POTENTIAL OF HYBRID PV SYSTEMS FOR RURAL SOUTH AFRICA – ADDRESSING INCOME ACTIVITIES AND WATER SUPPLY-

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Abstract

The national grid and piping extension for providing electricity and water services will certainly in the coming decades not reach rural areas of many African countries. In order to use and manage local energy and water sources, off-grid power supply systems are able to provide, depending on the local conditions, cost-effective solutions. The establishment of hybrid Photovoltaic PV systems based on local renewable sources (wind, water, biomass), on diesel engines and on storage systems may be designed not only to provide electricity for basic uses, but also to power incoming activities. Off-grid power supply systems contributes also for solutions in water scarcity, by powering water pumping for irrigation in agriculture activities, for village water supply and for conservation of natural livelihoods. Furthermore drinking water supply in rural areas, by means of water treatment systems based on membrane filtration; improves health conditions and avoids diseases for the human population.

Experiences and well developed local networks in South Africa shows to be a "turn key" player to develop sustainable solutions and to scale-up hybrid PV systems for supplying energy and water to rural areas and to other African countries. The challenge to scale-up new renewable energy technologies in the next years is that they have to be cost-effective, affordable and feasible for rural populations. The experiences described in this paper present several technology choices for combining energy and water supply based on local resources as alternative solution that promote social and economic development in rural communities.

Key words: hybrid PV systems, off-grid energy and water supply

1. BACKGROUND

According to available statistics from the National Electricity Regulator and the Department of Minerals and Energy, the level of electrification in South Africa has risen from 36% in 1994 to 71% at the end of 2004. The number of rural households electrified countrywide has risen from 12% in 1994 to 51% in 2004. Roughly 80% of SA land is used for agriculture and subsistence livelihoods. The potential for off-grid supply systems accounts then for around 50 % of the rural population, nature reserves and agriculture issues.

The South African National Research and Development (R&D) Strategy (DST, 2002) states that for sustainable development to take place, rural and urban communities should have access to innovations for effective solutions compared to those utilised previously. Access to environmentally friendly technologies should be promoted by supportive incentives measures, that enable transfer and adaptation into developing countries. The challenge for the New Partnership for Africa's Development NEPAD (2005) and the South African Energy R&D strategy (DST and DME, 2006) is to fully develop the available energy resources and to promote innovative, competitive, equitable and sustainable energy systems for various economic and social sectors across South Africa and the continent. (Brent, 2008).

In spite of South Africa's high potential of renewable energies, their use is very low. In off-grid electrification major experiences have been initiated in an effort to widen electricity access in remote areas. To date this has been limited to the provision of Solar Home Systems (SHS) that supply electricity for single households. The SHS technology has also been used for providing schools and clinics in remote areas with off-grid electricity. Whereas the programme was seen to have reasonable success in the electrification of clinics, there have been problems as far as the electrification of schools is concerned. A survey established that of the 1,400 systems installed in 12 schools in 1996 and 1998 only 6 % were found partially operational in 2000 (Malzbender, 2005).

South Africa faces water stress further exacerbated by climate change impacts and therefore the need to improve water use efficiency. Adapting technologies with a lower carbon footprint will contribute towards climate change mitigation and adaptation (Turpie, 2005). Agricultural water use can be supported by investing in existing technologies with an integrating concept for water-use efficiency at local communities. Technology choices rank from irrigation technologies such as drip, mulching, water harvesting, etc. to water supply with water treatment technologies such as desalinisation technologies.

Hybrid PV systems for household electricity supply, for powering income activities and water management systems provide long-term solutions for sustainable development in developing countries. Several strategic options require immediate support and further research such as new emerging technologies, local resources identification, social behaviour change, rural capacity building and the transition to a low-carbon economy. Best practices and countries' experiences that have been successful on implementing hybrid PV technology solutions underlay recommendations in order to improve local institutional, technological, economic and social frameworks specially for rural communities primarily based on agriculture activities.

2. INCOME ACTIVITIES AND ENERGY SUPPLY TECHNOLOGY CHOICES

Where villages and communities are not highly dispersed, an option for rural energy access is the establishment of „energy supply centres", either independent or e.g. suited at a schools, health clinics or other commercial facilities like garages, shops or farms. A hybrid PV system design will be able to supply electricity not only for providing electricity for single house holds, but also for promoting income activities especially in the agriculture sector and of for example processing products from the main agriculture activities.

