's Association or SHG members) use the services of the business centre to process their raw materials and then sell the finished product. Water purification and TV-DVD are however businesses managed by the MUBC itself. The customers include anyone in the village who wants to obtain these services and there is no subsequent transaction to markets outside the village.

Table 2 depicts the calculations for the manure mixer unit. Since the final processing cost (INR 4.04)/[USD 0.07] is lower than the ATP (INR 5.0)/ [USD 0.09], it is decided to retain the processing cost at the same level. Calculations done for the customer's final selling price show that since the price (INR 12.75)/[USD 0.23] is below prevailing market rates (INR 14.0), this is a profitable business. Table 2 depicts calculations for the *sattu* grinder. Here, the final processing cost is higher than the ATP and hence the processing charge is brought down to INR 2.5[USD 0.045], equal to the ATP. It can be seen that even with such a low charge, the business is not profitable for the customer as the market rate for the finished good is INR 12[USD 0.21] per kilogram whereas the production cost is INR 13.51[USD 0.245]. The customer in this case might be forced to cut down on profits or may ask the SMU business centre to further lower their rates.

Table 3 depicts the calculations for the TV-DVD where it is assumed that 15 people come to watch TV at a time. Calculations are done on a per hour basis and from the user survey it is found that customers are willing to pay up to INR 5.56[USD 0.10] per hour based on their current TV rental and travel costs to the nearest town. Since the business centre's own entertainment cost is only INR 2.0[USD 0.036] per hour, the hourly rate is fixed for INR

5[USD 0.09] per hour based on the ATP. Hence this business is a highly profitable one and can be used to cross subsidise other businesses for periods of time. Similarly, for water purification, it was found that the ATP is high (INR 2.0[USD 0.036] per litre) owing to frequent disease from poor quality drinking water. It was found that the service cost per litre of water is around INR 1.66[USD 0.30] per litre and therefore a sale price of INR 2.0[USD 0.036] per litre was fixed. This again is a highly profitable business for the MUBC.

Table 3: Details of MUBC for its clean water supply & TV/DVD entertainment business activities.

MU Business Unit (INR/litre)	Water Purifica-tion[USD]	MU Business Unit (INR/Hour)	TV/DVD Entertain-ment
Annualized Equity for setting up of unit	0.02 [0.0004]	Annualized Equity for setting up of unit	2.35 [0.04]
Buying cost of Electricity	0.03 [0.0005]	Buying cost of Electricity	1.05 [0.019]
O&M cost	1.00 [0.018]	O&M cost	10.00[0.18]
Logistics Cost	0.00	Logistics Cost	5.00 [0.09]
Value Appreciation of service	5%	Value Appreciation of service	10%
Business Risk	5%	Business Risk	5%
Inflation	8%	Inflation	8%
% of profit	25%	% of profit	25%
Service Tax	7%	Service Tax	7%
Service Delivery Cost	1.66 [0.030]	Entertainment cost per person, assuming 15 person at one time	2.00 [0.036]
Reference: ATP	2.00 [0.036]	ATP	5.56 [0.10]
Profit/Loss	0.34 [0.006]	Profit/Loss	3.55 [0.06]
Sale Price	2.00 [0.036]	Final Entertainment Cost per person	5.00 [0.9]

In addition to the above, the effect of change in LUCE on the production cost of different services was determined as depicted for the manure mixer in table 4 below.

Table 4: Effect of change in LUCE on the costs at levels of the business model for the manure mixer activity

LUCE (INR[USD]/kWh)	Buying cost of electricity. (INR[USD]/kg)	Total production cost (INR[USD]/kg)
7[0.127]	0.21[0.003]	4.04[0.07]
10[0.18]	0.3 [0.005]	4.19[0.07]
15[0.27]	0.45[0.008]	4.44[0.08]
20[0.36]	0.6[0.01]	4.68[0.08]

Discussions

The above analysis has been used to arrive at prices for services and the impact of the LUCE on these prices in an attempt to develop a sustainable business model for the MUBC. It is observed that with the inclusion of productive loads, in addition to lighting, efforts need to be put into building markets and constantly gauging the performance of finished products from use of productive loads. Even if one product is less profitable in the beginning, it can be cross-subsidised with other products or high profit yielding activities such as TV-DVD or water purification. The price per service can be gradually increased once greater demand has been built for the product over time.

Secondly, in addition to the need for strong market linkages, the output from productive loads is highly dependent on the season. Activities should be planned such that there are one or two activities involving productive loads throughout the year depending on season. When no such planning is possible, other activities such as TV-DVD or water purification can ensure sustained income for the business.

And thirdly, the effect of the LUCE on the final processing cost as shown in Table 4 is quite small compared to the total cost of the product due to the large number of other factors that come into play. Hence, as per the results of this paper, SPVPP operators can charge a higher rate for electricity to recover their costs faster or invest more capital (percentage equity) and keep tariffs above existing market tariffs. Since as per the model discussed in this paper the consumers are not paying for electricity on a per unit basis, but rather for services, concerns that high costs of solar power electricity in rural areas will deter customers can be addressed through such a pricing mechanism and model, rather than direct sale of electricity.

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Standardization of photovoltaic mini-grids for electrification of isolated communities in Amazonas-Brazil

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Abstract

Modular standard PV mini-grids are presented as an efficient way for energy concessionaries and project developers to determine the basic configuration of PV mini-grids, estimate implementation costs, O&M costs, and LCOE. Eight standard PV mini-grid configurations are designed to attend isolated rural communities located in the Brazilian Amazonia ranging from 10 to 50 consumer units, consumption from 30 to 100 kWh/day and power demand from 3 to 10 kW. Results show that modular standards have a maximum deviation of 5% in costs and size in comparison to custom design.

Keywords: PV mini-grids, solar energy, rural electrification, standardization.

Introduction

Electrification of rural households in Amazonas-Brazil has been successfully carried out by the *Programa Luz para Todos* (*in english,* Light for All Program) of the Ministry of Mines and Energy[1]. It has been an enterprise of admirable dimensions that has already served more than 2 million households[2].

In the Amazonia region, difficulties sum up due to great land dimensions, low demographic density, spread out communities, dense hydrographic layout, numerous flooded areas and compact rainforest. Locations that cannot be reached by the power grid and that represent more than half of the territory of the State of Amazonas[3], will have to be electrified with isolated generation systems, in which environmental issues require that the primary energy source be 100% renewable. PV mini-grids are the leading option for electrifying this region due to abundant year-round solar irradiance and since other energy resources such as biomass or hydropower have not yet been estimated.

Amazonas Energia Eletrobras, the Brazilian Power utility company for the region, has the goal to electrify 3000 isolated communities by the end of 2012. Unfortunately, the company has limited resources (qualified personnel) and finds rather difficult to estimate the budget of the project for the bidding process that will be held with several private companies. To estimate the budget, a rough design of the mini-grids must be made according to energy and power demand of the communities. Previous socio-economic studies in the region have shown that Amazonian communities have similar energy consumption patterns and have 10 to 30 Consumer units[4], energy consumption 30 to 100 kWh/day and installed peak power 3 to 10 kW. (Di Lascio, 2009). A typical PV mini-grid installed in the Amazonian by the *Luz para Todos* program in 2011 is shown in Figure 1. (Guascor Solar do Brasil, 2011)

Figure 1: PV mini-grid in Amazonia. 9.6kWp for 19 Consumer Units.

Research Objectives

The following research has been carried out to develop standard PV mini-grids that can be used to rapidly determine a referential design of mini-grid. The main objectives are:

- Size the modular basic unit. Quantities, power and other characteristics of PV panels, inverter/grid managers, charge controllers and batteries that form the Basic Modular Unit.
- Determine the number of combinations needed of the Basic Modular Unit that can fully supply the range of communities present in the Amazonas.
- Economic analysis to compare standardized mini-grids with custom designed mini-grids (one by one design).
- Estimate cost structure of the mini-grids (Io, O&M and LCOE) according to the number of consumer units and therefore have an estimate budget cost for massive electrification in the region.

[1] Visit the official website of the program at: *http://luzparatodos.mme.gov.br*

[2] This research work is part of the author's Master Thesis of the Postgraduate Program Renewable Energy at the University of Oldenburg in Germany, and was performed entirely in Manaus, Brazil with the collaboration of the German Technical Cooperation GIZ and the Brazilian Power Utility Company *Eletrobras Amazonas Energia* in 2011-2012.

[3] The State of Amazonas is the largest Brazilian State with a total area of 1.577.820,2 km².

[4] CU – Consumer Units, is the gathering of several electric appliances which common characteristic is they receive energy from a unique point, with individualized energy metering and corresponding to only one consumer. Consumer units can be a house, school, community center, church, etc.

Methods

Standardized design is an approach that subdivides a system into smaller parts (modules) that can be independently created and then used in different combinations to drive multiple functionalities. Regarding PV mini-grids, besides reduction in cost due to lesser customization, and flexibility in design, modularity offers other benefits such as augmentation (adding new solution by merely plugging in a new module). A downside to modularity (and this depends on the extent of modularity) is that modular systems are not optimized for performance. This is usually due to the costs created of over sizing the systems to fit a majority of users (Wollny, 2006). The 4-step process used to determine size and number of standards is briefly shown in Figure 2.

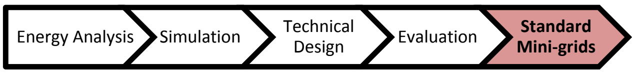

Figure 2: PV mini-grid standardization process.

The first step, *energy analysis*, will analyze power and energy consumption for each type of consumer unit (see Table 1) and also for the whole community. Standardization requires identifying groups (bins) of users that have similar characteristics (consumer units, energy and power demand). Energy binning is a statistical method that will be used to find if a relation exists between energy/power and number of consumer units. (Carvajal, 2012), (Cramer, 2008)

Table 1: Energy and Power characteristics of community buildings (obtained from fieldwork by Amazonas Energia).

Consumer Unit[5]	**Installed Peak Power Wp**	**Daily Energy Demand kWh/day**
Household	117	1.17
School	500	2.00
Community center	300	3.45
Church	150	0.45
Health post	200	2.56
Radio post	100	0.45
Monitoring system	100	2.40
Community pump	90	0.54

Appliances and equipment usually present in the communities are: illumination (CFL), communication (small TV, small Radio and antenna) and refrigeration. Visits to communities in the region have shown that typical households have an installed peak power 110 to 120W and energy consumption of 1000 to 1300Wh/day (Eletrobras Amazonas Energia, 2011). Real-time power measurements have shown that there is no significant difference between weekdays and weekends since industrial and commercial activity is low or inexistent. Load curves will vary according to the size of the community and the type and amount of consumer units (see Figure 5).

Solar resource is also evaluated in this step according to measurements taken in nearby communities. See Figure 3.

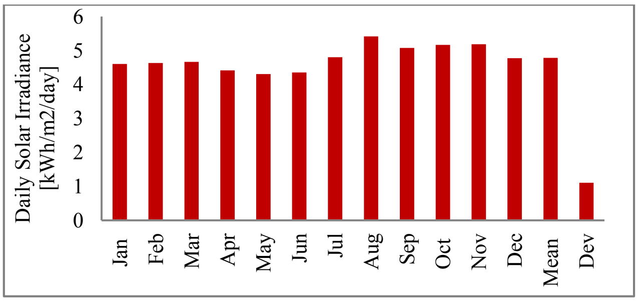

Figure 3: Mean Solar Irradiance in Amazonia.

The second step, *simulation*, will size the components (PV panels, battery bank, charge controllers and inverters) for the defined groups from the previous step. The hybrid optimization simulation software HOMER v2.86 will be used to model and simulate the standards. The input conditions for the simulation can be seen in Table 2. The PV system is divided into three *block groups* that will be standardized, as seen in Figure 4.

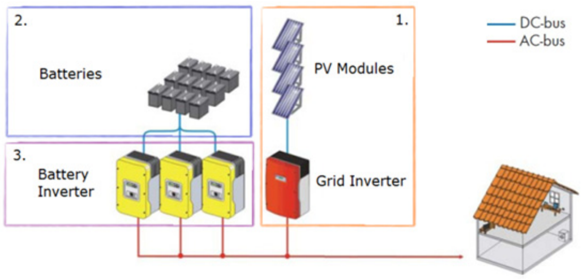

Figure 4: Blocks to be standardized for the Mini-Grid.

The third step, *technical design*, consists in defining the minimum technical characteristics that each component must have according to the component´s availability in the market. For this several manufactures have been consulted. The forth step, *evaluation*, consists in comparing the standard design with custom ones and also performing the cost analysis to determine Initial investment (Io), (O&M) and LCOE[6]. (see Eq.1). The standardized mini-grids will be sized according to the number of consumer units – CU's, energy consumption, power demand and solar resource and also with reference to 71 isolated communities from which information is available at the energy concessionary Amazonas Energia Electrobras and that have already been electrified with PV mini-grids.

[5] Average power and consumption for typical buildings in an Amazonian community. Values vary depending on distance from urban centers, socio-economic level, life quality and other habits.

[6] The cost effectiveness of PV systems and other ENERGY options should be compared in terms of their life-cycle costs of energy in money per kilowatt hour ($ per kWh). The Levelized Cost of Energy LCOE is calculated in present-value terms, discounting both the costs and benefits (kWh) over the typical 20 to 25 years used in appraisals of PV investments. It considers a discount rate *i* (~6%) and Degradation Rate *DR* (~98%). See Eq.1. (Lazard, 2008)

Table 2: Simulation Parameters for HOMER v2.86.

Parameter	Value/Characteristic
Batteries	
Battery Type:	Vented lead-acid, tubular-plate. OPzS
Nominal capacity	600 Ah (1.2kWh)[7]
Nominal voltage	2V
Minimum state of charge[8]	60%
Batteries per string	24 (48V Bus)
Minimum battery life	7 years
Autonomy days	2 days
PV modules	
Solar panel	Steps of 1000W
Lifetime:	20 years
Derating factor[9]	80%
Slope:	4.8º
Azimuth (W of S)	180º
Ground reflectance	20%
Temp. coef. of power	-0.4%/C
NOCT	47ºC
Efficiency at STC	13%
Inverters and Charge Controllers	
Controller/Inverter type	Steps of 1kW
Lifetime	10 years
Efficiency	95%
Controller capacity relative to inverter	100%
Controller efficiency	85%
Maximum Annual Capacity Shortage[10]	15%

$$LCOE = \frac{Io + \sum_{n=1}^{N} \frac{O\&M}{(1+i)^n}}{\sum_{n=1}^{N} \frac{Energy \times (1 - System\ DR)^n}{(1+DR)^n}} \qquad \textbf{Eq. 1}$$

Results

The energy analysis results and the experiences in the region show that power peak is at nighttime between 18:00 and 22:00. It is also interesting to see that the base load is quite small in comparison to the peaks, since people leave home and do not leave any appliances on during the day. (Figure 5)

Eight groups of communities have been established for which a mean power and energy consumption value have been specified. For these groups, the simulation was performed to size PV Power, Battery Capacity and Inverter Power. (See first and second column of Table 3)

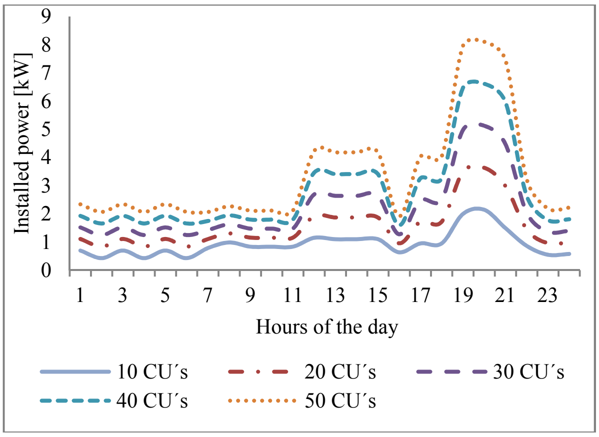

Figure 5: Load curves for communities in the Amazonia.

Table 3: Standards needed and simulation results.

Community characteristics				Simulation results			Standard mini-grids	
Group No.	#CU	Energy Demand kWh/day	Power peak kW	PV Power kW	Battery Capacity kWh	Inverter Power kW	# Type I	# Type II
1	10-15	30	2.9	9.7	144	3	3	
2	16-20	37	3.6	12.1	192	4	4	
3	21-25	45	4.4	14.4	240	5	5	
4	26-30	52	5.1	17.2	288	6	6	
5	31-35	59	5.9	20	336	7		4
6	36-40	67	6.6	22	384	8		5
7	41-45	74	7.4	24.3	432	9		6
8	46-50	82	8.1	27.4	480	10		7

Two *Basic Modular Units* have been determined: Type I and Type II (see Table 4). With the combination of the Basic Modular Units, the 8 groups of communities can be supplied. Table 3 also presents the quantities of Modular Units Type I or II needed.

Table 4: Basic Modular Unit sizing by blocks.

		PV Power	Battery Capacity	Inverter Power/Grid manager
Standard Basic Modular Unit	Type I 10 to 30 Consumer Units	3kW	48kWh	2kW
	Type II 31 to 50 Consumer Units	5kW	96kWh	4kW

[7] This small battery size was considered to have small steps during the simulation. Later on this was altered to run a simulation with the definitive battery model and type.

[8] A low DOD (depth of discharge) is required to extend battery life to the maximum. Battery manufacturer Hoppecke offers a 1500 cycle battery life at 80% DOD. Considering only one cycle per day this would be approx. 4 years.

[9] A factor that accounts for losses due to temperature effects, dirt, etc.

[10] The maximum allowable value of the annual capacity shortage, as a percent of total annual load.

The LCOE has been calculated using Eq. 1 and has been plotted dependent to Number of Consumer Units. This can be seen in Figure 6 for riverside and dry land communities. Generation cost with Diesel is around 0.48 to 0.69€/kWh, without installation and O&M costs and usually these operate only 3 to 4 hours a day. Cost breakdown structure is shown in Figure 7 and 8 where it is important to notice the impact that transportation and civil works have.

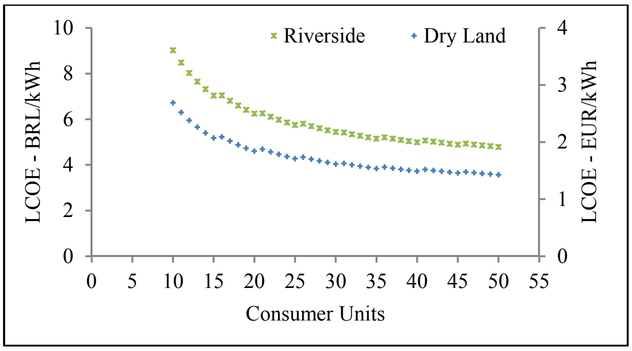

Figure 6: Levelized cost of energy for PV mini-grids in Amazonas[11].

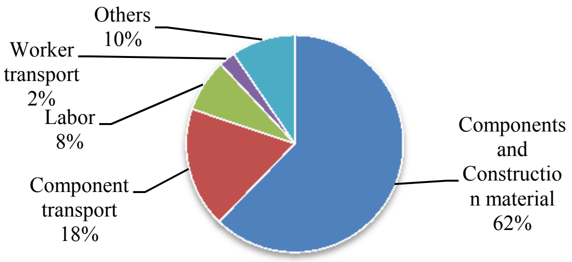

Figure 7: LCOE cost break down.

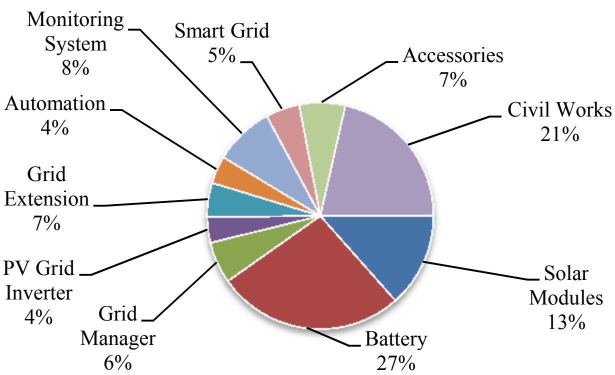

Figure 8: Mini-grid Implementation cost break down.

Discussion

Standardization saves time since it allows rapidly designing, installing and later expanding the mini-grid. But standardization tends to over dimensioning and an over budget is created that has to be covered finally by the energy concessionary. The company must decide if standardizing is worth it, depending on project deadlines and even political interests.

Most standardized systems have an average deviation of 4 to 5% in comparison to customized system. The small deviation is because the components available in the market already come in standardize sizes, so at the end customized systems are standardized to the components they are made of.

PV generation costs almost double generation cost with Diesel, nevertheless from an economical point of view, PV systems are better, since they have a broader lifespan and also deliver 24hour energy supply.

Once basic needs are satisfied, the connection of other appliances will likely be considered, such as: ventilation, mixers, computers, etc. It is still a discussion at concessionaries if isolated communities should be able to satisfy absolutely all energy needs (as people in urban centers do) or if there should be a limit to the energy they receive from the state due to the location of their homes.

PV mini-grids are considered the best option for electrification of remote communities in Amazonia. Nevertheless, designing 100% PV systems to match all year demand is not the most efficient way to go. Considering high radiation values in the region, the mini-grids are likely to be over-sized and have significant energy surplus during most parts of the year. A hybrid system (PV+Diesel) to cover the energy shortage during low radiation seasons could help to reduce the size of PV components specially the battery bank, which is the most sensitive component and has high pollution potential.

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[11] The Real is present-day currency of Brazil. Its sign is R$ and its ISO code is BRL. The exchange rate used for this study was. 1.00 EUR to 2.52 BRL. (October 2011)

Product-Service System Design Approach for the Base of the Pyramid Markets: Practical Evidence from the Energy Sector in the Brazilian Context.

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Abstract

In Emerging Markets, the product-service system (PSS) design approach may represent a promising solution as a socially and environmentally sound path to economic development. In addition, the energy sector has a major role for the social-economic development and is central to poverty alleviation. Therefore, this study aims to analyse the challenges of increasing the well-being of the low-income population by means of proposing functional systems of products and services for the energy sector with an emphasis on achieving more sustainable results. The research adopts an exploratory approach, it is qualitative in nature and it is composed of two main stages; a literature review and literature based analysis of case studies. As a result, this research outlines the potentials of designing product-services systems for BoP Markets.

Keywords: Product-Service System; Base of the Pyramid; Emerging Markets, Energy Sector.

Introduction

The Base of the Social and Economic Pyramid (BoP) market consists of over four billion people who live on less than $2-8 per day (Hammond et al., 2007). The importance of the BoP Market increases since billions of these customers are joining the market economy in the nearby future. For instance, Brazil has a population over 190 million people, of which in 2011, the low-income class represented 24%. The average available income of the urban low-income Brazilian population has grown by almost 50% in the period between 2005 and 2011 (Cetebem BNG, 2012).

A major challenge regarding the BoP Market is to support customers to improve their lives by providing access to products and services in culturally sensitive, environmentally sustainable, and economically profitable ways (Hart & Prahalad, 2002). Addressing this challenge means to design new solutions that could be a driver for market transformation towards a more sustainable society by means of both clean technological solutions and changes in habits and lifestyle, favouring the efficient and rational use of natural resources.

However, the BoP Market presents a unique challenge that requires a revaluation of traditional business models. In view of its features, the product-service system (PSS) design approach can potentially be an answer for these BoP Markets. The PSS concept consists of a system of products, services, supporting networks and infrastructure, closely involving final consumers and stakeholders in the value chain and beyond. The PSS solution is designed to be competitive, to satisfy customer needs and to have a lower environmental impact than traditional business models. Finally, the PSS design approach is potentially capable of stimulating the necessary changes in current production and consumption patterns (Mont, 2002). In Emerging Markets, the PSS design approach may represent a promising solution as a socially and environmentally sound path to economic development (UNEP, 2001).

One of the paths towards improving the conditions of BoP customers refers to access to moderns sources of energy (Pereira et al., 2011). The BoP household energy is a market opportunity equalling a value of $228 billion. Nevertheless, these customers lack access to modern, clean and affordable sources of energy, resulting in pollution, health problems, higher electricity costs and inefficient energy-using devices (Hammond et al., 2007). For instance, the BoP energy market could benefit of sustainable PSSs such as pay-per-use systems, solar photovoltaic off-grid solutions for remote areas and combinations of products and services to support income generation capacity.

In this context, the major objective of this study is to gather and analyse data about sustainable PSS solutions in order to understand the challenges and potentials of applying a PSS design approach in the BoP energy market. Evidence from existing case studies is used to underline these challenges and potentials. Finally, drawing upon these analyses, we discuss possible contributions of the PSS design approach to provide energy solutions for the BoP Markets.

Research Objectives

This research aims to identify, summarize and discuss the current literature on energy related PSS for the BoP energy market. The scope of the study and focal points to be discussed are the challenges and potentialities of designing for the BoP Market that can address the characteristics, strategies and business models articulated in the PSS design approach. Accordingly, the study deals with the following research questions:

1. What are typical examples of PSS for the BoP Market in the energy sector?
2. What are the challenges of designing sustainable PSS for the BoP Market in the energy sector?
3. How can PSS guidelines address the challenges of designing sustainable combinations of products and services for the BoP Market in the energy sector?

The research adopts an exploratory approach, qualitative in nature and was developed by means of a broad literature review and literature based case analysis.

Methods

Within the research strategy a protocol was initially developed to define the objectives, databases, keywords, and inclusion and exclusion of search criteria for the study. In addition, international reports were consulted, such as those published by the World Resources Institute, the World Bank and the United Nations Environmental Programme. Both these approaches were used to identify relevant example cases of PSS solutions for the BoP market. These examples were selected using the following criteria:

1. Examples must address real problems, be implemented, or at least be in a pilot stage;
2. Examples must provide a combination of products and services for the BoP Market in the energy sector;
3. Examples must strive towards generating lower environmental impact, economic benefits, and increase the well-being of the population compared to previous or current reference situations.

The following eight examples were selected:

1. Programme ECOELCE: Exchanging recyclable waste for discount in the energy bill (Brazil).
2. Programme COELBA: Energy efficiency in low-income communities of Bahia (Brazil).
3. Programme COPEL: Energy efficiency in low-income communities of Parana (Brazil).
4. Programme PRODEEM: Solar photovoltaic (PV) systems in off-grid rural areas (Brazil).
5. Project PAMENU: Access to modern sources of energy (Uganda).
6. Project IndiGo: Pay-As-You-Go solar system (PV) (Sudan).
7. Project TEMASOL: Energy access to remote rural households (Morocco).
8. Project SELCO: Solar lighting for the poor (India).

In our study, these eight cases were analysed. In this publication the comparison between the data gathered from examples 1 and 2 are presented. Further general conclusions were drawn on the basis of all eight cases. However, as a result to the limitations of this paper the main focus of this publication is the discussion of challenges of the analysed PSS.

Designing for the Base of the Pyramid Markets

The BoP Market presents a unique challenge that requires new business models and innovation approaches. In order to address these markets, new integral design methodologies, tools and courses have to be developed, which bring together user context research, business development, sustainability and new technological innovations (Diehl, 2009). Thus, the efficiency of products, services and processes would need to be improved, resulting in the development of completely new products and services, and entirely new functional systems of products and services (Castillo et al., 2012). According to Mont (2002) such system-based solutions should facilitate a shift from current offers to a system designed to provide a certain quality of life to the customer and, at the same time, minimise environmental impacts of the system.

In accordance with Castillo et al. (2012), the design requirements for the BoP Markets can be defined and addressed by taking into consideration four interrelated clusters: Desirability, Feasibility, Viability and Sustainability. This means that a PSS design approach for the BoP Market is based on a deep understanding of the socio-cultural context to satisfy the user's needs – Desirability; explores technological requirements through design in order to transform promising ideas into concrete and adequate solutions – Feasibility; defines a reliable financial model – Viability; and finally, improves the environmental and social impacts that a solution entails – Sustainability.

The challenges of the Base of the Pyramid Energy Markets in the Brazilian Context

In order to achieve higher standards of social and economic development developing and emerging countries need to increase their energy consumption in comparison to industrialized nations (Geller et al., 2004). For instance, in Brazil the total energy consumption increased by nearly 240% between 1980 and 2011 (MME, 2012).

According to some authors, the major challenges regarding the BoP energy market are policies to advance energy access, energy efficiency and renewable energy use (Bazilian et al., 2012; Geller et al., 2004; Pereira et al., 2011). The public sector alone is unable to provide solutions in energy provision for low-income households. As a result private companies, in collaboration with other stakeholders such as NGO, communities facilitators and government, play an important role (Gradl & Knobloch, 2011), such as presented in the case studies in the next section.

Results

The Programme ECOELCE: Exchanging waste for discount in the energy bills.

The Programme ECOELCE aims to provide discounts in the energy bill of COPEL (Companhia Paranaense de Energia) customers, mostly of them low-income, in exchange for solid waste with market value. The ECOELCE pilot project was launched in 2006 for low-income communities in the city of Fortaleza (Brazil), and in 2007 was officially available for all COELCE customers (Lima et al., 2009). Nowadays, it is present throughout the State of Ceará (Brazil), and has 64 collection posts (38 fixed and 26 mobile posts) across 27 cities, serving about 90 communities. The programme involves 42 partners among recyclers, associations, government agencies and private companies (COELCE, 2012).

Results of the Programme ECOELCE

Economic Impact: The main economic impact of the programme is the decrease of illegal connections and non-paying legally connected customers. The customers, particularly those in low-income communities, benefit from discounts in their energy bill. In some cases, the customer achieves a reduction of over 90% or even the total liquidity of the energy bill. The average energy bill of a low-income customer in Brazil is around $15 per month. After five years, the programme provided more than $800,000 discounts in energy bills. Additionally, 57% of the defaulters customers participated in the first year of the programme, resulting in a reduction of debts with COELCE and illegal connections (Lima et al., 2009).

Social and Environmental Impact: The programme resulted in an energy economy of 11,684.87 MWh[1] per year, which is related to the yearly amount of recycled material collected (COELCE, 2012). The programme reached about 405 thousand registered customers and collected 12,700 tons of recyclable residues. The communities served by the programme had an increase in living conditions through the reduction in the volume of solid residues improperly disposal on urban environment.

The Programme COELBA

The Programme COELBA is an energy efficiency initiative for low-income communities created in 1999 and carried out by the NGO CDM (Cooperação para o Desenvolvimento e Morada Humana) in the city of Salvador (Brazil). The programme was coordinated and financed by COELBA (Companhia de Eletricidade do Estada da Bahia). The project aims to provide assistance to low-income households by guiding customers with safe and efficient use of electricity.

Results of the Programme COELBA

Social Impact: As a result of the Programme COELBA more than 100 communities benefited, around $22 million were invested and 1.5 million low-income customers were served. At the beginning, the project had six facilitators who supported five communities. In 2010, there were 102 facilitators providing service to 67 communities in the metropolitan area of Salvador and in other cities of the State of Bahia. Besides facilitating the lives of consumers and strengthening the relationship with the community, COELBA proposes to collaborate with the inclusion of low-income youth in the labour market (COELBA, 2012). The project and the related energy efficiency components generated employment to 200 people (AVSI Foundation, 2010).

Economic and Environmental Impact: The energy efficiency initiatives involved the replacement of old appliances, primarily lamps, light bulbs and refrigerators. The Programme Nova Geladeria (Programme New Refrigerator) sold 18 thousand new, high efficiency refrigerators at a fraction of retail costs. In 2008, to allow access to more efficient refrigerators, 100% subsidy was offered to 51 thousand residential consumer units that met the following criteria: the customers had regular electrical connection, they paid their electrical bill in a timely manner and they were registered in the Social Tariff programme. In addition, 525 thousand high efficiency lamps were distributed. A survey applied among the communities targeted by the Programme Nova Geladeira confirmed a reduction of 33% of energy consumption in 2008 compared to the previous year and 46% reduction compared to a projection of consumption without the project intervention.

The Programme ValeLuz COELBA, launched in 2008 and developed parallel to the Programme COELBA, aimed to stimulate the recycling of light bulbs and old appliances. The customers exchange recyclable materials for discount coupons that can be applied towards their energy bills. The materials collected directly benefitted two participating communities that managed to sell solid recyclable waste and old household appliances parts.

[1] Referring to the Programme ECOELCE II (2010-2011).

Discussion

In this publication, we focus on discussing successful interventions in the BoP energy market in order to characterize effective guidelines for applying the PSS design approach. The practical evidence collected represents some of the typical examples of PSS solutions for the BoP energy market in the Northeast of Brazil. Drawing upon the cross analysis of the case studies, the study shows some recurrent challenges (Table 1).

Table 1: Sustainability challenges based on a comparative analysis of PSS case studies.

	Sustainability challenges in BoP energy market
Economic	- Increase access, quality, and affordability of products and services, adjust energy consumption (bills) of low-income consumers to their ability to pay; - Reduce commercial losses from non□paying legally grid-connected customers and the number of illegal connec-tions; - Increase the utilization of Government subsidies (e.g. social tariff); - Support income generation capacity.
Environmental	- Increase access to information in order to improve energy efficiency and conservation at household level; - Promote the use of renewable energy resources.
Social	- Invest in customer relations; - Rely on intermediary stakeholders (e.g. NGO, community facilitators) to reach customers; - Stimulate entrepreneurship and create employment conditions in low-income communities.

Based on the analysis of the challenges regarding the BoP energy markets the following PSS design guidelines were identified as possible answers in the literature consulted (Table 2).

Table 2: PSS guidelines based on Baines et al. (2007), Mont (2002) and Tukker (2004), that could be applied for the BoP energy market.

	PSS Guidelines
Mont (2002)	- Minimise the environmental impacts of the customers' needs; - Promote closed material cycles; - Facilitate innovation beyond the incremental level; - Improve the relationship with the customer and require a higher level of customer involvement.
Tukker (2004)	- Provide integrated and customized solutions; - Build unique relationships with clients; - Support faster innovative approaches; - Create added value throughout the stakeholder value chain. - Fulfil customer needs with minimal material use and emissions.
Baines et. al. (2007)	- Create added value by increasing services elements (value-in-use), customization and quality; - Require manufactures and services providers to extend their involvement and responsibility in the solution life cycle (e.g. maintenance, take-back, recycling, re-use, remanufacture and refurbishment); - Lead to reduced resource use and waste generation; - Promote the involvement with the customer and other stakeholders.

The overall conclusion of this publication leads to the identification of several guidelines in the PSS design approach that may present answers to some of the challenges of the BoP energy markets. The key point behind the successful adoption of PSS in the BoP energy market is the relationship between the company and their stakeholders, mainly with the final customer. In addition, the economic viability of the system relies on affordable products and services. The findings presented in this publication identify some potential guidelines to design sustainable PSS for the energy sector of emerging markets. Hence, they support the notion that PSS is a promising approach for dealing with the challenges of increasing the well-being of the low-income population (BoP) by proposing functional systems of products and services for the energy sector with an emphasis on achieving more sustainable results. Further studies will be carried out in order to develop a framework for adoption of PSS solutions in the BoP energy market.

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Geographic, technological and economic analysis of isolated diesel grids to assess the upgrading potential with renewable energies A case study of Tanzania

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Abstract

In Tanzania off-grid electricity is mainly supplied by diesel generators. This causes harmful air pollution and leads to high power generation cost. Contrary to that renewable energies can provide affordable and environmentally sound power. This paper indicates that a potential of at least 22 MW is available for upgrading isolated diesel grids to hybrid grids. The electricity is supplied by state-owned utilities and private cooperatives, representing two contrary business models. A geographic analysis is developed in order to localize isolated diesel grids. Furthermore, detected diesel grids are analyzed in terms of installed capacity, operators and tariff structure. With rising fuel prices, it is expected that upgrading with renewable energies will become the most competitive option for rural areas of Tanzania.

Keywords: hybrid grids, rural electrification, off-grid supply, geospatial analysis

Introduction

Isolated diesel grids

Electricity is mainly supplied by distributed diesel generators in remote areas of many developing countries (Platts, 2009). This extensive use of diesel gensets is based on little initial costs, high reliability and ease of installation (ESMAP, 2007). But they include disadvantages as electricity costs are high due to expensive fossil fuel imports and high transportation costs (Breyer et al., 2011). Furthermore, diesel generators contribute to local and global environmental pollution (ESMAP, 2007).

The expansion of existing diesel grids with renewable energy systems (RES) could significantly reduce the electricity costs and the emission of air pollutants (Dekker et al., 2012). So far, the required high initial investments prevented renewable energies from being introduced on a larger scale. Instead of that more “affordable” diesel generators were favored even though resulting in higher power generation expenses over time (IEA-RETD, 2012).

Taking into account that fossil fuel prices are projected to increase (IEA, 2011) while costs for renewable energies are decreasing (IEA-RETD, 2012) and are already competitive with diesel-based generation (Schleicher-Tappeser, 2012), retrofitting diesel grids with renewable energies will become economically viable in many locations. It is already feasible to integrate RES in existing isolated diesel grids under current technological conditions (ARE, 2011). For this integration the preexisting technical, economic and financial infrastructure can be used.

Even if it seems economically and ecologically very attractive to extend or substitute isolated diesel grids by RES, only few information can be found in the scientific literature about this. Isolated diesel grids are often stated as very important for decentralized energy supply, (Zerriffi, 2011), (Brent & Rogers, 2010) & (ARE, 2011) but no detailed information (e.g. on capacity or operators) is provided. Substantial characteristics of isolated diesel grids and barriers for the introduction of RES remain unclear. Within this study these topics are analyzed, as it is crucial to understand the diesel power generation to successfully implement the new RES.

Case study country - Tanzania

Tanzania is chosen as case study country because it is representative for the situation in a number of African countries: Insufficient energy supply impedes economic development in rural areas, although renewable energy sources are abundant (BEST-AC, 2012).

The east African country comprises an area of 947,300 km² with a population of 46 million (CIA, 2012). It is one of the world’s poorest economies with a GDP of 528 USD per capita (World Bank, 2012) and an electrification rate of only 11%, that even falls below 2 % in rural areas (Rickerson, 2012).

The total installed power capacity in Tanzania adds up to 1,185 MW, which is supplied mainly by hydro followed by gas and oil power sources (Platts, 2009). Electricity is distributed by a transmission grid of 3,800 kilometers, which covers the country from the north-west to the south-east, representing the most prosperous and populated regions (AFDB, 2012). Areas not covered by the main transmission grid are supplied by isolated diesel grids.

Tanzania lacks domestic oil resources, therefore fossil fuels need to be imported. The annual expenditures for crude oil imports add up to 6.5 % of the GDP (IRENA, 2010). Moreover, electricity costs in rural areas are increased by high transportation costs resulting in a low overall access to electricity. Despite all these unfavorable conditions, Tanzania has been ranked among the top 10 countries in the world for establishing sustainable business models for RES-based mini-grids (Gerlach et al., 2013).

Although the injection of RES is challenging due to the complexity of management systems, lack of investment resources and lack of technical knowledge (GVEP, 2011), it could reduce electricity costs and improve the quality of supply. By that it is possible to relieve Tanzania's national budget, to enable economic growth and to increase the electricity access in rural areas.

Research Objectives

As aforementioned, it is crucial to analyze the current diesel power generation system to find proper ways of extending or substituting them by RES. Doing this, our paper focuses on the following three research objectives:

1. Localization of isolated diesel grids
2. Analysis of isolated diesel generator size
3. Analysis of isolated diesel grid operators

Research objectives are worked on in the presented order above. First, it is necessary to localize and identify isolated diesel grids. Based on these outcomes the size structure is analyzed. Finally, operators and operating models are studied and associated to the outcomes of research objective 1 and 2.

Methods

Prearrangement of the data base

Required information on diesel power plants in Tanzania are extracted from the UDI World electric power plant database (Platts, 2009). The database provides information on 40 different categories for each plant. For this study data on unit, plant, operator, capacity, fuel type, status, city and geographic location are relevant. Plants are considered for further investigation, if the primary fuel type is diesel and the plants are stated as operating. Nevertheless, it is assumed that a much higher number of diesel generators are installed. These are plants, that are operated by individuals or small and medium-sized enterprises. Although these plants probably reflect a high potential for the upgrade with RES, they are not considered within this study due to the lack of proper data.

Localization of isolated diesel plants

The localization of off-grid diesel plants is executed as a geospatial analysis using ESRI ArcGIS 2010[1]. The prearranged data from the UDI World electric power plant database is visualized in ArcMap 2010. Additionally, the national electricity transmission grid is included according to existing geospatial data taken from the African Development Bank (AFDB, 2012). Isolated diesel plants are localized by adding a buffer zone of 50 kilometers around the transmission grid and excluding all plants within this area (Szabó, 2011). The remaining diesel plants outside the buffer zone are identified as isolated off-grid plants (Fig. 1).

Analysis of isolated diesel generator size

The size classes of the identified isolated diesel plants are statistically analyzed by applying SPSS 15.0[2]. A descriptive statistical analysis is conducted and the sample is illustrated in a box plot (Fig. 2) and main statistical parameters are calculated.

Analysis of isolated diesel grid operators

Operators are assigned to localized isolated diesel generators in the previous research steps 1 and 2. The proportion of installed capacity and number of plants is calculated with SPSS 15.0. Further information on tariff structure, financial performance, technical performance and purposes of electricity supply is extracted from literature review.

Results

Localization of isolated diesel plants

In total, 28 isolated diesel generators were identified in eleven different locations (Fig.1 – dashed green boxes). Thus, it is assumed that each location represents an isolated diesel grid. The accumulated installed capacity of all isolated diesel grids is 21.8 MW. Six isolated diesel grids are located in the southern part, three in the western part, one in the central part of Tanzania and one on the island of Pemba (Fig.1).

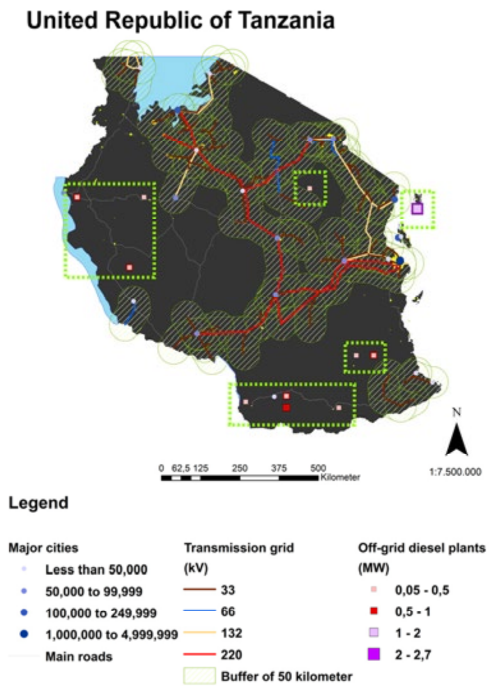

Figure 1: Isolated diesel grids in Tanzania.

[1] ESRI ® Arc Map™ 10.0

[2] IBM ® SPSS™ 15.0 for Windows Evaluation Version

Analysis of isolated diesel generator size

More than two thirds of the identified diesel plants have an installed capacity between 0.3 and 0.7 MW. The median of the sample is 0.65 MW. The range is 2.64 MW, with a minimum capacity of 0.06 MW and a maximum capacity of 2.7 MW (Fig. 2).

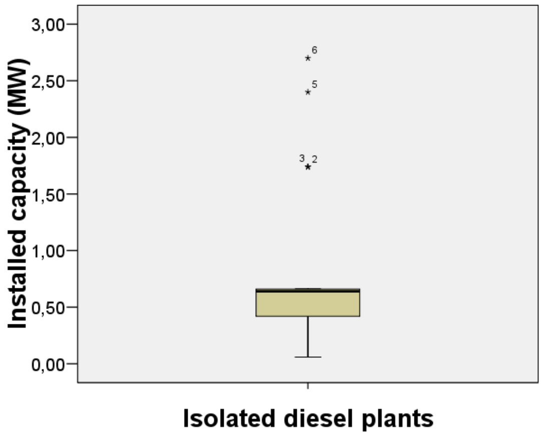

Figure 2: Boxplot of isolated diesel generators in Tanzania. Diesel plant parameters in the boxplot: N: 28, Median (MW): 0.65, Average (MW): 0.74, Maximum (MW): 2.7, Minimum (MW): 0.06.