PV Hybrid System Technology Choices

- → Grid integrated PV hybrid Systems based on available resources: solar, wind, water and biomass complemented as well with conventional technologies such as Diesel engines and storage systems enable village power and water supply, for income and agriculture activities as well as for tourism and preservation of national reserve parks,
- → Off-grid PV hybrid Systems for remote areas are foreseen, where they are cost-effective solutions against grid extension.

PV mini-grid hybrid systems: The case of South Africa

Background

A hybrid mini-grid energy system is defined as an grid independent system, but builds up with several local power generators and loads a inter-tied grid community. Energisation service employs a combination of conventional and/or renewable energy technologies. Such energy systems allows for the provision of a comprehensive electricity service, where 220V AC 50Hz can be supplied as per grid. This then allows for standard 220V appliances to be used.

A direct output of a three year investigative project to understand the complexity of rural electrification (Szewczuk et al, 2000) was the identification of projects to pilot hybrid mini-grid projects in South Africa. The then Minister of Minerals and Energy extended the mandate of the then National Electricity Regulator to facilitate the implementation of pilot hybrid mini-grid energy systems with a view to use these pilots projects to gain experience and understanding of such energy systems so that a national roll-out plan can be developed. CSIR was contracted to co-ordinate the development of an implementation plan with Shell Solar Southern Africa being the implementation company.

Technology System Design: Hluleka Nature Reserve

To reduce risks and increase the probability of success emphasis was placed on proving the technical concept first, hence the decision to implement South Africa's first mini-grid in a nature reserve. Thereafter, with the technical dimension of the mini-grid being proven the social dimension of implementing the pilot mini-grid was addressed.

The main role-players in this mini-grid are:

- The Eastern Cape Provincial Government who are the responsible body for the nature reserve
- The National Electricity Regulator who were mandated by the Minister of Minerals and Energy to facilitate the piloting of hybrid mini-grid energy systems
- Shell Solar South Africa (Pty) Ltd who were the implementing organisation and
- CSIR who co-ordinated the development of an implementation plan

Since an integrated approach was followed in this pilot project a water treatment plant for the nature reserve was also implemented. To ensure as much benefits being accrued to the local community as was possible the following tasks were undertaken:

- Local work committee was established
- Manual labour was employed for periods of two weeks on a rotational basis
- A skills audit was performed and a database established of local skills.
- Local components were used where possible with as much as possible being sourced in the Eastern Cape Province
- The nature reserve personnel were trained to use the new equipment.

The electricity generation system for the nature reserve is provided by two small wind turbines, each being a Proven 2.5 kW machine, and a photovoltaic array consisting of 48 X 100W solar panels. (Figure 1). Included in the electrical generation system is a control system, batteries for electricity storage and a diesel generator as a backup. This system provided the electricity for the electrical appliances for the nature reserve, namely lighting, office equipment etc.

Solar power via photovoltaic panels is used for pumping water out of a nearby river before the water is treated in a filtration plant. Hot water is provided by solar water heaters and liquid petroleum gas (LPG). Due to the erratic solar insulation of the nature reserve LPG is also used to supplement the solar water heaters in providing hot water. LPG is also used for cooking. Figure 2 shows three solar water heaters as well as the LPG bottles outside three of the twelve chalets in the nature reserve.

Fig. 1:: Wind, PV array and solar water heaters and LPG bottles at Hluleka Nature Reserve

Technology System Design: Lucingweni village

To demonstrate the suitability of hybrid mini-grid energy systems in communities several villages and settlements in the Hluleka area were surveyed and the communities consulted. This process, undertaken by Shell Solar South Africa, resulted in the identification Lucingweni village, 10kms from the Hluleka Nature Reserve, as a site for a hybrid mini-grid system. Lucingweni village has 110 households.

Criteria adopted in the identification process for application of the hybrid mini-grid include:

- Identification of the consumers energy demand (adequate density) to optimize system employment.
- Community Profile, Suitability and Acceptance.
- Most Efficient use of natural resources available.
- Project Sustainability:
- Community participation, transfer of skills, employment creation.
- Economic Stimulation, development of small commercial off-shoot industries.
- Risk Evaluation.
- Environmental Impact and Ascetics.
- Technical, Commercial and Financial Viability.