Analysis of isolated diesel grid operators

Four different operators, categorized in state-owned utilities and private cooperatives, run isolated grids. State owned utilities are the Tanzania Electric Supply Company (TANESCO) and the Zanzibar Electricity Corporation (ZECO). The two private electricity cooperatives are operating in the rural towns of Urambo and Mbinga.

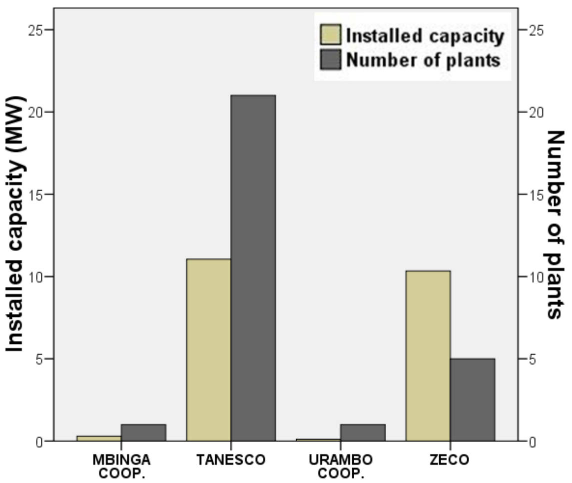

Figure 3: Installed capacity (MW) and number of plants per operator.

Table 1: Isolated diesel grid operators.

Operator	Number of plants	Installed capacity (MW)	Organization type
TANESCO	21	11.05	state-owned
ZECO	5	10.33	state-owned
Urambo coop.	1	0.11	private
Mbinga coop.	1	0.29	private

TANESCO comprises the majority of installed capacity with 11.05 MW, followed by ZECO with 10.33 MW. The two cooperatives have a minor proportion of installed capacity in the Tanzanian off-grid sector (Tab. 1 and Fig. 3).

The comparison of electricity retail prices for off-grid mini-grids detects huge differences among the operators. TANESCO charges 0.03 USD/kWh[3], whereas almost the tenfold price is charged by the Urambo electricity cooperative (Tab. 2). As a state-owned utility TANESCO's electricity tariff is subsidized by the government, leading to a loss of 0.42USD per generated kilowatt hour (Tab. 2). These losses accumulate to a deficit of approximately 36 million USD annually (Eberhard, 2010).

Table 2: Tariff structure of isolated diesel grid operators[4].

Operator	Tariff (USD/kWh)	Generating costs (USD/kWh)	Financial performance (USD/kWh)
TANESCO	0.03	0.45	**-0.42**
ZECO	0.06	0.45	**-0.39**
Urambo coop.[5]	0.28	0.15	**0.13**
Mbinga coop.	N/A	0.15	N/A

The calculation of levelized cost of electricity (LCOE) indicates, that RES are already cost-effective compared to diesel generators. The introduction of photovoltaic systems (PV) bears the potential for savings of 0.18 USD per kilowatt hour (Tab. 3) despite the fact that PV initial cost are exceptionally high due to rather unfavorable business conditions (World Bank & IFC, 2012). In addition capital expenditures are not considered in the calculation of diesel LCOE, which would make PV even more attractive.

Table 3: LCOE Diesel vs. RES.*

	PV	Diesel	Cost advantage RES
LCOE (USD/kWh)	0.27	0.45	**0.18**

*input parameters for calculation: PV –Yield/annum: 1,600 kWh/kWp, Capex: 3,250 USD/kWp, Opex: 32.5 USD/kWp, IRR: 0.2, IRL: 0.18, ER: 0.2, Inflation rate: 0.11. Diesel – Fuel costs: 1.36 USD/liter, Capex: 0 USD/kWh, Opex: 0.04 USD/kWh.

Discussion

The developed methodology is applicable for the localization of isolated diesel grids in general and used here for the case of Tanzania (Breyer, 2012). A potential of 22 MW installed capacity is detected, that offers great economic and ecological potential for an upgrade, especially with regard to the advancing diesel parity of RES (Schleicher-Tappeser, 2012). However, insufficient data and oversizing of the buffer zone probably might lead to the overlook of isolated grids. For Tanzania the installed capacity of all operating isolated diesel grids is

[3]Domestic Low Usage Tariff up to 50 kWh
[4] Exchange rate: 1 USD = 1,596.33 TZS
[5] Parameters refer to the situation in 2005 (Ilskog et al., 2005)

stated 30 MW as opposed to the 22 MW detected (Eberhard, 2010).

Isolated diesel grids provide electricity in structurally weak and remote areas. Here, a low population density, low electricity demand and low income are major constraints for an extension of the main transmission grids. This assumption is validated by the results: Isolated diesel grids where predominantly localized in the poorest areas of Tanzania. As these grids are located close to population centers, it is assumed that they supply power for public, domestic and small productive use.

TANESCO and ZECO comprise the majority of installed capacity and the most diesel generators. Thus, it is important to concentrate on isolated grids of the two state-owned utilities for achieving an improved implementation of RES. Both utilities charge low electricity tariffs due to high subsidies. This results in an unsustainable business model, which leads to a deficit in Tanzania's national budget. The inclusion of RES could reduce the losses of this business model. However, for a sustainable electricity supply and the introduction of RES with the help of private investors, it is necessary to correlate tariffs to real generation costs.

The isolated diesel grids run by the electricity cooperatives hold only a minor proportion of the off-grid sector. However, a much larger number of diesel generators are likely operated informally by individuals and communities, which might contribute a significant share to the power generation. Hence, power generation apart from state-owned utilities presents an interesting business model, as it succeeded in setting cost-reflective tariffs, reducing the costs of operation and maintenance and improving the willingness to pay for electricity services (Marandu, 2002).

With the introduction of a framework for renewable energy small power projects in 2003 (EWURA, 2011), an important precondition for private and cooperative investment in the distributed electricity sector was created. Nevertheless, the framework failed in incenting renewable energy projects in remote areas. For a successful implementation of RES in existing isolated grids it is necessary to improve the framework in one crucial term: A clear regulation regarding the control, management and ownership of hybrid grids upgraded from former diesel grids is required. If this condition is met, the upgrade of the existing isolated diesel grids can improve the reliability of electricity supply. Furthermore, it is possible to increase the capacity of isolated grids and enable a higher electricity access in rural areas.

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Regional and structural differences of barriers to implement renewable energies

- Implications for less or least developed countries -

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Abstract

The implementation of renewable energies (RE) is one of the main pillars to fight global greenhouse gas emissions and increase access to clean and affordable electricity. Despite the urgent need of developing RE capacities, they diffuse rather slowly. To accelerate the implementation it is crucial to understand the barriers and challenges for RE. Within this work a broad literature overview is conducted to identify and structure the barriers. In addition, case studies are analyzed to find regional and structural differences. Looking at these differences enables a more specific help for implementing RE in less or least developed countries (LDCs). The analysis reveals that main barriers for LDCs are lack of trained staff and high initial costs.

Keywords: innovation systems; energy policy; technology diffusion

Introduction

One of the major threats for global mankind is the anthropogenic driven greenhouse effect and the resulting climate change (e.g. leading to sea level-rise and weather extremes) (IPCC, 2007). In addition, clean and affordable energy supply is a backbone of sustainable development and wealth for countries and people worldwide (Breyer, Werner, Rolland, & Adelmann, 2011; Programme, 2005).

The latest development of dramatically shrinking costs of renewable energies (REs) (especially photovoltaic) fundamentally changes the market situation (Bhandari & Stadler, 2009; Price, 2011). Currently these GHG emission-free technologies are already cost-competitive compared to oil-fired plants on islands or in rural areas (Breyer, Werner, et al., 2011; Clarke, 2008). Increasingly, they even challenge gas or coal power plants without any subsidies (Breyer, Görig, Gerlach, & Schmid, 2011; IRENA, 2012a, 2012b). Combining these issues, REs have the potential to become the main power generation technologies due to ecological and economic reasons.

Despite these two advantages, yet only few new REs (photovoltaic and wind power) have been installed on a global scale (International Energy Agency, 2012). This leads to the assumption that additional barriers exist beside the economic ones. Painuly for example mentions technological, financial, social, institutional and market distortions or failure as potential barriers (Painuly, 2001). It is crucial to remove these barriers for the implementation of REs to target the GHG emission reduction goals and secure a sustainable and affordable future energy supply.

Trying to help poor people in least developed or developing countries, developed countries often apply their established technologies without taking the different framework conditions in the supported countries into account. This leads to wrongly directed developing aid or support by global organizations. Less or least developed countries (LDCs) have to be analyzed according to their main barriers for implementing RE to successfully support them. They are especially interesting for micro energy systems as the distributed power generation in rural areas is one solution to improve their energy supply system.

Research Objectives

The analysis of identified barriers for implementing REs supports decision makers and investors to create a renewable friendly framework to push the global Energiewende and to ensure access to sustainable energy. Only after understanding the barriers of RE's implementation, it is possible to remove them successfully. Many basic studies on barriers of RE development (cf. Owen, 2006; Painuly, 2001; Unruh, 2000; Verbruggen et al., 2010) have been published over the last decade and underline the scientific and practical relevance of this topic. In addition, consider more country specific or regional case studies are available. Within this paper, these case studies are used to identify the specific barriers of LDCs. As opposed to the reviewed research papers and case studies, this paper focusses on a regional comparison of barriers as new approach.

The analysis follows three main research questions:

- What kind of main and sub barriers exist in general?
- What regional or structural differences can be identified?
- What are the main barriers in LDCs?

Methods

To answer these questions, a broad literature analysis is performed. Many country specific case studies have been conducted over the past years. These studies are identified by researching "barrier AND renewable energies" in the title, abstract and keywords of all papers of the science direct journals.Almost 350 articles are found. They are scanned to get representative studies about developed, newly industrialized, and least developed countries[1].

First, the main barriers are extracted and clustered with their sub barriers along the commonly mentioned categories. To structure the barriers, mainly peer-reviewed papers without specific regional context are investigated (Beck & Martinot, 2004; Boyle, 1994; Negro, Alkemade,

[1] According to the UN

& Hekkert, 2012; Owen, 2006; Painuly, 2001; Reddy & Painuly, 2004; Timilsina, Kurdgelashvili, & Narbel, 2012; Union of Concerned Scientists, 2002; Unruh, 2000; Verbruggen et al., 2010; Wee, Yang, Chou, & Padilan, 2012). The identified main barriers are clustered along the four categories: technical, economic, political, and social as shown in Fig. 1.

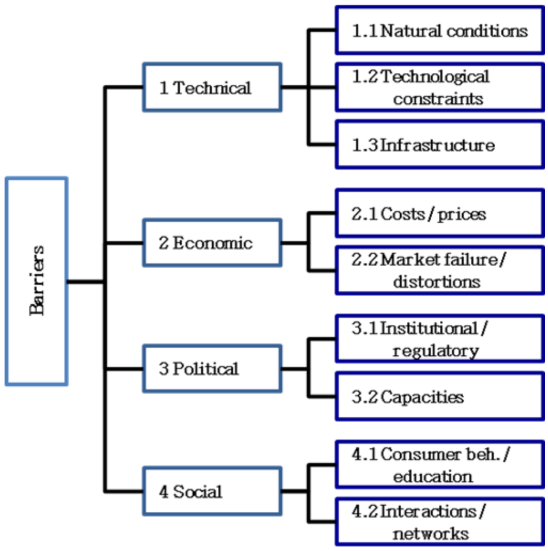

Figure 1: Clustering of barriers in categories and main barriers.

Using this overview as framework, the barriers within the case studies are analyzed. Following Negro's approach, the mentioned sub-barriers are associated to the main barriers to evaluate the importance of each (Negro, Alkemade, & Hekkert, 2012). In addition the case studies are seperated according to the studied countries to underline the differences of developed and LDCs. This enables more specific measurements to remove these barriers in LDCs.

Results – Case study analysis

Tab. 1 reveals the results of the evaluation of the case studies along the barriers of Fig. 1 for DCs and newly industrialized countries (NICs), Tab. 2 for LDCs. The more important one specific barrier in one specific country the more "+" are indicated. An "o" means only slight importance and "-" shows that the barrier is removed for this sub category.

Table 1: Results for DCs and NICs.

	DCs				NICs				
Barrier	USA	GER	UK	AUS	BRA	CHI	MEX	SA	MLY
1.1				+		- +		o	
1.2	o	+		+		+ +			+
1.3				+	o	+			
2.1		o	+	+	+	+	+	+	+
2.2	+ +	+	+	+ +	+		+ +	+ +	+
3.1	+ +	- -	+	+	+	+ +	+ +	+	+
3.2	+			+	+				
4.1	+ +	-	+ -	+		+		+	+ +
4.2	+	- +	+	+					+
Source	1, 2, 3, 4	5, 6, 7, 8	5, 9, 10	11, 12, 13	14, 15	16,17, 18, 19	20	21	22

USA: United States of America, GER: Germany, UK: United Kingdom, AUS: Australia, BRA: Brazil, CHI: China, MEX: Mexico, SA: South Africa, MLY: Malaysia.

Source: 1: (Sovacool, 2009a), 2: (Sovacool, 2009b), 3:(Sovacool, 2009c), 4: (Sovacool, 2009d), 5: (Lipp, 2007), 6: (Klessmann, Held, Rathmann, & Ragwitz, 2011), 7: (Umweltbundesamt, 2007), 8: (Forschungsstelle für Umweltpolitik, 2007), 9: (Brennand, 2004), 10: (O'Keeffe & Haggett, 2012), 11: (Wright, 2012), 12: (Effendi & Courvisanos, 2012), 13: (Martin & Rice, 2012), 14: (do Valle Costa, La Rovere, & Assmann, 2008), 15: (Pereira, Camacho, Freitas, & Silva, 2012), 16: (Sun & Feng, 2012), 17: (Ling & Cai, 2012), 18: (Liu, Lund, & Mathiesen, 2011), 19: (Huo & Zhang, 2012), 20: (Lokey, 2009), 21: (Pegels, 2010), 22: (Ali, Daut, & Taib, 2012)

Table 2: Results for least developed countries.

	LDCs					
Barrier	TZ	ETH	BNG	NEP	SAs	PAK
1.1						
1.2	+			+	+	+ +
1.3	+	+			+	+
2.1	+ +	+ +	+	+	+	+ +
2.2	+			+		+ +
3.1		+ +	o	+	+	+
3.2		+	+	+	+	+
4.1	+ +	+ +	+ +	+ +	+ +	+ +
4.2			+	+		o
Source	23, 24	25	26	27, 28	29	30, 31

TZ: Tanzania, ETH: Ethiopia, BNG: Bangladesh, NEP: Nepal, SAs: South Asian countries, PAK: Pakistan (last two are not LDCs, but studies looking at rural electrification).

Source: 23: (Ahlborg & Hammar, 2012), 24: (Rickerson, Hanley, Laurent, & Greacen, 2012), 25: (Mulugetta, 2008), 26: (Alam Hossain Mondal, Kamp, & Pachova, 2010), 27: (K.C., Khanal, Shrestha, & Lamsal, 2011), 28: (Gurung, Kumar Ghimeray, & Hassan, 2012), 29: (Palit & Chaurey, 2011), 30: (Mirza, Ahmad, Harijan, & Majeed, 2009), 31: (Bhutto, Bazmi, & Zahedi, 2012)

Tab. 1 and 2 show that natural conditions are in general no limiting factors for REs according to the literature review. In DCs as well as in LDCs renewable sources are sufficiently available. The intermittency as technological constraint is mentioned for US as well as for Germany and China. In addition, in China and in LDCs (excluding Bangladesh) the technological constraints refer to the availability and understanding of RE technologies. This can be seen as an often occurring barrier for RE in LDCs. Infrastructure in DCs and NICs is a minor hurdle and points out the denied grid access for RE operators. For LDCs, infrastructure as barrier has the same importance as technological constraints. It means that the basic infrastructure to install and operate RE plants is lacking and not only the grid-access.

The economic barriers are consistently higher rated than the technological. The higher levelized cost of electricity (LCOE) of RE compared to the LCOE of the relatively cost effective conventional large scale power supply is pointed out as important barrier in DCs and NICs. REs face the same barrier in LDCs, but the conventional power supply in these countries is more expensive (especially in rural areas with off-grid diesel power plants), which leads to a lower cost gap between RE and fossil plants. The high initial investment effort is an additional barrier for RE, which is crucial in LDCs due to lack of private capital and high capital costs (mentioned for Tanzania, Ethiopia, and Pakistan). Market failure and distortions as barrier are based on lock-in dilemmas and / or monopolistic market structures in DCs and NICs. Especially countries with a powerful established utility and strong connection to fossil resource exploration are concerned (e.g. USA, Australia, South Africa, Mexico). Market barriers for LDCs are not as important as for DCs and NICs. The exclusion of new private companies is mentioned to be the highest barrier in DCs.

The institutional and regulatory barriers are part of the political barriers. They are especially important for the success of REs in DCs as well as in NICs. The example of Germany shows that a proper regulation (eg. feed-in law) can be the main driver for the implementation of RE despite all other barriers. Many of the analyzed countries are still lacking a proper regulatory framework, in addition they even subsidize conventional power sources (e.g. USA, Mexico, China). LDCs face similar problems on the institutional level. In terms of capacities, LDCs have often weak administrative systems, which slow down the support of REs. In DCs, a missing centralized authority – means differentiate legislation in different federal districts of one country – complicates the bureaucratic processes. For NICs, the political capacities have no influence on the implementation of RE.

Finally, the social barriers are analyzed. In each investigated LDC, consumer behavior and education represents a strong barrier. This is mainly based on the lack of well trained workers and educated consumers, which have no awareness regarding RE. In DCs a lot of proper qualified workers are available, but in some countries the people have a lack of interest or comprehension, while in NICs the people seem to be excluded from the entire decision process whether to use RE or not. The last barrier is defined by networks or interactions among groups and people, this barrier is not mentioned for NICs. In DCs citizens initiatives have often started to push the implementation of REs. Nevertheless, opposition currently arises especially against wind power due to its visual impact (e.g. Germany, UK). In LDCs missing networks among communities to share experience or knowledge can be seen as main barrier on this level.

Discussion

To respond to the first research question, the general structure of barriers and sub-barriers is illustrated in the method section. For the second and third question, the analysis of the country case studies reveals clear differences in barriers for implementing REs between DCs / NICs and LDCs. Thus it is very important to target the specific impediments in LDCs to effectively support REs there and not only copying the measurements of DCs or NICs.

The first major barrier in LDCs is the lack of education and awareness. Without removing this, proper installation, operation, and maintenance cannot be assured, which are very crucial for sustainable implementation of REs (cf. Yadoo & Cruickshank, 2012). Education programs in schools and technical colleges should improve the qualification of local staff. The second major barrier includes the high initial cost combined with lack of investment capital or high capital costs. Micro finance schemes target this barrier by enabling private investors to invest into REs (cf. Gradl & Knobloch, 2011). Looking at these two barriers and potential solutions explains the imperfection of taking only experiences from DCs into account. DCs have traditionally proper access to trained workers and capital, therefore the aforementioned measurements (especially micro financing) can only evolve by looking at LDCs and their needs.

The scope of this work is limited to the dimension of the sub-barriers and their evaluation is relatively undetailed. Future research should therefore analyze the dimensions of the sub-barriers and use them for comparison. By this, more detailed solutions for removing barriers of implementing REs can be given.

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A 'Three-Step-Approach' to Energy Implementation

- Examples from a PV hybrid grid in Tanzania

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Abstract

In an ongoing research project, a 'three-step-approach' is used to study rural electrification and the use of a small PV-diesel grid at a community centre in Ihushi, Tanzania. The paper gives some preliminary results from the current research. It also describes the three steps of investigation by which social actors are identified, cultural change studied, and long-term feasibility evaluated. As an answer to the critique of the 'drivers-and-barriers' concepts, we suggest this model as a way of capturing the dynamic and long-term aspects of implementation processes and of adding a more culturally informed stance to actor oriented research.

Keywords: Rural electrification; PV-diesel hybrid system; Social feasibility; Barriers; Three-step-approach; Tanzania.

Introduction

In this paper, ongoing research concerning rural electrification in Tanzania is used to illustrate how a 'three-step-approach' may be applied on a study of energy implementation. A main purpose of this model is to support the development of actor oriented research (on changes in the use or supply of energy) in a more culturally informed direction. The 'Three-step-approach' has been developed by anthropologist Annette Henning during many years of teaching master students at the European Solar Engineering School (ESES) at Dalarna University. The research model is presently being tested in field by PhD student Caroline Nielsen.

Figure 1: Ihushi Development Centre

Ideally, both the development and implementation of technology start out with an investigation of the needs and priorities of a particular group of people. This is not always possible. As is the case in the research we present here, an energy system might already be in place. In other cases there may be funding especially for the introduction of PV or wind energy, or the implementing organization may be knowledgeable only in one particular technique.

Unfortunately, many energy implementation projects tend to begin at quite an opposite end, with a particular technical solution to an environmental problem or an assumed social problem. The task then becomes a matter of having the technology adopted by suitable users. The surprise when finding reluctance among these to adopt the product (despite obvious benefits) is what generally makes the investigator look for barriers, or to ask social scientists to inform and improve the behavior of energy end-users (Wilhite 2008).

Ryghaug & Sørensen (2009) have pointed out that energy efficiency policies, as well as researchers working with energy efficiency have tended to view 'non-technical' aspects of energy performance as obstacles and barriers to technological progress. In their article on the Norwegian building industry, they argue that the failure in improving energy efficiency is an effect of an assemblage of particular policy-making, market processes, and professional and industrial practices. A similar argument has been put forward by Wilhite (2008). He comments on the fact that promised reductions in energy demand rarely pan out, and that the usual policy approach to this fact is to work harder to loosen up the barriers to technology penetration. He argues that both technologists and 'behaviouralists' have tended to oversimplify the ways that technologies and socio-cultural contexts interact to affect energy-using practices.

Common to these authors is their critique of the dominant focus on barriers, and the simplistic picture this gives of the dynamic and complex processes changes are really about. The term barrier implies that we must find and remove what ever it is that prevents the (often taken for granted) positive developments and improvements to occur. In this paper, we take a somewhat different stance in suggesting a model which takes as its point of departure indigenous perceptions of problems as well as dynamic interactions between technology and the people who handle it or are affected by it.

The 'Three-Step-Approach'

The 'Three-step-approach' focuses on the culture-specific, subjectively experienced modifications of everyday life, on change, durability and feasibilty. Still, the approach is suggested here as a way of studying and analyzing unique cases of energy transitions in ways which make them comparable and possible to act upon.

The model draws from scientific sources within Social Anthropology, Sociology, Development Studies and Political Science, as within the History of Technology and Science and Technology Studies. An important purpose with developing this model has been to facilitate for researchers, investigators and consultants who lack substantial social scientific training to make better use of this huge body of knowledge. It leaves room also for more advanced social studies, however. The model may be used in its own right, or for improving or structuring research based on other actor oriented concepts, such as 'user-centered design', 'technology assessment', 'barriers and drivers', etc.

The 'Three-step-approach' is built up as three steps of investigation, each with its own focus of attention. The first step is to become more clearly aware of who the relevant social actors are, and what their internal differentiation looks like. During a second step, processes of change and modification are studied. The third step is to check basic prerequisites for a successful long-term energy implementation. These three steps of investigation may also be described as three perspectives or objects of investigation. Consequently, during a research process, you may find it more useful to alter between the perspectives rather than to pursue the three steps one at a time in a clear-cut way.

The Tanzania Case Study

In 2008 a PV-diesel hybrid system was installed at Ihushi Development Centre (IDC), near Mwanza, Tanzania (Figure 1). This community based organisation runs a vocational training centre, a carpentry workshop, and a business centre, where computers can be used and courses are held. There is also a preschool, a meeting hall, a guest house, two offices and a kitchen. Interconnected solar panels and a diesel generator supply power for lighting, computers, a copy machine, a TV, a refrigerator, the charging of mobile phones for the villagers, and tools of varying kind (Nielsen 2012).

A SIDA-financed project started in 2011. The aim of this research is to suggest ways of improving both social and technical feasibility of mini-grids supplied by renewable energy in general, and the hybrid PV-Diesel system at IDC in particular. The project is a multi-disciplinary collaboration between a technical expert of small-scale electricity systems, a social anthropologist, and a PhD student. Qualitative interviewing and participant observation are the main methods used in the social parts of the study (Figure 2). Interviews have been carried out in English as well as in Swahili, which is the national language of Tanzania. Five months of fieldwork has been carried out during 2011 and 2012, and another three months are planned for 2013.

Figure 2: Interviewing

Relevant social actors

The first of the three steps of investigation concerns the process by which relevant social actors are identified. In our case study, this part of the investigation is closely connected to how different individuals or groups of people are linked to the PV-diesel mini-grid at the Ihushi Development Centre. Consequently, at this stage we have sought information about who is (or, in some other study, who *will be*) involved in, or affected by, the electrification project. We want to identify the users or presumptive users of electricity. But we also need to know which individuals and/or organizations are responsible for promoting and handling the hybrid mini-grid system.

Our ongoing mapping of relevant social actors makes a long list, of which we will mention only some here. Employees at the IDC centre constitute a core group of actors consisting of vocational training teachers, kindergarten teachers, night guards, a driver, a manager, a man working with electric installations, and employees working in the kitchen, guesthouse, business centre, café and shop. At the centre, we also find children staying in the kindergarten, students in sowing and carpentry, and villagers and students who take computer classes. Furthermore, we find villagers stopping by to have a cup of tea or a chapati at the café, or to have their mobile phones charged at the IDC shop.

From our outsiders' perspective, we have quite easily been able to differentiate between these individuals, and to categorize them according to age, gender, etc. For instance, kindergarten teachers are women in their thirties, while teachers in sowing, carpentry, masonry and welding are all middle-aged men. More difficult, however, is to learn about the culture-specific ways in which these individuals differentiate between themselves.

It is a universal feature of human societies that we (as human beings) tend to see ourselves and others as belonging to different groups with differing characteristics. Differentiation may be explained by class, caste, ethnicity, professional belonging, etc. Biology is particularly commonly used for producing culture-specific ideas about differences between 'us' and 'the others'. Essential here, is to understand that biology does not speak for itself. In a huge variety of ways, human beings interpret biological variations in age, skin colour, sex, etc.

Differences may also be emphasized, de-emphasized, or ignored depending on context and situation. Still, there are no societies where all persons have the same influence over each decision, and where everyone has exactly the same rights and duties (Hylland Eriksen 2000). To better understand culture-specific differences, one can keep in mind the difference between vertical and horizontal differentiation (Figure 3). The vertical dimension has to do with inequality in terms of power or rank, while the horizontal dimension involves aspects of differentiation that do not have to be expressions for inequality.

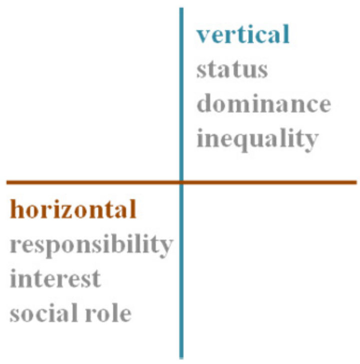

Figure 3: Social differentiation

In order to understand the ways in which the various categories effect, or are affected by, a particular energy system, it is important to combine the researchers' outside perspective on the varying roles and opportunities with native perspectives. The following result from our study may illustrate the importance of listening closely to what different social actors have to say about a certain technology. It turned out that people in difficult economic situations tended to emphasize the economic and health related benefits from using PV lanterns rather than kerosene. Many of them claimed that if they had had enough capital to invest in a PV lantern, this would be given high priority. In contrast to such utterances, people who actually had the financial ability to buy a PV lantern did so to a much lesser extent than the poor claim they would do if they could.

Cultural change

The second step involves learning more about the everyday life of each of the relevant social actors, and to try and understand how daily life might change by the introduction of a technology (Winther 2011, 2012). How does each of these individuals and groups perceive the proposed measures? Who gains, and who loses, and according to whom?

The two concepts 'energy service' and 'energy carrier' are useful tools for analyzing energy-related cultural change. These concepts may help us understand how the services which energy provides might be altered for a certain group of people. They may also help us investigate what a change of technology or energy carrier may mean for men and women, the young and the old, the wealthy and the poor, and the educated and the not so educated (Clancy 2002, Shove 2003, Wilhite 2008). The following examples from our ongoing research illustrate how these concepts can be applied on a certain context.

The presence of the PV-Hybrid system at IDC has changed the activities at IDC and the possibilities in the village in two major ways. It has introduced services that were not available before, and it has enabled a transition from the use of one energy carrier to another in order to perform already used energy services. New services cover activities that can be performed by electricity exclusively, such as the charging of mobile phones and use of computers. Services which previously were achieved through other energy carriers than electricity include, for example, the use of electric sewing machines and irons, and machines for carpentry work such as drilling and cutting wood.

What impact an energy carrier has on the performance of a certain activity depends on many different factors. For instance, the users of the electric sewing machines mean that their work is less physically demanding with the use of electric machines. However, they also perceive their actual work to be very similar to when it was done with pedal machines. The carpenters, on their part, experience a much higher efficiency in their work thanks to the use of electric machines, resulting in higher productivity as well as more time to relax.

As an outsider, it is easy to take things for granted, such as believing that electrification is always desirable and for the good. For successful energy implementation, a well informed ground for decision is most essential, however. Mehlwana (1997) showed, for instance, how an important reason for failure of a South African solar electrification project, was the fact that the commonly used kerosene served as a social lubricant. It was always available; you could borrow it from neighbors, or purchase it in small affordable quantities. As it turned out, in that particular context, electric power had severe difficulties competing with those qualities.

Long-term feasibility

The third step of investigation involves an estimation of whether or not a project has what it takes to become fully implemented, and to achieve long-term success. This step is inspired by the socio-technical systems approach, launched in the 1980s by authors in the Science and Technology genre, such as Bijker, Hughes and Pinch (1990). A basic idea here is that technical systems not only are dependent on technical components in order to function, but on social components as well. Two examples from the History of Technology will provide illustration to some of the most basic prerequisites for a successful long-term technology implementation. The first is a success story, the other a story of failed implementation.

The first example tells us about the introduction of the electric light bulb (Hård 1990). Edison and his colleagues did not invent the light bulb, as often assumed. Neither was the light bulb per se the key to their success, but organizational ability. Edison had support from financiers and political decision-makers. Through media and spectacular light shows, arranged during dark winter nights, an intellectual reading population was convinced that electric light was superior to both gas and ark light. Still, according to Hård (1990), the most important achievement of Edison and his colleagues was to start about a dozen companies for production, distribution, and maintenance. They managed to create a complete chain of coordinated companies and products.

The second example concerns the first steam engine that, in 1728, was brought to Sweden from England (Hård 1990). It was to be used for ore-mining. The social actors who tried to carry the technology into the Swedish society had the power and economy to do so. They had access to the technique, and they were well informed about its possibilities and limits. Still, the project eventually failed. One reason were the many technical problems related to the transfer from the industrialized England to the colder, wood-based country Sweden. However, according to Hård (1990), the primary reason why this energy implementation project failed was lack of a long-term functioning organization. An extreme import had been put on two knowledgeable men from Uppsala and Stockholm. When these lost interest in the rural life, powerful supporters lost interest in the project.

These two historic examples clearly illustrate the fact that a technical solution is never enough. Certain features are recurrent characteristics of a successful technology implementation. Among these we find a perceived credibility in the technique and the promoters. We find relevant knowledge among producers, suppliers and consumers, as well as accessibility for consumers. Other recurrent features are long-term management and commitment, enough economic and political strength to carry through the project, and a complete chain of coordinated companies and products (Edquist & Edqvist 1980: 42, Henning 2000, Hård 1990).

In the ongoing research on electrification of a community centre in Tanzania, we have only recently begun to analyze the long-term feasibility of the PV-hybrid system. Preliminary results concern perceptions of credibility, a long-term working organization, knowledge and accessibility, management and economy.

IDC is a well established organization actively working on many different levels to support and improve the living conditions in their target villages. They are, after many years of community based work, regarded as a credible organization amongst villagers and collaboration partners. PV technology is not only used at the center, but is spread amongst other institutions and private households in the villages. The technology has been adopted amongst many villagers as a source of energy supreme to many other alternatives. However, it has also been met by skepticism by others, who have previously experienced or heard of PV systems that were failing after short time.

Every day, a few of the employees at IDC are operating the electrical power system. When extensive maintenance or replacements are required, an external electrician is called in, and IDC's proximity to the large city Mwanza makes technical equipment, advisors and electricians rather accessible. Although IDC is well established in its target area, and has several committed employees, it is to a large extent driven forward by a few strong individuals. Without saying that this is a problem, it is something to reflect upon and to be aware of. IDC has the ambition of becoming self sufficient, and is working hard to implement and extend income generating activities. Financial support for investments and running costs is received from mainly one of their partner organizations. This may not necessarily be contradictory to economic sustainability if it is achieved over a very long time. Still, if such support suddenly is reduced, it may even be difficult to cover running costs.

Concluding remarks

The 'drivers-and-barriers' approach to technology implementation is commonly used among scientists and other investigators, often with good results. Accordingly, in a review of literature on rural electrification in East and Southern Africa, Ahlborg (2012) found that the concepts 'drivers' and 'barriers' were common vocabulary in discussions about rural development. The 'drivers-and-barriers' approach has also received some substantial critique, however (e.g. Guy & Shove 2000, Ryghaug & Sørensen 2009, Wilhite 2008). As an answer to such critique, we have suggested a 'Three-step-approach' to energy implementation. We have described here three distinct ways in which the dynamic and long-term aspects of implementation processes may be captured and a culturally informed approach added to actor oriented research.

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Renewable energies and their impact on local value added and employment

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Abstract

Communities can benefit on a large-scale from the use of renewable energies (RE), which induce important local benefits due to their decentralized structure. This paper deals with the question, how to quantify the generated effects of value added and employment on a local scale. Value added is calculated as the sum of three components: tax revenues, company profits and wages, which are generated by the involved agents along the value chains of the examined RE technologies. The knowledge of local value added and employment effects can be an important factor concerning the acceptance or RE technologies as well as the further expansion of decentralized and renewable energy generation.

Keywords: local value added; renewable energy; regional development.

Introduction

In the context of the transition from fossil-fuel-based to renewable energy systems, communities play an important role. They are a driving force for the expansion of renewable energies and can benefit at the same time. Many municipalities and districts have ambitious climate protection objectives that even exceed the targets set at national level. Besides an increased awareness of the need for climate protection measures, the main reasons for the community involvement are regional economic effects that can be induced by the use of renewable energy sources. As previously imported fossil fuels or final energy is replaced by local energy sources, a series of value-added steps take place in the community itself due to the RE's decentralized structure. As a result, this can have a positive impact on local value added and employment in the region.

Research Objectives

The link between the expansion of RE and economic benefits has been discussed in numerous studies. However, most of these studies have a different geographical focus (mostly the national level) and do not include assessment of value added. For Germany, the different types of profits and costs have been analyzed in Breitschopf et al. (2010 and 2011a) and the effects on employment in Lehr et al. (2011). Furthermore, Breitschopf et al. (2011b) give an overview of the existing international literature on the assessment of employment impacts. In Bundesministerium für Verkehr, Bau und Stadtentwicklung [BMVBS] (2011) a method to quantify local value added has been developed, which however does not cover the whole value-added chain, but only the operation phase. Hence, until recently, a transferable method that allows for a detailed analysis of the extent as well as the distribution of local value added and employment had been lacking. Concerning the different potentials to generate local value added by different RE technologies, the knowledge gap is even greater. A fact that is all the more surprising when one considers that the positive effects of RE on economic development are a central motive for local actors concerning their expansion in many communities (Stablo & Ruppert-Winkel, 2012). Accordingly, there is a high demand for such information and knowledge.

It was against this background that the Institute for Ecological Economy Research (IÖW) developed a model to quantify generated effects of value added and employment by RE on a local scale.[1] For the first time, a transferable method is available, that makes it possible to quantify the economic effects for an average community as well as typical decentralized RE technologies along the value chain. The knowledge of the opportunities as well as the success factors for expanding RE in a region can help communities to benefit from a restructuring of the energy system towards decentralized energy supply.

Methods

Quantifying municipal value added and employment effects

The IÖW model presently contains a wide range of RE technology value-added chains, representing a broad portfolio of distributed power and heat-generating facilities, the supply of biofuels for transport and wood fuels for power and heat generation as well as a local district heating network fed by RE. Thus, substantially all technologies and plant sizes in the areas of electrical power, heat generation as well as wood and biofuels, that would be applicable to an average municipality are analyzed. Special cases such as large-scale hydropower, offshore wind energy and deep geothermal, which due to their site requirements are found in only a few municipalities, are not currently included in the model.

The primary basis for assessing value added in the model is an analysis of the specific turnovers relating to the installed capacity[2] along the RE technology value-

[1] Meanwhile, the model has been extended to the quantification of the effects for the state and federal scale.

[2] The reference value for solar thermal systems is installed collector surface and for wood and biofuels it is the produced amount.

added chain. The analysis is restricted to turnovers directly relevant to renewable energy (that means all components and services to produce, install and operate the RE technology). The value added chains are broken down uniformly into four value-added stages, which reflect the various phases of the life cycle of a RE facility and thus provide for comparability across all technologies: in the stages *Systems Manufacture* and *Planning & Installation* one-time impacts, arising before a facility is placed into operation, are accounted for. The stages *Operation and Maintenance (O&M)* and *System Operator*, on the other hand, contain annually re-occurring effects that continue throughout the entire operational lifespan of a facility.

The four value-added stages are in turn accordingly subdivided into various value-added steps, depending on the specific technologies involved. Systems Manufacture accounts for the manufacture and production of the various components, whereas O&M includes items such as maintenance and fuel costs. The System Operator stage includes energy supply profits and their associated tax revenues (see Table 1 for the example wind energy).

Table 1: Value-added stages and steps of wind energy.

Value-added stage	Value-added step
Systems Manufacture	e.g. tower, generator, rotor blade
Planning & Installation	e.g. grid connection, fundament
O&M	e.g. service and maintenance, insurance, lease
System Operator	profits and associated taxes

For each of the value-added steps the cost-structures of investments in the specific technologies and the system operations turnover are identified. An allocation of the individual cost items to a value-added stage makes determination of turnover for each of these stages possible. In addition to these direct costs and revenues that arise through the investments in the specific value-added stages, further operational revenues are generated. In contrast to (one-time) investment costs, these costs are incurred annually during the operational lifespan of a facility. During operation a need for replacement parts arises, which induces an additional component demand that must be accounted for in the value-added stage Systems Manufacture.

Principally, three value-added components are being ascertained across all value-added stages; added together these yield a total municipal value-added impact. Specifically, these are:

(1) After-tax profits of the participating enterprises
(2) Net incomes of the employees involved
(3) Taxes paid on business profits and on adjusted gross employee income.

With respect to taxes, it is possible to distinguish between municipal, state, and federal tax revenues. In the regional value-added analysis, taxes at the municipal level are significant; these consist primarily of business taxes and the municipal share of income taxes. The first two value-added components, profits and incomes, provide indirect benefits to the local community by increasing purchasing power. Local tax revenues, on the other hand, flow directly into the municipal treasury.

Profits

To determine profits at each of the value-added stages, the operating profit margin is utilized, which compares the annual profit (before taxes) of an enterprise to the turnover achieved in the same period. In this case, before-tax results were used for the calculation. The profit-turnover ratio is drawn from statistics compiled by the German Central Bank (Bundesbank, 2011), which extrapolates figures based on data from the annual financial statements of German companies for the years 1997 to 2009. This pooled data includes results from approx. 140,000 financial statements per year of non-financial enterprises, including both incorporated and non-incorporated companies. The assignment of enterprises according to business activity in the German Central Bank study is based on the German Classification of Economic Activities (WZ-2003) from the Federal Statistical Office. Because the various renewable energies are not specifically itemized here, comparable branches were consulted. The average profit-turnover ratios of the various branches were used to establish a mean value for the years 2000 to 2009.

In two cases, a different method had to be applied. For the assessment of the profits for System Operator, before-tax earnings were calculated with the help of average return on equity for each of the corresponding RE technologies; this information was drawn from the Renewable Energies Act (EEG) Progress Report (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit [BMU], 2011). The profits earned in connection with the provision of wood fuels were calculated from turnover minus cost of provision.

Employment and income effects

The income effects as a function of turnover are ascertained for each of the value-added steps; in addition to the data on income this method also provides results on employment effects.

Initially the employment effect is calculated as the number of persons employed. The Federal Statistical Office publishes figures on employment numbers and turnover; these figures, broken down by branch are allocated to the corresponding value-added steps. Thus, an indication of jobs per euro of turnover can be ascertained, which multiplied by turnover per kW installed capacity yields a figure for the number of employees per kW. Wages and salaries in euros per kW are determined on the basis of an average gross annual income in the business branch of the corresponding value-added step, as determined from Federal Statistical Office sources.

An exception is the calculation of management salaries for the stage System Operator. For these, typical specific management compensation figures on a per kW basis were taken from an analysis in the IÖW project EXPEED (Hirschl & Weiß, 2009). The number of employees per kW is then determined as the quotient of the specific income and a typical gross monthly income for the corresponding Federal Statistical Office occupational category. In the case of the provision of wood fuels, the employment and income effects are ascertained on the basis of the specific working-time requirement for each of the value-added steps.

Taxes

Calculation of the tax load of an enterprise is essentially dependent on its corporate structure. Therefore enterprises contributing to the value-added process are subdivided into incorporated and non-incorporated companies in order to account for differences in tax structure. The calculation of net income is derived from gross annual incomes of the occupational categories in the value-added stages under consideration, taking into account the current tax environment as well as Social Security contributions.

The municipalities profit in the value-added process in two ways. First, enterprise profits are subject to business taxes that are paid almost entirely to the municipality. Only a tax levy has to be paid to the federal government and the states. Second, the municipalities participate in a share of the taxes assessed on wages and income. On the one hand, participants in a partnership pay personal income taxes in addition to business taxes. On the other hand, local municipalities profit from the payroll taxes of employees in the firms.

Method implementation for an average model municipality

By way of illustration, the method was implemented to an average model municipality, which has 75,000 residents and is characterized by an installed capacity according to the German average of installed capacity per capita as well as by an average of manufacturing capacity in the considered year 2011.

Therefore the installed capacity in 2011 is an essential input. It is the basis for the calculation of the manufactured components and the planning and installation. The im- and export of components and technologies are taken in consideration as well.

For the local value added generated by the operation of the facilities, the installed capacity before 2011 was relevant (half of the newly installed capacity in 2011 was also added). To determine the effects by biomass supply, the consumption in 2011 was taken as a basis. Based on the installed capacity, the specific value per resident in Germany was calculated and then multiplied with the residents of the model municipality.

Results

In total, 9.3 million euros of municipal value added were generated within the average model municipality in the year 2011 by the manufacturing of the components, the planning and installation of RE systems, O&M and the system operator.

Figure 1 shows the model results for the different RE technologies. The most important contribution was generated by the solar power. This can be explained by the enormous amount of newly installed solar systems in the year 2011. More than half of the value added in this industry was composed of the wages of the employees followed by company profits. Of the total municipal value added, a share of 4.4 million euros was after-tax profits of the participating enterprises and 4.1 million euros were net incomes of the employees involved. 0.8 millions were the municipal share of the taxes paid on business profits and on adjusted gross employee income. About 166 employees in the average municipality had a job in the RE sector.

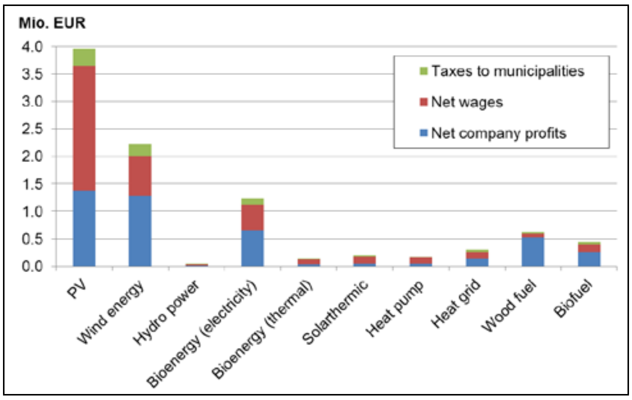

Figure 1: Municipal value added in the average municipality differentiated by RE technologies.

In Figure 2, the results for the four value-added stages are depicted. It can be seen that the production stage contributed the largest share to the total municipal value added in the year 2011. But in sum the continuous effects i.e. the effects generated by O&M and the operator, were bigger than the one-time impacts by production as well as planning and installation etc. Moreover, the size of the continuous effects will increase year by year whilst the expansion of the renewable energies proceeds. This means that, although production is very important relating to the value added by RE, the continuous effects are significant as well. This is a good message for all municipalities, which do not have manufacturing industry in their region.

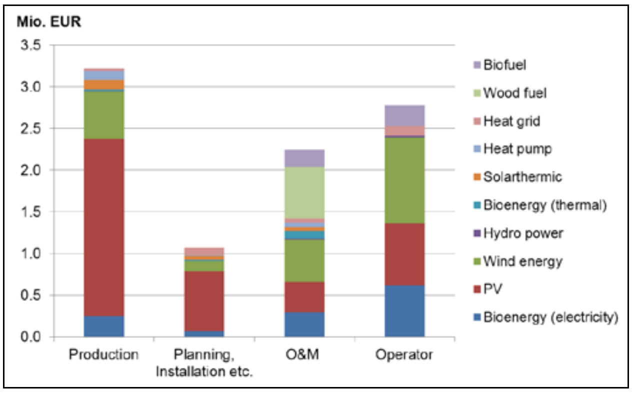

Figure 2: Municipal value added in the average municipality differentiated by value-added steps.

Discussion

The knowledge of value added as well as employment generated in connection with RE technologies on a local and regional scale is increasingly gaining in importance. Until recently, a method for a detailed analysis of the effects had been lacking. The model developed by the Institute for Ecological Economy Research can be used to quantify the effects of value added and employment for different geographical units (community, region, state or country). The model results are not only technology specific but, due to the modular structure of the model, the effects can be calculated for every value adding step along the value chain as well as every component of value added. Given the knowledge of the locally installed RE capacity and the local RE companies along the value chain, a model implementation for various geographical areas is possible. The potential for transferability is thus an important feature of this method. However, collecting the necessary data is often a difficult task.

The model results for the average model municipality in the year 2011 show, that the use of RE technologies can make an important contribution to municipal value added and local employment. The extent of the impact on the local economy varies depending on the RE technology considered in the model as can be seen in Figure 1. There are several reasons for this. On the one hand, the effects depend on the installed capacity and the biomass consumption in the community. On the other hand, differences regarding the cost-structures of investments in the specific technologies, the different feed-in-tariffs under the German Renewable Energies Act (EEG) as well as the specific employment intensities lead to technology-specific profiles with regard to municipal value added and employment effects. Naturally, the community benefits the most if all of the value-added steps of a specific RE technology take place within the region. But significant effects can also be generated even if this is not the case, for example if there is no local production but a high level of installed RE capacity and vice versa.

With the presented method, the direct effects induced by the use of RE systems can be quantified. The model is not constructed to determine indirect effects generated on upstream value-added stages. A possible inclusion of these indirect effects, i.e. by coupling the developed model with other methods, such as input-output, might result in higher municipal value added and employment effects. For a comparison of the results with other studies it is thus necessary to verify the effects considered and their comparative validity.

Impacts on the local economy that result from a substitution or a crowding out of economic activities (i.e. conventional energy generation) due to the use of RE cannot be quantified either by means of the method presented here. An assessment of these effects is a complex task which requires further research. Lehr et al. (2011) have quantified net employment effects for different expansion scenarios on the country level and they illustrate, that altogether the net effects are still positive. However, the distribution of the effects can be very heterogeneous and this can imply that in individual communities the balance is negative, whereas in other communities positive effects are generated.

Moreover, the presented methodology focuses on monetary valuation and is thus only one aspect of an assessment of sustainable business practices, as the ecological and societal aspects are initially not considered. Nonetheless, the economic effect of value added is an important criterion that can contribute an element of impartial objectivity. For instance, the quantification of the regional economic effects that can be induced by the use of RE sources in specific municipalities or regions makes it possible to compare the results with data on value added and employment in other sectors of the economy. This can be of assistance for local decision-makers since it enables them to assess the magnitude of the impact on the regional economy. In addition, the collection of the input data necessary for the model implementation in a specific community or region (installed capacity, companies along the value chain, etc.) can facilitate a targeted cluster management for the RE sub-sectors as it focuses on the various enterprises and investors along the value chain.

The assessment of local value added and employment effects can thus be an important factor concerning the local acceptance of RE technologies as well as the further expansion of RE in a region.

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III. Scientific Papers

Technology

Appropriate Microenergy Techniques: A Shortcut to Balancing the Social Systems of Informal Settlements in Cairo, Egypt

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Abstract

Both energy and recycling have become a worldwide primary necessity due to the increasing production of solid waste. In this paper, recycling is looked at as the main instrument in how it can contribute substantially to greening Cairo's urban poor in informal areas while concurrently encouraging the residential own microenergy techniques. In a way of celebrating the problem of garbage accumulation within another problematic aspect of informal housing sector challenges and its inappropriateness for the quality of life of the inhabitants, a self-sufficient recycling prototype for the informal settlement in Cairo is tackled to achieve sustainability of the heart of the city, mainly through microenergy production techniques using garbage, and substantially by promoting the residents' sense of belonging and connectedness in support of the community and the environment. It is hypothesized that proper use of waste from energy can be attained by using biogas plants to achieve a certain level of sustainability in the urban poor.

Keywords: Waste, Microenergy, Informal Settlements, Cairo.

Introduction

I have investigated a number of recycling techniques and renewable energy production technologies that can be used to change the urban, environmental, economic, and social face of informal communities in Cairo, with the potential to promote commitment by stakeholders to own their development Initiatives. Over the span of 10 years, I have supervised a number of high-profile students' investigations that resulted in a variety of options and solutions; all relates to the recycling potential and its feasibility in informal settlements to formulate "sustainable community adaptation plan."

Since 2005, recycling and renewable energy applications in urban development have been studied in our research work ESU-Lab in the Architectural department, Faculty of Engineering, in cooperation with other disciplines of Engineering (Mechanical & Electrical Engineering). In this context, several research thesis, themes, and international projects (TEMPUS - FP7; IRSES) have been developed with foreign partners in USA and Europe as well as professors and young researchers from Mansoura University to examine preliminary selected case studies and their potential to represent the feasibility of using such systems as an approach to improve renewable energy integration in urban context, energy efficiency, water distillation and food production.

In August 2008, the local Sustainable Consumption and Production Programme for Cairo City, prepared by the National Sustainable Development Framework Strategy suggested the following procedures:

- Upgrading slum areas and providing services and infrastructure, as well as preventing the growing-up of new areas.
- Providing slum dwellers with access to land and low-cost building materials.
- Offering better land use planning and management for energy saving.
- Promoting measures of energy saving; such as efficient lighting.
- Encouraging energy-efficient building design.

In a way of celebrating both the dilemma of energy production, efficiency, and carbon emissions, and the problem of garbage accumulation, all within another problematic aspect of informal housing sector challenges and its inappropriateness for the quality of life of the inhabitants, this research is to develop self-sufficient recycling prototype for the informal settlement in Cairo to achieve sustainability of the heart of the city, through; a) production of electricity power using garbage, b) production of new building materials using garbage, c) creating new job opportunities for the residents, d) educating them on participating communities' initiatives, e) strengthening crime prevention, f) reinforcing the residents' sense of place, and g) promoting their sense of belonging and connectedness in support of the community and the environment; whilst maintaining the original urban fabric of the focus area.

Research Objectives

This research aims to examine local recycling and appropriate microenergy systems in the form of biogas produced from waste, as a combined approach to balancing and promoting both the quality of life and social systems of informal settlements in Cairo, Egypt.

Hypotheses

A waste-to-energy plant facility in the form of biogas plant is hypothesized to contribute to the growth and sustainability of Moqattam, Cairo, by adapting a manufacturing purpose with significant investment for equipment, building use and creation of new green jobs. Given a special focus on the informal settlements, the research approach is based on the above governmental strategy toward the Egyptian urban and rural areas, whilst supported by recommendations on the employing the ideas of - and adopting the techniques made available by international expertise. Recycling processes and transformation of the existing building roofs of the targeted area at Moqattam into green roofs are combined with the development concept, to conform more productivity of energy by composting.

Informal Sector Recycling in Developing Countries

Hundreds of thousands of the residents in the developing countries depend on recycling materials from waste for their livelihoods (Medina 2009). Keeping in mind the Millennium Development Goals and their focus on poverty reduction - and of waste strategies on improving recycling, one of the major potentials in solid waste management in developing countries is how best to work with the informal sectors to improve their livelihoods, working conditions and efficiency in recycling, while bring it into successful business. (UNDP 2005)

The general characteristics of informal recycling are reviewed in Figure 1; highlighting both positive and negative aspects of its processes and applications. Despite the health and social problems associated with informal recycling, it can provide significant economic benefits that need to be retained, mainly by allowing for a renewable energy source, produced by the local residents.

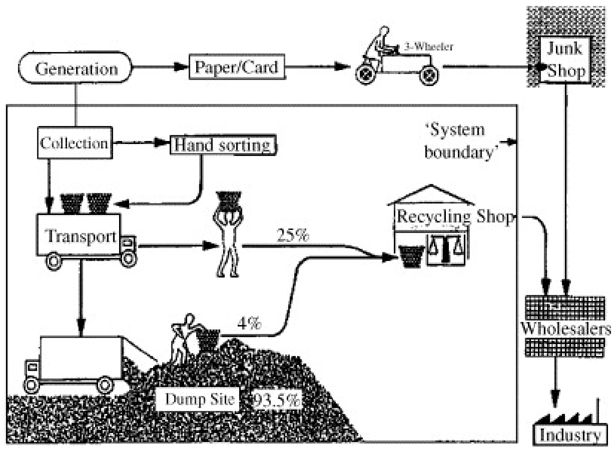

Figure 1: Four types of informal recycling: an example of an informal recycling system. (Wilson 2010)

Microenergy Planning for Growing Cities

According to Scheinberg (2012), the energy priorities that need be better addressed in city planning include but not limited to:

- using waste as an energy feedstock. This goes hand in hand with other municipal services such as waste collection and sanitation;
- electricity access for the urban poor which needs more urgent focus; and
- a well functioning transport system that does not solely rely on private car ownership, but also on public transport and non-motorized transport is imperative.

In addition to recycling, this project based approach adopts the concept of building roofs' conversion in the area into green roofs, combined with the development concept of recycling to conform more productivity of energy by composting.

Acquiring Microenergy Systems from International Expertise

Municipal recycling generally implies substantial investments in high-income cities, mainly in knowledge and infrastructure for valorization; motivated by the financial pressures from comparatively modern disposal, Figure 2. (Scheinberg 2003)

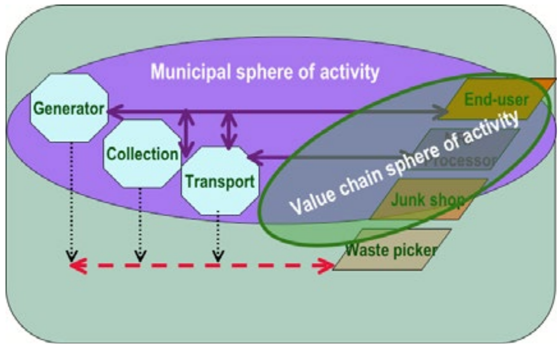

Figure 2: Municipal recycling as experienced in high-income countries. (Mitrovic et al.)

The main financial benefit perhaps is the avoided costs of disposal. Getting materials to the value chain is simply less expensive than modernized disposal. On the other hand, low- and middle-income communities – such as our example in Cairo - suffer almost the same pressure that subsequently lead to cities and regional governments claiming an exclusive right to valorize the materials in the waste stream, besides getting revenues from marketing materials. To these cities, recycling should mean that they are seeking the "gold in the garbage;" not just to avoid disposal, but rather to celebrate and finance it, while having interest in pushing value chain actors out.

Case Study: Moqattam Informal Settlement, Cairo

The area suggested to examine this proposal is located in Moqattam, Cairo. From the daily garbage (8000 Ton) produced in Cairo, one-third is collected and conveyed to the garbage city of Moqattam. Table 1 indicates the amount of the garbage in the seven major categories of materials.

Table 1: Amount of seven major categories of per-day garbage materials collected in Moqattam. UN-Habitat Report (2009)

Iron	0,05	10,238			120,000
Copper	0,13	26,619			139,000
Aluminium	0,40	81,904	Metal in total		152,000
Tin	3,90	798,564	4,48	917,325	139,000
Nylon Bags	0,13	26,619			156,000
Soft Plastic	0,30	61,428	Plastic in total		72,000
Transparent Plastic	0,70	143,332	1,13	231,379	152,000
Cloth/ Textiles	1,00	204,760	1,00	6,447	240,000
Glass	32,40	6 634,224	32,40	2 895,588	250,000
Paper	1,50	307,140	Paper in total		76,000
Cardboard	1,40	286,664	2,90	593,804	125,000
Organic Waste	20,00	4 095,200	20,00	1 787,400	514,000
Rabbish	20,00	4 095,200			
Nakdah	15,30	3 132,828			
Total:	97,21	19 904,720	61,91	6 431,943	
	(%)	LOOSE (m3)	(%)	(m3)	density LOOSE (kg/m3)

Household garbage per day

Mokottam (m2)	Site (m2)			
250000	11060	4,43%		
20 476,00	907,0868		(m3)	
4300	190,49		(t)	density: 210 kg/m3

Figures 3, 4 illustrate the location and anticipated sequential phases of recycling for the selected site. The process starts with 1) sorting the garbage; 2) trading the recycled matter with other areas into the energy-to-waste-plant; and 3) adopting more green spaces in the outdoors and on roof tops, while facilitating the required energy links to and from the area.

Figure 3: Sorting and Recycling Process. (Albadawy et al.)

Figure 4: Greening the informal selected area. (Albadawy et al.)

Figure 5 discusses the energy potential of recycling the garbage of the selected area by ratio and weight factors. Daily garbage composition is investigated for iron, copper, aluminum, plastics, textile, glass, paper, glass, and organic waste. A waste-to-energy plant facility will be constructed at a vacant site adjacent to the existing Municipal Solid Waste management (MSW) plant and is hypothesized to contribute to the growth and sustainability of Moqattam, Cairo, by adapting a manufacturing purpose with significant investment for equipment, building use and creation of new green jobs. The method suggested is based on the assumption that the entire garbage collection processes can be implemented by local residents.

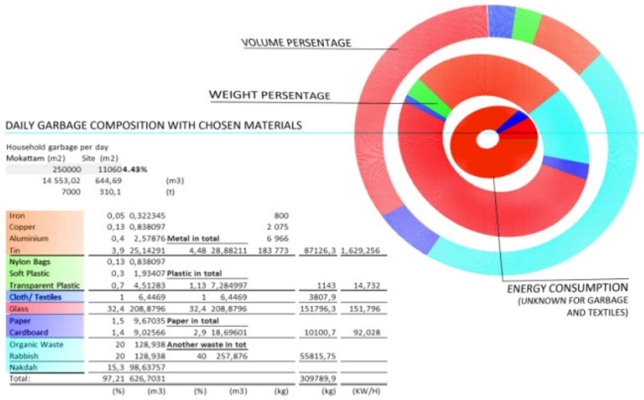

Figure 5: Daily garbage/energy potential. (compiled by Albadawy et al.)

According to a number of site visits and author's meetings with stakeholders, the area needed for the energy plant can be either facilitated by the local government or purchased by a group of landlords as private investment. Civil society and NGOs are expected to play a key role in this focus. Return on the investment (ROI) will primarily include energy production from waste in the form of electricity. Appropriate measurements of the site will be ensured to reduce the GHG emissions and comply with the Egyptian law of the environment (Law 4/94). The thematic project phases and success indicators are discussed in Table 2.

Table 2: Thematic project outline. (The author)

Activities	Outcomes	Suggested Entities of Implementation	Verifiable Indicators
- Selection of eligible area for implementing the project. - Awareness on source segregation benefits. - Informing waste collection company of segregated waste collection methods. - Creating incentives for segregation. - Preparing solid waste segregation and collection strategy among districts.	- Segregated waste in the selected district. - Increase efficiency of recycling - Lowering the cost of segregation process. - Energy produced from waste in the energy plant. - Green jobs created.	- EEAA - Media - NGOs - ENCPC - Universities - Cairo Governorate. - GIZ	- Rates of segregated wastes. - Numbers of people aware of the segregation methods and benefits. - Decrease amounts of accumulated waste. - The amount of energy produced from waste in the energy plant. - The number of green jobs created.

Methods

A biogas, waste-to-energy plant is recommended to consume a fraction of segregated food waste/ vegetable waste from homes, markets, restaurants and black water from community toilets as the source. The plant will be installed at the vacant site adjacent to the existing Municipal Solid Waste management (MSW) plant in Moqattam, Cairo. A couple of combined heat and power plants of 200kWe and 60kWe are proposed to be installed. It would consume from 10MT up to 30MT of organic waste and 21 MT of septage per day.

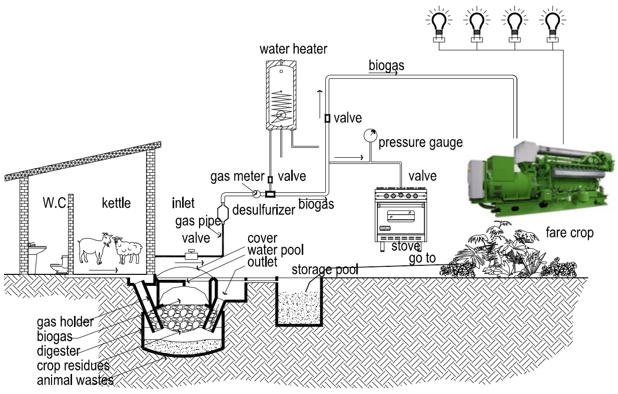

Figure 6: Schematic waste and energy flows in the system including biogas production and usage (the author)

As indicted above, such a plant achieved with technical assistance of biogas techniques and technologies can be facilitated by the German International Cooperation (GiZ) through one of the internationally funded programs, coordinated by Egyptian universities.

My claim to foster recycling as a potential microenergy solution for Cairo's informal settlements' problems is tackled with a schematic design approach. The area selected to examine the suggested approach is located in Moqattam, Cairo; an informal, poor community that is also known as the "garbage city" which contains a slum settlement on the outskirts of the capital city of Egypt. The main approach to tackle its multi-faceted challenges goes deeply into the identity roots of the community by the analytical research and investigates the main parameters of this area. With one of the largest informal settlements of the world, a substantial power is found to give the most efficient recycling system (up to 80-85% recycling efficiency). Reducing the conflict between this successful waste disposal system and the poor living condition for people was the main design target. Integrating both parameters will the design process base for developing quality of life and spatial qualities.

Discussion

Community Sustainability Adaptation Plan with the Help of Microenergy Techniques

Experience shows that appropriate, local recycling can be highly counterproductive to establish new formal recycling and energy production systems without taking into account informal systems that already exist. The preferred option is to integrate the informal sector into waste management planning and energy producing business, building on their practices and experience, while working to improve efficiency and the living and working conditions of those involved.

In the above sense, I suggest long term collaboration with international partners to be built to prepare for our successful projects and expansion. The partners may not provide capital; rather they are welcome to allow for the strategy and regular management support that can make Microenergy systems possible in these areas. Accordingly, the inhabitants in the proposed pilot city of Moqattam are the direct customer of our provided recycling solution. People can be paid to drop their recyclable into the underground waste containers. The more people do recycle with, the more recyclable will be acquired. Environmental NGOs can support this business in several ways, for instance carrying out social promotion in the public area, holding environmental education in the schools, universities and residential areas; this requires further cooperation with all stakeholders, mainly international partners.

The suggested biogas plant - as a means of waste-to-energy production - is a model that will normally require prerequisite awareness raising and capacity building programs of the residents in the skills to support this development. In addition to their role of paving the way for international partners to get involved, I can envision the nearest universities' major role in coordinating this effort within each locality. From my personal experience in such areas, the media can play an important role if utilized as public eco-awareness improvement as well as a free marketing and advertizing tool - with good information spread. The collaboration with international partners seems to me to create a win-win mode: the project manager receives sponsorship from large producers to increase profitability and social influence, while allowing producers the possibility to launch their green marketing.

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Experimental analysis of the dynamic behavior of a solar PV/diesel hybrid system without storage

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Abstract

The present study discusses the potential problems linked to the integration of PV systems to a local grid. Particularly, the study is focused on the voltage regulation, current supply and harmonic distortion issues due to the integration of a PV system on a standalone diesel generator, basing on the experimental results of the "flexy energy" prototype. This prototype is composed of a 2.85 kWp PV array, a 3.3 kW single phase inverter and a diesel generator rated at 9.2 kW. Results show that "well designed" inverters generate very small voltage harmonics and current distortions, even when high PV penetrations are considered. Also, it is found that the PV generation leads the distribution feeder to shift toward higher voltages.

Keywords: PV/Diesel hybrid system, Dynamic behavior.

Introduction

Renewable energy resources such as wind or solar are often the most efficient option for making electricity available to the billions of people that currently do not have access to it. Due to recent advancement in technology and competitive costs of electricity generation from wind and solar photovoltaic, the use of renewable sources of energy is being encouraged nowadays (Rehman et al., 2011).

In particular, the photovoltaic power production promises to be a clean, widely applicable renewable energy source available for the rural electrification in sub-Saharan Africa region. Indeed, countries of this region are well endowed in solar resource: their mean daily solar radiation exceeds 5.5 kWh/m^2/day. They are, therefore, good locations for PV systems. (Azoumah et al., 2010). However due to their unpredictable nature, photovoltaic systems are often coupled to diesel generators to meet efficiently the load demand. (Deshmukh & Deshmukh, 2008; Hochmuth, 1997; Shaahid & El-Amink, 2009; Papadopoulos & Maltas, 2010; Ashari & Nayar 1999). Besides, the integration of PV systems to an utility grid or to standalone diesel generators can have significant impacts on the power quality if appropriate cares are not taken. In fact, the electricity grids must have standard conditions of supply to ensure that the end use equipments and infrastructures can safely and efficiently operate. These conditions are commonly referred to as power quality requirements and are defined in standards or by supply authorities. They are commonly related to voltage and frequency regulation, power factor correction and harmonics (Passey et al., 2010). A very significant issue linked to these technical requirements is the PV penetration level on the grid. It has been shown that a high PV penetration level can lead to unacceptable conditions for the grid (Mohamed & Zhengming, 2010). Hence, the aforementioned technical requirements need to be satisfied to maintain a reliable and a safe electricity distribution network.

This paper deals with an experimental study of the dynamic behavior of a hybrid PV/Diesel system without storage facility called "flexy energy" prototype. This prototype has been set up in the framework of the validation of the "flexy energy"concept wich is an original approach developped by the Solar Energy and Energy Saving laboratory of 2iE. This concept consists in decentralized electricity generation through hybrid PV/Diesel systems without storage in batteries and with a smart management of the energy production and loads to be supplied.

Experimental analysis of the dynamic behavior of the "flexy energy" prototype

This paper discusses the potential problems linked to the integration of PV systems to a local grid are. Particularly, the study is focused on the voltage regulation, current supply and harmonic distortion issues due to the integration of a PV system on a standalone diesel generator, basing on the experimental results of the prototype under consideration.

Experimental set up

The experimental set up is a hybrid solar PV/Diesel system without energy storage in batteries. It is composed by a 2.85 kWp PV array, a 3.3 kW single phase inverter and a diesel generator rated at 9.2 kW (see Figure 1).

This prototype is implemented on the site of the International Institute of Water and Environmental Engineering (2iE) at Kamboinsé, located at 15km of Ouagadougou, Burkina Faso (Yamegueu et al., 2011). Two resistive load banks of 4 kW each are used to simulate the load profiles. A grid analyzer (C.A 8310) is used to study the quality of the power generated by the system in terms of voltage and current harmonics (www.chauvinarnoux.fr).

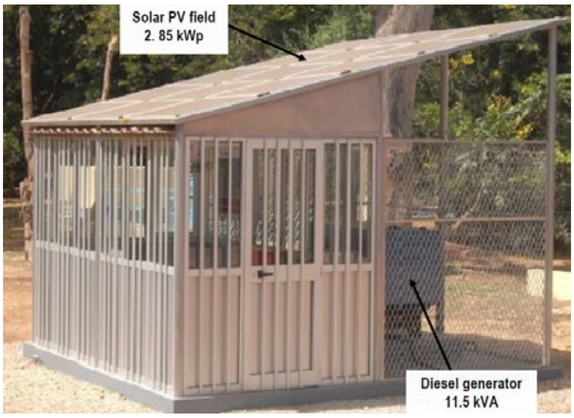

Figure 1: Prototype of the”flexy,energy”concept.

Results and discussion

In this section, the experimental results concerning voltage fluctuations, current supply and harmonic distortion issues of the “flexy energy” prototype are displayed and discussed. As, the prototype studied includes a single-phase inverter, the PV generation is then connected to one phase of the diesel generator.

Voltage of the grid Figs 2-4 display the voltage of the grid (of each of the three phases) when the PV inverter is connected respectively to the phase 1, phase 2 and phase 3 of the diesel generator.

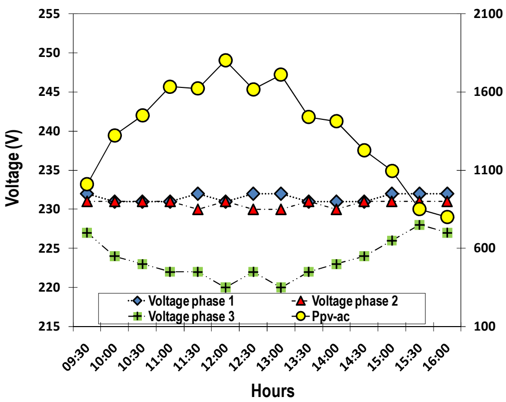

Figure 2: Grid’s voltage for the PV system connected to the phase 1 of the diesel generator.

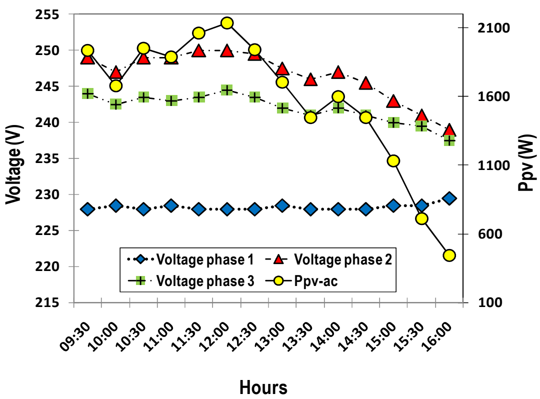

Figure 3: Grid’s voltage for the PV system connected to the phase 2 of the diesel generator.

In each scenario, one can observe a voltage imbalance on the grid. This can be explained in the present case by the PV generation imbalance on the grid; indeed, as already mentioned, the facility under consideration has a single-phase inverter connected to one phase of a three-phase’s diesel generator. In the three scenarii, one can see a voltage rise on the phase where the PV generator is connected to. One can conclude that the PV generation causes the distribution feeder to shift toward higher voltages (Graf, 1996).

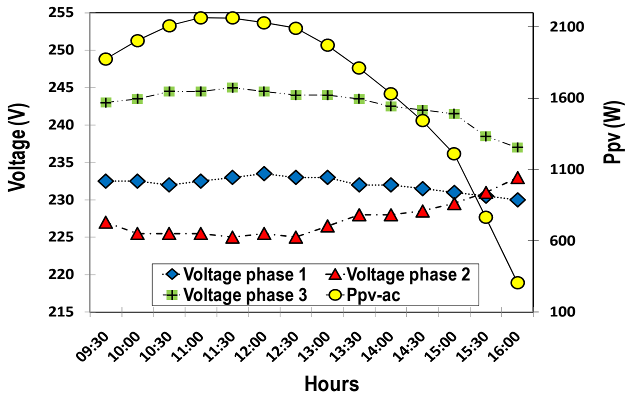

Figure 4: Grid’s voltage for the PV system connected to the phase 3 of the diesel generator.

Also, it can be noticed that in each scenario, the higher the PV penetration, the higher the voltage rise. However, the voltage rise in the phase where the PV generation is injected, for each scenario, remains in the range allowed by the standard (EN 50160) in low-voltage distribution network. In fact, the standard EN 50160 states that the variation of the voltage should be in the range of ±10% of the nominal voltage (Markiewicz & Klajn, 2007) and in the three scenarii studied here, the voltage increased by less than 10% of the nominal voltage (phase to neutral voltage). In the three cases, the mean voltage rise is respectively 0.7%, 7.2% and 5.5%.

The voltage imbalance observed here can also be explained by the asymmetric nature of the loads used for experimentations.

Current of the grid Figs. 5-7 show the current of the grid.

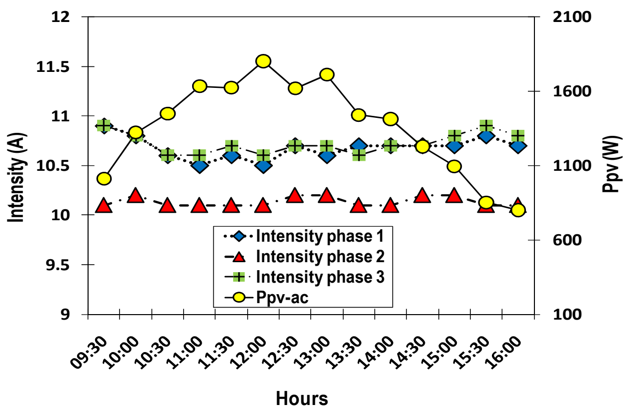

Figure 5: Grid’s current for the PV system connected to the phase 1 of the diesel generator.

The values of the current in the grid are studied for each scenario ie when the PV generator is connected respectively to the phase 1, phase 2 and phase 3 of the diesel generator.

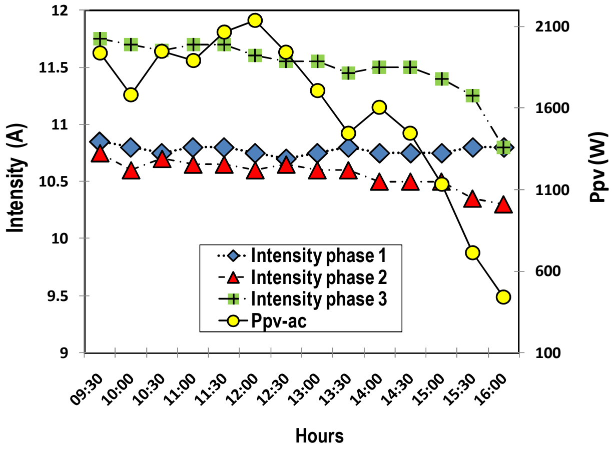

Figure 6: Grid's current for the PV system connected to the phase 2 of the diesel generator.

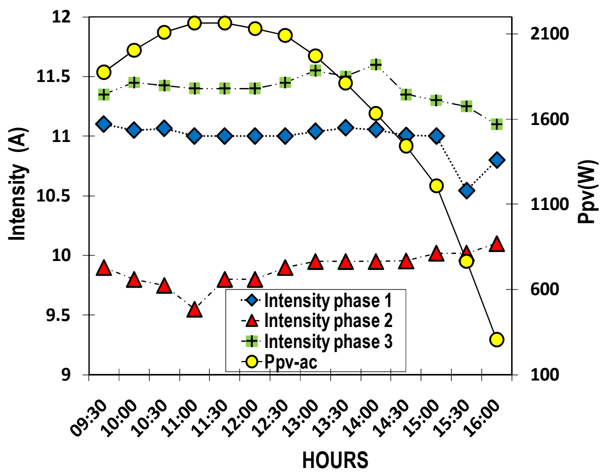

Figure 7: Grid's current for the PV system connected to the phase 3 of the diesel generator.

In the three scenarios, one can observe a current imbalance on the three phases of the grid. Moreover, the current supplied to the phase 3 of the grid is higher than those on the other phases regardless of the PV injection phase. As the current supplied by the system depends on the load on the feeder, one can state that the imbalance behavior of the current supply observed is due to the asymmetric nature of the three-phase loads used in this study.

Therefore, asymmetrical loads connected to a three-phase network can lead to imbalance of current and voltage in the grid (ERDF; CA).

Harmonics. In this section, the effect of the PV generation on the voltage and current grid's harmonics is studied. Figs 8 and 9 show respectively the current and the voltage total harmonic distortions (THDI and THDV) of the grid when the system is connected to the phase 1 of the diesel generator. In Figure 8, it can be observed that the current harmonic on the PV connexion phase is higher than voltage harmonics on the two other phases. In fact, one has a current total harmonic distortion (THDI) of 4.5% on the PV connexion phase while it is about 3.7 and 4% respectively on the phases 2 and 3 of the diesel generator. By comparing these harmonics values, one can say that the maximum contribution of the inverter to the THDI is almost 0.5%. This is in the line with the standard which states that a typical requirement for a grid-connected PV inverter is that it produces no more than 5% THD of its full rated current (HESPUL).

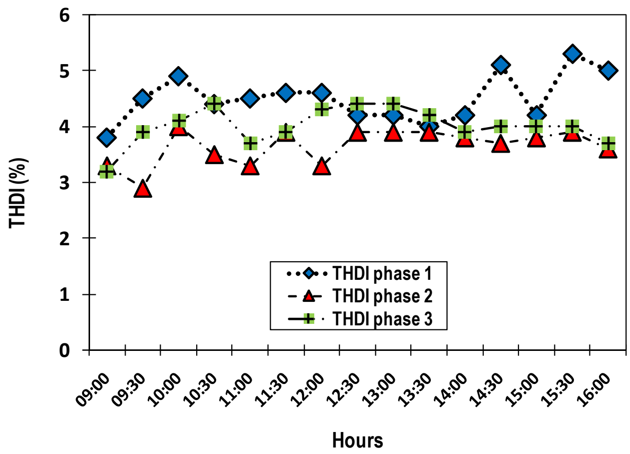

Figure 8: Current harmonic in the grid.

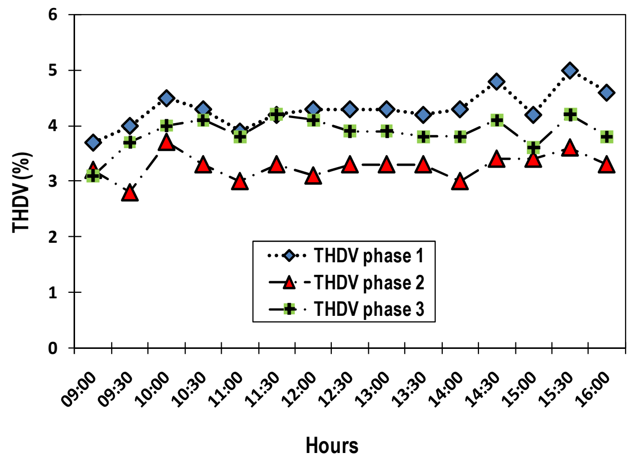

Figure 9: Voltage harmonic in the grid.

On the other hand, harmonic currents interact with the impedance of the grid to produce harmonic voltage. As one can see on Figure 9, voltage harmonics on the PV injection phase is higher than those on the two other phases. Indeed, the voltage harmonic on the phase 1 is about 4.3% while it is about 3.3% and 3.9% respectively in the phases 2 and 3. So, the harmonic increase due only to the PV generation is about 1% or 0.4% (compared respectively to the phases 2 and 3). However, whatever the grid phase is, the voltage total harmonic distortion (THDV) is in the range allowed by the standards (between 5% and 8% in LV) (Markiewicz & Klajn, 2007; Bower & Ropp, 2002).

Finally, the presence of harmonics on the other phases of the grid where there is no PV penetration indicates that the voltage sources as the alternator of the diesel generator contain pre-existent harmonics which exist even when linear loads are used (Schneider Electric), as those of this study.

Conclusion

The combination of renewable energy sources such as PV with diesel generator appears to find increasing appeal in implementing decentralized electricity generation systems for remote areas.

An experimental study of the dynamic behavior of a PV/diesel hybrid system without storage is addressed in this paper. One finds that the PV generation causes a voltage increase in the injection feeder, and the higher the PV penetration, the higher the voltage rise. Especially, for the present study, this voltage rise leads to a voltage imbalance on the grid due to the fact that the prototype under consideration has a single-phase inverter. This situation may cause damage to the users (loads). Thus, care should be taken to ensure that for a PV/diesel hybrid system, the PV rated power connected to each phase of the grid is as equal as possible.

The experimental results also indicate that the PV generation leads to an increase of current and voltage harmonics but this increase never reaches a critical level when high-quality sine-wave inverters are used. Therefore, the basic conclusion is that "well designed" inverters enable very small harmonic voltage and current distortions, even when high levels of the PV penetration are considered.

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Development and evaluation of a guideline for testing small-scale biogas stoves

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Abstract

High dependency on woody biomass in Uganda has raised concerns about indoor air pollution and climate change. Biogas is a clean alternative; however to increase the number of installations, the associated technical challenges must be addressed. This study considers the performance of the stoves promoted under the Uganda Domestic Biogas Program with the aim of supporting the development of Ugandan stove standards. The stoves had average cooking efficiencies of 33% to 44%. The workmanship of the stoves was poor. Most of them had no gas taps, short frames and were unstable; factors which could cause injury or damage to property. For future work, other factors to consider are gas pressure, effect of wind, ignition time and the air intake.

Keywords: Biogas, Stoves, Uganda

Introduction

Like most of sub-Saharan Africa, biomass fuels cater for over 90% of Uganda's annual energy consumption (Davidson et al., 2007). Woody biomass is typically used to provide heat and light in homes; in institutions like schools, prisons and hospitals; in restaurants and hotels; in small scale industries like lime, bricks and clay tiles; and in agro-based industries like tea, tobacco and fish smoking (Walekhwa et al., 2009).

The high dependency on woody biomass has raised serious environmental and health concerns related to climate change and indoor air pollutants respectively (Singh and Sooch, 2004). Poor household air quality is linked to pneumonia, lung cancer and chronic lung disease. Globally, it leads to approximately 1.6 million premature deaths annually (Ezzati et al., 2004).

In Uganda, a lot of agro waste is underutilised. Crop waste is burnt in fields while animal waste is left to decay and emit greenhouse gases like methane (Walekhwa et al., 2009). Anaerobic digestion allows for the utilization of this waste to produce biogas, a mixture of flammable gases that can be used for cooking, lighting, generating electricity and fuelling vehicles. Biogas has 50-70% methane, 30-50% carbon dioxide and traces of hydrogen sulphide and ammonia (Igoni et al., 2007). A calorific value of 17700 KJ/kg was assumed for the biogas in this study (Bond, 2009).

Biogas production is a clean and renewable naturally-occurring process with benefits such as energy access; improved food production through use of the slurry by-product as a fertiliser; reduced deforestation, erosion and soil degradation; improved indoor air quality and sanitation; and local job creation (Igoni et al., 2007).

The number of biogas installations across Africa has increased due to national domestic biogas programmes in various countries (Bos & Kombe, 2009; Khandelwal & Gupta, 2009). However, technical, environmental, financial and social questions remain. To increase the number of installations, rigorous answers to these questions must be provided (Pandey, et al., 2007).

The Uganda Domestic Biogas Programme (UDBP) started in 2009 and works towards the creation of a viable commercial sector for small-scale biogas digesters by providing subsidies to farmers for biogas installations. UDBP is hosted by Heifer International and supported by the Dutch Ministry of Foreign Affairs with technical aid from the Netherlands Development Organization (SNV) while the Humanistic Institute for Cooperation of Developing Countries (Hivos) manages the fund (Bos and Kombe, 2009; Pandey et al., 2007).

Biogas Burners

Biogas stoves are simple appliances used to combust biogas that should be stable, safe and ensure that the correct fuel/air mixture is supplied so that ignition is controllable and so that the flame produced is stable (Ariane, 1976). As shown below, the biogas stove design includes a gas supply tube, a valve, injector jet, primary air opening, throat, mixing tube, burner head, ports, pot supports and body frame (Khandelwal & Gupta, 2009).

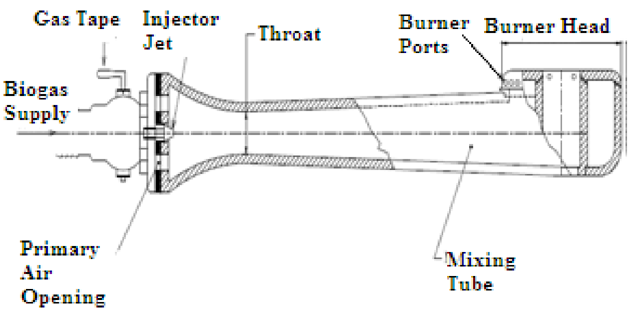

Figure 1: Biogas Burner (Khandelwal & Gupta, 2009).

Biogas burners operate on the principle that the pipeline pressure drives the gas and air into the burner head (Fulford, 1996). Gas consumption rates vary according to the pressure provided by the biogas plant and the diameter of the inlet pipe (Khandelwal & Gupta, 2009).

Research Objectives

The study aims to increase the understanding of the technical performance of the biogas stoves promoted by

Heifer International Uganda, under the Uganda Domestic Biogas Program in order to support the Uganda National Bureaus of Standards as it develops national stove standards. The specific objectives were to:

- Assess the physical structure and quality of nine locally fabricated Lotus-2 biogas stoves
- Use the Water Boiling Test Protocol to evaluate the performance of the nine stoves
- Determine the CO and CO2 emissions from the stoves

Methods

The stoves were tested using the Water Boiling Test (WBT) Protocol, version 4.1.2 (Bond, 2009). The WBT is a laboratory simulation of a basic cooking process that is performed at both high and low power. In high power, the tester uses the stove to bring 5 litres of water to boil in a standard pot without lid. In low power, the temperature of the remaining water is maintained at about 3°C below boiling point for 45 minutes. Before and after each phase, the flow of biogas was read off the flow meter, the pot and water were weighed and water temperature was recorded. The key parameters investigated by WBT are: cooking efficiency, specific fuel consumption, time to boil, burning rate and fire power. The figure below shows the apparatus that was used.

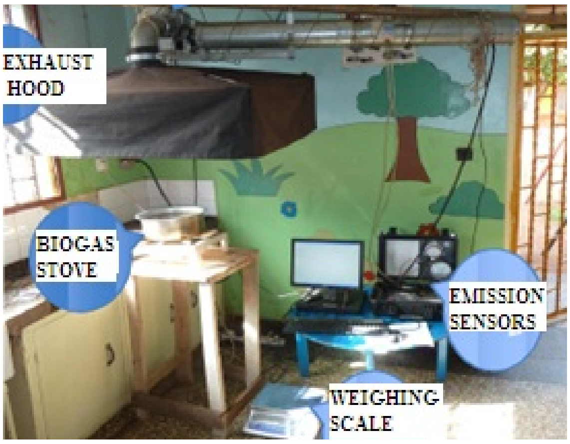

Figure 2: Experimental Set up.