Figure 2 below shows a picture of the resultant mini-grid at Lucingweni village.

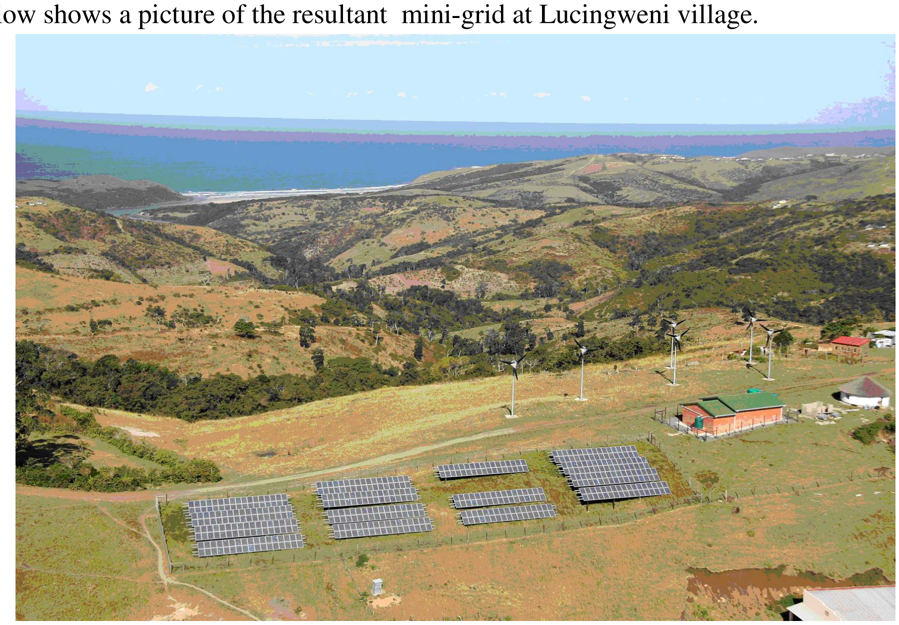

Fig. 2: Lucingweni 86 kW hybrid mini-grid

Power Generation is achieved through the use of a combination of solar photovoltaic panels and wind generators and their associated control, accumulation and distribution equipment providing a nominal electricity generation capacity of 86kW. In brief this consists of the erection of 6 X 6 kW mast mounted wind generators (6m tall) and an array of 560 X 100W solar photovoltaic panels mounted on steel structures and a building to house the control system and a bank of batteries for storage.

3. WATER SUPPLY AND ENRGY SUPPLY SYSTEM CHOICES

Off-grid power supply systems are able to provide water at local level with large-scale impact potential. In order to supply water, it is needed to invest in innovated technologies and system solutions that improve the use of local renewable sources, by using local components.

Hybrid PV systems for water supply choices

- → PV Water Pump Systems such as driving pumps, irrigation systems, value adding facilities to provide fresh water for agriculture and village purposes, to secure and improve agriculture activities,
- → PV Water Purification Systems, based on membrane filtration, to provide drinking water for local inhabitants, to prevent diseases and to protect the environment,
- → PV Water Supply Desalination System Technologies to provide water at defined proper sites, capacities, etc. Autonomous water treatment technologies such as reverse osmosis desalinisation.

PV water pump system PVPs for irrigation

Small PV water supply systems offer numerous advantages over water supply systems utilising conventional power, they may be the only practical water supply solution in many regions where the logistics make it too expensive or even impossible to supply diesel generators with the required fuel. Small PV Water supply systems are ideal for meeting water requirements for villages between 500 and 2000 inhabitants and small-scale irrigation purposes (up to 3 hectares). Small PV Water supply systems run mainly automatically, require little maintenance and few repairs. In areas where PVPs have entered into competition with diesel-driven pumps, their comparatively high initial cost is offset by the achieved savings on fuel and reduced maintenance expenditures.

PV water pump S\systems are used principally for three applications:

- Village water supply
- Livestock watering
- Irrigation for agriculture activities

PV Water Pump Systems can be used to obtain potable water for people, drinking water for domestic animals, and irrigation for field crops. In planning such a system, one must keep in mind the fact that the pumping system is only part of a higher-order system with diverse control mechanisms Hahn (2000).