Emissions were tested using the Portable Emissions Measurement System (PEMS #2009), manufactured by the Aprovecho Research Centre. The PEMS has an exhaust hood which draws gases upward where they are mixed and sampled. Concentrations of CO and CO_2 are measured in real-time by a data acquisition system, calibrated in terms of pollutant mass per volume.

Stove safety was assessed by examining possible causes for injuries to the stove user (Johnson, 2005). The stoves were checked for sharp edges that could entangle a cloth or injure the users. The stoves' stability was tested by tipping them. The temperatures of the stove frame were also taken during operation. The stoves were tested for leakages using a soapy liquid that was rubbed along joints and areas of potential leakage.

The tests were performed by staff from the Centre for Research in Energy and Energy Conservation (CREEC) at Nsambya Babies' Home, Kampala, Uganda. The home was selected because it has a $12m^3$ digester that is monitored by CREEC and which would provide a steady supply of biogas during the tests.

Results

Analysis of Stove Physical Structure

The following table shows all the stoves that were tested.

Table 1: Analysis of Physical Structure and Quality.

Stove Image	Comments on stove
	**Bremenn Stove** • Non- uniform size of burner ports • Low height of pan support
	**Double Burner Stove** • Burner made of copper pipe with single air intake • Low heat flow • Some burner ports did not work • No air-intake
	**Ideal Stove** • Low height of pan support
	**KEJ Stove** • Short height of pan support • Gas leaked at burner port • Frame gets hot and heat is transferred to its supporting table
	**Luwiki Stove** • No jet • Short height of base support
	**PSEM Stove** • Short height of base support
	**PSEM LargeStove** • Low height of pan support
	**REO Stove** • Low height of pan support
	**Tusk Stove** • Low height of pan support

Table 2: Physical Structure of the stoves

Parameter	Bremenn	Double Burner	Ideal	KEJ	Reo	Psem	Psem Large	Tusk	Luwiki*
Frame Height (mm)	120	137	121	94	120	118	160	120	113
Burner to pot distance (mm)	25	26	35	35	30	30	10	30	24
Burner Head Diameter (mm)	72	126/130	70	65	67	70	160	70	65
Number Burner Ports	20	25 & 28	20	20	20	21	40	20	20
Burner Ports' Diameter (mm)	6	2	6	5	6	6	5	6	5
Total Area of Burner Ports (mm^2)	565	79 & 88	565	393	565	594	785	565	393
Injector Jet Nozzle Diameter (mm)	5	6	6	5	6	8	5	6	4
Diameter of the throat (mm)	28	24	26.8	24	27.5	26.5	38	28.2	27
Mixing Tube Length (mm)	159	130/128	162	145	160	149	192	158	175
Presence of the primary air opening	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

*Luwiki had no jet and did not undergo any further tests.

Table 3: WBT and Emission Results (Values are an average of three test runs)

		Bremenn	Double Burner	Ideal	KEJ	Reo	Psem	Psem Large	Tusk
HIGH POWER	Time to boil (min)	22±6	29±10	25±10	23±3	18±2	23±6	21±4	15±2
	Burning rate (g/min)	13±3	12±4	15±6	16±4	18±3	15±5	17±4	20±4
	Cooking efficiency (%)*	41±2	41±6	38±5	33±4	37±4	37±4	35±4	37±5
	Specific fuel consumption (g/h/l of water)	172±33	146±53	188±74	205±52	220±41	195±68	215±52	248±59
	Firepower (kW)	3.5±0.7	3.2±1	4.1±1.7	4.5±1	4.8±0.9	4.2±1.5	4.7±1.1	5.5±1.3
	CO to boil (g/l of water)	1.4±0.08	3±2	3.4±2	15.5±0.6	4.5±0.2	0.4±0.2	6.5±0.2	3.7±0.2
LOW POWER	Burning rate (g/min)	8.5±2.8	6.±1.2	7.7±1.4	10±4	10±1.6	8.5±2	9±5	11.5±5
	Cooking efficiency (%)	44±4	42±4	35±9	38±3	42±2	37±3	37±4	41±4
	Specific fuel consumption (g/h/l of water)	118±33	87±20	111±21	147±62	142±11	126±29	143±79	185±103
	Firepower (kW)	2.3±0.8	1.7±0.3	2.1±0.4	2.6±1	2.7±0.4	2.3±0.5	2.6±1.3	3.1±1.4
	CO to Simmer (g/l of water)	0.6±0.02	1.7±0.9	2.2±2	20±10	6.6±0.2	0.7±0.2	9.6±4.6	4.7±2.9
PERFROMANCE	Fuel to Cook 5L (g)	720±37	677±98	787±78	964±274	884±38	858±115	785±34	1031±399
	Energy to Cook 5L (MJ)	12±0.6	11±1.6	13±1.3	16±4.5	14.5±0.6	14±1.9	15±4.2	17±7
	CO to Cook 5L (g)	10±0.3	29±12	28±25	177±54	55±0.3	3.4±1.2	80±24	42±14
	CO_2 to Cook 5L (g)	383±18	365±45	393±60	470±156	522±70	431±53	432±151	531±91
	Combustion efficiency** {CO_2/ [CO+CO_2]} (%)	97±0.2	93±3	93±5	73±4	90±1	99.3±0.2	84±1	93±1

* Cooking efficiency is percentage of energy in the fuel that is used to heat and vaporise the water in the cooking pot.
**Combustion efficiency is a measure of how much of the total carbon in the fuel is completely burnt to produce CO_2.

Stove Safety

Every stove, except the KEJS, had a mild steel frame welded with pot rest and gas burner components that were made of cast metal. The KEJS was made out aluminium. None of the stoves had sharp or harmful edges. All stoves except the Double Burner had round frames, were unstable and fell after being tipped. The stoves did not have valves to control the gas flow. All the stoves, besides the double burner, had frame temperatures above 110°C during operation. The double burner had a frame temperature of about 67°C during operation. All stoves passed the leakage test.

Discussion

The data in Table 2 and Table 3 shows that even though the Bremenn, Ideal, Reo, Psem and Tusk stoves were dimensionally similar they were differences in their performance. During the high power phase, the Tusk stove boiled water in a shorter time. It also had the highest firepower and consumed more fuel. This may have been due to variations in gas pressure, which depends on the gas production rate. Investigation of the gas pressure and velocity, which were not monitored during the tests, might provide more insight into how variation in pressure would affect stove performance (Khandelwal & Gupta, 2009).

Another factor that affects stove performance is the amount of air in the air/gas mixture (Khandelwal & Gupta, 2009). The Psem Large had the largest burner port area, throat diameter and longest mixing tube, all of which may have led to over dilution of the fuel by excess air and, thus, affected its combustion efficiency. This would have made ignition more difficult.

Insufficient air also affects stove performance (Fulford, 1996). The KEJ stove has a smaller throat diameter and shorter mixing tube than most of the other stoves. This may have led to poor mixing of the air and fuel, causing incomplete combustion and formation of the lethal carbon monoxide gas (Khandelwal & Gupta, 2009; Ezzati, M. & Kammen, D.M., 2001).

The stove's ability to transfer the heat produced during combustion is an important aspect of its performance (Fulford, 1996). The KEJ and Ideal stoves had combustion efficiencies of 73% and 93% respectively. However, their cooking efficiencies were between 33-38%. These stoves have the largest burner-to-pot distances that may have affected the heat transfer. In the space between the burner and pot, the burning gases may have mixed with surrounding air, thus, reducing the flame temperature. On the other hand, the Psem Large stove has the shortest burner-to-pot distance, leaving little room for the flame to develop and transfer heat to the pot (Fulford, 1996).

Generally, the stoves' cooking efficiency was higher during the low power phase than during the high power phase. The stoves' cooking efficiencies between 33% and 44% are lower than the Chinese and Indian Standard benchmarks of 55%. However, one should be cautious when comparing results produced using different protocols (Khandelwal & Gupta, 2009).

The WBT protocol rewards evaporation and renders it useful work. Thus during the low power phase, the stove with the highest evaporation rate is deemed the most efficient (Bond, 2009). These results suggest that the cooking efficiency may not be the most accurate parameter to assess stove performance (Jetter et al., 2012). The Ideal stove has the lowest cooking efficiency of 35% in the low power phase; even though it has a low specific fuel consumption rate of $111gl^{-1}h^{-1}$.

With frame temperature as high as 110°C for all the stoves except the Double Burner, they were considered unsafe (Johnson, 2005). As a result of the high temperatures and short frames the platform supporting the burner was heated. The KEJ stove had the shortest frame and, during its operation, the wooden stove platform was charred. The damage to the platform may have contributed to the high CO readings associated to the KEJ.

All the stoves were found to be unstable and had no valves to control the gas flow into the burner head. This points to poor workmanship in the stove fabrication.

Conclusion

The stoves that were tested were found to operate in both high and low power phases with cooking efficiencies of 33% to 44%. The fabrication of the stoves was poor as most of the stoves were unstable, had no control valves/taps and had short frames. These factors could lead to injury of users or damage of property.

The results of the WBT and safety tests were useful in determining the suitability of a burner for various cooking tasks as they use different measures to present the stove performance during different cooking phases. However, these tests may not suffice in describing the performance of biogas stoves. Additional factors need to be considered such as gas pressure, the effect of wind and ignition time.

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Frequency Control Applying Plug-in Electric Vehicles Based on Costumer Behavior in Electric Power Networks and Micro-Grids

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Abstract

A micro-grid is mainly consisted of distributed energy resources and energy storage systems. Electric vehicles (EV) can be assumed as both appropriate power generation units and storage devices. As it is planned, one million EVs will be applied till 2020 in Germany which could provide us with a great electric power potential and can be very useful in controlling the power network. A simulation has been done on a 39-bus IEEE standard network regarding the results of TU Chemnitz's psychological studies on the costumer's EV using behavior. The simulation outcomes show that, utilizing the potential of the vehicle's batteries could be very effective in the frequency control of power networks and micro-grids. Additionally is this controlling method also very environment-friendly.

Keywords: Electric Vehicles; Micro-Grids; Frequency Control; Psychological Studies; Aggregator; Smart Grid.

Introduction

With the increasing popularity of plug-in vehicles and the electro mobility industry, it is requisite to investigate their available potentials and effects on the power network's operation. Automatic demand control (ADC) was proposed before, next to automatic generation control (AGC) as an applicable method for secondary frequency control in electric power networks (Ameli et al., 2011) especially smart micro-grids. The electric vehicles (EVs) could also be very useful in this case because of their battery's characteristics of lower energy and quick response time. In other words in addition to the technical benefits, this potentials could also be applied for helping the electric power networks to maintain their stability by mean of ancillary services such as voltage and frequency regulation services (Luo et al., 2012; Wu et al., 2012). Micro-grids are commonly consisted of renewable energy resources like wind turbines or solar power units that have uncontrolled power output and so It's difficult to estimate their output power. The presence of energy storage systems which could store the generated power in specific times and deliver the consumers with energy every time it's needed is very essential (Ota et al., 2009). Battery energy storage could perform an important smoothing role because of their natural intermittency and ensuring grid-wide frequency stability (Ota et al., 2010). Utilizing smart grid capabilities, we could be aware of each vehicles state of charge (SOC) and know the amount of available power capacity from all the plugged-in vehicles (Han et al., 2011a; Shimizu et al., 2010). Regarding Germany's second national report about electro mobility, it is predicted to have about 1 million EVs in the streets of Germany by 2020 (NPE, 2011). Knowing that a single battery could provide 10-30 kWh (Han et al., 2010), there will be a considerable amount of power capacity (around 6 GW) which could be very advantageous for Germany's power network frequency regulation or a part of its power grid such as available micro-grids. An aggregator is necessary to deal with the small-scale power of the vehicles for providing the regulation service on an appropriate large-scale power (Han et al., 2010; Han et al., 2011b; Han et al., 2011c). Smart Grid capabilities are unavoidable for the aggregator's better performance in collecting data from the car owners. It's also inevitable to consider the psychological behavior of the human beings in using an electric vehicle and connecting it to the power grid (TU Chemnitz, a; b). The minimum and essential requirement of the vehicle owners for joining the ancillary service is to be guaranteed about the charge of their battery to a desired level (up to 80 %) by the next driving. In addition some incentives such as direct payment or lifetime warranty of the battery should be given for voluntary participation of the vehicle owners (Han et al., 2011c, d). It's also good to notice that the electric vehicles aren't producing harmful gases like CO_2, NO_x, NMH, CO and PM. Therefore applying electric vehicles is very environment-friendly and should be one of the main policies of all countries.

Research Objectives

The main Objective of this research is to show how the potentials of the electric vehicle's batteries could help the TSOs[1] in controlling the electric power network or a part of it such as operating micro-grids. These batteries could easily replace fossil-fuel power plants for secondary frequency control and are very clean energy resources. The application of these batteries is investigated in the following sections.

[1] Transmission System Operator

Methods

As it was mentioned before, the performed simulation in this research is based on the results of TU Chemnitz's psychological studies (TU Chemnitz, a; b). Due to these studies, the vehicle drivers are divided into three groups: park + ride users (P+R), park + charge users (P+C) and public car sharing users. The P+R users have their private charging boxes and were able to charge their cars at home but the P+C users must charge their cars at public charging stations. These groups are separated into day chargers (5 am- 5 pm) and night chargers (5 pm- 5 am). As it can be seen in Figure (1), almost all of the P+R (80%) users were charging at nights and just a little (15%) of the P+C users were charging at these times. Therefore a large number of batteries will be available during the day that could inject their stored power to the network at peak load times and also at low load times they could consume the generated power of the base load power plants and the unplanned generations of the renewable energy resources such as wind turbines (for example in micro-grids), which is called wind to vehicle (W2V) in the TU Chemnitz project. These abilities increase the whole efficiency of the system operation.

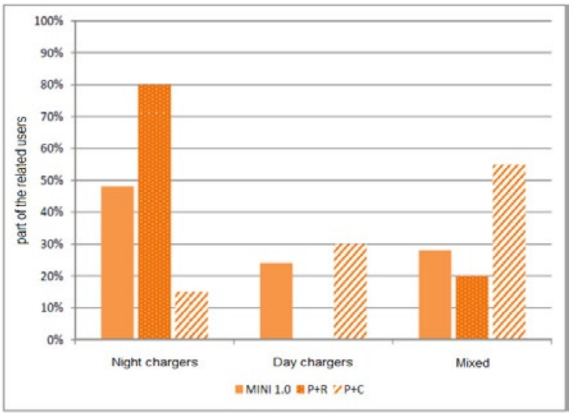

Figure 1: Part of the night and day chargers in the Mini E V2.0 project (TU Chemnitz, b).

The simulation in this paper is based on these data and is carried out for different operation scenarios to show how the vehicles could maintain the power network's frequency stability. An aggregator is used for collecting a large number of batteries to maintain a considerable amount of power which will be applied for controlling issues in power networks or micro-grids. Smart gird capabilities could be very helpful in the performance quality of the aggregator in collecting precise data from the electric vehicles. Each battery has three different states as follow: charging, discharging and standby. The aggregator must optimally choose and organize the state of each vehicle for the power grid's regulation aspect. Different scenarios and case studies are defined in the following section.

Simulation and Results

The IEEE 39bus Standard Network is applied for this research simulation to show the impact of the electric vehicles for secondary frequency control purposes. The Single-line diagram of the network is shown in Figure (2). The network consists of 9 generators, 19 loads and 46 transmission lines.

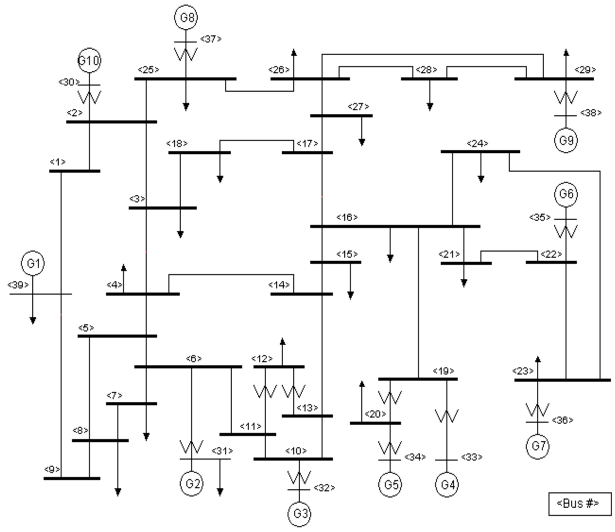

Figure 2: Single-line diagram of IEEE 39bus network.

Mini E's Technical data

A full charging period of the batteries lasts 4-10 hours regarding the available power amperage. The P+R users and more than half of the P+C users need 4 hours for the full charging procedure. We consider this data in these studies. Each Mini E battery has a 28 kWh usable capacity which could provide us with circa 6 kW power per vehicle (BMW Group). A vehicle battery can reach its maximal power in only 0.001s (Guille, 2009). As discussed, we have two main groups of vehicles. The first group is charging at the day period and the other one at the night period. We consider two aggregators in the network.

Night chargers

The vehicles charge their batteries during 24:00-6:00 because of the low electricity price in this interval (Mallette & Venkataramanan, 2010), but the optimal charging time is defined by the aggregator. We consider two aggregators at nights. Aggregator1 collects 10000 available vehicles (60MW) and aggregator 2 includes 5000 vehicles (30 MW). Different case studies were simulated during this period but just two main scenarios are analyzed in this paper as follow:

Scenario 1: Generation increase of 70 MW

A generation increase of 70 MW happens at the 20th second of the simulation that is caused by wind turbines, this leads to a frequency increase of 50.42Hz, as it can be seen in figure (3). Figure (4) shows that the power plant governors aren't able to bring back the frequency to its nominal value (50Hz). The aggregator1 and 2 are acting quickly and bring back the frequency by charging the available batteries as secondary frequency controllers (see figure (5)).

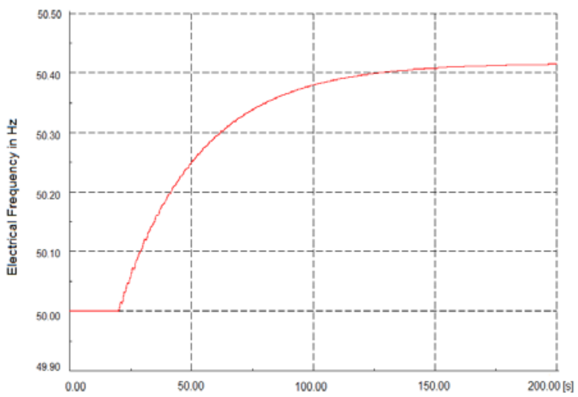

Figure 3: Increasing network frequency after generation increase.

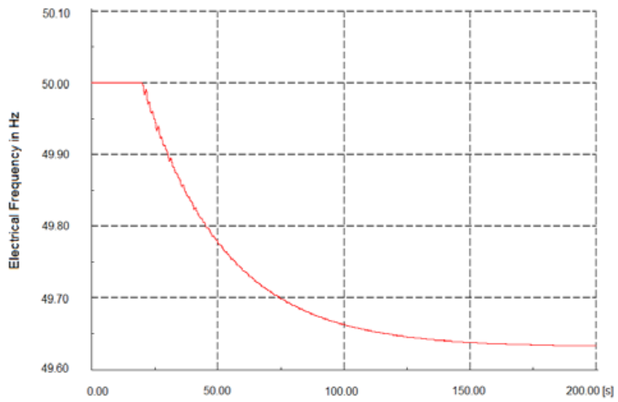

Figure 6: Decreasing network frequency after load increase.

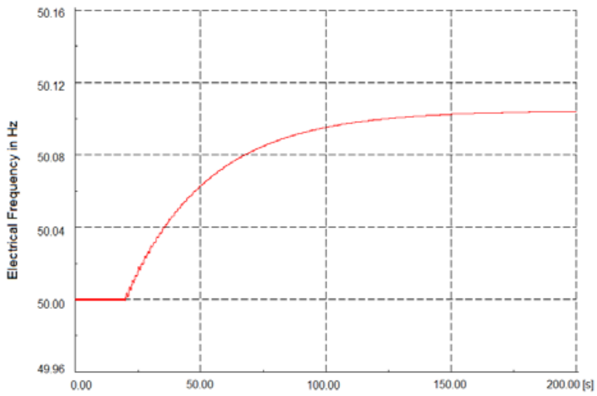

Figure 4: Impact of the primary frequency control (power plant governor system) on the frequency deviation.

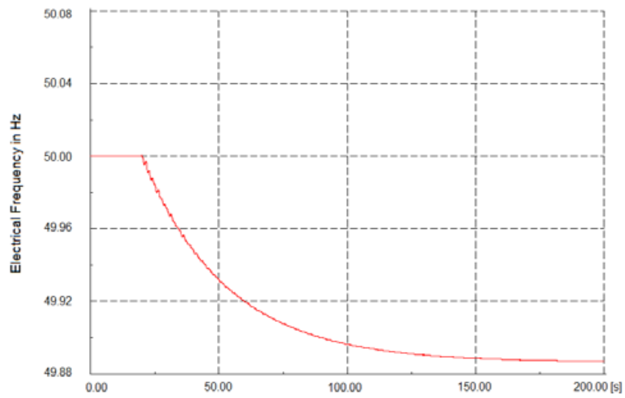

Figure 7: Impact of the primary frequency control (power plant governor system) on the frequency deviation.

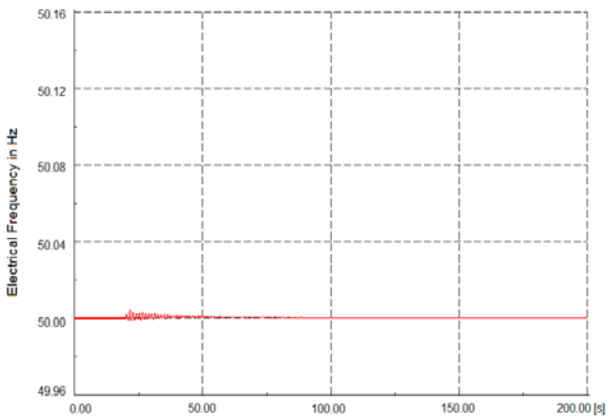

Figure 5: Impact of the electric vehicles as secondary control on the frequency deviation (W2V function).

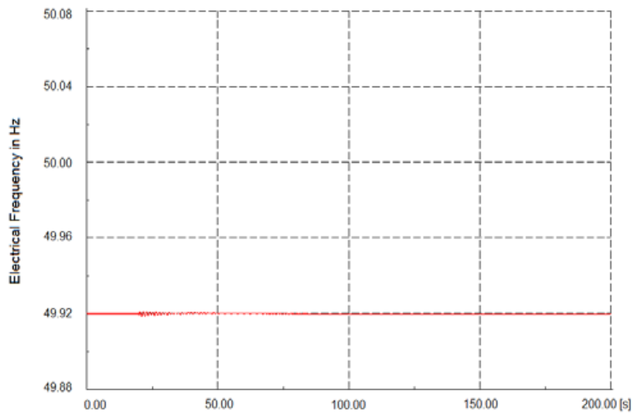

Figure 8: Impact of the electric vehicles as secondary control on the frequency deviation.

Scenario 2: Load increase of 50 MW

A load increase of 50 MW in the 20th second of the simulation reduces the network frequency to 49.62 Hz. This is displayed in figure (6). The system governors are also this time, not able to bring back the frequency value (figure (7)). But the aggregators apply the charged batteries to generate adequate power to bring back the frequency to its nominal value which could be seen in figure (8).

Day chargers

The electricity price is from 12:00-17:00 lower than the other times, therefore the cars could be charged during this period or can provide us with power if needed. Similar scenarios like the night charger part were defined in this case too, but as the results are similar to the ones before, we don’t present them in this paper.

Discussion

The simulation results show that the application of electric vehicles is very effective as secondary frequency controllers for the whole power network stability and its related micro-grids. In both scenarios were the vehicles able to bring back the frequency to its nominal value (respectively from 50.42 Hz in scenario1 and 49.62 Hz in scenario2 to 50 Hz). The available potential of these vehicles in 2020 (around 6 GW) could really help Germany's power grid operators in maintaining the stability of the network without any concerns. Smart grid capabilities are inevitable for the better realization of these ideas. The consumers can also earn money by participating in the electric market using their vehicle's batteries. Furthermore are these vehicles totally environment-friendly and are preventing the emission of greenhouse gases that is also a very important constraint in any power network operation planning. Finally, the use of EVs is strongly recommended for system operation issues like secondary control, power reserves and storing the extra power of renewable energy resources. Further researches will be investigated in different frequency control levels such as primary and territory controls.

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IV. Scientific Papers

Evaluation and Assessment

Performance of SHS in Bangladesh: Findings of a Technical Audit

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Abstract

Solar Home System (SHS) based rural electrification has experienced a considerable growth in Bangladesh since the start of the RERED Project in 2003. This paper reports on the findings from a technical appraisal of SHS in Bangladesh. Two hundred geographically dispersed installation sites were visited, and the SHS components were collected from the suppliers' and manufacturers' production lines to assess the technical quality. The physical characteristics of the SHSs and their system components were tested in the field and also in the lab to ascertain compliance with and deviations from the approved specifications. Despite the overwhelming success of the project, the study revealed various shortcomings. Notable among these are: incompatible and sub-optimal component configurations, faulty installations and a lack of an effective quality assurance mechanism. The findings highlight the need for a more effective quality assurance mechanism to protect consumer investment and rights.

Keywords: Solar home system (SHS), Standard, Quality assurance, Bangladesh.

Introduction

Bangladesh is experiencing a steady economic growth during the past decades and since 2004 annual growth in gross domestic product (GDP) has been around 6% (WB, 2011), against an electrification coverage of 50% and one of the lowest per capita electricity use of 252kWh (BPDB, 2011). The average rate of annual growth in demand for electricity was 7.16% for the period 2001–2011. The Solar Home System based rural electrification program in Bangladesh is supported by international donor agencies like the WB, GEF, GIZ, KfW, ADB and IDB who provide soft loans, 30 partner organizations (PO) (mostly non-government organizations or NGOs), who distribute the systems and conduct servicing, the suppliers and manufacturers of the equipment, and professionals. Central to the industry is the Infrastructure Development Company Limited (IDCOL) of Bangladesh, which is a non bank financial institution, established by the Government of Bangladesh.

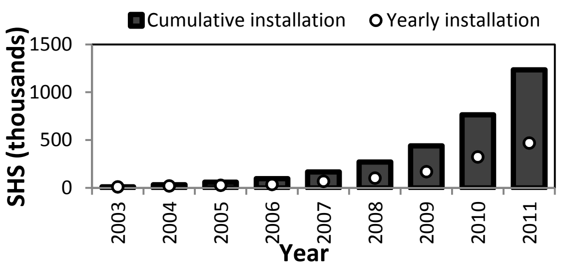

Figure 1: SHS installation status till 2011.

IDCOL is responsible for distributing loans to the POs, the selection of POs and the collection of the loan repayments. It is also responsible for training and monitoring the POs and setting the standards for SHS. The solar home systems comprise panels ranging from 20 to 130 Wp, with battery sizes varying from 30 Ah to 130 Ah and a number of illumination loads from 2 to 8 (ranges from 5 to 8 watts each).

Research Objectives

As of now over 1.7 million SHSs, capable of generating 85 MW of electric power, have been installed in Bangladesh. The market has grown steadily over the past years and new suppliers and manufacturers are entering the market. So, the project has reached a point where more robust regulatory and quality assurance frameworks are needed to safeguard end users' investments and the sustainability of the initiative. It is therefore imperative that the updates to the existing policies, specifications and guidelines are based on an appraisal of the field performance of the SHSs.

The objective of this study was to

- Perform a very small scale root level investigation. Test the approved components of different manufacturers and suppliers.
- Test a few working and troubled SHS units in the field.
- Observe the service quality of the POs by visiting the households.
- Provide recommendations to IDCOL in quality affairs.
- Provide recommendation to IDCOL for necessary modification of the technical standards.
- Provide recommendations to POs and manufacturers to improve the quality of goods and services.

Methods

The technical audit was carried out in four phases. The evaluation of the SHS equipment in the field, evaluation of the equipment through laboratory testing, evaluation of the performance of the POs in the field by observing the maintenance schedule, after sales service and by interviewing the consumers in the field and the evaluation of the local manufacturer's quality control mechanism and working environment. The standards mentioned in this paper are the technical specifications (IDCOL, 2005) for Solar Home System (SHS) of IDCOL's RERED program.

Two hundred standalone SHSs in five geographically dispersed locations in rural Bangladesh were visited in April and May, 2011. The sites represented a variety of PV module types and system components, aged between 1 and 8 years in local microclimates from coastal to inland regions. The SHS sites were selected at random. The visit to every SHS site started with the collection of relevant information such as the age of installation and specifications of the system and their components. The data were obtained from the original agreement between the owner of the SHS and the supplier or PO. Tests and observations were carried out as part of the field investigation.

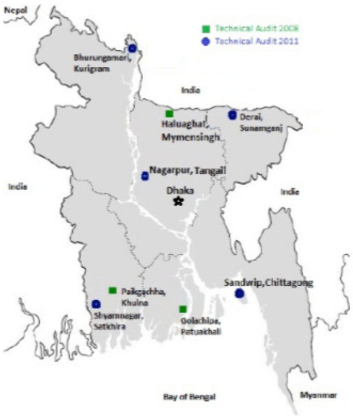

Figure 2: Location of field investigation.

The field investigation includes the load calculation, observation of the installation of the solar panels, technical parameters measurement of the SHS components and measurement of the switch contact resistance and resistance of the house wiring. Laboratory testing includes the compliance test of the approved equipments from the major suppliers' production lines.

Results

Field Investigation

System Integration: The capacity of the panels and batteries were noted during the field visits. The connected load of each consumer was calculated. In some cases the consumption pattern of the electricity was also monitored by the use of data loggers.

Table 1: Connected load Vs panel capacity.

Panel capacity (Wp) Connected load (W)	20	40	45	50	65	75	80	85
<10	16	-	-	-	-	-	-	-
11-20	15	4	-	6	1	-	-	-
21-30	1	16	-	20	2	-	-	1
31-40	1	8	1	27	9	-	-	1
41-50	-	6	-	16	6	3	-	9
51-60	-	-	-	2	3	1	-	6
61-70	-	-	-	4	3	-	1	4
>70	-	-	-	1	-	1	-	4

Table 2: Battery capacity Vs panel capacity.

Panel capacity (Wp) Battery capacity(Ah)	20	40	45	50	65	75	80	85
30	30	-	-	-	-	-	-	-
50	2	-	-	-	-	-	-	-
55	-	23	1	-	-	-	-	-
60	-	8	-	1	-	-	-	-
80	-	1	-	3	1	-	-	-
100	-	-	1	16	5	-	-	-
130	-	-	-	1	-	-	1	24

There is no standard guideline for an SHS package design in Bangladesh. The POs design the package according to the customer's need. Generally the designed packages are overloaded with small capacity of panels, combined with higher capacity batteries. Optimum battery size should be calculated along with the output watt-hour for the packages for a given panel size. Proper guidelines should be incorporated for SHS package design. For proper system sizing a few systems should be monitored and studied carefully throughout Bangladesh for the operating conditions and operating pattern with the help of data loggers. A supplementary document on SHS package design should be prepared and given to POs to make optimum designed packages.

Panel Installation: Proper installations of the panels were observed by measuring the azimuth, tilt and shading on the panels.

Table 3: Panel Installation status.

Observed criteria	Optimum Value	Criteria satisfaction (%)
Azimuth	South	**80.76**
Tilt	$20^o \sim 30^o$ (optimum for Bangladesh)	**75.14**
Shading	No shading on the panels	**61**
Overall	-	**27**

Out of the 200 inspected systems only 69 systems (34.5%) were found fulfilling proper installation criteria.

Charge controller observations: Four technical specifications of charge controllers were tested during the field visits. The charge controllers that satisfy the technical standards are given as percentages in table 4.

Table 4: Compliance of charge controllers.

Specification	Standards	Criteria satisfaction (%)
High voltage disconnects	14.3±0.2	**53.5**
Low voltage disconnects	11.6±0.1	**15.5**
Self power consumption	< 20 mA	**66.5**
Functionality of the indicators	Mandatory	**82**

Out of the 200 inspected systems in the field only 18 charge controllers (9%) comply with the above mentioned four criteria. The acceptability level is very poor. All the suppliers should have the compliance certificate from the authorized testing centers before their charge controllers are approved for the program. The majority of charge controllers tested in the field are seen to have a low voltage disconnect (LVD) point much lower than the standard value. The LVD point of the charge controllers is very important for the proper operation of the SHS. Lower LVD operation means higher DOD operation of the battery. Higher DOD operation reduces battery life. It is reported from the charge controller suppliers that the POs requested them to produce charge controllers with lower LVD, because they believe that lower LVD points will provide extended hours of SHS operation.

Battery observation: Only 71 batteries (35.5%) out of the inspected 200 batteries were found to operate and be maintained properly in the field.

Table 5: Battery observation with standard practices.

Specification	Standards practices	Criteria satisfaction (%)
Level of electrolyte	Optimum level	**68.1**
Deviation of Specific gravity in different cells	< 0.25 (gm/L)	**89.6**
Corrosion in connector	No corrosion	**67.5**
Terminal connection	Good (no loose or broken connection)	**85**
Placing of the batteries	With proper ventilation	**80.2**

Switches and house wiring observation: Out of the tested 385 switches, only 167 switches (43.3%) showed contact resistance within the acceptable limit.
Almost all the wiring (97%) have resistances beyond the acceptable limit. Poor maintenance and joined, twisted, thin and long wires are responsible for poor wiring conditions, in which case the quality of in-house wiring has been marked as not satisfactory. The percentage of systems with unsatisfactory wiring increases consistently with age. This shows that maintenance degrades and misuse of wires increases with the age.

Table 6: Quality of switches and house wiring.

Specification	Standards practices	Criteria satisfaction by SHS (%)
Switch contact resistance	Contact resistance <0.5 Ohms	**43.3**
Voltage drop in the house wiring	Wire resistance <0.5 Ohms	**2.8**

Complaints of the customer about the POs: Customers who have finished all the installment payments complained to the audit team that they are not getting any service from the PO after the loan repayment period. A mechanism should be there to ensure the services to the consumers after completion of the installment.

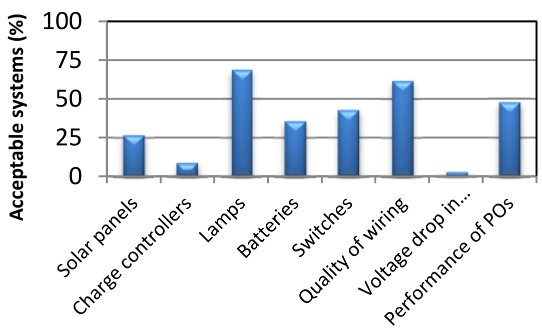

Figure 3: Summary of field investigation (percentage of systems maintaining acceptable values of the parameters).

Laboratory tests

During this work there were no laboratory facilities for testing the solar panels under STC condition in Bangladesh. So the panels were not tested. In order to keep the names of the suppliers confidential, they are named as A, B, C, D, P, Q etc.

Batteries: Out of the tested 24 batteries of four battery manufacturers, the capacities of 8 batteries (33.33%) are found to be less than rated; among them the 30Ah battery of manufacturer A is a battery with much lower capacity than the rated. The program standard does not allow DOD of batteries more than 75% at 11.6 volts while discharging at C10 rate. Only four batteries (16.67%) were found to have a DOD less than the specified limit at LVD (11.6V) point.

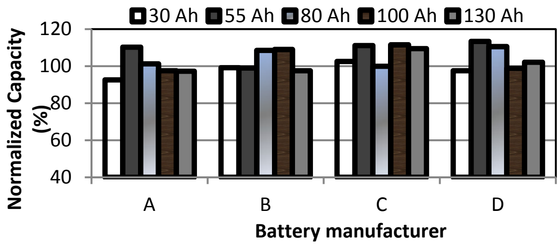

Figure 4: Normalized capacity of batteries.

Charge Controllers: None of the charge controllers comply with all the program standards. The charge controller ensures the proper operation of the SHS. The POs and manufacturers who compromise the quality of the charge controllers should be brought to account. The equipment manufacturers are required to have compliance certificates from the testing authorities before their equipment are approved for the program. So it is evident that the manufacturers either do not maintain quality control mechanism or they change their design after the approval without informing the authority. It is observed that some manufacturers provide very low grade diodes with higher forward voltage as blocking diode at the panel terminal of the charge controller, which reduces the charging efficiency. Again, some manufacturers provide low quality switching devices at the load terminal, which reduces discharging efficiency. Charging and discharging efficiency of the charge controllers at rated current should be included in the technical standards of the program. Manufacturers using electromagnetic relays for switching devices showed higher self consumption in their charge controllers. They should be advised to use solid state devices to reduce their self consumption within the IDCOL specified limit.

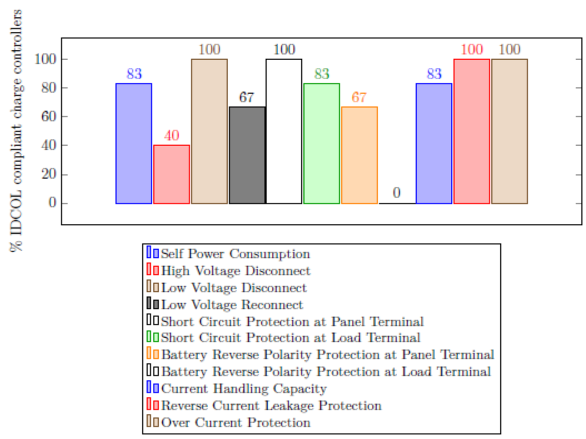

Figure 5: Summary of charge controller test.

Lamp Inverter Circuits: Out of the five manufacturers of fluorescent lamp inverter circuits only three (60%) comply with all the required standards.

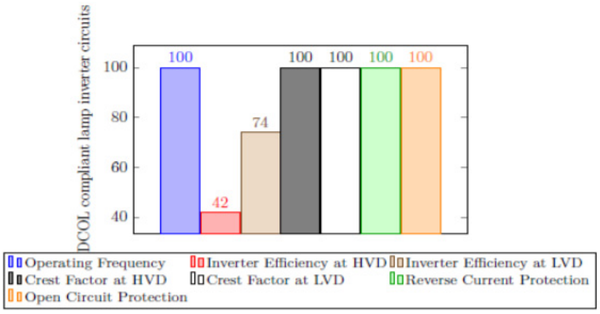

Figure 6: Summary of lamp inverter circuit test.

Limitations of the study

The sample size was too small in comparison to the population. The distributions may not reflect the exact condition but cover the systems of major players of the program. Out of the 30 partner organizations (POs) the team could investigate systems of only 13 POs and these POs covered more than 90% of the total installed SHS under the program. Some POs have activities only in some localized area, those were outside the area of investigation. 224 panels, 15 batteries, 35 charge controllers and 24 lamp inverter circuit manufacturers are enlisted to supply their products to the program. Most of the suppliers have more than one approved model. Some of the approved models are not in the market anymore and some of the suppliers are providing their products only for some specific POs. It was difficult for the audit team to investigate the systems of all these suppliers and POs within the limited time. Thus this work investigated the systems and equipments of the POs, manufacturers and suppliers who are the market leader. Future studies should include systems of all the POs and equipments of all the approved suppliers and manufacturers to get the exact picture of the program.

Discussion

IDCOL has been playing a pioneering role in disseminating SHSs in Bangladesh. It has exceeded the expectations of the donors and implementers, and the Bangladesh program has become exemplary as one of the most successful programs of SHS based rural electrification. 5% of our total population are getting electricity through this program. IDCOL organizes regular training for the PO personnel to educate them about the quality and maintenance requirements. It also publishes and distributes different books and manuals to educate the POs' technical persons as well as the users. The micro credit systems, after sales services from the POs and technical quality monitoring by IDCOL ensure consumer satisfaction. Despite the decrease of the buy down grants (USD 90 initially to USD 25 at present), the increasing selling rate of the SHS indicates the sustainability of the project.

As the market is growing very rapidly and new manufacturers and suppliers are entering the market, the competition is increasing and the suppliers and manufacturers are competing over the price, while sacrificing the technical quality of the equipments. Necessary measures should be taken to compel the manufacturers and suppliers to comply with the standards set for SHS. The market has become significantly large and consumers are the people who are living in the rural areas (most are middle and lower middle class). A strong quality control mechanism has become imperative to secure the consumers' rights. On the other hand technical support should be provided to the manufacturers, suppliers and partner organizations to help them understand the technical specifications and also to modify the design of the component parts where required. The technical audit found that none of the charge controller or lamp circuit manufacturers produce equipment which completely comply with the technical standards set for the SHS program of Bangladesh. The efficiencies of the devices are out of the specified range, the crest factor of the lamp circuits is beyond the tolerable limit, and some major protections are absent. Some of the battery manufacturers are producing batteries with much lower capacities and some are producing much higher capacities than the rated. There should be a state of the art research laboratory for random testing of SHS equipment in Bangladesh to ensure the quality of the end product. A strong quality control mechanism is required for the manufacturer to keep their product quality not only during getting the initial compliance certificate but also to maintain it throughout their production phase. The technical specification of the SHS should be revised to incorporate the specifications for modern adaptive charge controllers and LED lamps which are currently entering the SHS market. The results of the first technical audit were published in 2011 (Chowdhury et al., 2011).

Acknowledgement

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Interconnected mini-grids for rural energy transition in Nepal

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Abstract

In rural areas of Nepal, the use of traditional biomass for cooking and kerosene lamps for lighting is still common. In spite of presence of some renewable based technologies such as solar home systems (SHSs) in some of the remote areas, the desired socio-economic benefits are not yet visible. Therefore, the focus in providing energy access in rural Nepal has been gradually shifting towards energy supply infrastructure improvements. Micro-hydro, solar and hybrid mini-grids for rural energy supply are increasingly being installed in Nepal. This paper analyses rural energy transitions from traditional and conventional resources to renewable based interconnected mini-grids. Two cases of interconnected mini-grids such as micro-hydro mini-grids in Baglung district and PV-wind hybrid mini-grids in Nawalparasi district are used to analyze ongoing rural energy transitions.

Keywords: rural energy transitions, mini-grids

Introduction

Electrical energy has become one of the basic need and driving force of modern life. However, more than 1.3 billion rural populations- one in five globally- still do not have access to electricity (UN, 2012). Lack of electricity has also hindered the access to healthcare, education and employment opportunities for these populations. Providing energy access to them has recently become global priority. The United Nation is celebrating year 2012 as "Sustainable Energy for All" (UN, 2012). While providing energy access to these populations, environmental limits of our planet should also be considered. In such case, direct transformation from traditional resources to renewable based technologies through leapfrogging is desirable over conventional energy technologies such as diesel generators etc. (Rehman, et al., 2010). In some rural areas, renewable based individual technologies such as Solar Home Systems (SHS), solar lanterns etc. are already available. Despite their environmental and health benefits such systems can not help much in socio-economic transformation due to their limited capacity. A transition towards more reliable and sustainable energy supply infrastructure such as interconnected mini-grids is desirable. Mini-grids can be considered as a pre-grid electrification in rural areas and should be compatible to central grids for future interconnection. In this context, the paper explores the ongoing rural energy transition through renewable based interconnected mini-grids in Nepal. Nepal is a small landlocked Himalayan country between India and China with a population of 28.8 million. 85 % of the populations are still living in the rural areas. The per capita income is US $ 562 and GDP growth rate is 3.5 % (Sapkota & Tamrakar, 2011). Energy resources in Nepal can be broadly classified into three categories namely traditional, commercial and renewable. Traditional sources mainly include biomass such as firewood and account for more than 85 % of total energy supply in Nepal (Sapkota & Tamrakar, 2011). Commercial resources include kerosene, diesel, petroleum, grid electricity which are commercially available in market for purchase. Renewable resources include solar, wind, micro-hydro, bio-gas etc. Transitions from traditional towards commercial and renewable resources are desirable. The ultimate goal is to make transitions to renewable resources.

Government efforts have made it possible to provide electricity services to about 56 percent of the population in the country, including 9 % from RETs (Sapkota & Tamrakar, 2011). In the rural areas, only 49 % of the population has access to electricity (REEGLE, 2012). Further, Nepal is going through severe energy crisis. Due to civil war and political instability in last 20 years, many hydropower projects could not be completed. The lack of sufficient electricity generation for power supply has forced to impose regular load shedding, sometimes as high as 16 hours a day. Furthermore, Nepal Oil Corporation is almost bankrupt and government always has to provide high amount of subsidies to maintain the smooth supply of the petroleum product in the country. This has hindered many renewable energy power project financing. The difficulties has been also experienced in rapid extension of the national grid for rural electrification due to remote topography, dispersed settlement, limited electricity generation and financial problems. The transportation cost for conventional fuels such as diesel and kerosene is also very high. In this context, the supply of power to remote rural areas in Nepal from clean and reliable distributed mini-grids seems to be cost effective and sustainable options and require less time to develop.

Recently, six micro-hydro plants in Baglung district are interconnected to form a mini-grid and wind-solar mini-grid has been installed in Nawalparasi district. This paper addresses such ongoing rural energy transitions from traditional and conventional resources to renewable based interconnected mini-grids along with theoretical and empirical problems and impacts associated with such transitions.

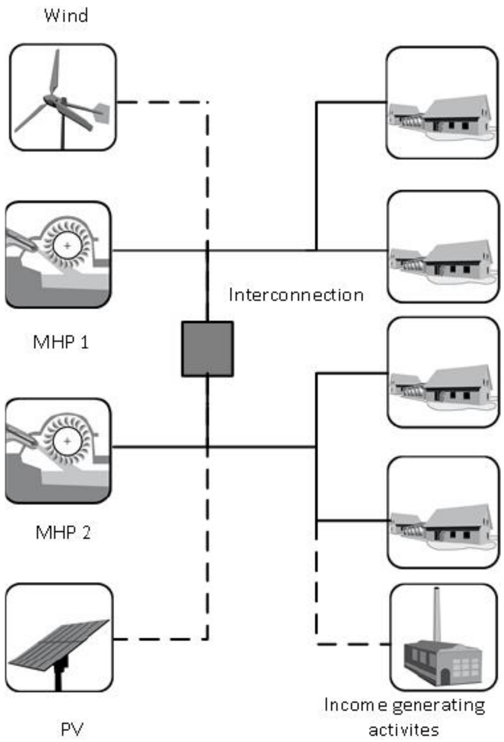

Figure 1: Schematics of interconnected mini-grids.

Research Objectives

This paper aims to investigate the rural energy transitions through renewable based interconnected mini-grids in developing countries like Nepal. Technical, operational, organizational, financial and social aspects of such rural energy transitions will be analyzed.

Methods

This paper reviews the rural energy transitions via renewable energy based interconnected mini-grids in Nepal. First of all, existing national and rural energy policy and organizational framework in favor of such transitions in Nepal has been investigated. Then, the interconnected mini-grid transition phenomenon in Nepal has been explored. This analysis is based on role of government institution, donors, energy industries, local non-government organizations (NGO) and local communities. Further, case studies of interconnected micro-hydro mini-grids and PV-wind hybrid mini-grids to elaborate rural energy transition in Nepal have been presented based on the interviews with respective system operator, responsible staff at Alternative Energy Promotion Center (AEPC), field visits and analysis of corresponding project reports.

Regulatory and Organizational Framework

The historic development on rural electrification using micro-hydro power started during sixth five year plan (1980-85) with the launching of rural electrification project from Agriculture Development Bank. The licensing requirement for micro-hydro was waived, the micro-hydro electricity price was deregulated, 50-75 % of the subsidy for add on electricity was provided and income tax was waived for micro-hydro projects. During the eighth periodic plan (1992-97), energy sector was given special priority. Hydro power policy 1992 was put in place, Alternative Energy Promotion Center (AEPC) was established in 1996 and Rural Energy Development Program (REDP) was initiated in August 1996. In recognition of the potential of micro-hydro as alternative means of providing electricity to the remote rural areas, further national policies were formulated to support rural electrification using micro-hydro mini-grids.

With the rationale of creating conducive environment to self-motivate and mobilize local institutions, rural energy user groups, non-government organizations (NGO), co-operatives and private sector organizations for the development of rural energy resources government of Nepal has introduced rural energy policy in 2006 (AEPC, 2006). It aims at reducing dependency on traditional energy and improving living standards by integrating economic and social activities with clean and cost effective energy in rural areas. This policy further revised subsidy rate and disbursement criteria on the basis of geographical conditions, population and available resources. Further, the policy plans to develop and expand rural energy system on the basis of cluster. This shows that the policy formulations are in favorable directions for rural energy transitions using renewable energy based interconnected mini-grids in Nepal.

Further, subsidy policy for renewable energy was further revised in July 2009 (AEPC, Subsidy Policy for Renewable (Rural) Energy, 2009). The adjustment in the existing subsidy policy was necessary to increase development impact in terms of increased service delivery efficiency and increased access to the poor and socially disadvantaged people in rural areas of Nepal. The direct incentives for various renewable energy technologies are presented in table 1. In addition, indirect incentives such as custom and Value Added Tax (VAT) exemptions for renewable energy technologies (RET) are also prevalent (AEPC, 2009) (Sapkota & Tamrakar, 2011).

Table 1: RETs subsidies in Nepal.

RETS	Subsidies
Micro/Mini Hydro	US $ 1821 – 4357 per kW
Solar PV Home Systems	US $ 29 – 143 per system
Institutional Solar PV / Water Pumping	US $ 214 – 14826 per system
Wind Energy	US $ 2214 per kW

Alternative Energy Promotion Center (AEPC) is a government institution established in 1996 under the ministry of Environment, Science and Technology with the objective of developing and promoting renewable energy technologies in Nepal (AEPC, 2012). Further, Energy Sector Assistance Program (ESAP) (1999 – 2012), supported by Denmark, Norway, Germany and UK helped in micro-hydro and solar PV dissemination and institutional strengthening of renewable energy sectors. It will continue as National Rural and Renewable Energy Program (NRREP) (2012-2017). Rural Energy Development Program (REDP) started in 1996 with the help of United Nations Development Programme (UNDP) (since 2003 World Bank as well), supported in community micro-hydro and other rural energy sectors. This program is now continuing as Renewable Energy for Rural Livelihoods (RERL). Renewable Energy Project (2003 – 2012), supported by European Commission, helped in dissemination of institutional solar PV for computers, refrigerator in educational and health services as well as pumping drinking water (Sapkota & Tamrakar, 2011). Further, district development committee (DDCs) and village development committee (VDCs) are also providing financial support for renewable based technologies dissemination. AEPC has become a role model in developing countries for promotion of renewable energy technologies and rural energy transitions since its establishment in 1996. The programs from AEPC are the main drivers of rural energy transition in Nepal.

Interconnected Mini-grid Transition

The demand of energy in rural areas of Nepal is ever increasing. More households from rural areas are getting access to electricity through on-grid and off-grid applications. From the year 2006 to 2011 alone, 20 % more rural populations were provided with electricity access in rural areas of Nepal (REEGLE, 2012;AEPC, 2006). In the rural areas where micro-hydro is not available, Solar Home system (SHS) can be first step to introduce renewable energy systems. This technology can still be used to replace kerosene lamps in rural areas where 33 % of the population are still using kerosene lamps for lighting (REEGLE, 2012). Though more than 0.5 million such systems are already installed, the desired socio-economic benefits are not yet visible (Sapkota & Tamrakar, 2011). In the areas, where there is already social acceptance for renewable energy technology, upgrading energy supply structure using mini-grids could be favorable options. In the other hand, the situation is better in the rural areas where micro-hydro mini-grids are available. There are more than 2500 micro and Pico-hydro plants installed in Nepal with total generation capacity of 20 MW (NMHDA, 2012). Some of these plants are already overloaded and size upgrading is not an option as they are mostly utilizing maximum capacity of available water potential. Interconnection of nearby micro-hydro mini-grids can solve the problem. For the long run interconnected mini-grids with possibility of expansion using various renewable energy sources such as solar, wind etc. are desirable solutions. Lack of financing and suitable regulatory framework seems to be the major obstacles for mini-grid transitions in Nepal.

Case Study

Following pioneer projects in interconnected mini-grids visualize the ongoing rural energy transition in Nepal. These projects are milestones for rural energy transitions in Nepal as it shows the viability of interconnected mini-grids as alternative to central grid extension and bring positive changes to the societies involved.

Interconnected Micro-hydro Mini-grids

In July 2011, six micro-hydro power plants of Baglung district has been synchronized as pilot project for interconnected micro-hydro mini-grids in Nepal.

Technical aspects

The total 107 kW electricity produced from these six isolated micro-hydro plants is connected to 8 km long 11 kV transmission line. Each micro-hydro unit is connected to mini-grids via synchronization unit. The system is supplying electricity demand for 1200 households. Recently, the system has been connected to central grid as well (AEPC, 2012). Due to interconnection, quality, reliability and availability of electricity have been enhanced. Voltage and frequency of the system became stable (390 – 415 V/ 49 – 50.5 Hz). Income generating end-use like NCell communication tower (15 kW) and stone crusher (40 hp) has been initiated.

Financial aspects

This project was possible due to financial support from UNDP/REDP and local community and technical support of "Renewable Energy for Rural Livelihood" program of AEPC. Additional financial support is needed for further institutionalization of the co-operative, smooth operation, repair and maintenance and capacity building.

Organizational and operational aspects

Urja Upatayka Mini-grid Co-operative has been established for the regular operation of mini-grid. The co-operative function as grid operator and electricity distributor whereas each micro-hydro projects will work as Individual Power Producers (IPPs).

Social aspects

Every individual in the community is aware about the project and its contribution. Misuse of electricity has been reduced. Inter community co-ordination seen due to the establishment of the co-operative. Community confidence level has been increased to construct, own and manage bigger projects. Communities are ready to follow the regulatory framework developed by the co-operative. Mini-grid is converting as social entity for generation, transmission and distribution of rural energy. Communities are convinced that micro-hydro connected to mini-grid can be permanent source of electricity.

PV-Wind Hybrid Mini-grids

PV-wind hybrid mini-grids pilot project has been installed in Dhaubadi, Nawalparasi district of Nepal in 2011. The project site is 20 km away from national power grid and 23 km away from East-West Highway.

Technical aspects

Two sets of 5 kW wind-turbines complimented by 2kWp solar PV has been installed to satisfy the daily demand of 43.5 kWh. The storage system has been designed to match the load patterns and the wind-solar power output, in order to achieve a balance between the demand and supply. A total of 36 batteries (in 2 groups and each with 12V, 200 AH at C/10; 40 kWh at 50% depth of discharge) are installed to store one-full day electricity output that can satisfy about 3 days' needs for lighting. The system supplies the electricity demand for cooking, lighting etc. for 46 households in the village (ADB, 2011). So far, only 30 % of the generated electricity is consumed which gives enormous amount of surplus electricity for income generating activities. The project is expected to reduce the use of kerosene, firewood and batteries and mobilize abundantly available wind and solar resources.

Financial aspects
The system has been financed by Asian Development Bank and developed in co-operation with AEPC and local communities. Revenue generated by co-operatives from consumers is primarily used for operation, management and maintenance of the project.

Organizational and operational aspects
A rural energy service company has been established to ensure project viability, knowledge sharing and pro-active private sector involvement. For the long term sustainability of the project "Hoorhoore Danda Co-operative" has been established. It has formed steering committee which developed its own mechanism for the operation, management and maintenance of the system.

Social aspects
The social acceptance of this project is similar to previous one. The profit from the project is used to develop further infrastructure such as information and telecommunication center, health clinic etc. in the village and provide loans for the benefit of the rural communities.

Conclusion and Discussion

This paper has explored the rural energy transition via renewable energy based interconnected mini-grids in Nepal. Within short span of time, Nepal has become role model for developing countries for renewable energy dissemination and rural energy transitions. In Nepal, renewable energy based inter-connected mini-grids are becoming favorable option as they are modular, robust and reliable. As developed countries are in transition path from conventional energy to renewable energy, rural energy transition is leapfrogging from traditional energy to renewable energy. Such mini-grid systems are being designed in such a way that it can be interconnected directly to other mini-grids or central grid and also able to act in island mode in case of problem in other grid. In the long run, mini-grid can help in stabilization of other grids and vice-versa. It can also contribute positively in income if the generation is excess.

As the demand for energy changes, the form which supplies this energy also should change. SHSs were considered adequate before to meet mainly lighting demand in rural areas of Nepal. However, the higher demand for energy makes mini-grids installation already favorable.

The primary idea of this paper was to inform ongoing mini-grids transitions in Nepal and its relevance in improving socio-economics of rural areas. There is a need to perform detail study on interconnected mini-grids in order to highlights its benefits and viability. The technology for interconnection between micro-hydro is available. However, further research and development in interconnection of synchronous generators such as micro-hydro and asynchronous generator such as PV is required. The rural energy policies should be amended in order to support further realization of interconnected mini-grids. Further work is also required in improving business and operational models for interconnected mini-grids so that multiplier effects can be realized and interconnected mini-grids become mainstream sources for rural electricity supply.

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Analyzing drivers and barriers for renewable energy integration to small islands power generation – tapping a huge market potential for mini-grids

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Abstract

This paper summarizes findings on how socio-economic and natural factors influence the introduction of renewable energies to island electricity grids. A statistical regression model is used determining drivers and barriers of successful technology specific renewable energy implementation to islands. Eight financial, market, policy and natural factors are analyzed. The existence of a regulatory framework, using e.g. a feed-in tariff, is proved as being most important for the large-scale implementation of young renewable energy technologies as PV and wind energy. Hydro energy in contrast depends on high hydro potential, indicated by elevation of islands. Furthermore a spatial Geographic Information System analysis of global islands is carried out, depicting area, location and population information of the world's more than 80,000 islands.

Keywords: socioeconomic factors; global islands; statistical regression modeling; GIS analysis

Introduction

Global demand for energy resources has reached its current peak in 2011 and is expected to increase further during coming decades (IEA, 2011). Renewable energy (RE) integration into major electricity grids is accelerating since the last decade and especially remote areas are in the forefront of high share RE integration (IEA RETD, 2012). In this context, global islands are mini-grids by geographic isolation and have special characteristics of electricity generation. They can achieve faster than other areas high shares of RE, due to small overall system capacities. Therefore, many islands are today challenged by problems, which are expected for continental countries within coming decades (Jensen, 2000: vi). Grid connection to continental countries is often not economically feasible, in consequence of large distance or small maximum loads. For this reason, the vast majority of islands is heavily relying on diesel gensets for electricity supply (Platts, 2012). Hence, islands have very high specific greenhouse gas emissions (GHG). These islands are characterized by one of the highest energy costs globally (Breyer & Gerlach, 2012), caused by increasing costs for fuel, high transportation costs and limited scaling effects. At the same time, many islands have promising natural conditions, such as high wind speed, high solar irradiation or geothermal activity, to use RE for power generation. Though the integration of RE in isolated islands systems is highly complex in terms of grid stability and electricity storage, technical problems can be solved, which "gives the freedom to actually choose any configuration between 0 % and 100 % renewables" (Franzen et al., 2011: 6). Current high specific energy costs and promising conditions of RE use are resulting in economically viable use options for RE. Therefore, a growing number of islands is switching to RE technologies, while other decision makers often hesitate to tackle system change and conserve fossil fuel based electricity generation options (IRENA, 2012).

Identifying drivers and barriers or technology diffusion problems for RE implementation on islands can be analyzed by statistical means. However, multivariate tools remain scarce in this context, even for continental countries. Only few studies conducted that especially Renewable Portfolio Standards and other policies have limited influence on RE share (Carley, 2009; Gan & Smith, 2011; Menz & Vachon, 2006). These studies are often limited by regional focus or analyze only selected RE technologies.

Research Objectives

This paper deals with the determination of drivers and barriers for the implementation of RE technologies within geographical island grids and analyzes a maximum global market potential of islands.

In this context, socio-economic factors are often described as being main barriers to RE implementation on islands (Painuly, 2011). Hence, the Fourth IPCC Synthesis Report urges for an identification of barriers of RE rollout by asking "[w]hat factors influence the possible deployment of sources in meeting GHG mitigation pathways" (Fischedick et al., 2011: 798).

At the same time, islands as an overall research subject are poorly investigated. This 'black box' even involves the amount of global islands and inhabitants, as well as their regional distribution. It is estimated that globally more than 100,000 islands of considerable size exist, of which might be more than 10,000 inhabited. Overall, at least more than 500 million people are islanders (Marín et al., 2005). The concrete market potential cannot be easily accessed, due to weak estimations.

Hence, following research questions are derived:

- What is the theoretical market potential of islands, indicated by the number of islands and their inhabitants?
- Which socio-economic and natural factors determine the diffusion of RE technologies on small islands?

Methods

Geospatial analysis

The GIS (Geographic Information System) analysis of global islands identifies a global theoretical maximum market potential. The analysis has two steps: First, identifying global islands and second, overlaying them with population density information.

Spatial information is based on GADM database for Global Administrative Areas (GADM, 2012). Population information are available in a 30´´ resolution and date from 2010, which are extracted from LandScan 2011 Global Population Database by the Oak Ridge National Laboratory.

Global offshore islands are identified by cutting all continents from the database. Islands are transformed from shape to raster format with an edge length of 154.3 m. Afterwards global population density information can be added to the database. Finally the global island directory contains information on location, size, population and country. This database helps validating the global approach of the statistical regression within this paper. The GIS analysis is carried out by using ESRI Arc Map[1] and MATLAB[2].

Statistical regression analysis

Statistical modeling of socio-economic and natural parameters helps identifying drivers and barriers for RE implementation in island mini-grids.

Input Data: A multiple regression analysis is used to determine the influence of independent variables on one dependent variable. The dependent variable is the RE capacity share of total power plant capacity, which is based on the global power plant data base of Platts (2012), Werner et al. (2011) and The Wind Power (2012). Few values are updated via literature review. Independent variables, which are potential main drivers and barriers of RE integration, are identified via literature review based on the framework of Painuly (2001). Potential key drivers with good data availability are used for the statistical model (Tab. 1). These include financial, market, policy and natural characteristics. A supportive regulatory framework has been defined by the existence of a feed-in tariff (FIT), net-metering scheme or quota system, but net-metering and quota system are rarely applied. Market competition and utility ownership are local values, while the regulatory framework and energy vision are national characteristics. The values of GDP per capita are used as locally as possible; due to the fact that 62 cases are independent or semi-independent island states, excellent data availability is given. Natural characteristics are regional values as well: Hydropower is depending on two factors - discharge and the height difference between inlet and outlet, which potentially rises with island's elevation. Considering that local data for water availability and precipitation on small islands is not validated, elevation is used as indicator for the hydro potential. Additionally, wind speed and solar irradiation are measured.

[1] ESRI ® Arc Map™ 10.0
[2] The MathWorks Inc., MATLAB 7.12.0.635, R2011a

Table 1: Socio-economic and natural input parameters.

Variable	Main source
GDP per capita in PPP [USD]	CIA, 2012
Utility ownership	REEEP, 2012
Market competition	REEEP, 2012
Regulatory framework	REN21, 2011
Energy vision	REN21, 2011
Irradiation [kWh/m²/year]	Breyer et al., 2011
Wind speed [m/s]	NASA, 2012
Elevation [m]	CIA, 2012

Sample: Defining a sample for the regression analysis is crucial for generating valid results from the method. Due to good data availability only independent and semi-autonomous island states are used for the basic sample. Islands with major base load power plants (existence of nuclear of any size or large coal capacities > 500 MW), grid connections to continental entities, a population > 3 million inhabitants on any island or a total power plant capacity of more than 2 GW on any island are excluded from the analysis. Additionally, eight best practice examples with outstanding RE achievements on different levels are added to the sample to better display possible reasons for RE success (El Hierro, Graciosa, Réunion, Kodiak Island, King Island, Kaua'i, Hawai'i and Fuerteventura). All entities accumulate to 70 cases with 17 million people.

Calculation and validation: The regression analysis with the statistical program SPSS Statistics[3] is done with a stepwise approach. Hence, only model parameter, which can significantly contribute to the explanation of the RE capacity share on analyzed islands remain in the model and the calculations. Variables with a significance level below 95 % are excluded from the model. This ensures a maximum explained variation (R^2) of the dependent variable with a limited number of factors.

All results were checked for multicollinearity, autocorrelation, heteroscedasticity, the existence of linear relationships and distorting outliers (> factor 3.5 of standard deviation).

The analysis is carried out for different energy scenarios: Scenario 1 *all RE*, including PV, wind, hydro, geothermal, bioenergy, as well as waste-to-energy; Scenario 2 *new RE*, excluding the very mature RE hydro energy; Scenario 3-5 analyzing only *PV*, *wind* or *hydro energy* as the most important RE technologies for contribution to RE share. Bioenergy, geothermal and waste-to-energy are not separately analyzed, since they are only present in very few islands, which is not sufficient to calculate valuable results on the basis of a regression approach.

Results

The main results of the GIS analysis of global islands are shown in Tab. 2. The spatial analysis of global islands reveals an overall amount of 87,129 islands of significant size > 0.0238 km². 13 % of them are statistically inhabited. Approximately 742 million people live on these islands; more than one third of them alone in Indonesia.

[3] IBM SPSS Statistics, 15.0.0

Table 2: Amount, area and population information of global island analysis, listed by population size class.

Population size class	Islands	People [1,000]	Area [1,000 km²]
<1	75,786	0	715
1-100	7,310	126	213
100-1,000	2,134	775	482
1,000-10,000	1,237	4,132	1,010
10,000-100,000	457	14,380	2,440
100,000-1,000,000	151	45,383	727
1,000,000 - 10,000,000	41	136,325	1,754
>10,000,000	13	540,457	2,731
Inhabited, >1	**11,343**	**741,578**	**9,358**
Total	**87,129**	**741,578**	**10,073**

Table 3: Countries[4] with the largest number of islands and total island population.

Country	Total islands	Island population [1,000]
1 Canada	13,670	1,628
2 USA	7,426	9,525
3 Chile	6,269	189
4 Indonesia	6,050	243,600
5 Australia	4,110	575
6 Sweden	3,028	224
7 Philippines	2,272	101,005
8 Estonia	2,173	44
9 Finland	2,035	80
10 China	2,034	11,687

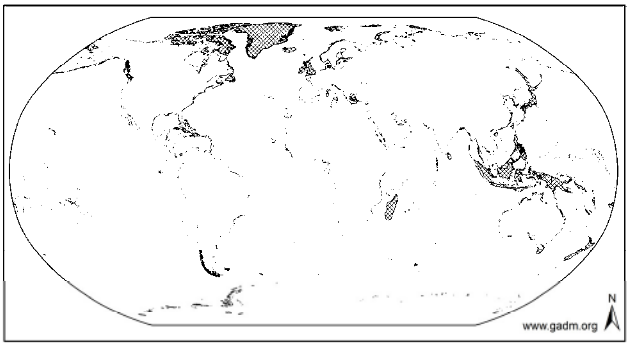

Figure 1: Global distribution of islands.

Globally, the average population size of an island is 8,511 with an average island size of 117 km². Considering all populated islands, the average population size is 65,378 with an average island size of 825 km². Global islands cover a total area of 10,073 km², which is roughly the size of Europe. This huge area can be explained by the size of very few very large islands. The ten biggest islands account for already 56 % of the area of global islands. In terms of population, the 10 most populated islands have an even bigger influence on total population size – they account for 68 % of total island population.

Tab. 3 and Fig. 1 show the regional distribution of islands. 56 % of global islands belong to 10 countries. While Canada has the most islands, most inhabitants can be found in Indonesia.

For the determination of a market potential for small island electricity system, it is necessary to define the term "small island". One possibility is to define it by maximum population on an island (Tab. 2). Small island electricity systems on islands with less than three million inhabitants, as defined in the statistical regression analysis, accumulate to 98 million inhabitants on 11,310 islands, which is 13 % of global island population. Even if only mini-grids up to 10,000 inhabitants are considered, a maximum market potential of 5 million inhabitants remains (0.7 % of total island population).

Table 4: Results of stepwise multiple regression analysis for different energy scenarios.

Dependent variable	Explained variation[5] (R^2)	Explanatory variables
1. All RE	0.260	Elevation, energy vision, reg. framework
2. New RE	0.303	Reg. framework
3. PV	0.393	Reg. framework, market competition, GDP
4. Wind energy	0.096	Reg. framework
5. Hydro energy	0.151	Elevation

The statistical regression analysis reveals that RE implementation is determined only to a limited degree by socio-economic and natural factors (Tab. 4). The stepwise regression selected different factors for scenarios 1-5. If we consider scenario 1 (all RE technologies) the variation of RE capacities can be explained to 26 % by three potential drivers: max. elevation within an island entity, existence of an energy vision and supportive regulatory framework. If the hydro energy capacity is excluded from RE sources, remaining RE are strongly determined (30 %) by one single driver: existence of a supportive regulatory framework (scenario 2). PV is determined to 39 % by regulatory framework, market competition and GDP (scenario 3), while wind energy is also determined to 10 % by the regulatory framework (scenario 4). Only the distribution of hydro energy among islands can only be explained with a natural factor - elevation accounts for 15 % of variation.

Overall the socio-economic factor utility ownership (public or private) has no statistically significant influence on any RE scenario. Also natural factors solar irradiation and wind speed are not significantly explaining RE distribution on islands.

Discussion

The GIS analysis has proved being a valuable insight on global island landscape and answered the first research question. Identifying 87,000 islands with 742 million inhabitants in the first step and connecting them with socio-economic and natural data allows determining

[4] Depending territories are generally excluded (exception: Finland includes Åland Islands).

[5] R^2 ranges from 0 to 1. 0 means that the RE distribution explains 0 % of the variation; 1 explains 100 %.

investment options of high interest. Indonesia and Philippines are very promising in terms of island number and population.

The bigger an island and the larger its population, the more valid is the estimated population. Hence, small islands may have statistically reasoned and methodology based population sets, which especially holds true for the population size class 1-100. Considering this constraint a possible valid mini-grid market potential of 1,000 to 10,000 inhabitants on 1,237 islands still accumulates to 4.1 million inhabitants, which is to great extent an untapped RE mini-grid potential.

Statistical regression modeling can be used to determine the influence of socio-economic and natural factors on the success of RE rollout on islands. The explained variation of 10-39 % among different analyzed RE scenarios is rather high for a complex phenomenon within a sample with totally different socio-economic and natural preconditions. It is surprising that natural conditions seem to influence RE investment decisions on islands only to limited extent. The importance of feed-in tariffs (FITs) for successful implementation of all RE (except hydro) depicts the high initial investment costs of RE in comparison to oil based electricity generation in the past and consequently answers the second research question. This underlines that secure investment conditions attract enough private capital to push the implementation of RE. Worth mentioning is that PV depends to 25 % on a, while variation of wind energy can only be explained to 10 % by a well-established regulatory framework. With the current conditions and the expected learning curve trend of RE (Breyer & Gerlach, 2012) as well as diesel gensets operational costs becoming more expensive, the importance of FITs is expected to decline in future. The influence of a FIT for successful RE implementation has been already proved by plenty of authors at least for continental countries (Negro et al., 2012).

However, the validity of the underlying statistical model can be potentially increased by more disaggregated and detailed databases for other socio-economic factors such as corruption, political stability, lack of information of locals and decision makers, missing acceptance of new technologies, target conflict with tourism, absence of local experts, missing personal engagement or interest rate. Including only socioeconomic factors with good data availability restricts the global validity and constitutes a bias of undefined extent. Also other promising policies have to be dealt with in future, e.g. investment subsidies. The sample size can be extended by adding information on exact power plant locations. Therefore, further research should focus on enhancing the sample of the regression by locating exact power plant coordinates and improving quality of mentioned additional socio-economic data.

It is highly recommended to introduce a supportive regulatory framework, for instance in form of a FIT, and long-term energy goals in form of an energy vision. Additionally, project planners should consider socio-economic factors such as regulatory framework and energy vision in early planning stages of RE projects. Furthermore, governments should introduce incentives for electricity utilities to invest in RE capacities, which potentially lower the island's overall electricity expenditures. These actions are very likely to accelerate the deployment of new REs, such as wind power or PV, on islands.

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Energy Supply on Amazon Remote Communities in Brazil: A Study Case for the Communities of Terra Nova, Mourão and São Sebastião

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Abstract

Since the introduction of the Law 10.438/2002 in Brazil, there is a legal obligation to provide energy supply to all the Brazilians, both the ones living in urban areas and the ones living on remote areas. Due to this obligation the power supply companies had to deal with a whole new challenge and environment: providing energy at small communities located at Amazonas River Basin and other extremely remote areas in Brazil. One of the main reasons for not providing electric energy to such remote communities is the massive investments needed and almost no information/experience related with operation and maintenance costs for those kinds of systems, besides the low profitability and the fact that most of the supply has to be done with isolated systems. The aim of the paper is to present three study cases comparing energy supply costs for three remote communities in Amazonas with different energy sources and systems concepts. It´s important to emphasize that the power supply costs for remote areas cannot be compared with the Brazilian Grid electricity prices due to issues associated with the scale and scope of the off-grid systems presented at this article.

Keywords: Remote areas, power supply costs, off grid systems, solar energy.

Introduction

To achieve the goal of providing power supply on Brazil remote communities, mostly located in rural areas, the Law 10.438/2002 (Brazil, 2002) established the universalization of electric energy supply through a program called "*Luz Para Todos*" (LpT). During almost nine years, 2.9 million rural households and 14.4 million people have been provided with electricity. According with the Brazilian Census 2010, there are still 728 thousand households, most of them located on extremely remote areas without any power supply in Brazil. The end of the "LpT" Program was postponed to 2014 in order to provide electricity to those remote communities which the power supply investment costs are above three times the price for non-remote rural areas attended by "LpT" program. All the progress achieved by the regulatory framework for rural electrification on remote areas and for decentralized energy supply opens new concepts of energy systems for those areas.

Research Objectives

The main objective of the article is to study and analyze application of different power systems conception on three communities located in Amazonas State, and be able to point out which one of them would result on lower power supply costs. The systems studied were the following:

- MICGI PV (CPV): 100% photovoltaic solar power plant;
- MICGI Hybrid – PV+Diesel backup (CPVDb): photovoltaic solar power plant with diesel working as a backup;
- MICGI Hybrid – PV+ Diesel Generation (CPVDg): photovoltaic solar power plant with diesel generator participating in the generation;
- MICGI Diesel 1(CDg_1): diesel generation system with 24 hour monitoring;
- MICGI Diesel 2 (CDg_2): diesel generation system without monitoring;
- SIGFI PV(IPV): 100% individual photovoltaic solar systems

The paper will compare the power supply costs with the five systems mentioned above for the remote communities of Terra Nova, Mourão and São Sebastião. The paper is organized into five parts. The first and second ones describe the motivation its motivation and objective. The third one describes the method, hypothesis, premises and characteristics of the communities which the study case took place. The results and discussion are presented at the fourth and fifth part of the paper.

Methods, Calculation Formulae

The estimation of power supply generation costs was done considering a number of assumptions, such as:

- Systems characteristics;
- Remote communities in which the systems would be installed and its access characteristics, logistics to transports equipment and number of households;
- Monthly power energy supply per household;
- Diesel fuel costs and transportation;

Assumptions on Fuel and Hardware Costs

The systems analyzed were, as already mentioned, solar plants (100% solar and hybrid system – adding diesel as a backup or participating on the energy generation), individual systems (100% solar) and diesel plants with and without monitoring. All the systems were dimensioned to provide 45 kWh monthly per household in communities with 30 households.

All the systems were dimensioned to provide power supply considering the rules established by ANEEL (Brazilian Power Supply Regulator).

ANEEL´s regulation defines specifications for reliability, quality and duration (Table 1).

Table 1: ANEEL´s Specifications for Power Supply with Intermittent Resources*on Remote Areas.

Monthly Guaranteed Availability (kWh/month/household)	Baseline Consumption (Wh/day/household)	Minimum Autonomy (hours)	Minimum Power (W/UC)
30	1.000	48	500
45	1.500	48	700
60	2.000	48	1.000
80	2.650	48	1.250

*intermittent resources are solar, wind and biomass.

The capacity needed from photovoltaic solar panels, batteries, inverters, controllers and diesel generators were dimensioned using the information from São Gabriel da Cachoeira as a reference (Esteves (a), 2011). The city is located at the Amazonas State´s extreme northwestern into Alto Rio Negro River Basin. It´s also is one of the country's border towns. The location´s coordinates are shown in Table 2.

Table 2: São Gabriel da Cachoeira´s Coordinates.

Latitude	Longitude	Daily Average Temperature
0° 7.8' south	67° 4.8' West	31ºC

The irradiation level determined the availability and capacity of photovoltaic energy generation. The solar irradiation used in dimensioning was 4,8 kWh/m^2/day (Esteves (a), 2011). The equipment efficiencies and system losses shown at Table 3 were applied.

Table 3: Equipment Efficiencies and Systems Losses.

Variable	%
Load Factor	25%
Inverter Average Efficiency	80%
Generation Losses	30%
Distribution Losses	3,2%
Maximum Battery Discharge	60%
Inverter Losses	1%
Diesel Participation*	28,7%

*hybrid systems

The load curve used in dimensioning is shown in Figure 1. The following equipment's were considered to build the curve:

- 4 lightning points
- Television
- Satellite receptor
- DVD
- Radio
- Fan
- Refrigerator

The generation plants will distribute the energy generated with a low voltage net with a maximum length of 1 kilometers. The distances between the households were considered lower than 40 meters (Esteves (b), 2011). The banks of batteries have different voltage depending of the purpose. For the collective systems, it was dimensioned a bank with 48 volts and for individual systems with 24 volts.

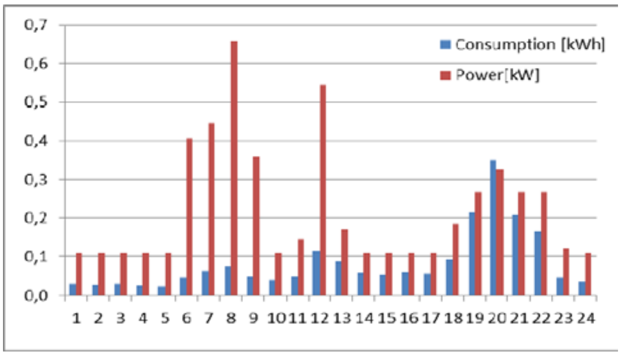

Figure 1: Load Curve used in Dimensioning.

The labor, transportation, installation, maintenance and equipment's costs were calculated and defined through several indexes and proxies. The number of personnel for the systems installation and maintenance, as well as the working hours required for both activities was estimated based on questionnaires applied to the stakeholders from Brazilian distribution companies which have experience on the attendance of remote communities and therefore are aware of all the challenges related to it. Table 4 show the proxies applied to equipment indexes.

Table 4: Equipment Costs Index.

System	Solar Panel (R$/Wp)	Inverter (R$/kW)	Controller (R$/kW)	Battery (R$/Wh)	Diesel Generator (R$/kVA)
CPV	6,98	3.484	2.011	1,37	-
CPVDb	6,91	3.540	2.011	1,37	1.326
CPVDg	6,91	3.484	2.011	1,47	1.326
CDg_1	-	-	-	-	1.326
CDg_2					1.326
IPV	7,66	5.568	1.789	1,94	-

The differences between the costs index for collective and individual systems comes from the economies of scale provided by the collective systems. The labor necessary to install and maintain the systems were composed by engineers, senior and junior technicians (Table 5).

Table 5: Installation Labor Personnel and Salaries.

System	Engineers	Senior Technician	Junior Technician
Collective			
Number	2	2	4
Salary (R$/h)	50	20	10
Daily Fee (R$/day)	100	60	60
Individual			
Number	1	2	2
Salary (R$/h)	50	20	10
Daily Fee (R$/day)	100	60	60

The indexes for personnel and equipment transport costs were build based on information provided by the distribution companies (Table 6).

Table 6: Personnel and Equipment Transport Cost Index.

Variable	Price (R$/h)
Personnel	
Ferryboat	40
Motorboat (ferry)	17
Motorboat (rent)	280
Bus	15
Car	81
Equipment	
Index (R$/kg/day)	2,18
Insurance	3%

CAPEX and OPEX

In the deployment costs, the maintenance of the main equipment's such as solar panel, inverter, controller and batteries were estimated via prices index calculated through a prices database build to this purpose, as showed at Table 4.

The costs of accessories, construction and structure for the solar panel were determined as a percentage of the main equipment's costs. This percentage was estimated based on projects already developed in Brazil (Soares et al., 2010). The deployment time for individual systems was defined as 4 hours and for the collective systems 30 days plus 72 hours of commissioning.

Concerning the operation and maintenance procedures, it was considered an annual visit for the preventive maintenance, both for the solar photovoltaic and hybrid plants and the individual systems (Soares et al., 2010). For the diesel plants with 24 hours monitoring was considered 2 operators working in 8 hours shift, and for the one without monitoring 3 preventive visits per year. All operational and maintenance team were composed by 1 senior technician and a junior technician, and it would take 5 hours for the maintenance of the collective systems and 1 hour and 30 minutes for the individual system. The corrective maintenance for the solar photovoltaic and hybrid plants were defined as one visit without the need to replace any equipment. For diesel plant without 24 hours monitoring 2 visits per year and for the individual system, the number of visits per year was calculated based on the fails index of the equipment (Table 8), meaning that each fails represents one operational and maintenance visit.

Table 7: Equipment Fail Index.

Equipment	Fail Index (%)	Useful Life (Years)
Inverter	3,1	10
Controller	2,6	10
Batteries	3,9	7

For the hybrid systems which have the diesel participation in it, another maintenance costs were taken into account: oil changing and oil´s waste discharge (Table 8). Petrobras is the company responsible for delivering the oil in the remote communities and the distribution companies responsible for the waste transportation.

Table 8: Oil and Waste Costs.

System	Oil		Oil´s Waste	
	liters	Price – R$/L	liters	Price – R$/L
CPVDb	825	2,27	41	6,00
CPVDg	2.635		132	
CDg_1	18.082		904	
CDg_2	18.082		904	

Descriptions of the Locations

The reference communities for the study case were the ones named Terra Nova (Barcelos City), Mourão (Eurinepe City) and São Sebastião (Autazes City). The equipments must be transported to the communities by river (fluvial transportation), and it takes, respectively, three, eighteen and two days to do so. All the personnel involved both with the system´s installation and maintenance comes from the main office of the distribution company. To transport the personnel to install the systems and maintain it, it takes 8h45 minutes travelling by river to get to Terra Nova, 4h30 minutes to get to Mourão and 4h10 minutes to get to São Sebastião (Esteves (b), 2011).

Power Supply Costs Estimation – Composition, Hypothesis, Parameters and Premises

The energy generation costs systems are divided in deployment costs (Capex) and operation and maintenance costs (Opex).

$$CAI = CI + COM$$

Where:
CAI: Generation Cost on Remote Area;
CI: Deployment costs;
COM: Operation and Maintenance costs.

The CAPEX was calculated as the sum of material, transport (both equipments and personnel) and personnel costs.

$$CI = C_{Mat} + C_{Transp} + C_{Pessoal}$$

Where:
C_{Mat}: Materials Costs;
C_{Transp}: Transport Costs;
$C_{Pessoal}$: Personnel Costs.

And the operation and maintenance costs are the sum of both preventive and corrective maintenance and the replacement of equipment. The replacement costs are composed by the cost of the equipment, the transport of equipment and personnel costs.

$$COM = COM_{prev} + COM_{Cor} + C_{Reposição}$$

Where:
COM_{Prev}: Preventive Maintenance Costs;
COM_{Cor}: Corrective Maintenance Costs;
$C_{Reposição}$: Replacement Costs.

The generation cost is defined through a cash discounted flow divided by the total energy generated during 25 years of operation.

$$Custo_{geração} = \frac{\sum_{t=1}^{n} \frac{CI_t + COM_t}{(1+r)^t}}{E_t}$$

Where:
CI: Deployment Cost;
COMt: Operation and Maintenance Cost;
Et: Energy Generated;
r: discount rate;
n: Planning horizon.

The discount rate applied was the WACC of 7,57% calculated by the Brazilian Electric Energy Regulator for the third cycle of tariffs revision.

Results

The generation costs for both communities are presented at Fig. 1 and Table 11. The energy cost generation is strongly influenced and affected by the access logistics to the communities. For instance, to transport the equipment to Mourão it takes at least 18 days and on the other hand to take the same amount of equipment to São Sebastião it takes only 2 days. It reflects directly on the energy costs for the PV Plant and a SIGFI System, therefore it ends up costing in Mourão almost 2 times the price than in São Sebastião. The same behavior is observed comparing São Sebatião to Terra Nova and Mourão with Terra Nova. Lower impacts are observed on both Diesel Plants and PV Hybrid +Diesel Generation because the weights of those systems are smaller and the operation and maintenance cost responds for most part of the VPL.

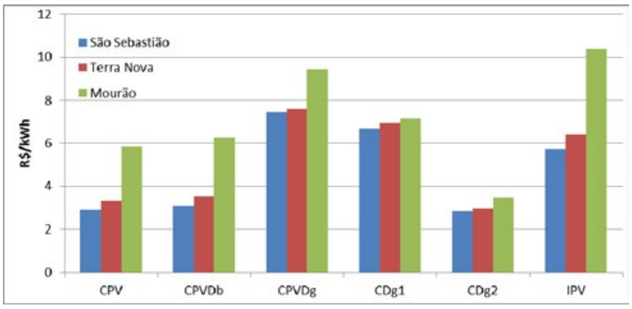

Figure 2: Energy Generation Cost in the Communities.

When comparing the different systems for the same community, the CDG_2 and PV MIGDI are the ones with lower energy generation costs. It´s also important to point out that for the CDG_2 it was considered just 2 preventive visits and if more visits than this were necessary then the system would cost more than the PV MIGDI. Observing the energy costs for São Sebastião, the PV MIGDI and CDG_2 have at least half the price of all other systems simulated. This can be explained as a combination of system optimization and economies of scale.

Table 9: Power Supply Costs (R$/kWh).

Systems	São Sebastião	Terra Nova	Mourão
CPV	2,91	3,32	5,83
CPVDb	3,1	3,53	6,29
CPVDg	7,45	7,61	9,44
CDg_1	6,69	6,95	7,16
CDg2	2,85	2,96	3,48
IPV	5,73	6,42	10,37

The diesel generation systems with 24 hours monitoring, the operational and maintenance costs responds for more than 80% of the VPL, meanwhile at the PV Plant there is equilibrium between deployment and operation and maintenance costs. The hybrid system with diesel participation at the energy generation is the one that presents the higher energy costs.

Table 10: Relation Between Opex and Capex (Opex/Capex).

Systems	São Sebastião	Terra Nova	Mourão
CPV	7,78%	9,45%	13,33%
CPVDb	8%	9,67%	13,58%
CPVDg	36%	38,5%	32,74%
CDg_1	76,2%	77,58%	32,75%
CDg2	15,87%	16,80%	18,57%
IPV	11,43%	13,17%	16,21%

Analyzing the investments costs share for São Sebastião, it can be observed that, on average, in the installation the equipment costs responds, in collective systems, between 68-80% of all investment costs and personnel between 13-28%. For individuals systems the equipment's represents almost 90% of the investment costs.

Table 11: Investment's Cost Share – São Sebastião Communities (%).