PV water pump irrigation system: The case of Katuba community, Republic of Zambia

Background

In the project area, the rainfall water available season starts from November to March. The farmers are unable to get agriculture production during the winter and summer periods from April to October. However, the community is assisted with a perennial water reservoir. Currently, the farmers are using water from this reservoir through use of buckets and with one small gasoline engine which assists in the irrigation.

The main barriers to supply water in dryseasons were the high cost of gasoline, which is not profitable for the local farmers for providing water. Besides, the pumping capacity of this gasoline pump engine is limited. According to the study, the water needs are to supply at least 50 m^3/day of water that is required for the irrigation of the local crops on one hand, and for washing and for cattle on the other. A PV irrigation system will actively be used in the winter and summer seasons from April to November. Additionally, water ise required for cattle throughout the all year and during the drought days in the rainy season. Continuous water availability within a year will increase the crops and cattle. Additionally, the use of clean water avoids diseases which will in turn affect the quality of the cattle and livestock.

Technology and System Design

The PV water pump system was designed for agriculture purposes to irrigate one hectare of local crops, and provide water for cattle and washing animals in the Katuba region.

The PV system irrigates 0.5 hectare of tomatoes and 0.5 hectare of potatoes during the winter and summer period i.e. April to November and provides fresh water for cleaning and washing livestock, and additional water during drought days in the rainy season. The supply water requirements are 50 m^3/day. Based on this water requirement, solar radiation of 4.76kWh/ m^2/day (1737 kWh/m^2/year), and the pressure head of 10 metres from the reservoir to the storage tank, a PV generator of 1.35 kW_p was selected. According to this dimensioning, a suitable water pump was selected which was able to pump 1.4 litres per second.

Fig. 3: System Irrigation for the Katuba region (pilot project).

The selection of the capacity of the pump is based on the use of furrow irrigation which has a relatively low utilisation efficiency of between 50- 60%, as compared to drip irrigation with an efficiency of between 75-95%. As farmers gain more experience, drip irrigation will gradually be introduced. Introduction of drip irrigation will lead to a reduction of investment cost through reduction of the size of the water pump, and corresponding PV generator. In addition to providing power supply to the PV generator and pump, an energy management system will be instituted to ensure that the PV system works during day time to pump water into the storage tanks required for irrigation, and at the same time store energy in the batteries for use for lighting of the farm houses at night.[Why not introduce efficiency measures first?]

PV Water Purification System for Drinking Water

Even at places where freshwater is available it is very often not suitable for human consumption. Germinative pollution (bacteria, parasites, ...) are one of the major reasons in rural areas for gastric and intestinal diseases in the adult population and the main reason for infant mortality. The solar powered Water Pumping and Purification System WATERpps easily provides water for drinking and domestic use from various sources even in remote regions. So it can significantly improve living conditions for large numbers of people.

PV water purification systems: The case in Lao People's Democratic Republic

Background

Currently many of rural areas have no access to reliable water, often because piped systems are too expensive to install and maintain, while wells and boreholes are either not serviced and break down or are hand-dug so are also liable to collapse depending on the season. Furthermore these systems do not guarantee the hygiene of the storage unit for the water, which is an important source of contamination. An alternative system choice is necessary. Water purification systems for rural communities should provide affordable drinking water accessible to the majority of the rural inhabitants, resulting in a impact improvement in health and overall productivity.

PV water pump and purification systems has been installed and tested in three villages in Vientiane province in the Lao P.D.R.: Ban Koy, Ban Naphor and Ban Xo. The systems has been tested with a monitoring system in the three different villages. Different raw water sources were used in the three villages. The systems were intensively monitored over a 140 day period between March and July 2007. The monitoring included measurements of the system performance, drinking water output and total amount of purified water, maintenance effort, energy balance and water quality. Furthermore, people in the remote villages are able to run the system autonomously. The systems were installed by trained technicians and the monitoring was mainly done by a trained local operator (Appel 2008).

Technology and system design

The WATERpps is a solar powered device which is used to set up a water supply in areas which are not connected to the electricity grid. It is constructed as one compact unit, including the filtration system, the control electronics and the power supply. It is very simple to use and its design makes it easy to transport.