Systems	Equipment's and Materials	Equipment´s Transport	Personnel	Personnel´s Transport
CPV	79	8,0	12,8	0,2
CPVDb	79,2	8,4	12,2	0,2
CPVDg	78,8	7,5	14,4	0,2
CDg_1	68,8	2,6	28,2	0,4
IPV	90,1	8,4	1,4	0,4

The O&M´s costs share varies considerably from the system type used. The systems that have diesel participates in the generation have more than 80% of preventive O&M. The main reason is that in Brazil usually the distributions company designates technicians to work in 24 hours shifts monitoring the diesel generator. Maybe with the introduction of smart grid and automation this scenario could change.

Table 12: O&M's Cost Share –
São Sebastião Communities (%).

Systems	Preventive	Corrective	Replacement
CPV	3%	2%	95%
CPVDb	7%	2%	92%
CPVDg	84%	1%	15%
CDg_1	1%	1%	98%
IPV	2%	19%	79%

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Optimal Operation and Control Strategy of a PV/Diesel Hybrid System Without Battery Storage: An Economical Analysis

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Abstract

To be efficient, hybrid electricity generation systems involve some forms of control. These later could enable an optimal management of the electricity production and loads to be supplied by the system. However, these control systems can be relevant only if they could help reducing the electricity production cost. This paper is focused on the study of a hybrid PV/diesel system without storage in batteries called "Flexy Energy" prototype. Basing on an economical analysis, this prototype without an automation system is compared to the identical one with an automation system to supply a same load profile. Results obtained show clearly that the automated system help to achieve a reduction of the electricity production cost of about 2.9% compared to the same system without a control system. Also, as the automation system cost is slightly dependent of the installed power, the reduction of the electricity production cost will be certainly more important if high powers are considered.

Keywords: Economical analysis; PV-Diesel hybrid system.

Introduction

In developing countries, the awareness of the sustainable development concept and the need to produce a reliable and affordable electric energy for decentralized areas have promoted the integration of alternative and competitive power generation systems. PV/Diesel hybrid systems appear as one of the most reliable hybrid electricity generation systems (Seeling-Hochmuth, 1997), (Ajan et al., 2003), (Dekker et al., 2012), (Muñoz et al., 2007), (Wichert, 1997), (Phuangpornpitak & Kumar, 2011), especially in rural areas of Sub-Saharan Africa region. In addition, most of these hybrid PV / diesel systems include batteries of storage and then present some drawbacks due to these later: high investment cost, short lifetime of batteries which multiplies their replacement, etc. Also structures for recycling batteries are non-existent in sub-Saharan Africa region and batteries are released in the nature after their use what constitutes a serious environmental problem. For these above named reasons, hybrid PV/diesel system without batteries of storage could provide appropriate technological and cost-effective solutions for the electrification of remote areas i.e. those where there is no existing grid (Ajan et al., 2003), (Azoumah et al., 2011) , (Yamegueu et al, 2011). However due to the intermittence of the solar radiation and the dynamic behavior of the load demand, an optimal strategy to operate and control the system is very important. This optimal management strategy could be very complex due to many reasons. The main of them are:

- the non-linear characteristics of some components of the system (Seeling-Hochmuth, 1997), (Abedi et al., 2012),
- the obligation of the system to provide at real time the electricity for loads with respect to the standard (frequency and voltage variation),
- the operation of the diesel generator in its optimal range, between 70-80% of its rated power (Yamegueu et al., 2011), while ensuring the higher PV penetration available. This range can be stretched in 60-90% of gen-set rated power.

Research Objectives

This study aims to present a new approach of control strategy able to ensure the reliability of PV/Diesel hybrid systems without battery storage while guaranteeing the lowest electricity production cost. This work has been done in the framework of the development of the "Flexy Energy" concept which is an original approach developed by the Solar Energy and Energy Saving laboratory of 2iE. This concept consists in decentralized electricity generation through hybrid PV/Diesel systems without storage in batteries and with a smart management of the energy production and loads to be supplied.

The first part of this paper displays the strategy operation performed; the second part shows results of an economic assessment for a case study where the approach proposed has been applied.

Methods

Several authors have studied and experimented PV/Diesel hybrid system with batteries storage, (Khelif et al., 2012), (Muñoz et al., 2007), (Shaahid & El-Amin, 2009), (El-Hefnawi, 1998) but just a few have carried out feedback experiences about those without batteries of storage (Lau et al. 2010), (Yamegueu et al., 2011). The study conducted here is based on experiences derived from a PV/diesel hybrid system without storage named "Flexy Energy" prototype. This prototype consists of a PV array of 2.85kWp coupled with a diesel generator rated at 9.2kW through a single phase inverter of 3.3kW.

Besides, it has been pointed out that the random nature of the solar source, the varying nature of the load demand, the balance between the power supply and the load demand are some of the main difficulties in the operation of hybrid systems, especially in those without batteries.

Some of the main operation constraints in PV/diesel hybrid system without battery storage are reported below:

- Diesel gen-set operating conditions
  - Optimal operating range: generally between 60-90% of the gen-set rated power;
  - Need to stop and start automatically;
  - Runs for a sufficient period of time to reach operating temperature.
- Inverter operating conditions
  - Need to be synchronized with the diesel generator
  - must allow disconnection of the PV field in case of blackout gen-set;
  - Ensure maximum PV penetration into the system.
- Load demand
  - Avoid interruption of production when changing from one source to another;
  - To be supplied in real time;
  - Use the excess energy produced by the PV array.

Load profile management

The requirements for supplying a growing population with electricity in a developing country ask for a thorough knowledge about the evolution of load demands (Herman & Kritzinger, 1993). Then, the load management strategy is a key issue in the hybrid system operation.

The management method proposed in this paper consists first of categorizing loads in three types from a typical load profile. Thus, the loads can be connected and disconnected in order of priority:

- Critical loads: these loads must be continuously satisfied and at real time, for instance a fridge that contain vaccinates in a rural area;
- Secondary loads: households electrical devices for example. The non-supplying of electricity could not cause any critical trouble.
- Dispatchable loads: loads that can be met at other times of the day without negative impact on the consumer. Dispatchable loads are the most importants in this study because the operation strategy is based on them. In fact, in rural areas, these loads generally consist of water pumping systems, molding millet points, water purification system and irrigation systems etc…they must be able to be easily managed.

The load profile is managed to ensure operating a gen-set in its optimum range with a judicious adjustment of the dispatchable loads and a maximum satisfaction of critical and secondary loads. Consequently in this case, one can use efficiently the PV generation. The peak load corresponds to the gen-set rated power; the different dispatchable loads are distributed appropriately within hours of low consumption so as to maintain the load profile in the optimal range of operation of the diesel generator, i.e. between 60% and 90% of the rated power. Then, it is necessary to find a tradeoff between the dispatchable loads to be supplied, the hours of feeding and the operating range of the diesel generator that will ensure an optimal functioning of the system. Figure 1 presents the load profile management of the case studied starting from the real profile of the area to the optimized one without changing the global daily energy consumption.

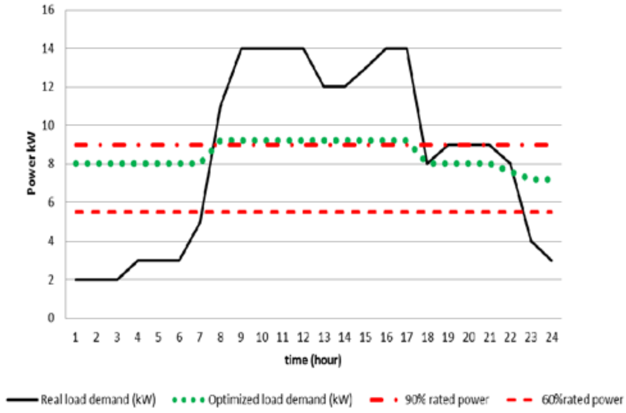

Figure 1: Load profile management.

Automatic control strategy

To be efficient, hybrid electricity generation systems involve some forms of control which could enable an optimal management of the electricity production and loads to be supplied. However, these control systems can be relevant only if they could help reducing the electricity production cost. The second part of the method, developed in this study, consists of implementing an automatic program to avoid the Diesel gen-set operates at low load, i.e. less than 60% of its rated power. Threshold power below which it is not allowed to operate the gen-set is defined. A minimum setting time of idle operation of the gen-set and a delay transition range is integrated because once started the frequent cycles start / stop can cause wear and then ageing parts of the Diesel gen-set. The automatic program also avoids the overloading of the generator, which means that the loads supplied by this later are always lower than its nominal power.

Table 1: Cost of automaton system.

Designation	Quantity	€/unit
Electrical box	1	435.11
µ pilot PLC	1	824.23
AC transducer	3	244.27
contactor	4	229.01
24Vpower supply	3	68.70
cable	1	251.91
Control program	1	3,816.79
Supervision program	1	2,213.74
Installation	1	839,69

Results

Case study results

The methodology presented above has been applied on a hypothetic load profile of a rural area in sub-Saharan Africa (figure 2). Initially, the gen-set rated power able to supply this demand must be equal to 14 kW. But by distributing loads into critical, secondary and dispatchable loads while supplying the same energy 202kWh per day, one obtains a new peak load equal to 9.2kW (figure 2). After this load profile management, an automatic control strategy module has been performed and added to the "Flexy Energy" prototype. This module consists of a PLC1 "µpilot" integrating a suitable program in C language and µladder and a data recorder system to simulate the smart management of the system.

Loads used to simulate the demand consist of: two resistive loads banks of 4kW each, and 3 motors of 2kW each. These loads have been judiciously distributed into normal, secondary and dispatchable loads. Experimentations conducted point out the technical feasibility of the automated system. However as stated above the study is especially focused on the economical viability of the system.

Economical analysis

The objective here is to evaluate the costs of the systems with and without the automation control. In the two cases an economical analysis, based on Life Cycle Cost assessment by taking into account the investment cost, maintenance cost, operation and replacement costs of each component of the system (PV array, diesel generator, inverter, automaton, etc.) throughout 20 years life span of the system has been performed.

Table 2: Data for economical evaluation.

Costing data considered for the economical evaluation	
Diesel oil cost (€)	0.92€/l
DG lifetime	8 years
PV lifetime	25 years
Inverter lifetime	8 years
Discount rate (energy system)	8%
Discount rate (automation module)	10%
Escalation rate	4%

The economic model used is a mix of the one performed by (Notton, et al., 1998) and (Ajan et al., 2003). The results obtained are presented in the table 3. Table 2 presents the data used is this study. The total LCC is expressed as follow:

$$LCC=\sum_{i=1}^{4}(C_{I,i}+C_{M,i}+C_{O,i}+C_{R,i}-C_{S,i}) \qquad (1)$$

The index i represent the different components of the system i={PV array, Diesel Gen-set, Inverter, automaton system} and I, M, O and S are respectively the Investment, Maintenance, Operation , Replacement and Salvage.

All these costs (C), recurring or non-recurring are actualized by using the factors of actualization:

$$AF_{RC} = \frac{\left(\frac{1+i}{1+a}\right)\left[\left(\frac{1+i}{1+a}\right)^{d}-1\right]}{\left(\frac{1+i}{1+a}\right)-1} \qquad (2)$$

$$AF_{N-RC} = \frac{\left(\frac{1+i}{1+adj}\right)\left[\left(\frac{1+i}{1+adj}\right)^{d}-1\right]}{\left(\frac{1+i}{1+adj}\right)-1} \qquad (3)$$

adj is the actualization rate for non –recurring cost. It is computed using this formula:

$$adj = \frac{(1+a)^{ni}}{(1+i)^{ni-1}} - 1 \qquad (4)$$

With ni as a number of years between two successive payments for component i. d is the life span of the system.

Sensibilities analysis

The sensibilities of interest and escalation rate have been studied to evaluate the economical effects in the electricity cost.

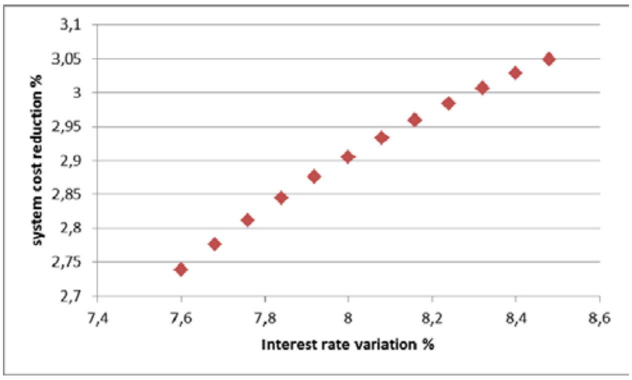

Figure 2: Sensibility of interest rate.

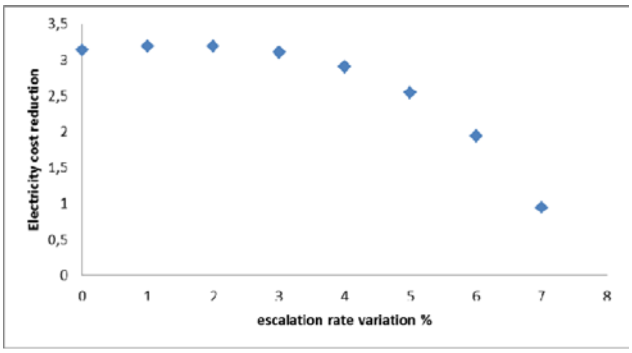

Figure 3: Sensibility of escalation rate.

[1] Programmable Logic Controller

Figures 2&3 present the percentage of reduction of the electricity production cost by varying in figure 2 the interest rate and in figure 3, the escalation rate. There appears a decrease in the percentage of reduction in the cost of electricity between 3.13% and 0.94% for a growing value of escalation rate and a slight increase in the percentage of reduction in the cost of electricity between 2.78% and 3.05% for a growing interest rate.

Discussion

From the obtained results (table 3), it is first noted that, for the case study, the implementation of a load profile management strategy has led to the optimization (reduction) of the gen-set size, reducing of 4.8 kW compared to the real case, i.e. € 3,940 saved, Second, the automation allows to generate a reduction cost of €10,628 compare to the system with a manual exploitation. This corresponds to a reduction of the electricity production cost by 2.9% compared to the same system in manual operating i.e. 0.7c€ per kWh produced. Also, study of the sensitivities of interest rate and escalation rate shows that the percentage reduction in system cost due to automation is very weakly dependent of economical parameters. The rates of reduction obtained show that due to its relative high investment cost, the automation could not be judicious for small systems. However as the cost of the automation module is relatively fixed and non-related to the size of the system it is clear that the reduction of the electricity production cost will be more important for systems of big sizes.

Table 3: Economical results.

PV/Diesel hybrid system cost	Without automation	With automation
Initial cost (€)	23,832	34,585
Annual O&M cost (€)	32,0292	287126
Gen-set salvage value (€)	571.5	508.2
Replacement cost(€)	23,257	36,663.9
Total energy supply over the life span (kWh)	1,454,400	1,454,400
LCC (€)	365,829	355,200.6
NET SAVINGS: €10,628		

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Site selection, an important factor for successful Biogas installations

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Abstract

Thirty million Euros have been committed to the African Biogas Partnership Programme by the Netherlands Government to finance 70,000 digesters, knowledge management, fund management and technical assistance over a five year programme (2009 to 2013). With such initiatives already underway, the infrastructure and resources needed to effect energy production and waste management through small-scale biogas digesters are already being put in place. Success of these programmes depends on suitable site selection for efficient long term digester performance. This paper presents a rational method for site selection that aims to ensure maximum potential for success of the installed digester.

Keywords: Biogas 1; Site selection 2; Sub-Sahara Africa 3; anaerobic digestion 4.

Introduction

Sub-Saharan Africa (SSA) is confronted by an energy crisis in both commercial (petroleum products, natural gas, coal, and electricity) and biomass (firewood, charcoal, and agricultural by-products). Energy has been in short supply, and has been provided at a cost, and in a form and of quality that has restricted its consumption by the majority of the people in the SSA region (World Energy Outlook, 2009; Parawira, 2009). The continent's energy utilization and demand is expected to continue to grow as development progresses at rates faster than those of developed countries (Parawira, 2009). The desire for improved quality of life and increases in the population, together with energy demands from the transport, industrial and domestic sectors will continue to drive this growth (Parawira, 2009).

Lack of access to clean and efficient energy can impact human health in many ways. The most important direct health effects result from the air pollution caused by burning solid fuels, often indoors on open fires and simple stoves (WHO, 2006; Singh and Sooch, 2004). Globally, three billion people are exposed to biomass smoke in poorly ventilated rooms, making biomass smoke one of the most important sources of indoor air pollution (Barnes et al, 1994). Poor household air quality is linked to pneumonia, lung cancer and chronic lung disease. It is estimated that it leads to approximately 1.6 million premature deaths annually (Ezzati et al., 2004).

Production of biogas through anaerobic digestion is a relatively simple technology that can be implemented at commercial, village and household scales. This gas has a combustible methane (55-70%) and carbon dioxide (30-45%). It is colorless gas that burns with clear blue flames at an ignition temperate range of 650 $^{\circ}$C to 750 $^{\circ}$C (Sathiyanathan, 1978). Biogas is useful as a fuel substitute for firewood, dung, agricultural residues, petrol, diesel and electricity. In the process of biogas production an organic fertilizer is also produced.

The climatic problems associated with greenhouse gas emissions have contributed to the recognition of anaerobic digestion as a technique to produce renewable energy (De Baere, 2000; Wim, 2006). Production and use of biogas will reduce the use of fossil fuels, thereby reducing the CO_2 emissions. Controlled anaerobic digestion reduces emissions of greenhouse gases and intensifies the recycling of nutrients within agriculture (Zhang et al., 1990; Amon et al., 2006, Clemens et al., 2006).

The number of small-scale biogas installations across Africa is increasing due to national domestic biogas programmes, such as supported by the African Biogas Partnership Programme, which aims to construct 70,000 biogas plants in Rwanda, Tanzania, Kenya, Uganda, Ethiopia, Cameroon, Benin and Burkina Faso by the year 2013 (Renwick, 2007). Success of these programmes depends on suitable site selection for efficient long term digester function and to ensure that farmers value the products the digesters bring. Here we present a rational method for site selection that aims to ensure maximum potential for success of the installed digester. This is important for project design and has wider implications for the success of biogas programmes worldwide.

Research Objectives

Reliable, cost-effective and sustainable energy supply is one of the main factors for development and economic growth. Identification of sites suitable for implementation of energy projects requires a careful selection procedure. Many factors may need to be considered before sites are selected for energy projects; for example, energy demand, site conditions, quality, quantity and distribution of feedstock. Therefore, assessment of the potential biogas project site and user is complex for practitioners, engineers, donors and policy makers who are not familiar with biogas technology.

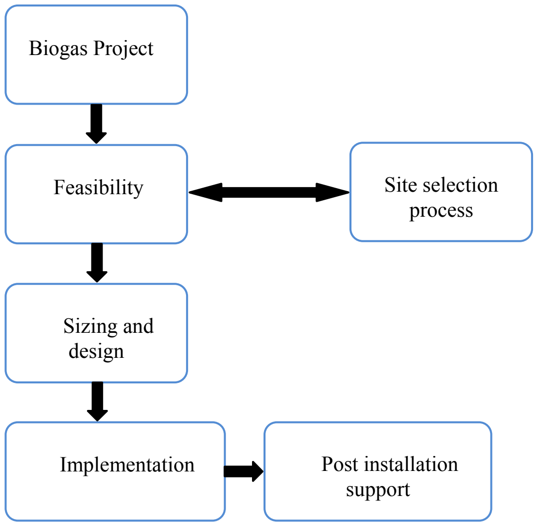

Figure 1: Project selection and implementation tool.

The general objectives are:

1. to promote the increased installation of biogas digesters in Sub-Sahara Africa,
2. to increase biogas technology awareness with policy makers and other practitioners,
3. to support the transfer of biogas knowledge and know-how,
4. to promote post-biogas digester installation training.

Methods

A questionnaire to select sites for installation of biogas digesters was administered in the village of Tiribogo, Muduuma Sub-County, Mpigi district, near Kampala, Uganda. The questionnaire was used to collect data on demand for biomass fuel, availability of feedstock and water, and ability to deal with organic waste management. Each of the 54 households in Tiribogo was interviewed once in a 30-minute structured questionnaire, consisting of a list of closed questions on how the household manages resources, such as farm, manure, water, fuel wood and kitchen residues. The proportion of households in Tiribogo with access to animal manure is relatively low because people are mainly involved in growing crops, which do not produce much organic waste as the crops are sold off, and so the crop residues are not retained in the village.

The householders interviewed were mainly women. The data collected were used to generate fact sheets and to rank the households using a simple numerical weighting system while applying a multi criteria decision approach. Ranking of households for suitability for installation of a flexible balloon biogas digester considered four factors; availability of feedstock, access to water, requirement for biogas and ability to train others.

Availability of feedstock

The feedstock is the material that is fed to the digester for anaerobic digestion to take place. Different materials have different digestion properties, and result in biogas of different compositions and quality. In general, all types of organic waste can be used for anaerobic digestion as long as they contain protein, carbohydrates, fats, cellulose, or hemicelluloses. Lignin, however, as found in wood products, is not easily broken down by anaerobic digestion (Riuji, 2005). Selecting a consistent mix of substrates with high energy content that is readily available to the bacteria, such as simple sugars and fats, maximises biogas production. By contrast, feeding the digester highly variable substrates with nutrients locked away in compounds that bacteria cannot easily digest, such as lignin and cellulose, leads to poor biogas yields.

One of the most important factors to the successful implementation of a biogas digester is the availability of the feedstock. The amount of biogas that could theoretically be produced depends on the type or breed of livestock and the livestock management system. For livestock kept in zero grazing conditions, the availability of that manure is 100%, whereas for cattle kept in stables only at night, manure available is ~50%.

In Tiribogo, cattle and pigs are kept in semi-zero-grazing environments, where they are grazed during the day, and penned at night for milking and security.

The amount and nature of feedstock are key factors in determining the optimum size of biogas digester, the volume of water required and the amount of biogas to be generated. If the installation requires more feedstock than is available to the household, the digester will not perform effectively. Brown (2006) suggested 1-2 cows or 5-8 pigs would supply adequate feedstock for a single four-person household digester. The raw material for digestion must be conveniently available on a daily basis i.e. a minimum of 30 kg fresh weight of cow manure or 15 kg fresh weight of vegetable waste or equivalent per household per day (Smith et al., 2011).

The quantity of organic waste produced each day, W_F (kg fresh weight day^{-1}), was estimated as

$$W_F = W_L \times n \times p_m$$

where W_L is the live weight of the animal (t), n is the number of animals contributing to the digester, and p_m is the production of manure for each kg of live weight (kg manure) (t live weight)$^{-1}$. The live weight of cows in Tiribogo was assumed to be 180 kg (W_L = 0.18 t cow^{-1}). If cows were put out to graze during the day and penned only at night, the number of cows in the household was multiplied by 50%, as only ~50% manure was fed to the digester (n = 0.5 x number of cows kept in the household). The amount of manure produced by cows (p_m) was assumed to be 90 kg (t live weight)$^{-1}$ (Chen, 1983). The live weight of pigs in Tiribogo was assumed to be 55 kg (W_L = 0.055 t pig^{-1}). Again, if penned only at night, the number of pigs in the household was multiplied by 50% (n = 0.5 x number of pigs kept in the household). The amount of manure produced (p_m) was assumed to be 75 kg (t live weight)$^{-1}$ (Chen, 1983). Organic wastes other than cow and pig manure provide additional feedstock that was accounted for similarly.

Water availability

Water is used in SSA households for drinking, cooking, hygiene (bathing, laundry, washing hands, food and dishes) and irrigation (Rosen and Vincent, 1999). The amount of water used by a household depends on the availability of the water source. Water Aid (2012) suggested that the average person in the developing world uses 10 dm^3 day^{-1} for drinking, washing and cooking. Much of this water can be recycled into the biogas digester, so reducing additional labour for water collection. The amount of water required to run a biogas digester depends on the type and amount of feedstock. For optimal anaerobic fermentation, the dry matter content must be between 2 and 5% (Preston, 2011). This means that for each 10 kg of dry matter there is a need for about 200 dm^3 of water. Pandey et al. (2007) expressed this as approximately equal volumes of water and fresh dung being fed into the digester daily. From this the daily requirement for water to run a biogas digester, F_W (dm^3 day^{-1}), can be estimated as

$$F_W = M_F \times \frac{F_{DM}}{100} \times \frac{200}{10} = M_F \times \frac{F_{DM}}{100} \times 20$$

where M_F is the amount of manure (kg fresh weight day^{-1}); and F_{DM} is the percentage dry matter in the manure. Assuming a dry matter content of 10%, this translates to $F_W = M_F \times 2$.

Householders in Tiribogo collected water either from a borehole or an open well. The majority of the householders interviewed spent under one hour collecting water each day, but some householders spent over two hours. Batzias et al. (2005) suggested that water should ideally be within a distance of 20 to 30 minutes from the installation. Therefore, for practical purposes, in view of the significant amounts of water needed, 1 hour time to travel the two ways to and from the water source was set as the limit for an installation.

Grazing regime

Households were further scored according to the grazing regime used because this determines whether the household considers manure to be a valuable commodity or a disposal problem. The scores used have a range of 0-5 as opposed to the 0-10 range used for the amount of organic wastes. This approach ensures that the grazing regime has only 50% influence in selecting households compared to amount of organic waste. The ranges selected for the scores are subjective, but were arrived at by expert judgment. The scoring is as follows:

- zero grazing; score = 5;
- night stabling; score = 3;
- pastoral grazing; score = 0.

Manure management regime

Households were also scored according to the manure management regime, again with a range of 0-5, as this could impact the value of the bioslurry to the household. The scores are show below:

- mulching / composting; score = 5;
- application of manure directly to crops; score = 3;
- dumping of manure; score = 1.

Results

Under this project, a range of digester with volume 4 m^3 to 8 m^3 were to be supplied to nine households. To run a 4m^3 digester requires a minimum of 30 kg fresh weight of cow manure or 15 kg fresh weight of vegetable waste or equivalent per household per day (Smith et al., 2011). Using a 5 kg day^{-1} safety margin, it was assumed that a minimum of 20 kg day^{-1} of fresh organic waste would be needed to run the digester. Fig. 2 shows the quantity of organic waste generated by households in Tiribogo. Households with capacity to generate more than 20 kg day^{-1} are considered to have potential to sustainably supply the required feedstock for a family biogas digester. The red line shows generation of 20 kg day^{-1} of waste; households with capacity to generate more than this required amount were scored as being able to sustain a biogas digester. Households below the red line were eliminated on the basis of not being in position to meet the minimum quantity of organic waste required to sustain a biogas digester. 31 % of the interviewed households were able to generate over 20 kg fresh organic waste day^{-1}. In practice, a larger digester of 8 m^3 is better suited to homes in Tiribogo that require about 2,000 dm^3 biogas day^{-1} to meet cooking needs.

Fig. 3 shows the extra water that would be needed by each household to run a biogas digester assuming all household organic waste is used in the digester (households with negligible organic waste have been excluded from the figure). The majority of households would require an extra 40-100 dm^3 of water each day.

Combined scores

All scores taken together give a maximum potential score for a household of 50 points. The summed scores are shown in table 1. This shows the 9 highest scoring households, as listed in table 1.

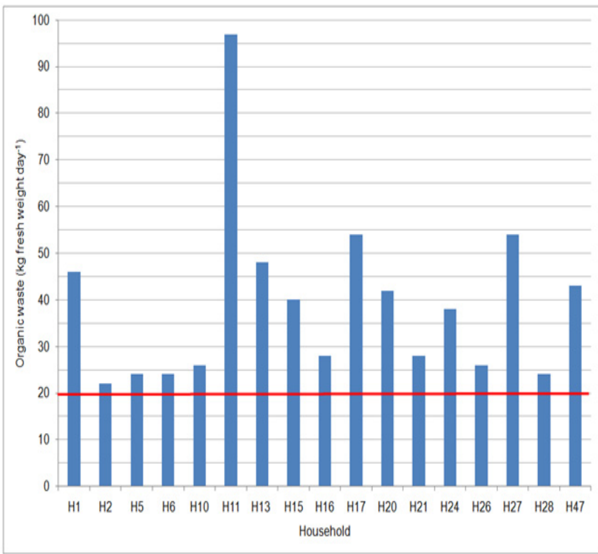

Figure 2: Quantity of organic waste per households.

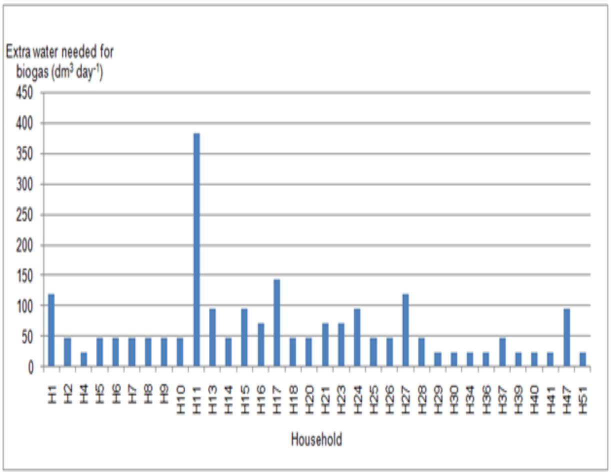

Figure 3: Quantity of extra water needed per households.

Table 1: Organic waste, water requirement and estimated biogas for households.

	Householder code	Quantity of organic waste (kg day^{-1})	Water required (dm^3 day^{-1})	Estimated biogas (dm^3 day^{-1})	Score
Digesters installed	H11	97	290.4	4,312	42
	H1	46	92	1,960	41
	H17	54	162	2,280	35
	H27	54	162	2,440	35
	H47	43	129	2,510	35
	H13	48	144	2,240	34
	H5	24	72	960	30
	H21	28	84	1,200	30
	H24	38	114	1,640	30
Not installed	H6	24	72	1,120	29
	H26	26	78	1,080	29
	H15	40	120	1,760	27
	H10	26	78	1,240	26
	H20	42	126	1,720	26
	H2	22	66	1,000	25
	H16	28	84	1,200	24
	H28	24	72	1,120	23

Discussion

This is an approach that attempts to rationalize site selection to determine which sites are more likely to be successful in using a biogas digester. A site selection system will assist practitioners, engineers, donors and policy makers during the pre-feasibility and feasibility studies; it will inform them whether biogas is suitable for the intended end users.

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The role of energy in development processes

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Energy poverty and demand modeling for the case of Arequipa (Peru)

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Abstract

Is there such a phenomenon as an energy poverty penalty? If so, can it be empirically proven? By establishing a robust energy demand model, this paper develops a framework for methodologies to assess energy poverty and to investigate ability and willingness to pay for energy at the micro-level. The results link the issue of poor energy service with issues of poverty traps and development opportunities. They are consistent with views of researchers and practitioners, proving the existence of an energy poverty penalty, which postulates that the poor pay more (relative to their total income) for energy services of poor quality than higher income people. Data were collected from 342 households and micro-businesses in the rural area of Arequipa, Peru. Mobile phone coverage was partly identified as a viable proxy for remoteness criteria and used to build the data strata, thus facilitating model replication for different geographical areas. Results give valuable insights for potential microfinanced energy service interventions.

Keywords: Energy poverty penalty; Poverty traps; Energy demand modeling; Development; Quality; Microfinance; Peru

Introduction

According to the World Energy Outlook 2012, about 1.3 billion people live without access to electricity and nearly 2.6 billion use traditional biomass for cooking (WEO, 2012). It is estimated that another billion are left with unreliable electricity networks (AGECC, 2010). This underserved population's energy service supply can be summarized with three main characteristics: poor quality, hazardous to health, and high cost. This paper follows a definition of the term quality as the characteristics of a product or service that bear on its ability to satisfy stated or implied needs (ASQ, 2013). In this sense poor energy service quality can refer to insufficiencies, unreliability, dangers in usage, low durability, unfitness, lack of after-sales service and even non-affordability, in the sense of poor financial services.1 This work builds upon the general idea that if these kind of aspects occur due to poverty and related structural handicaps it is referred to as "poverty penalty" which mainly states that the poor pay more than richer people for basic services due to living in a "high-cost ecosystems" (Prahalad & Hart, 2001). Literature often deals with energy poverty, and although, many ways to measure it have been introduced in the last decade, there is still no common consensus on this issue (Nussbaumer et al., 2012). Herein the concept of an energy poverty penalty is developed. The existence of an energy poverty penalty implies that poorer people tend to spend more on energy services in relation to their total income than comparatively richer people. This hypothesis is fairly intuitive, considering that people living in poverty are more likely to live off-grid, and alternative energy applications to grid-based power are usually much more expensive (DFID, 2002). Moreover, they often suffer under a poor energy service quality with respect to unfitness referring to a low degree of adaptability to their specific needs and situations. This occurs often due to an urban bias of energy service providers causing greater and more frequent expenses (Kebir, 2010). If empirically proven, the concept of the energy poverty penalty has strong implications because of its impact on development opportunities of households and micro-businesses2. Literature suggests that access to modern energy technologies/ sources3 can make a substantial difference by increasing the productivity of micro-businesses and improving the quality of life of poor households (Gomez-Echeverri, 2002). As a consequence, a better energy service quality could well serve as an essential tool to fight the energy poverty penalty and ultimately in achieving the Millennium Development Goals (MDGs) (UNDP, 2005).

As underlined by the above mentioned statistics, energy poverty is a highly relevant issue. Recently, the UN General Assembly has declared the years 2014-2024 to be the "*Decade of Sustainable Energy for All*" (UN, 2013). Improving energy service quality is expected to have a huge multiplier effect in terms of a development impact (Levai et al., 2011).[4] According to the International Energy Agency, "without access to modern, commercial energy, poor countries can be trapped in a vicious circle of poverty, social instability and underdevelopment", which makes it an "indispensable element of sustainable human development. (WEO, 2004: 335). Within in this paper, efforts to improve energy service quality are referred to as energy inclusion. *Energy inclusion* may be defined as a

[1] Many of these aspects are often interrelated.

[2] This paper follows the definition of Cull et al. 2006 who define very small (micro) enterprises, herein referred to as micro-businesses, as enterprises with less than five employees" (Cull et al., 2006: 3018).

[3] Access to modern energy technologies usually refers to households´ and micro-businesses´ access to renewable energies for electricity generation, clean cooking facilities (clean cooking fuels and stoves), and other heating, cooling and mechanical power appliances (e.g. for crop drying, hot water generation, efficient fridges/ freezers, water pumping, etc.). However, this paper emphasizes the general energy service quality and remains ignorant to specific technologies.

[4] The multiplier effect refers to positive impacts on health, education, and, consequently, labor productivity through lower opportunity costs for education (e.g. children do not need to collect firewood), reduction of indoor smoke, and an expansion of household productive activities.

process of improving energy service quality for vulnerable and low-income groups (at an affordable cost)[5].

Nonetheless, as of now, successful implementation schemes of energy inclusion remain scarce, mainly because they lack a systematic approach to assess the target groups' behavior patterns, as well as the key elements of demand estimation of the target groups' willingness and ability to pay (Levai et al., 2011). High initial investment costs and a lack of access in rural areas (absence of distribution and maintenance networks) often prevent dissemination in those areas. Hence, both practitioners and academics are currently making efforts to identify successful implementation schemes for energy service improvements for low-income people. As of now, a range of development organizations have identified microfinance institutions (MFIs) as the ideal partners for achieving the goal of energy inclusion, following their aim of financial inclusion (Levai et al., 2011).[6]

Reviewing energy literature reveals that conventional energy demand models have too much of a focus on developed countries and on energy forecasting. Only a few models actually deal with developing country contexts and are based on status quo analysis. Notable exceptions include (Bhattacharyya & Timilsina, 2010), (Swan & Ugursal, 2009) and (Urban et al., 2007). Moreover, energy is very often reduced to electricity consumption, which is inaccurate in the sense that electricity consumption only constitutes one part of the energy demand. Both of these issues are addressed within this paper.

Research Objectives

There is little empirical data dealing with the issue of energy poverty, especially regarding the role energy plays in development processes, e.g. poverty reduction efforts. Therefore this paper aims to shed light on the relationship between energy service quality and its poverty implications. Also, to date, market research on the energy demand of rural populations has often been neglected due to the involved time effort and related survey costs as well as previously inconclusive results (Martinot and Cabraal, 2000; Kebir and Heipertz, 2010). Practical experiences have shown that a lack of identification and systematization eventually leads to project failures. On the one hand, an increasing involvement of MFIs can be observed[7], but on the other, there is a bottleneck at the point of effective demand identification techniques to ensure efforts are targeted toward better energy service quality. This interplay lays the foundation of this paper's motivation to contribute to a solution for this bottleneck. The center of attention are building the people themselves by investigating their energy use patterns in a model performed for the regional specific case of Arequipa (Peru).[8]

Having said that, the central research questions addressed here are:

Is there such a phenomenon as an energy poverty penalty? And if so, can it be empirically proven?

Methods

Field Study

In total, 342 households/ micro-businesses[9] are surveyed in 38 villages, based in 32 out of 109 existing districts in seven out of eight provinces of the department of Arequipa (Peru). The challenge is to find a representative sample from the Arequipan rural population in order to draw conclusions for their energy demand pattern. Mobile phone coverage exhibits a unique characteristic by enabling a clustering of all villages according to the penetration of the mobile market. Therefore different degrees of mobile phone are used as a proxy for remoteness. A set of 3,356 villages of the department of Arequipa is divided into four categories.[10] The division results in a list of four different levels:

1st level coverage by all three providers: 86 villages
2nd level coverage by only two of the three: 565 villages
3rd level coverage by only one of the three: 491 villages
4th level coverage by none of the three: 2,214 villages

In order to guarantee a randomized sample, each level's villages are sorted randomly and then drawn with a skipping pattern. A skipping pattern of ten results in a sample of eight 1st level villages, a pattern of 50 in ten 2nd level and nine 3rd level villages, and, lastly, a pattern of 200 in twelve 4th level villages.[11] Thus, a total of 38 villages constitute the sample for the village profiles. Moreover, nine households/ micro-businesses are selected randomly in each village for interviews leading to a total sample of 342 questionnaires. However, as it turns out, the sample villages cannot always be used due to a variety of reasons.[12] In these cases, the nearest village with the same mobile coverage level is chosen.

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[5] Technically this already form part of a better energy service quality.

[6] Having the ideal distribution network and continuous proximity to their customers, MFIs are expected to be able to design inclusive credits for improved energy services bringing down the prohibitive initial investment cost and facilitating the necessary after-sales services.

[7] This is underlined by the fact that the major international donor institutions such as World Bank, UN, IDB and ADB are designing energy programs for MFIs.

[8] Peru was chosen based on a market-driven approach to assess countries' potential worldwide for successful dissemination of energy services through microfinance networks.

[9] Often mixed in the sense of home businesses.

[10] There are only three mobile phone providers active in Arequipa: Movistar, Claro and Nextel. Data was obtained via OSIPTEL (Organismo Supervisor de Inversión Privada en Telecomunicaciones), a public entity responsible for the supervision of the telecommunication sector, with data publicly available under: http://www.osiptel.gob.pe/coberturamovil/.

[11] Different skipping patterns were used in order to have an approximately equal number of villages from each category.

[12] Non-existence, total population lower than nine, village as mining industry settlement, village only consisting of off-season fincas, and village being too difficult to access.

Asset indexing

Generally speaking, income is the criteria of choice when it comes to the measurement of living standards in developed countries, whereas in a developing country setting, the preferred metric is an aggregate of households' consumption expenditure (Sahn & Stifel, 2003). This is the case for a range of reasons, chief among them being the seasonal variability of earnings and the high percentage of self-employment, not accounting consumption of self-produced goods as income. In any case, collecting reliable income or expenditure data is an extremely difficult task, especially due to resource limitations. For this reason, rather than income or expenditure, in this study, data were collected that capture living standards, such as ownership of durable or productive assets (e.g. electronics or animals), infrastructure (e.g. grid access), and housing characteristics (e.g. number of rooms, source of drinking water). In this paper, hence, an asset-based approach is considered, as previous authors have done.[13] For the construction of the asset index, the Filmer & Pritchett Procedure (2001) was used. Polychoric correlations are often preferred over the Filmer & Pritchett Procedure since it can be based on ordinal variables. However, due to data characteristics this was not possible.[14]

Descriptive and quantitative data analysis

The data analysis has been separated into descriptive and regression analysis. In the first part, the dataset is thoroughly analyzed regarding consistency. Moreover, various correlation pairs are formed to draw first insights from the dataset with respect to the validity of the remoteness proxy, and sample behavior in relation to overall statistical data. Data are plotted in different forms to figure out determinants of relative energy expenditure. The regression analysis is performed as an OLS (ordinary least squares) regression analysis in four different model configurations.

Results

The paper´s central result is that there is statistically significant and robust evidence in the descriptive and regression analysis for the existence of an energy poverty penalty. OLS estimations show that people lacking access to electricity have to pay significantly (at 1% level) more relative to their total income. This result is accompanied by two interesting facts. First, if the asset index is increased by one unit point, total expenditure increases by S/. 22.[15] As a conclusion, asset rich persons pay more for energy in absolute terms (income effect). However, a further modification shows that people with access to electricity (which also tend to have higher asset indices due to correlation index of 0.37) also do not pay significantly more in absolute terms; even to the contrary, data show less expenditure, though this is a statistically insignificant difference. Combining these results indicates that having no access to electricity (as a main characteristic of being energy poor) compensates or even outweighs the income effect, leading to significantly higher relative expenditure and insignificant higher absolute expenditures. These results imply the existence of a strong energy poverty penalty.

Moreover, data reveals that electricity accounts for 54% of total energy consumption, and when filtering out observations that certain households do not seem to spend anything on energy but electricity (unrealistic assumption), the percentage decreases further to 39%. This is interesting to note considering the fact that the majority of policies are designed for electrification projects (WE0, 2011). As a result, the energy poverty penalty is likely to be even stronger if energy decomposition is analyzed in more detail.

Remoteness is identified as a concept of several dimensions. Mobile phone coverage is empirically tested to serve as a proxy for the degree of remoteness. However, neither distance nor mobile coverage show significant results on energy expenditure. Thus, the hypothesis that mobile phone coverage can explain better the concept of remoteness than mere distance (e.g. due to Arequipa´s diverse topographical landscape) could not be confirmed within this sample analysis. It is rather assumed that mobile coverage merely reflects the development of the mobile market but is still useful for data stratification according to descriptive data analysis.

Further results show that the status of a micro-business indicates a higher willingness to pay for energy. In contrast, data indicate that there are no preferences revealed with regards to a large demand for alternative lighting. Moreover, the sample percentage of dependency on biomass is double the total Arequipan average.[16] Considering the implied adverse health effects of indoor pollution due to dependency on biomass, recommendation for action is given. Additionally, willingness to pay seems to be present, considering average monthly expenditure of about S/.64 per month on fuel wood. Furthermore, opportunity cost is calculated to amount to one hour per day when data are averaged over the entire month. Although deforestation is increasingly becoming an issue, so far the majority does not perceive increasing fuel wood prices. Anecdotal evidence is found with respect to low energy service quality in the sense of load shedding

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[13] Please see (Sahn and Stifel, 2003), (Moser and Felton, 2007), (Young, 2010) and (Harttgen et al., 2011) for more information.

[14] By using Filmer & Pritchett the developed order of the ordinal variables gets lost. Further, data suffer from the introduction of extra correlations through the generation of multiple dummies and thus negative correlations come up between variables from a single ordinal source variable. Yet, as different variable types are used, the underlying bivariate normality could not be satisfied and consequently too many missing values are generated which could not be solved by variable recoding.

[15] S/. indicates the local Peruvian currency Soles, hereby S/. 2.55 = USD 1.00 (status from Nov. 12th 2012). Considering that average total energy expenditure is S/. 83.49 and the asset index has a range from -0.71 to 1.08.

[16] Within the rural sample, 43% of the population depends on biomass, whereas statistical urban and rural data come up with a figure of 21.8%.

leading to appliance breakage.[17] In the decomposed department analysis, the region La Unión turned out to have a comparatively high rate of off-grid population paired with high-income levels measured through the asset index. Although the result needs to be interpreted with great care due to relatively low sample size in this case (n=18), a follow-up of this potential market (indicated high demand structure) is recommended. A low up-take of energy for productive uses is determined but put in relative terms because of the intangible nature of energy.[18] Basic robustness tests indicate robustness for all modifications of the OLS model.

Discussion

Nonetheless, within the scope of this paper, a range of drawbacks is encountered. The on-grid and temporarily off-grid sector[19] could only be considered for the rural area, leaving out semi-urban and urban settings, representing important demand sectors. Moreover, the sample size for the off-grid sector turned out to be very small (n=63). While it is attempted to distinguish residential and micro-business energy demand, small enterprises had to be ignored completely.[20] The asset index is only constructed as a mixed index, not distinguishing between households and micro-businesses. High data quality remains a difficult task in these settings. Especially with respect to expenditure data, which are crucial to this analysis, measurement errors cannot be excluded (e.g. multiple use patterns, intangibility of energy, local research team dependency). As a result, the model has comparatively low explanation power considering its R^2 (ranging from 11%-13%) and coefficient relevance. Data do not tend to be distributed normally, and furthermore, non-linear relationships are not taken into consideration.

The proof of the energy poverty penalty has strong policy implications. Its existence raises questions on the impact of this penalty with respect to causing a trap that is prohibiting people´s development, or merely delaying their development path (Sachs, 2004). Policy action needs to be designed accordingly to overcome this challenge and achieve the MDGs. The results further support the proposition that methodologies can be developed in order to effectively model rural energy demand. With the aid of these tools, there is a systematic base to investigate the relevant information for policy action and strategy on the governmental level, and for business model development in the private sector, especially financial institutions serving low-income people. Further research should also focus on innovative tools of observational data acquisition for qualitative variables, but also new methods to obtain quantitative data, such as reliable expenditure and income data on the micro level. Moreover, empirical research is needed on the productive use of energy in terms of a catalyst for development. An in depth research on the temporarily off-grid sector as a potential market for energy service improvements is further needed.

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[17] It has been estimated that the cost for a better energy service quality (e.g. through the implementation of charge controllers) is considerably lower than the cost of repair for damaged appliances and replacement.

[18] The intangible nature of energy refers to the semantic problem of the word "energy" in surveys. Even though this issue has been carefully considered in the design of the questionnaire (e.g. by not mentioning the word energy per se but describing energy usages), there is still reason to believe that some energy-dependent activities are not considered as such and thus are neglected in the data.

[19] The temporarily off-grid sector is comprised of people living in areas that suffer from frequent outages leading to a highly interrupted energy supply. This sector so far is not further defined.

[20] According to the used definition, small enterprises refer to enterprises with more than five employees representing another potential market for intervention beyond the scope of this paper.

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The Potential for Linking Microfinance Practices and Renewable Energy Technologies in Kenya - "Exploring the Niche"

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Abstract

The paper explores the potential of microfinancing renewable energy technologies (RETs) with a focus on small-scale solar products and biogas plants as an approach to providing solutions for household energy needs and, thereby, contributing to poverty reduction. The explorative research approach applies qualitative analysis. The results reveal the significant role of opinion makers and awareness campaigns, the importance of local need assessment as well as maintenance and training issues. The study focuses on the interests and perspectives of different actors involved in the credit giving process (i.e. MFIs, NGOs, providers of RETs, clients and potential clients). Financial analysis shows that linking MFIs with RETs can be economically feasible.

Keywords: Microfinance Institutions; Renewable; Energy; Renewable Energy Technology; Solar; Kenya.

Introduction

Access to modern energy services[1] is considered a prerequisite to poverty reduction. Numerous studies have proven that no or limited access to modern energy services has negative effects on economic and social development, on health and the environment (Kabutha, Sengendo, Winiecki & Morris, 2007; United Nations Industrial Development Organization (UNIDO), 2009; Sokona, Mulugetta & Gujba, 2012). In Kenya, only 16 percent of the population has access to electricity, a central part of modern energy services (World Bank, 2012). The problem is especially significant in rural areas where less than 5 percent of the population is connected to the national grid (Kabutha, Sengendo, Winiecki & Morris, 2007). Due to this limited access to electricity, 83 percent of the households still rely on traditional biomass resources and fossil fuels for cooking and lighting (i.e. kerosene lamps) (World Energy Outlook, 2011). However, at the same time the potential of RETs in Kenya is strikingly high. In 2008, 66 percent of the electricity supplied by the national grid was already generated through RETs (1.3 GW), mainly through hydropower and geothermal (GIZ 2012). Oil-fired thermal production accounts for 33 percent (Kabutha, Sengendo, Winiecki, & Morris, 2007). Despite the rapidly developing solar market, electricity production through biogas accounts for 4 percent and the usage of solar for electricity production is almost non-existent (GIZ, 2012). Nonetheless, RETs, in particular small-scale solar products and biogas plants, can provide reasonably priced off-grid solutions that not only improve the connection to electricity but also ameliorate modern energy services in general.

A reason for the slow diffusion of small-scale RETs in Kenya is the lacking access to financial services. Only 7.12 percent of the population has access to the modern banking sector (Mwangi, n.d.)[2]. However, an adequate access to financial services is particularly important for the renewable energy sector since the initial investment for RETs is comparatively high even though the running costs are low. For that reason, this research supports the hypothesis that a more flexible way of financing RETs could improve the access of modern energy services. Microfinance institutions (MFIs) could fill the gap by financing small-scale renewable energy products. In addition to solar lanterns and micro-biogas plants, improved cooking stoves and briquettes are also referred to as RETs due to their contribution to improved energy efficiency.[3] So far, MFIs in Kenya have only rarely integrated renewable energy products into their portfolios, thereby creating a niche that is at the center of the following research study.

[1] In this paper the definition for modern energy of the International Energy Agency (IEA) is applied. Therefore, modern energy access is defined as "a household having reliable and affordable access to clean cooking facilities, a first connection to electricity and then an increasing level of electricity consumption over time to reach the regional average" (World Energy Outlook, 2011).

[2] Data was published by Financial Access Partnership (FinAccess) which conducts annual household surveys to establish the level of access to financial services in Kenya. According to the World Bank, 7.16 percent of the population had access to the modern banking sector in 2009 (World Bank, 2012).

[3] Even though briquetting and (improved) cooking stoves are not RETs in the narrower sense, this research study follows the common practice of including them in RETs, because of their contribution to improving energy efficiency. They were not only mentioned as important RET products during the interviews but are also considered because of their big potential in improving living standards in rural and slum areas.

Research Objectives

The aim of this paper is to explore the possibility of linking microfinance practices with small-scale RETs as well as to examine in how far this linkage can be economically feasible and thus contribute to poverty alleviation. Consequently, the research question reads as follows: Is there potential for microfinancing RETs in Kenya in an economical way?

The main focus is on the potential of different RETs in Kenya on a micro-level. The perspectives of different actors involved in microfinancing RETs are considered (MFIs, NGOs, providers of RETs, clients and potential clients) and the compatibility of their individual interests analyzed. Furthermore, the challenges institutions face when linking microfinance practices with RETs are highlighted. The results provide the foundation for evaluating the economic feasibility of microfinancing RETs.

Methods

The research is based on qualitative analysis. 16 expert interviews with different actors (MFIs, NGOs and Providers of RETs) were conducted and a focus group discussion was held.[4] In addition, a financial analysis was carried out.

In a first step, literature about microfinancing RETs, in particular Allet (2012) and Kariuki & Rai (2009) as well as literature that provides an overview of the potential of renewable energies in Kenya was analyzed (Kiplagat, Wang & Li, 2011). Furthermore, successful pilot projects concerned with small-scale RETs in general that were implemented in Nigeria, Ecuador, Mozambique and Ethiopia (Glania, Rolland & Pate, 2011) as well as projects that combine microfinance practices and RETs in Peru, South Africa, China, Nepal (Wisions, 2006) and Burkina Faso (Fondation Éneries pour le Monde, 2007) were evaluated.

The expert interviews were based on individualized guidelines which were revised after every interview, according to the results and information obtained.

To precisely differentiate the multiple points of view, interviews with representatives of different actors were conducted. To obtain an overview of the work and the structure of MFIs, interviews with KIVA/KIVA Zip, MicroAfrica, Rafiki – Deposit Taking Microfinance and KADET were held. The MFIs provided information on success and challenges they face when offering loans for RETs. The RET providers (TRONY East Africa Ltd., Power Options Ltd, Go Solar Systems and Davis & Shirtliff) offered insights into their portfolio and were asked about their disposition to work with MFIs. NGOs (Global Village Energy Partnership, Solar Aid, Sustainable Development for All, GIZ and the African Entreprise Challenge Fund) described their already existing cooperation structures with MFIs and shared their experiences regarding RETs in Kenya.

All interviewed partners were questioned about need assessment strategies and local energy requirements. Urban, rural, and slum settings were analyzed. Kibera, the second biggest slum in Africa, was also visited to evaluate the needs of those living in slums. Furthermore, a focus group discussion concerning the potential of RETs in Kenya was held with students of the Kenyatta University in Nairobi. To evaluate the role of the government the Ministry of Energy was consulted. The Ministry supported the research findings with financial and geographical data. Various technology suppliers provided price lists to support cost calculations concerned with the feasibility of RETs.

Results – Microfinancing RETs

The research findings indicate a high potential for combining microfinance practices and RETs in Kenya. All interviewed actors agree that, up to now, this potential is not being tapped and that already existing financial services only reach a very small percentage of the Kenyan population. RET products financed through MFIs can provide an affordable access to modern energy and thus reduce poverty effectively.

In the past, all interviewed MFI experts have been reluctant to integrate RETs into their portfolios. As our contact at KIVA stated, incorporating RETs necessitates changing their institutional structure since they have to adapt their modus operandi to these products. Loans on RETs require the provision of after-sales services and product specific assistance. MFIs lack this essential technological know-how. Additionally, by offering loans on such products, they are confronted with high administrative costs, which force them to demand high interest rates. At the same time, as the NGO Sustainable Development for All (SDfA) pointed out, a large percentage of the Kenyan population has been hesitant to take up a microcredit on energy products. Due to the high interest rates, they fear that they will not be able to pay back the loan and lose their property. Moreover, as many of the interviewed actors stated, the low quality of RETs in the past has caused consumers to lose trust in the technology and thus stick to traditional biomass resources and fossil fuels.

Nonetheless, RETs offer a great potential for increasing the overall access to modern energy services and thereby reducing poverty. Due to the suitable climate conditions and the cost effectiveness of the different technologies, solar energy products are the most promising off-grid RETs in Kenya. Nevertheless, the potential of small-scale biogas products as well as (improved) cooking stoves and briquetting is also promising.

Approaches to Microfinancing RETs

In order to explore this potential, flexible financing mechanisms have to be established. The biggest challenge is the initial investment in RETs, particularly for the poorer percentage of the Kenyan population. As our interview partner of TRONY stated, many are capable of spending the weekly amounts of money needed for kerosene but do not have the ability or willingness to spend larger sums at once for a technology they are unfamiliar with.

MFIs enable those without financial resources to profit from the potential offered by RETs by providing loans on small-scale energy products. Since MFIs alone are not interested in offering such financial services, different

[4] A list of the interview partners is attached in the appendix.

Table 1: Solar lantern (3,500KSh), loan duration 6 months with 140KSh savings per week.*

Interest rate**	Weekly amount to pay (KSh)	Cumulated costs (KSh)	Cumulated interest amount (KSh)	Amortization in weeks
2%	141	3659	159	26
20%	147	3822	322	27
40%	153	3981	481	28

* The weekly savings are calculated as follows: 20KSh for kerosene per day.
** SACCOs have interest rates between 1.5 - 2 percent; MFIs usually charge interest rates between 20 and 30 percent and for RETs up to 40 percent, according to all interviewed MFIs and NGOs.

cooperation structures between NGOs, providers of technology and MFIs can be established.

NGOs such as SDfA, can bring together MFIs and individuals wanting to take up a loan for RETs. By offering a guarantee to the MFI that the loan will be paid back, NGOs like SDfA or the Global Village Energy Partnership (GVEP) assist those in need of financial support while at the same time rendering it profitable for MFIs to integrate energy products into their portfolio.

By cooperating with MFIs, technology providers gain access to the already existing loan takers of the MFIs who become their potential clients. Thereby, they save money and time that would otherwise be spent on advertisement and other required due diligence. Their technological know-how and provision of after-sales services as well as training and maintenance assistance enable them to provide the expertise MFIs lack. Therefore, this cooperation structure benefits both sides.

Further Factors of Influence

When microfinancing RETs further significant factors have to be taken into consideration. Low awareness levels keep the demand for RETs at a minimum, preventing their potential from being tapped. Therefore, awareness campaigns aimed at improving the understanding of the possibilities these technologies offer are essential. TRONY and other providers and NGOs pointed out that opinion makers and the integration of the local population also play an important part in establishing sustainable microfinancing practices. Opinion makers convince prospective clients of the benefits of RETs. Furthermore, as SDfA stated, the integration of the local population in small-scale energy projects additionally increases the acceptance and awareness of RETs.

Previous experiences show that low levels of trust have inhibited the potential of RETs to be explored. In order to strengthen trust in RETs, “Lighting Africa”, a program implemented by the IFC\World Bank, has introduced certifications for energy products which guarantee high qualitative standards and reliability. MFIs such as Rafiki – Deposit Taking Microfinance and providers of RET such as TRONY have stated that such a certification process has led to a significant increase in trust in RET.

Low awareness and lack in know-how have often resulted in a wrong usage of energy products which underlines the significance of education and training measures and of the need to address maintenance issues (Power Options Ltd., Go Solar Systems). Technology providers and NGOs offer workshops, training seminars and classes aimed at educating the end users of RETs on the correct usage of energy products. Most RET-products require minimum maintenance and it suffices to train locals to enable them to fix eventual minor repairs.

All technology providers highlighted the significance of effectively adapting individual products to the specific local requirements. In Kenya, the potential of different RETs varies from region to region. In order to obtain the highest possible energy performance of the various RETs, the products have to be adjusted to the local conditions.

Financial Analysis

To promote the usage of RET products, the essential question is, in how far microfinancing RETs can be economically feasible. Is it possible to confront the initial investment of RETs with the running costs that arise when using traditional energy sources, like money spend for kerosene, phone charging and purchasing charcoal? A wide range of factors can be included in a financial analysis. However, in the following calculation only the savings for kerosene and phone charging are considered. Due to other factors (i.e. time savings, expanded working and learning time, independence from external energy providers, improved environmental and health conditions etc.) the weekly amount of savings will be somewhat higher for most customers.

The financial analysis shows the economic feasibility of solar lanterns, a frequently named bestseller among small-scale RETs in Kenya. These lanterns, whose average price lies at about 3,500KSh (40.74 US Dollar), can also be used for charging electronic devices such as cell phones. For the calculation a pay-back period of 6 month is considered. The weekly savings for the customers is fixed at 140KSh (1.63 US Dollar), since about 20KSh (0.23 US Dollar) are spend for kerosene per day. The calculation demonstrates that if the savings are used to pay back the loan the investment is amortized after a short period of 28 weeks even with an interest rate of 40 percent. According to this outcome microfinancing this kind of lanterns is cost-effective even for the poorest part of the population. It also demonstrates that high interest rates do not have to be insurmountable barriers in financing RETs.

Financial analysis concerned with other RETs come to similar conclusions and thereby underline the economic feasibility of microfinancing such products. These cost calculations cannot only be used to prove the economic feasibility of purchasing RET-products to the consumer but can also draw the attention of the other actors (MFIs, Providers, State) to the potential that lies in the market for microfinancing RETs.

Discussion

The results indicate the complexity and the potential of carrying RETs to low income households which represent the majority of the Kenyan population. High initial investment costs for RETs as well as high interest rates of MFIs still prevent many people from buying such products. However, the financial analysis demonstrates the affordability of RET products. The challenge is therefore to raise awareness and to create trust. With the ongoing improvement of the quality of RETs, providers offer better products. As a consequence, better conditions for a fruitful cooperation between MFIs and RETs providers arise. Further research should focus on a more income and region specific need assessment and on the in-depth examination of other financing sources and models that differ from MFIs. Examples for financing alternatives are SACCOs (Savings and Credit Cooperatives), CBOs (Community-Based Organizations) and VLS (Village Savings and Loans).

The share of RETs in energy consumption could be raised through an active participation of the Kenyan Government. The Ministry of Energy set the goal of extending the national power grid as far as possible by December 2030. Nonetheless, it is not an efficient solution for nationwide electrification, since the extension of the grid to distant and isolated areas comes along with dramatically high costs. Therefore, RETs offer affordable alternatives. Decentralized solutions can cost-effectively satisfy household energy needs and contribute to social, economic and environmental development.

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Appendix

List of Interviewed Partners

MFIs and SACCOs
Rafiki – Deposit Taking Microfinance (MFI) (13.09.2012)
Vision Africa (SACCO) (13.09.2012)
KIVA/ KIVA Zip (MFI) (18.09.2012)
KADET (MFI) (28.09.2012)
MicroAfrica (MFI) (28.09.2012)

NGOs
GIZ- ENDEV (Energizing Development) (11.09.2012)
GVEP International (11.09.2012)
SolarAid (Sunny Money) (12.09.2012)
GIZ – Department of Solar Energy (17.09.2012)
Sustainable Development for All (17.09.2012)
African Enterprise Challenge Fund (24.09.2012)

Technology Providers
Go-Solar Systems Ltd. (11.09.2012)
Power Options Ltd. (12.09.2012)
TRONY East Africa Ltd. (19.09.2012)
Davis & Shirtliff (24.09.2012)

Government
Ministry of Energy (18.09.2012)

Focus Group Discussion
Group discussion with Kenyan students (21.09.2012)

High-resolution global cost advantages of stand-alone small-scale hybrid PV-Battery-Diesel Systems

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Abstract

Rural electrification is a crucial factor for the development of countries globally. A lack of access to an electricity transmission and distribution grid due to a remote location leads to a widespread use of diesel generators to produce electricity. This is cost-intensive and leads to high CO_2 emissions. The present paper summarizes the results of a least-cost modeling approach which is designed to compare electricity generation costs from ubiquitous diesel generation with a hybrid PV-Battery-Diesel system. The inclusion of PV in the generation process will reduce the electricity generation costs in the long-term, as on a global scale many areas possess high potentials for PV applications through strong solar irradiation. Regarding the future, an energy system with a high share of renewable energies is the key to produce cost-efficient electricity.

Keywords: rural electrification; infrastructure; spatial cost modeling

Introduction

Globally still a significant share of population has no or only limited access to electricity (IEA, 2011). Most of these people live in rural South Asia and Sub-Saharan Africa (UNDP-WHO, 2009). Access to electricity is a crucial element for the overall development of a country. For instance, education, economic development and public health depend on the availability of electricity (Doll & Pachauri, 2010). A lack of reliable and affordable electricity therefore presents a main barrier for the progress of certain countries and regions.

As many of the remote areas are not covered by electrical transmission grids, isolated diesel generators are the prevailing standard to produce electricity in these areas (Platts, 2009). Other advantages of diesel gensets lie in the comparably low investment costs and an easy operational and maintenance structure. Distributed small settlements and overall low population densities in rural areas are the key problem regarding centrally organized electric power supply systems (Chaurey & Kandpal, 2010). The resulting dependency on local diesel generators in the above described “off-grid” areas leads to a strong dependence on the crude oil price. In times of menacing shortage of fossil fuel resources in the future and environmental concerns, this approach is no promising concept for the future. With regard to the steep learning curves and achieved grid-parity of small renewable energy systems under certain scenarios (Kost et al., 2012; Schleicher-Tappeser, 2012), investigations in this direction are the key to achieve global electrification.

Infrastructure is an essential element for the overall development of a country, transportation infrastructure being the base element. Energy infrastructure, as e.g. power transmission lines is not existent in many areas and expensive in remote locations, as there is only a comparably low demand for electricity (IEA, 2012).

Characteristics of the insufficiently electrified rural areas are low population densities (Zvoleff et al., 2009) with low load profiles, which make the installation of transmission lines expensive and less efficient and hence the hybrid renewable system more feasible.

Electrification influences several parameters as e.g. the Human Development Index (HDI) and the Gross Domestic Product (GDP) of a country. Infrastructure elements like roads, railways and power transmission lines are also considered here. The local situation in non-electrified areas is a result of the co-occurrence of different factors. Political stability, corruption and resource availability can be decisive elements in this development process.

Many areas with low electrification rates are located in areas where a high photovoltaic (PV) potential can be expected (Breyer et al., 2011). Solar irradiation as a local source holds the advantage of overall spatial availability which is only limited by climatic factors as well as the day and night rhythm. As a consequence, there are no transportation costs connected to PV resulting from fuel use, only the initial cost of transportation of the system to its designated site and the backup diesel genset.

Research Objectives

This paper presents the results of analyzing global electrification costs using a PV-Battery-Diesel system on a spatially refined resolution. The remoteness and accessibility of each location is regarded by considering the distance or more exactly the travel time to the next major settlement of more than 50,000 inhabitants. This factor is needed as the local diesel price differs from the national base price with remoteness being a significant impact factor. This is mainly associated with logistical expenditures increasing with diminishing accessibility. A model for assessing the economic potential of hybrid PV-Battery-Diesel systems versus diesel stand-alone systems including this aspect is compiled. Diesel stand-alone systems are the prevailing electricity generating technology in off-grid areas.

The following research questions are developed:

- What are the potentials to electrify areas with renewable energies in form of hybrid PV-Battery-Diesel systems?
- How competitive are these renewable energy solutions compared to traditional energy generation mostly based on diesel gensets?
- What is the local amortization time for the adopted system and where is it most feasible regarding the amortization rate?

Methods

This section describes the different methodologies used for the present study. The combination of diverse data requires a comprehensive analysis with two different approaches.

Geospatial analysis

GIS (Geographic Information System) analysis of spatial data is used to assess the global variability of environmental parameters regarding rural electrification.

The global travel time raster (Nelson, 2008) is analyzed and validated regarding the infrastructure data which can be drawn from the VMap0 data which origin from the Digital Chart of the World compiled by the National Imagery and Mapping Agency (NIMA) of the United States. The global travel time raster is a product of spatial infrastructure assessments, land cover analyses and a digital elevation model amongst other input parameters.

It therefore reflects the impact of missing infrastructural elements which is especially important for electricity generation and electricity access.

Furthermore, geo-referenced transmission lines, roads and railways[1] were extracted for each country, summed up and normalized to the respective country size to reflect their importance regarding low rural electrification rates. GIS is also used for the final depiction and interpretation of the cost model.

For this the resulting maps comprising the output of the cost calculations are summarized on the basis of the country classification to allow concluding propositions.

GIS analysis is carried out using ESRI Arc Map[2].

Cost-comparing model design

Model formation to calculate electricity costs for the two scenarios, diesel stand-alone systems and hybrid PV-Battery-Diesel systems, is carried out using Matlab[3].

The design of the approach is based on the modeling approach by Szabó et al. (2011). - Their spatial concept is adopted and extended from an African perspective to a global scale. Furthermore, input parameters and model assumptions were changed and updated.

Diesel transport costs are calculated using the global travel time raster by (Nelson, 2008). We assume that diesel is purchased for the national diesel price (Ebert et al., 2009) in the next major settlement. Transport costs of 4 per cent of the national diesel price[4] are added for every hour of travel time to the considered location. Initial PV costs are set to 2,000 €/kWp, battery costs are assumed to be 120 €/kWh. The interest rate is 8 % per annum. For the whole system a genset efficiency of 0.33 l/kWhel is adopted, the operational expenditure is set to 0.02 €/kWhel. Solar irradiation is given as hourly global horizontal irradiation in a raster with a 27'-pixel size (DLR). With this input the local diesel costs, the levelized cost of electricity, the share of PV in the optimized system and the amortization time of the system is calculated at each point.

Results

The calculation of the local diesel costs clearly shows the dependency of the price on local oil resources in the respective countries as well as diesel subsidies and tax policies. Also the raising of prices in remote areas due to higher transportation costs is observable (Fig. 1). The latter is especially recognizable in the large known remote areas like the Tibetan Plateau, the Saharan region as well as in parts of the Amazon Basin. The local diesel electricity costs range between 0.02 €/kWh and more than 2.00 €/kWh in remote areas.

The difference between electricity costs evolving from the pure use of diesel generators compared to optimized hybrid PV-Battery-Diesel generation (Fig. 2) shows the clear dependency on the diesel price – in regions with a low diesel price there is no cost advantage in the inclusion of PV in the system. This mainly occurs in countries with oil production, e.g., in the Middle East and North African (MENA) region.

The optimized share of PV in the local systems (Fig. 3) illustrates similar characteristics to the cost differences, however there exist some locations (e.g., South-Eastern Australia and Eastern Brasil) which include a comparatively higher share of PV in the system and have the same costs as a conventional fossil fuel based systems. This results from the remoteness of a location as well as from varying diesel prices. Here the advantage lies more in the mitigation of carbon emissions than in the direct financial savings compared to conventional systems.

The local amortization time for the optimized hybrid system varies between 1 and 15 years (Fig. 4) according to the percentage of PV in the system as well as the local diesel price at a given location.

The amortization time is especially important when considering the low financial possibilities for most people in rural less developed areas. In addition, a short amortization time allows people to benefit from the low cost electricity through low operational costs, as in systems with a high PV share, less diesel fuel is used as costly operational contingent.

[1] VMap0 Data.
[2] ESRI ® Arc Map™ 10.0.
[3] MATLAB. ® Version R2011b. The MathWorks, Inc.

[4] National diesel prices are given in USD converted to € with an exchange rate of 1.40 USD/€.

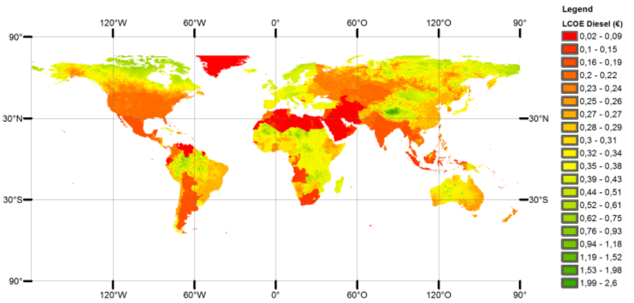

Figure 1: Local diesel cost (€/kWh). Red areas indicate low diesel costs; orange medium and green areas high diesel costs.

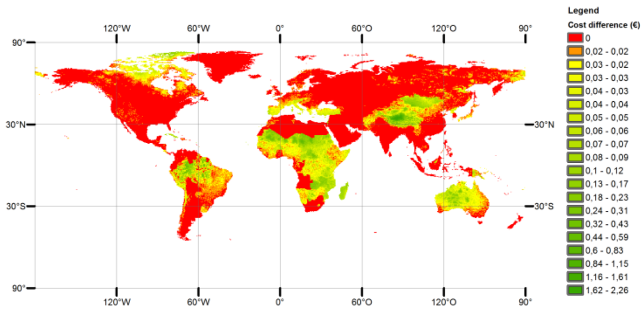

Figure 2: Difference between electricity costs generated by diesel and hybrid systems (€/kWh).

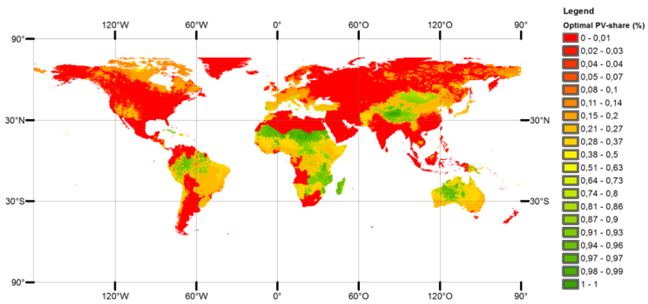

Figure 3: Share of PV in the modelled hybrid PV-Battery-Diesel system (%).

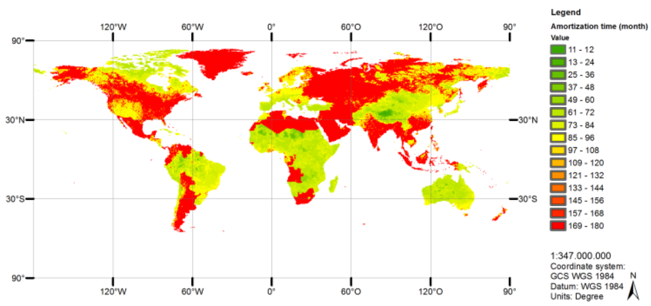

Figure 4: Time of amortization.

The country-wise analysis of this output shows that especially the poor underdeveloped countries in Sub-Saharan Africa and South Asia (except the countries with an extremely low diesel price) can benefit from the inclusion of PV in the electricity generating system.

Extracting the data from the cost difference raster for each country and normalizing it with the respective country size yields to the countries which can achieve the highest savings through an implementation of a hybrid PV-Battery-Diesel system compared to a conventional diesel system under the respective local conditions (Tab. 1). The outcome shows that the highest savings are mainly possible in African countries with low or medium development rates regarding their ranks in the HDI of the year 2011.

Table 1: Countries with the highest savings through implementation of hybrid PV-Battery-Diesel systems and their corresponding HDI rank 2011 from very high development to low human development (1. – 187. rank) (UNEP 2011).

Country (HDI rank 2011)	**Average saving (€/kWh)**
Zambia (164.)	0.16
Chad (183.)	0.15
Suriname (104.)	0.15
Malawi (171.)	0.13
Cent. Afr. Republic (179.)	0.11
Mauritania (159.)	0.11
Niger (186.)	0.10
Israel (17.)	0.10
Guadeloupe (20.)	0.09
Mongolia (110.)	0.09

Discussion

Regarding the research objectives the following conclusion can be drawn:

The results show that potentials for the upgrade of diesel systems or the new implementation of renewable PV-Battery-Diesel systems exist in many regions. However – these systems are only capable of competing with pure diesel systems in remote regions and in countries were the diesel price does not drop under a certain threshold.

Considering the amortization time the focus of the implementation of these systems is clearly on the most remote areas globally, as in these regions transport costs of diesel add significantly to the diesel costs for electricity generation. In addition, an implementation of these hybrid systems is also feasible in the long term perspective in regions where the optimized system consists of a lower share of PV – as it will still pay off in the future.

The developed cost calculation maps depict the strong influence of the high diesel price differences between neighboring countries as an effect of political structures and resource distribution (Nguyen, 2007). High subsidies and low taxes yield to the consequence that in many areas the inclusion of PV is not cost-effective, notwithstanding high solar irradiation.

Furthermore, the strong impact of the diesel price infers that the results are subject to changes regarding a change in the input diesel price which can easily result from political and economic decisions. That means that these results depict the current situation which is an artificial composite of political, economic and natural factors. In consequence, when transferring these results to future scenarios – all parameters have to be updated.

Comparing the countries with the highest saving opportunities (Tab. 4) in regard to their respective HDI rank, the huge electrification potential of hybrid PV-Battery-Diesel systems becomes apparent as a low HDI rank implies a low electrification rate, especially in rural areas (Narula et al., 2012).

Also, lowly developed countries are faced with high shares of rural population, e.g., in Niger about 83 % of the population lives in rural areas, comparable to about 80 % in Malawi (UNEP, 2011). This means that large targets of electrification objectives can be reached with an adoption of hybrid systems in these regions.

Presuming rising diesel prices in the long term the results suggest that the hybrid off-grid solution will be feasible in even more regions.

Summarizing the results and limitations it is possible to conclude that in many locations the lack of transmission grid infrastructure and access to electricity can be balanced and enhanced by the introduction of the described hybrid PV-Battery-Diesel systems instead of the single use of prevailing diesel generators or the connection to a centralized transmission and distribution grid. As most of the non-electrified regions are remote areas, the scope of this application is huge.

The inclusion of other renewable energy sources in the calculation can extend the approach. Spatially disaggregated hydro- and wind-potentials can drastically increase the share of renewable energies in the distributed electricity generating progress.

In the long term perspective these systems are also advancing with the development of more efficient, affordable batteries as a more capable storage option to minimize the share of backup diesel use.

Considering the strong relation to the diesel price, the ownership structures of grid operators and the electricity generating companies, the importance of distinct policy development in decision making processes becomes apparent.

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Comprehensive Country Ranking for Renewable Energy Based Mini-Grids Providing Rural Off-Grid Electrification

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Abstract

Access to electricity is a matter of course to most people on earth. Still there are far too many people that do not have the possibility to use electricity neither private nor for working. Renewable energy based mini-grids can be a solution for electrifying rural areas. Sustainable business models are needed and places for starting them. A worldwide country ranking for that issue shall help finding adequate countries. Top ten countries are presented and the top country, Rwanda is pictured in further detail.

Keywords: mini-grid, rural electrification, Rwanda.

Introduction

There are 1.3 billion people without electricity worldwide (International Energy Agency [IEA], 2011). Especially in Africa and South-East-Asia there are countries with high population but only few people have access to electrical energy. Electricity is the essential basis for the improvement of elementary needs, like light, communication, education, health and safety. Further, electricity is often the first step leading to commercial and industrial activities. Several Photovoltaic (PV)-based off-grid systems are available on the market (Breyer, Werner, Rolland, & Adelmann, 2011) but due to the additional focus on commercial and industrial activities, in this work mini-grids are emphasized. An overview of literature reports on mainly PV-based mini-grids can be found at Werner and Breyer (2012). Self-sustaining island systems are mostly the only possibility to bring electricity to people living in rural areas and to grow local economy. In consequence of rising fuel prices, renewable energies become more and more interesting and especially photovoltaic (PV) systems are an adequate technology for mini-grids since they are easy to install and to maintain while solar energy is available everywhere for free. The technics of self-sufficient mini-grids do work properly and are sufficiently tested. Nonetheless there seems to be no public mini-grid which works without subsidies, yet.

Research Objectives

The aim is to bring electricity to not electrified people not only by providing them the system, but by establishing sustainable business models which work on a long-term and might be reproducible. This requires a project development including sustainable financing and system operation (Breyer et al., 2012). Pure economics emphasize that stable PV-based mini-grid business models are possible (Cader, Hlusiak, & Breyer, 2013).

Still, not every country with non-electrified regions is predestined to be among the first ones for implementing business models of mini-grids. Political and economic instability can be criteria for exclusion or high subsidized diesel fuel can make a renewable energy-based mini-grid completely uneconomic compared to a diesel generator. It is important to start with an overview on all countries to find out which are adequate for developing a business plan. A comparison of all countries regarding relevant characteristics shall lead to a country ranking concerning the implementation of business models for mini-grids and finally to possible target countries.

Methods

For filtering and ranking those countries that are interesting for business models of mini-grids, different characteristics of countries have to be compared and rated. These are chosen by their relevance for starting a business of electricity supply. There have been identified two main criteria regarding starting a business. The first one is the market potential and the second one is the political and financial environment. Both criteria are based on several indicators giving country specific information.

To realize the ranking a comprehensive spreadsheet has been created. It is included to use the option to choose exclusion criteria and weighting factors. The factors presented in this paper are those which were finally considered as the best.

Relevant countries

For comparison of the countries it is reasonable to exclude nations which are definitely not relevant for this study. Otherwise they might distort the results of ratings. Countries that are already electrified sufficiently do not need electrification activities and do not need to be regarded in the further process. Countries have been excluded by this criterion in case of having electrification rates over 95 % and less than 200,000 people in rural areas without electricity (data from (United Nations [UNDP], 2007; IEA, 2004, 2010; UNDP & World Health Organization [WHO], 2009; World Bank, 2010a). Most of industrialized nations are excluded that way.

Next step is to exclude countries which are definitely unsuitable for starting a business: countries with high political instability or very low diesel prices. Nations that belong to the 5 % of lowest political stability worldwide (World Bank, 2010b) are excluded as well as countries for which existed a travel warning from the German Ministry of Foreign Affairs in April 2012 (German Federal Foreign Office, 2012). Renewable mini-grids have to compete with low diesel prices. Thus countries with a pump price for diesel of less than 0.25 USD/l are excluded from the ranking (Deutsche Gesellschaft für Internationale Zusammenarbeit [GIZ], 2012; World Bank, 2010c). 89 remaining nations have been evaluated with the following criteria.

Market potential

The market potential index is based on three criteria and amounts to 40 % of the total ranking. The absolute amount of rural people who are without access to electricity (*rpwoe*) and thus potential users of mini-grids is calculated by the rural population (World Bank, 2010a) multiplied by one minus the rate of rural electrification (UNDP & WHO, 2009). It represents 50 % of the market potential. For not neglecting nations with little population, the electrification rate (*er*) of the whole country is also included in the market potential with 30 % (UNDP, 2007; IEA, 2004, 2010; UNDP & WHO, 2009). As pure diesel grids are direct competitors to renewable mini-grids, pump price for diesel (*ppd*) is included with 20 % in the market potential, too (GIZ, 2012; World Bank, 2010c).

Political and financial environment

Focusing on starting a business, political and financial environment represents the major part of the final ranking with 60 %. It is composed of political stability (*ps*) (World Bank, 2010b) and inflation (*if*) (World Bank, 2009/2010) with each 15 %, corruption perception index (*cpi*) (Transparency International [TI], 2011) with 20 % and finally the ease of doing business index of the World Bank (*dbi*), which is a combination of 10 different criteria itself and influences not only political and financial environment with 50 % the most, but also the final ranking with 30 % (World Bank & International Finance Corporation [IFC], 2011). Country specific information like governmental attitude towards renewable energies would have been desirable for the ranking as well, but as there are no quantifiable numbers it has to be regarded for each interesting country itself like it is shown further down on the example of Rwanda. Different weightings of the criteria are demonstrated in Figure 1.

Figure 1: Weighting of criteria for country ranking.

Scoring

The ranking itself works by a scoring of each criterion. Countries can gain 1 to 10 points for each attribute, whereas 1 is worst and 10 shows best preconditions for renewable mini-grids. Scores are given in different ways depending on the data basis. For criterions like “electrification rate”, “pump price for diesel”, “political stability”, “corruption perceptions index” and “inflation”, which are in linear proportions, the ten scores have been evenly spread to the countries. For “rural population” and for the “ease of doing business rank” has been done a spreading on percentiles.

Using the described weighting, which is demonstrated in Figure 1, the final scoring of one country (*fs*) is reached with the following calculation:

$$fs = 0.4 * (0.3er + 0.5rp + 0.2ppd) \\ + 0.6 * (0.15ps + 0.2cpi + 0.15if + 0.5dbi)$$

Results

From scoring the countries, weighting different criteria and finally ranking all nations, results a ranking of all countries worldwide. This shows their applicability for starting business models of mini-grids compared to the other countries. Top 20 of the final ranking are presented in Figure 2.

Rwanda is on the top of the list followed by other African states like Zambia, South Africa and Botswana. There is only one country on the top 10 list which does not belong to Africa. This is Peru on the 10th position. Rwanda as an example how to look more intense on a target country shall be presented more detailed later. Regarding results of the two main criteria separately, top 10 lists look very different.

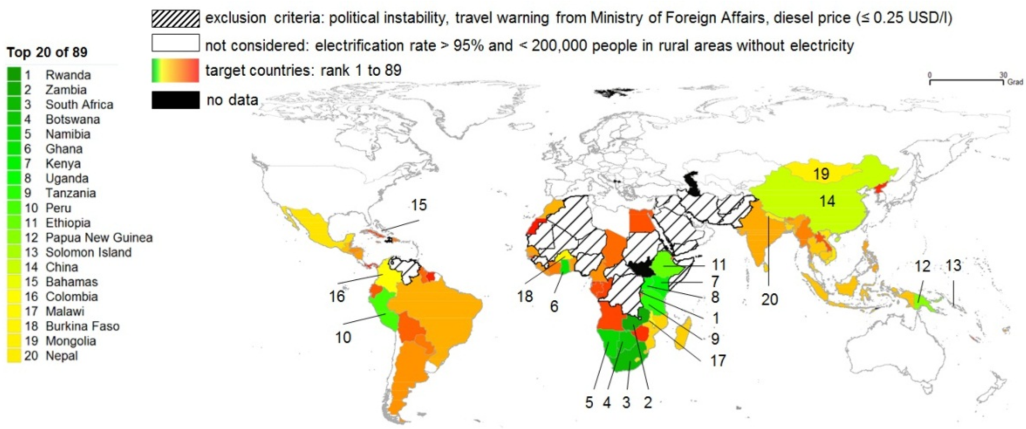

Figure 2: Result of Country Ranking: Top 20.

This is visible in Table 1and Table 2. Top countries of the market potential criterion are countries with low electrification rates and many people without access to electricity. Top ten countries are all from Africa. Top countries are Malawi, Uganda, Kenya and Tanzania.

Table 1: Ranking of market potential. Data are taken from (UNDP, 2007; IEA, 2004, 2010; UNDP & WHO, 2009; World Bank, 2010a/c; GIZ, 2012).

rank	country	electrification rate [%]
1	Malawi	9
2	Uganda	9
3	Kenya	16
3	United Rep. of Tanzania	14
5	Rwanda	5
6	Burkina Faso	15
6	Madagascar	19
6	Burundi	3
6	Chad	4
10	Zambia	19

Being under the top 10 of "economic and financial environment", means that the country offers good conditions for starting a business. Here are also countries with higher electrification rates as the potential users are not considered yet. Top countries are The Bahamas, Botswana and Rwanda.

Table 2: Ranking political and financial environment. Data are taken from (UNDP, 2007; IEA, 2004, 2010; UNDP & WHO, 2009; World Bank, 2010a/c; GIZ, 2012).

rank	country	electrification rate [%]
1	The Bahamas	87
2	Botswana	45
3	Rwanda	5
4	South Africa	75
4	Namibia	34
6	Antigua and Barbuda	95
7	Peru	86
8	Solomon Island	14
9	Colombia	94
9	Mexico	99

Country profile Rwanda

To get an insight into the top country of the ranking, Rwanda has been analyzed in more detail. Information which are interesting for sustainable business models of mini-grids shall be offered here

The east African state has been in civil war in the early 1990s and started rehabilitation in the end of the 1990s. Economy and income for people had to be recreated. Meanwhile there is a very good economic environment in Rwanda. The state systematically fights corruption and got a World Bank's doing business rank of 45, out of 183, in 2011 (TI, 2011; (World Bank & IFC, 2011). Especially rank 8 in getting credit and starting a business are excellent results in terms of thinking about business models focusing mini-grids.

Still there is a rural electrification rate of only 1 % which means that there is a rural population of 8.5 million people having no access to electricity. Figure 3 shows the population density in Rwanda and the transmission lines crossing the country. It is visible that there is a high population density but only few transmission lines. This is confirmed by Figure 4 which shows the nightlights in Rwanda. Only those people who have access to electricity can use it for lightning at night.

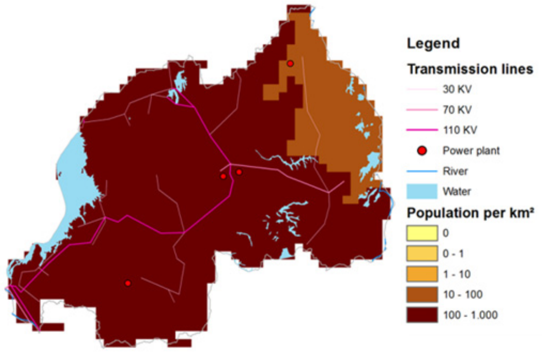

Figure 3: Transmission lines, power plants and population in Rwanda. Data are taken from Hijmans; National Geospatial Intelligence Agency; African Development Bank Group, 2012; Platts, 2009; Balk & Yetman, 2005.

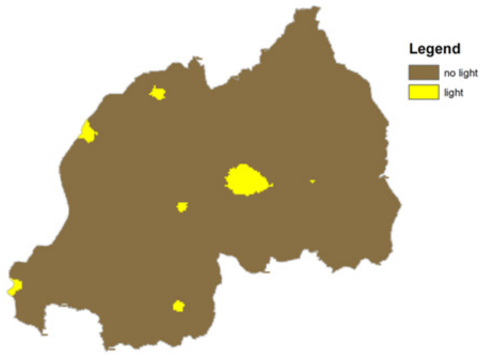

Figure 4: Nightlights at Rwanda. Data are taken from Hijmans; NOAA National Geophysical Data Center, 2007.

In Rwanda there are only some bigger cities like Kigali the capital, Gisenyi or Butare having light at nights. The rest of the country is dark as soon as the sun goes down although there are lots of people living in the dark areas.

Additionally Rwanda only produces half of its consumed electricity itself. Thus the country has urgent needs to expand its capacities. There are targets for electrification in Rwanda which say that there shall be 1,000 MW electric power capacities in 2017 while there were 90 MW in 2011. Conventional energy resources are very expensive for Rwanda as they do not have any resources themselves. There are investments in energy production with methane gas, hydro power, geothermal and solar power (German Trade & Invest [GTAI], 2011; Wilhelmi, 2011).

Regarding all these conditions Rwanda seems to be rightly on the first place of the ranking. It offers a good environment for implementing a sustainable business model of renewable mini-grids. Only one thing could be a barrier for that intention. This is that rural people are not living in settlements but have their farms spread on the hills (Wilhelmi, 2011). This situation would not be economic for a mini-grid because of long and expensive cables. This is something not considered in the ranking and has to be checked for each country separately. Still, as the general set-up is so positive, it might be worth to look for places in Rwanda where people live close to each other or are willing to move for electricity. Industry can be established and poverty can be fought that way.

Discussion

According to this work it can be stated that there are several countries which offer good preconditions for starting a sustainable business of electrifying rural people with renewable energy based mini-grids. The results show countries which seem to be on good way concerning sustainable development and can help entrepreneurs focusing on countries being adequate for starting a business. Adequate countries are different countries from southern and eastern Africa and Peru as a South American state. However, while working with the subject it became obvious that still every country has to be checked in detail like it has been done on the example of Rwanda in this paper.

Acknowledgments

This work has been partly enabled by financial means of the SMA Stiftungsverbund gemeinnützige GmbH and has been highly appreciated for gaining deeper insights on the role of renewable energy-based mini-grids for rural electrification in developing countries. The authors would like to thank Philipp Blechinger for contribution and helpful discussions.

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The Effect of Using Biomass Gasification as Source of Energy to Small Scale Bio-Ethanol Production

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Abstract

This paper presents the results of a study conducted to evaluate the effect of utilizing biomass gasification as source of energy in bio-ethanol production. The study assessed the effect in bio-ethanol production cost, when conventional energy sources are replaced with biomass gasification. Material characterization was done, followed by fabrication and testing of a 100 kW updraft gasifier prototype.
The developed gasifier was found to operate at an efficiency of 51%, equivalence ratio ranging 0.3 to 0.4, and the syngas produced had an energy value (LHV) of 2.02 MJ/kg. The energy cost in bioethanol production can be reduced by 17.6% by utilizing rice husk gasification as source of energy.

Keywords: Biomass, gasification, Bio-ethanol, economics.

Introduction

Bioethanol is produced through sugar fermentation of sugarcane juice, molasses, corn, cassava, and other starch related materials via distillation process. The major challenge with bio-ethanol production is its economic competitiveness against fossil fuel due to its high production cost caused by high energy cost incurred by the process. This process is energy intensive which requires 9.74 to 13.84 MJ to produce one litre of ethanol (Hohmann and Rendleman, 1993; Shapouri et al., 2002).

Research Objectives

Main Objective

The objective of this study was to develop a process heat integration model for small scale bio-ethanol plant through mass and energy balance.

Specific Objective

a) Develop a mass and energy balance for process heat integration.
b) b) Determination of rice husk properties.
c) Fabricate an updraft gasifier prototype and determine its performance characteristics.
d) Establish financial costs of using producer gas as source of energy in small scale bio-ethanol plants.

Methodology

The following methods were adopted;

2.1 Developing the Process Flow Diagram (PFD).

The PFD for bio-ethanol production was developed and considered to be the guideline in making the mass and energy balance in the model (refer Fig. 2.1).

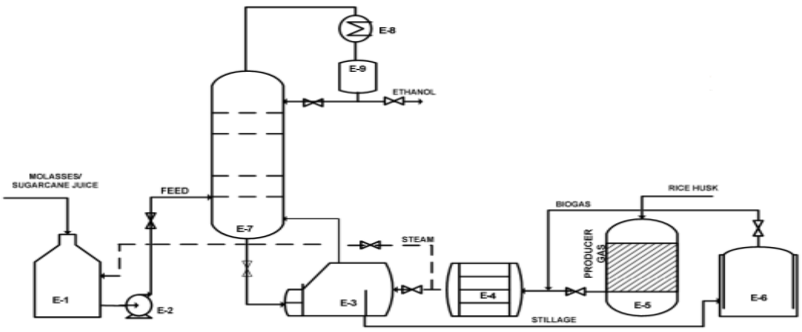

Figure 2.1: PFD for small scale bio-ethanol production.

Legend:
E-1 Fermenter; E-2 Pump; E-3 Reboiler; E-4 Boiler; E-5 Gasifier; E-6 Biodigester; E-7 Distillation column; E-8 Condenser; E-9 Reflux tank

2.2 Developing of Model Equations.

This approach involved derivation of equations and calculation of mass and energy balance for each unit operation making the entire process. This was done based on the laws of conservation of mass and energy, and application of some thermodynamics principles. the formulated equations were solved to obtain the concentration of species involved during gasification.

2.3 Determination of Proximity Analysis.

The proximate analysis to evaluate the characteristics of gasifier feedstock (rice husks) was done using an oven, muffle furnace and weighing balance. This analysis was done based on wet and dry basis. Wet basis analysis is an analysis done without removing water into the material tested, while the dry basis test is done after water is been removed. Table 2.1 presents the formula used in this analysis.

Table 2.1: Formula used in Proximity analysis.

Parameter on test	On wet basis	On dry basis
Moisture content	$\frac{(Initial\ mass - dry\ mass) * 100}{Initial\ mass}$,	$\frac{(Initial\ mass - dry\ mass) * 100}{Dry\ mass}$,
Volatile matter	$\frac{(Dry\ weight - Weight\ of\ char) * 100}{Initial\ weight}$	$\frac{(Dry\ weight - weight\ of\ char) * 100}{Dry\ weight}$
Ash content	$\frac{weight\ of\ ash * 100}{Initial\ weight}$	$\frac{Weight\ of\ ash * 100}{Dry\ weight}$
Fixed Carbon	Fixed Carbon = 100% - [%moisture - %volatile + %ash	Fixed Carbon = 100% – (%volatile + %ash)

2.4 Fabrication and Testing an Updraft Gasifier.

A 100 kW small-scale updraft gasifier prototype was constructed, operated and tested using rice husk as feestock.

2.5 Water boiling test

The heat energy absorbed by water in a water boiling test and heat loss by flue gases was used to estimate energy value for the syngas produced. The water boiling test was done based on the formula;

$$q_w = [m_w Cp_w(Tb - T_i) + m_w L]/dt$$

Where; m_w = mass of water, Cp_w = specific heat capacity of water, T_i, and T_b = initial and boiling temperature respectively of water, L = latent heat of vaporization of water, dt = rate of change of time

2.6 Energy Cost Analysis

The impact on process energy cost was evaluated in an Excel sheet, whereby the price of raw material, calorific value of the material, and conversion efficiency were considered in the analysis.

Results

3.1 Meeting the Process Energy Demand through Gasification

The mathematical model analysis results for mass and energy balance (see Figure 3.1), shows the gasifier was operating at fuel consumption rate (FCR) of 46 kg/hr, ratio of syngas production/ FCR of 2.33, and LHV of syngas being assumed to be 4.54 MJ/m^3.

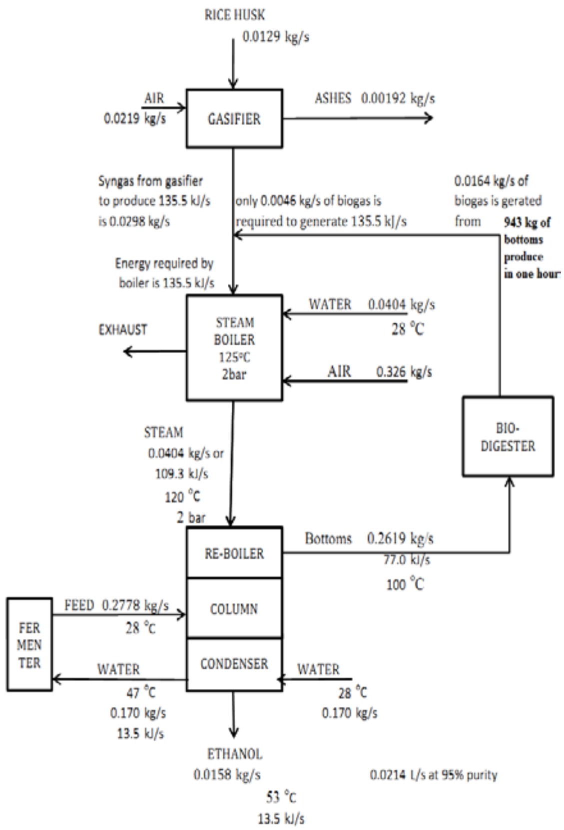

Figure 3.1: Mathematical model for material and energy balance.

The actual results from the gasifier prototype are presented in table 3.1. These results show that the developed gasifier was operating near to its optimal operating parameters.

Table 3.1: Results from the gasifier.

Parameter	Unit	Value
Air intake flow rate	Kg/s	0.05-0.07
Gas outlet flow rate	m^3/h	26.87
Equivalence Ratio	Φ	0.3-0.4
Specific gasification rate	kgh-^{1}m-^{2}	79.92
Gasifier Efficiency	H	51
LHV of producer gas	MJ/kg	2.02
Heat loss by gasifier	%	6.14

Proximate analysis for rice husk was carried out to quantify moisture content, volatile matter, fixed carbon, ash content, and its energy value. Table 3.2 shows a comparison of proximate analysis results between the tested samples for rice husk and results obtained from literature (Yusof et al., 2008; Lee Ven Han, 2004; Rozainee et al., 2010; Thipwimom et al., 2004).

Table 3.2: Proximate analysis results.

Parameter	Laboratory results (dry basis)	Literature data (dry basis)	% difference (dry basis)
Moisture (%)	10.88	8.45	22.3%
Volatile (%)	65	65.08	0.1%
FC (%)	20.19	14.87	26.3%
Ash (%)	14.91	17.61	25.7%
Bulk density (kg/m3)	128	115.73	9.6%
HHV (MJ/kg)	15.348	15.2	0.9%
LHV (MJ/kg)	14.105	14.22	0.8%

3.2 The Equivalence Ratio for Gasification

It is a ratio of stoichiometric air fuel ratio to actual air fuel ratio that determines syngas production by the gasifier. In the experiments, syngas was produced at the equivalence ratio ranging from 0.3 to 0.4, and the respective velocity of air flow into the gasifier was 6.5 m/s and 4.3 m/s.

3.3 Temperature Profile in the Gasifier

Figure 3.2 shows temperature variation within the gasifier zones (combustion, gasification, pyrolysis, and drying). The maximum temperatures recorded were lower than the recommended values in respective zones.

From the graphs, temperatures increased exponentially until the steady state temperatures were reached. The steady state temperatures decreased when fuel within the gasifier was being consumed to the minimum amount.

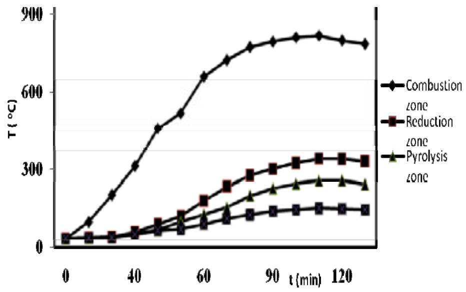

Figure 3.2: Temperature variation within gasifier zones.

3.4 Energy Value of Syngas and Gasifier Efficiency

Due to the absence of gas chromatograph, the energy value of syngas was estimated to be 2.02 MJ/kg through a water boiling test. Additional to this, a bluish clear flame observed indicated presence of large quantities of CO. Based on these results, the gasifier efficiency was analyzed to be 51%.

3.5 Impact on Bio-ethanol Energy Production Cost

Table 3.3 compares different type of fuels which have a potential of being used as energy sources to small scale bio-ethanol production plants. The cost of using electricity energy was considered as a reference conventional energy source. The negative sign in the last column of table 3.3 indicates an increase in energy cost, while positive sign indicates a reduction in energy cost when electricity is substituted with other type of fuels.

Table 3.3: Cost comparison for the potential energy sources in bio ethanol production.

Energy to produce	**Type of fuel**	**Calorific value of fuel (LHV)**		**Conversion**	**Fuel required to produce 1Lt EtOH**		**Average unit price**		**Total cost**	**% of Cost saved**
one Lt of ethanol		Quantity	Unit	efficiency (%)	Quantity	Unit	Amount	Unit	Tsh.	
	LPG	49.4	MJ/kg	70	0.34	kg	2,266	Tsh/kg	772	-145.0
11.786 MJ	Natural gas	38.1	MJ/kg	70	0.44	kg	1,133	Tsh/kg	500	-58.8
	Coal	33.8	MJ/kg	70	0.50	kg	600	Tsh/kg	298	5.2
	Charcoal	20	MJ/kg	70	0.84	kg	625	Tsh/kg	526	-66.8
	Electricity	3.53	MJ/kWh	90	3.71	kWh	85	Tsh/kWh	315	0.0
	IDO (Lt)	41.4	MJ/kg	85	0.33	Lt	800	Tsh/Lt	267	15.0
	Syngas	4.54	MJ/kg	65	3.99	kg	65	Tsh/kg	259	17.6

The fuels costs were derived based on the prices found in the energy market in Tanzania, and the percentage of cost saved upon substituting the conventional energy sources with syngas based on the formula below;

$$\text{Percentage of energy cost saved} = \frac{A-B}{A} x\, 100$$

Where; A = Total energy cost required to produce one litre of bioethanol by using electricity energy.

B = Total energy cost required to produce one litre of bioethanol by using other sources of energy such LPG, natural gas, coal, charcoal, IDO, syngas, and electricity itself.

On the other hand, the price of syngas was derived based on the formula below;

$$= \frac{\text{Total operating \& material cost}}{\text{Total syngas energy produced per year}}$$

From this analysis, the cost of syngas was obtained to be 35 Tsh/MJ, and this cost became the base to decide the price of sygas to be 65 Tsh/MJ.

Discussion

The developed mathematical model analysis of mass and energy balance results (refer figure 3.1), shows the possibility of generating syngas from rice husks. To validate this model a 100 kW rice husk updraft gasifier prototype was developed and tested. The test results of the gasifier (refer table 3.1) were compared with the results of the mathematical model, and showed no significant differences. The gasifier experimental results were promising and prompt the adoption of biomass gasification as source of energy to small scale bio-ethanol plants. Prior to gasification experiments, material characterization for the feedstock to be used (rice husk) was carried out. The test results were compared to the results from literature (refer table 3.2), and showed significant differences in moisture, fixed Carbon, and ash contents, however there were no significant differences in volatile matter and material energy value. These characteristics showed a good potential for the material to be used as feedstock for gasification process.

The recorded temperatures in the gasifier zones were lower than the recommended values for syngas to be produced (refer figure 3.2) which was drawn based on rice husk gasification. The reasons suspected to associate with the observed problem were temperature sensors not located exactly on the gasifier zones, lack of good insulation to reduction, pyrolysis, and drying zones which leads to loss of temperature.

Normally syngas is produced from a reduction temperature of 700^{o}C to 950^{o}C, and since syngas was produced, it is a proof that temperature within the gasifier reached the gasification/reduction, pyrolysis, and drying temperatures. Comparing the calorific value of syngas produced with syngas in literature data which is from 2.5-5.0 MJ/m^3, proves a good performance of the developed updraft gasifier.

Table 3.3 contains comparisons of various potential energy sources that can be used in small scale bio ethanol production plants. In this table, the direct burning of coal and IDO have positive impact on the energy cost in bio-ethanol production, however direct burning of these fuels have negative side effect on environment as well as on the boiler. This makes syngas from rice husk to be the favorable choice, because it burns cleaner with less environmental impact, and it reduces the energy cost by about 17.67%.

With the energy cost saving of about 17.67% upon substituting the conventional energy sources with syngas from rice husk to small scale bio-ethanol, proves the great potential of gasification technology to meet the energy demand in small scale bio-ethanol production.

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Developing a small-scale biogas digester in rural Tanzania. An ethnographic approach for the analysis of an untypical innovation journey.

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Abstract

The paper introduces a case study about the development process of a domestic biogas digester working with plant residues in rural Tanzania. The project is based on low tech principles and applied research in cooperation with a grass roots farmers' organisation. This study then offers insights about the specific conditions of innovation research in an NGO-context. As an example, the decision about the readiness for implementation of the digesters will be analysed in the paper. The results have a preliminary character. On a methodological level advantages and limits of the ethnographic research approach will be reflected.

Keywords: Ethnography of development cooperation and innovation, Appropriate Technologies, domestic biogas digester, non-governmental organisations.

Introduction

Microenergy technologies for decentralized energy supply are supposed to have the potential to alleviate two main global problems: climate change and poverty. Their implementation is promoted and put into practice by development cooperation organizations as well as through private sector activities, often in combination with a micro credits structure. Because of the exceptional vulnerability of the main target group of poor people in so-called developing countries, it is necessary to observe the implementation schemes from the very beginning of new projects.

The term „Microenergy-System“ refers to the broader understanding of the respective technical artefact in interrelation with its natural conditions, social and organisational structures, political frames, etc. (Philipp/ Schäfer 2009). It can be understood as a socio-technical system which is a sociological concept that stresses the embeddedness of technology in society. Regarding energy technologies, the concept was already successfully applied to the analysis of minigrids in India (Ulsrud/ Winther 2011).

This system-perspective however needs to be complemented by the understanding of technological developments as „dynamic, multi actor and decentralized co-production processes“ (Schot/Rip 1997: 257). This point of view enables the analysis of the development process itself, that is the emergence of a new socio-technical constellation. Inspired by this social constructivist perspective on technology development, a concept of Constructive Technology Assessment (CTA) was developed in the 1990s by NOTA, a Dutch organisation of Technology Assessment.

CTA focuses on the early development process of new technologies and works on a very practical level, promoting the intensified communication between engineers, potential users and other interest groups involved (Rip et.al. 1995, Schot/Rip 1997). An integral part is a dynamic feedback process which aims at including the opinions and needs of the potential users and other actors in the further development of the technology.

This basic idea makes it very interesting to be applied in the context of the micro energy sector, because in the context of development activities questions of participation, ownership and empowerment become even more relevant. However, as it is often the case in recent technical sociology and technology assessment, low tech and small scale implementations so far are not at the focus of the CTA-approach. Although its main protagonists claim that the approach is generally applicable (Rip/Schot 2002: 156) and note that also Non-governmental Organisations (NGOs), and not only R&D-sections of companies, can be developers and promoters of alternative technologies (Rip 2007: 98), the focus of studies and practical application lies in the analysis of new high-tech sectors such as nanotechnology or fuel cells (ibid. or Ornetzeder et. al. 2010).[1]

Studying an unusual case

The following case of a micro energy project brings together three important aspects: First it is carried out by an NGO that is, secondly, conducting research for the development of an innovative appropriate technology. Third, the research process is carried out in large parts directly at the place where the technology is supposed to be implemented with intensified contact with the future users from the beginning of the research process.

In summer 2012 I got to know a small group of people mainly engineering students and few graduated engineers who belong to a German non-governmental technical development cooperation association. They work on a biogas energy project that mainly is based in voluntary work, non-profit oriented and an open source development that follows low tech principles. In close cooperation with a grass roots organisation of mainly subsistence farmers in the rural Tanzanian region of

[1] As an exception, Hirsch-Kreinsen (2008) shows (though solely regarding industrialized countries) that also in the low tech sector a lot of research and development activities can be found and that this sector therefore can be described as innovative.

Kagera they are developing a new form of a domestic biogas digester.

In Tanzania the dissemination of domestic biogas digesters already started in the 1970s with a technology based on the feeding with animal dung (GTZ 2007). A feasibility and demand analysis of the local context and conditions carried out by the project leader in 2008 yielded the necessity to develop a small scale digester that can be fed with plant residues only, as the region has a vast majority of small-scale subsistence farmers that do not have enough cattle to run a digester with animal dung. This is a well-known problem throughout the developing world as Bond and Templeton (2011) have shown in their overview on the history and future of domestic biogas. A technical solution of this problem would be an important innovation in this field.

To confront this problem four pilot digesters have been constructed: two in Germany in cooperation with German universities and two in Tanzania with the farmers' association. Development research has been carried out directly in the field since 2010. Currently the two pilot digesters in Tanzania are being tested and in mid-2013 the decision, whether the technology will be implemented on the household level will be jointly decided by the engineers and the farmers' association.

Research Objectives

The sociological study on the implementation process of the biogas digesters is structured by two main research objectives. The first objective is to analyse the development process of the digesters as an emerging socio-technical system from a social science perspective. Central questions that will be addressed in this paper are: What are the advantages and problems of this approach to technology development? How are decisions taken and how are special requirements like the vulnerability of the target group addressed?

For the further research process, an important question related to the idea of participatory systems design will be, how the potential users and their needs are included in the development process as the development is taking place directly in their neighbourhood on the grounds of the farmers' association.

The second objective, that is the analysis of the project in the broader context of the development discourse, is connected to the issues mentioned above. How can the project be evaluated regarding central criteria of development cooperation like participation, ownership and empowerment? For the understanding of the project structure also the actors' motivations and overall concepts of development and development cooperation are seen as important factors.

Methods: taking a micro perspective

A qualitative social science approach is used to describe the innovation journey of the case study.

Through the method of active participant observation I am accompanying the group of engineers since one year, joining meetings and field trips, sharing mailing lists and becoming involved, as far as possible. Experiences and observations are captured by the method of taking ethnographic field notes (Emerson 2011). The approach can be understood as a reflexive form of Development Anthropology aiming at the study of development projects rather than examining "local" people to gain knowledge about them. Also the challenge of integrating technological artefacts into ethnographic fieldwork has to be considered in researching technology development (Braun-Thürmann 2006).

To get a holistic picture of the case, considering observations and oral accounts alone is not enough and triangulation in data collection is necessary. That is why semi-structured interviews are used to complement the observed aspects with missing background information and to integrate the perspectives of all the actors involved. Also, existing data material like project documents, reports and protocols are considered. Additionally, reflections with the group of engineers about the project, their motivations, and development cooperation are taken into account.

For the analysis and interpretation of the data Grounded Theory methods are used. Here it is possible to benefit already from reflections on the method application in the field of innovation research (Kehrbaum 2009).

Preliminary Results

The aim of the analysis is to describe influences, mechanisms, advantages and limits that shape the process of the development of the biogas digester on a daily basis and to analyse the relations between them. The data evaluation is still in process, but it is already possible to frame some important outcomes. A few examples drawn from field notes collected in various settings will be given in the following paragraphs.[2]

Example: Continuing research

An important and ongoing discussion in the project meetings of the engineering group in 2012 was whether they should go on with research or start implementing the first digesters. Remaining technical problems that would require further research concern the feeding process of the digester. One problem is that the feeding with pieces of banana trunks is very exhausting because they have to be cut in little pieces with a machete and the group members are trying to find solutions, for example smashing devices. The other problem is that the inlet gets blocked from time to time. Above that, they wanted to test a heating system for the digester to increase the gas production which still is not high enough.

In general the decisions of the German project group have to be approved by the management board of the German NGO. Both, the project as well as the management, are in close coordination with the manager

[2] Note that the sources of the following example are the group meetings and meetings with the board of the German organisation. So mainly their statements in group situations are reflected here.

of the Tanzanian farmers' association. For the daily project routines the Tanzanian project expert is responsible and supported by the German group members. The main financial sponsor of the project is the foundation of a big German company.

In the following it is possible to notice the different demands and interests of the actors involved. As it became clear to me in a group meeting in May 2012, the group feels a certain (time) pressure from the German foundation that is financing the project to start implementing and building the digesters. I wrote in my observations:

> *The foundation is the main sponsor for the whole project. Already in earlier group meetings I was told that they want to see results soon. They are said to have urged the construction of 15 digesters as soon as possible. Even the second pilot digester, that is clearly seen as a research plant by the group as well as by the Tanzanian partner organisation, officially is not a pilot digester anymore because there is already one. Some of the engineers expressed their doubts to start with the serial production of a technology that is not ready for implementation and carries the risk of compromising the trust of the community members.*

In July 2012 a big general meeting of the German engineers group (without the chairmen) took place with the aim of reflecting the status of the project. They finally wanted to take the decision whether they should start building digesters for the first farmers households in the same year or not. One of the two project leaders pointed out that for him the project has shown a certain regress, because the engineers were thinking that they had been close to series-production, but now he had doubts. The group discussed the situation openly and controversially. Two members pointed out:

> *The acceptance of the technology is good. That is why we should not rush. One can recognize this also in the remarks of John [the manager of the Tanzanian farmers' association], it's better to wait until it really works, because if not, we repeat the failures of all the decades before: to put a block of concrete that is not working. […] Also Oskar said that he likes to slow down the whole issue because building poorly engineered digesters can be dangerous, the whole project could fail because of that.*

Another member who was very active formerly but bowed out of the project, stated:

> *I like the project but what always was disturbing me a little bit is: Research is good, and to develop a product, but it took too long to reach the implementation. Also for the sponsors, for the PR. And there was not enough focus on earning money with it. For the foundation it is about PR and if we have in mind the sponsor, the construction of digesters is the biggest deficit. It would have been better to make these final adjustments later and to offer the digester as a finished product, also if the things will break later on. If the Chinese come up with their 500$ things, everything is over.*

This opinion clearly did not represent the majority of the group, but it offers an understanding of the contrasting interpretations of the situation. At the end they decided not to start with building the digesters yet and to continue research at least until the first quarter of 2013. This meant to continue collecting and analysing data and to test the heating system in Tanzania that was already planned. The chair person of the board supported this decision in a meeting in September:

> *I agree with your decision. One should not take 20 families as victims for experiments who get digesters that do not work properly afterwards. Because then we don't have to show up in this region ever again.*

Not only because of the sponsor there is a certain pressure on the project. The manager of the farmers' association also has to convince his community of the benefits of the research process. Already the mere concept of research itself as a long-term and open end process has to be explained and justified to the farmers as they want to see benefits for the community. Nevertheless, the manager also appreciated the decision of the group as it became clear in a meeting between him, project members and the German board during his visit in Germany in December 2012.

> *The manager underlines that for him it is clear that further research is required: "Necessary is research to the stage that there are no questions anymore. We have to be extra-careful when transferring a project to the community. We are responsible – to the community AND to the government."*

The project group, the board of the German NGO and the manager of the Tanzanian partner organisation feel responsible for the decisions. The subsistence farmers of the community, who were not present in these meetings as they took place in Germany, are considered as a group to take responsibility for.[3] The question of responsibility can be understood as consequence of the ascribed vulnerability of the subsistence farmers in need for protection. But their well-being is not the only relevant argument for the decision. The specific institutional interests and logics are influencing the positions as it became most obvious when the chairman of the German NGO was concerned about the reputation of the organisation.

The example of the biogas project can show advantages of research and innovation by NGOs as mentioned by Rip (2007) regarding three aspects. First, the group started to look for sustainable and appropriate technical solutions, independent of commercial interests, but on demand of local farmers. Second, the direct connection to the future users and felt responsibility led to a more open discussion about advantages and disadvantages of the new technology.[4] Third, the implementation debate shows that this kind of organisational constellation can give enough emphasis to concerns regarding the implementation of a technology. No premature 'product' was sold to show

[3] That they did not take part at these meetings does not mean that they cannot participate in decisions about the project. The manager has to justify his decision to the council of elders of the grass roots farmers' organization. How the project is discussed and perceived by the farmers is a question to be answered in the future research process.

[4] Rip observed that classical "enactors" (promoters and developers) tend to downplay disadvantages that almost every new technology has (ibid. 97f).

short term success or win market shares (against "the Chinese" in this example) although the pressure of competition for the implementation was strongly claimed by a group member. For various reasons the actors managed to resist the pressures put by the sponsor, one being certainly that the pressure of a once given donation is not that strong and the foundation is really supportive. But also the group does not want to repeat the former failures of technology transfer of inappropriate technologies and the manager is directly accountable to his farmers' association.

In turn, the project group has to deal with very scarce resources like little money, mainly voluntary work and therefore limited capacities that are curtailing the progress noticeable.

Micro perspective and beyond

The decision whether the digesters will be implemented or not is still open. But if the actors involved will decide not to start the implementation it does not necessarily mean that the project has failed. Such a scenario should rather be interpreted as a "successful failure" because non-matured technology was not forced on people with few resources.

The case study enables to look for the potential of the adaptation of micro energy technologies to the users' needs and to local contexts. It further highlights possibilities to overcome typical problems of development cooperation such as implementing unsustainable projects on the one hand or a total commercialisation of the energy supply on the other hand.

The limits of investigating an untypical case and taking a micro perspective have to be recognized: the results cannot easily be generalized. Moreover, an ethnographic perspective necessarily depends very much on the researcher itself. The participative approach entails the fact that the researcher is an active part of the world she studies, thus influencing and changing while studying it.

Nevertheless, as Burawoy (1998: 5) points out: "Like other handicaps, ethnographic condition can be dealt with on one of two ways, containing it or turning it to advantage." In his model of reflexive science he is offering four steps for connecting the "micro" with the "macro": Extending observer to participant, extending observations over space and time, extending from process to force and extending theory.

The study aims at providing an in-depth analysis of an exceptional case of an emerging microenergy system and its specific conditions. It bears the chance to reveal missing parts and underlying premises in our theories and gives the opportunity to discover emancipatory practices of embedding technology in society.

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"Small is beautiful!? Evaluating the sustainability of small-scale renewable energy projects in developing countries"

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Abstract

Access to sustainable and affordable energy services is a crucial factor to reduce poverty in developing countries. Especially small-scale and community-based renewable energy projects are recognized as an important form of development assistance to reach the energy poor. The WISIONS program run by the Wuppertal Institute has supported numerous of such innovative small-scale energy projects via its Sustainable Energy Project Support (SEPS) scheme since 2004. This paper presents the first step in the effort to evaluate cross-sectional energy development interventions at the local level, gather evidence on their effectiveness and measure their sustainability.

Keywords: community-based projects, renewable energy, evaluation, sustainability

Introduction

Today about 1.3 billion people still lack access to clean, affordable and reliable energy services to meet their basic energy needs (IEA/OECD, 2011). Renewable energy sources are expected to play a key role in increasing and improving access to energy in developing countries offering clean electricity, heating, cooking and lighting solutions to people and communities, who so far depend on traditional energy sources and/or expensive fossil fuels. This is especially true, since technological innovations and cost reductions in the last ten years have made renewable energies more competitive to traditional fuels (REN21, 2012). Nevertheless, these technologies still face a broad range of social, economic and structural challenges, requiring not only the development of new capacities and tools but also new ways of understanding and fostering technological innovation to accomplish widespread dissemination. The SEPS scheme (Sustainable Energy Project Support) of the WISIONS initiative addresses these issues by supporting innovative approaches and capacity development to respond to energy needs at the local level. Since 2004, a total of 64 projects around the world have been selected for SEPS support. These projects focus on different energy related needs, technologies and implementation concepts.

Although most of these projects could be completed successfully it is important to assess their sustainability some years after the initial project activities have been completed. The need for such an evaluation of development projects is recognized throughout the international community and reflects in the increasing attention the subject receives in publications of donor organizations and research institutions (e.g. Baker, 2000, ESMAP, 2003; Mansuri & Rao, 2003; Späth, 2004; FASID, 2008; UNDP, 2009; World Bank/IEG, 2012). According to Baker (2000) ex-post evaluations can help to answer the question of 'what works and why' and therewith guide improvements of project designs and practices by identifying success factors and explain failure. While many evaluations focus on one discrete project at a time the present evaluation was applied to a group of cross-sectional projects in terms of technologies, needs and regions. Studies by the Japan International Cooperation agency (JICA) (2010), FAO (2010), World Bank (2008), or Linn (2012) have shown that by evaluating a number of projects which have been implemented with a common framework, but under diverse contextual factors, can provide recommendations which are relevant across projects boundaries.

Research Objectives

The main objective of this paper is to evaluate the mid-term sustainability of small-scale renewable energy projects ex-post implementation. The key research questions addressed are (1) *Sustainability*: Whether or not the energy services and structures could be sustained over an extended period of time after the initial project activities were completed? (2) *Suitability*: What has been working as expected? What has changed from the original design and why? Which problems and challenges have occurred?

Thus, the analysis is focused on extracting information on performance and credible evidence on the effectiveness or inefficiency of different project components and designs. Moreover the aim is to explore if specific influencing factors, difficulties and/or necessary changes that had to be made can be regionally linked, are technology specific, universal or only particular to single projects. The results can (a) be used to effectively determine the future needs of the "WISIONS for sustainability" program and improve the quality of future projects (b) provide stakeholders with information on the major factors that influence the achievement or non-achievement of sustainability in small scale renewable energy projects in developing countries and (c) help other organization to learn from the experience and therewith avoid replication of poor project designs and practices.

Methods

The evaluation was designed as a semi-structured in-depth survey with the organizations that implemented and monitored the initial project activities. The survey approach was chosen as it is time effective and particularly suitable to address questions regarding how innovation occurs, why certain decisions are made, and why some processes work better than others (Baker, 2000). As the projects are worldwide distributed, on-site evaluation was considered to be too time and cost-intensive. Although there are inevitably limitations of the chosen approach, namely the problems to quantify and generalize the results, it is possible to provide an interpretation of the processes and impacts that have a high level of probability (Späth, 2004). Most of the supported small-scale energy programs focus on providing development assistance through the supply of electricity or other energy services to stimulate economic productivity and enhance quality of life. To measure these components this evaluation focuses not only on quantifiable evidence, such as the number of installations or number of beneficiaries, but also on qualitative aspects, such as impacts on society, awareness raising or network development. The data drawn from the interviews and additional documentation including progress and final reports from the original project phases were examined using statistical methods as well as content analysis tools. The analysis and the presentation of results concentrate on four categories (a) technical viability, (b) interactions with political level, (c) socio-economic development and (d) replication and dissemination.

Results

The evaluation sample consisted of 40 projects, which have been supported by the SEPS scheme of the WISIONS initiative in the period between 2004 and 2008. The response rate to the survey was 65% (26 projects), of which 23 projects were suitable for the evaluation. In the remaining 3 cases no information on the status of the projects was available.

The evaluation has shown that with 78% of the 23 projects the majority of the implemented small scale renewable energy interventions were successful, meaning that more than 50% of the original technical components and/or services were functioning 2-7 years after their first introduction. Of these 48% were fully functioning and 30% were largely operational, with only some installations or structures not functioning. Further 13% of the former projects were only functioning to limited extent, for example in one case out of 13 biogas digesters only three were still running. While 9% of the projects failed completely. In the group of cases that failed or are only operational to limited extent, technologies that utilize biomass as renewable fuel source represented the largest cluster. Whereas all projects that aimed to meet the need of preparing food with less energy inputs utilizing technologies like improved cook stoves and solar cookers are still fully operational.

Table 1: Overview projects and status.

	Technology	Need/Application	Country	Status 2012
1	Micro-hydro power	Electrification	Brazil	Fully operational
2	Solar PV	Electrification & Lighting	Namibia	Fully operational
3	Pico-hydro power	Electrification & Lighting	Philippines	Fully operational
4	Improved cook stoves	Food preparation	Laos	Fully operational
5	Biogas	Food preparation	India	Fully operational
6	Improved cook stoves	Food preparation	China	Fully operational
7	Biogas	Food preparation & heating	Jordan	Fully operational
8	Efficient pumps	Irrigation	India	Fully operational
9	Solar PV & efficiency improvement	Lighting	Mauritius	Fully operational
10	Solar PV	Lighting	Kenya	Fully operational
11	Efficiency improvement	Lighting	Mexico	Fully operational
12	Wind power	Electrification	Peru	Mostly operational
13	Solar cookers & improved cook stoves	Food preparation	Guatemala	Mostly operational
14	Biogas	Food preparation	Latin America	Mostly operational
15	Solar cookers	Food preparation	Nepal	Mostly operational
16	Solar PV & Wind power	Irrigation	Tanzania	Mostly operational
17	Efficient lanterns	Lighting	Sri Lanka	Mostly operational
18	Solar bakery	Commercial food preparation	Cameroon	Mostly operational (2011)
19	Liquid biofuel Jatropha	Irrigation	India	Not functioning
20	Biomass gasification	Productive use	India	Not functioning
21	Biogas	Electrification	Sri Lanka	Only functioning to a limited extent
22	Solar PV & Micro-hydro power	Electrification	Peru	Only functioning to a limited extent
23	Liquid biofuel Jatropha	Irrigation	Nepal	Only functioning to a limited extent

Technical viability

The evaluated projects indicate that the technical viability of the applied concepts strongly depend on two factors: (1) The reliability of the technical components (hardware) and (2) the availability of knowledge, expertise and skills (software) required during the whole lifecycle of the hardware, i.e. from their selection or design, through their construction and installation up to their operation and maintenance. In many cases (43% of evaluated projects) main technical components have been fulfilling the expected functions without major difficulties. However, the use of reliable technical components does not necessarily ensure sustainable operation of the concepts. Gaps in the 'software' factors may lead to difficulties or even to failure. Two notable examples are:

a) Improper use of the PV systems led to damage of some components in Namibia (no. 2), thus stronger emphasis on training of users was given on follow up activities to correct this issue.

b) The lack of empirically validated knowledge on the applicability of Jatropha led to very low supply of seeds in the project in Nepal (no. 23) and to the failure of the plantation in India (no. 19). On the other hand, the availability of adequate knowledge and skills seems to be crucial for responding to difficulties that emerge in the practical implementation. Adaption of the applied technology, major repairs or selection of new components were reported in 47% of the projects that are mostly or fully operational.

Interactions with political level

Between local projects and the policy level strong mutual influences exist. The evaluation results emphasize the importance of the following two forms of interaction: (1) the direct 'negative' effect national infrastructure developments can have on local projects and (2) the 'positive' effects small energy projects can have on national energy regulations.

(1) National programs for grid extension had severe impacts on four projects evaluated (17%). They resulted for the most part in the abandonment of the affected projects, as households with new connections to the national grid dropped the commitment to the decentralized energy systems. This is especially true for technologies that are not cost competitive with the electricity prices and the service quality (24-hour power supply) of the grid.

(2) Successful projects, if sufficiently communicated to the political level, can influence renewable energy regulations. To influence national regulations, the introduced technologies have to be cost-effective in relation to alternative energy regimes (e.g. kerosene, diesel generator, grid extension to remote areas) and/or their potential in the country must be proven. Although direct causal relationships are hard to detect, it can be stated, that two projects (no. 9 in Mauritius and no. 2 in Namibia), in some way or another, stimulated the decision to introduce support schemes –like feed-in-tariff or cheap loans– to foster the dissemination of the respective technologies.

Socio-economic development

The evaluation results indicate on the one hand the services and jobs already planned and established during the implementation phase still exist. On the other hand project concepts hardly triggered the generation of additional economic activities. In addition, the survey revealed that all on-going projects have socio-economic benefits for the local population. Benefits most mentioned were expenditure reductions of up to 40% on firewood (improved cook stove projects), higher income through increased agricultural productivity (irrigation projects), as well as better living conditions due to access to basic electricity services, clean water and lighting (electrification and lighting projects). Further, the results also show clearly that no productive use should be expected from small-scale (up to several hundred Watts per household) electrification projects. The principal use of these electricity technologies is for communication (mobile phone, radio, TV) and lighting.

Replicability and Dissemination

Small scale energy projects can to be understood as a first step in a process of the wider dissemination of renewable energy technologies. If they are successful and sustainable it is important that steps are taken to achieve increasing coverage. At the time the reviewed projects started their replication potential was considered to be high and most of the projects had developed concepts for local or regional dissemination. The findings of the evaluation show that the dissemination strategies have been generally suitable as in 78% of the cases the awareness and interest regarding renewable energy technologies could be increased. Furthermore it was possible to replicate either the technology or the management model in 40% of the cases. The evaluation data reveals that there are two factors that strongly influence the potential for replication. On the one hand replication depended on continuing involvement of the implementing organization. In all replicated cases the organizations continued to actively support the technology and were connected to or present in the region. On the other hand the high up-front investment of renewable energy systems was often mentioned as central barrier for replication. Meaning that donor funding or other forms of subsidies were needed for the replication in all but one case. This shows that although a system is successful and accepted by the users replication hardly happens on its own but that several conditions need to be in place before replication is possible. These conditions include long-term commitment within the implementing organization, strategies with an explicit focus on replication as well as availability of medium- to long-term funding.

Besides lacking finance options, other barriers mentioned are the low level of motivation of potential producers/users, problematic logistics in remote areas as well as the lack of local capacity to manufacture and install the technology properly.

Discussion

Comparing the findings of the evaluation of the small-scale renewable energy projects with other multi-project evaluations, several parallels but also certain dissimilarities can be discovered. Regarding the sustainability of the projects the results are comparable with an evaluation of 139 projects supported by the KfW bank (2011), where 79% of the projects were categorized as successful. While in a study from the JICA (2011) the success rate was slightly higher with 87%. The main reasons for failure identified by the later study were financial issues like insufficient budget for operation and maintenance and decline in demand (JICA, 2011). This could not be confirmed, by the evaluation of the projects supported by WISIONS, although funding has been identified as critical factor for the replication potential.

Our findings indicate that the most common reason for failure is the application of unsuitable technologies, driven by two main factors: The reliability of the technical components and the availability of adequate knowhow and skills. This observation is in line with the findings from an evaluation of rural electrification projects by the World Bank (2008), which acknowledged problems resulting from lack of technical capacity in rural areas and the logistical difficulties of servicing equipment as one of the major issues.

In terms of socio-economic development the World Bank evaluation found that electrification may bring the chance for small business activities but the overall impact of renewable energy technologies on productive activities was limited (World Bank, 2008). These results are confirmed by the present evaluation. More over the results suggest that not only electrification measures but interventions 'only' addressing energy issues can hardly trigger additional economic activities.

With focus on the replicability the presented results are supported by a study of Linn (2012) on the scaling up of development projects in Tadzhikistan. Long-term perspective and a proactive approach from the implementing organization have as well been identified as essential. Linn describes this as "stick-with-it mentality" (Linn, 2012).

The findings of the present evaluation indicate that in small-scale energy projects it is not only the reliability of the technology that defines the sustainability of a project. The availability of adequate knowledge and skills can strongly influence the technical viability of a concept. These 'soft' components are already crucial in the conceptualization and pre-development of the project (e.g. evaluating the suitability of a technology for the given ecological context), during implementation (e.g. ensuring quality of components and installation) and for the operation after project closing (e.g. ensuring adequate use and maintenance).

Moreover, the results show the influence that the political context can bear. It can improve the performance of a project (e.g. ensuring revenues in form of subsidized tariffs) and also close opportunities for some project concepts (e.g. through grid extension). First findings of other influencing factors -like involvement of local actors and the management model- indicate that in order to ensure long-term provision of clean energy service, the technical solutions should be appropriately embedded in the socio-cultural, political and ecological context.

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