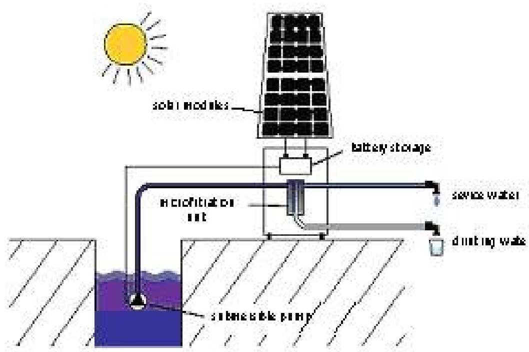

Fig. 4: Operating principle of the described water pumping and purification system WATERpps.

The device has a simple but effective mode of operation: a submersible pump extracts water from any raw water source. The water can either directly be used as service water, for example for irrigation purposes, or it can be pumped through a micro filtration unit in order to obtain clean drinking water. Two solar panels (55 W_p) supplies the device with energy. The energy is stored in two 42 Ah batteries in order to allow the system to operate without permanent solar radiation.

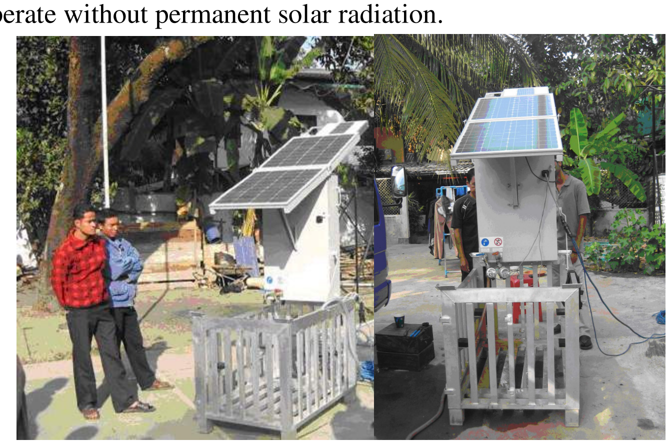

Fig. 5: Field test of a off-grid WaterPPS in Laos, Since January 07.

The simple mode of operation allowed the people in the villages to run the systems without any problems. All systems worked reliably, successfully providing purified water free from bacteria. However, the well water was found to be too acidic to meet Lao standards a pH value between 6.5 and 8.5, hence only the purified river water received the drinking water certificate. The disinfection of water is carried out physically by microfiltration and without using chemicals. This enables an energy autonomous operation close to the water source but far away from the public electricity grid.

Lessons learned

Since all water sources were turbid, the filter of the units clogged quickly. This strongly reduces the output, although the quality of the drinking water is unaltered. Over several periods of time no water was pumped due to a clogged filter. In these particular conditions, cleaning the filter is necessary approximately every 1000 litres. Prior to the study, it was assumed that filters would not get clogged that fast, which means cleaning intervals were set too large. Since the quality of the water greatly changes with variations in rainfall, in addition to other factors, the time taken for a filter to clog depends on ambient weather conditions. It can hence be assumed that maintenance efforts can be significantly reduced by installing a pre filter (e.g. a simple sand filter or a steel filter with a back flush mode) in front of the water inlet of the system. The energy supply was mostly sufficient. Temporary shortages only took place when the system was intensively used over a longer period of time.

All the systems worked under real conditions, including high temperatures and high humidity, without any problems. All systems provided germ free water during the whole period of monitoring. Maintenance effort tends to be high if the water source is significantly turbid. This is because the filters clogged very quickly. The energy supply has been mostly sufficient. Temporary shortages only take place when the system is intensively used over a longer period of time. The advantages of the WATER PPPs are the standardized measures for transportation, the fast implementation through folding mechanism, economical operation without fossil fuel, and technically simple maintenance.

PV water supply desalination system technology choices

Production of fresh water using desalination technologies driven by renewable energies is thought to be a viable solution for water scarcity at remote areas that lack of potable water and electricity. Desalination units driven by renewable technologies such as those driven by solar and wind energy, guarantee friendly to the environment, cost effective and energy efficient production of desalinated water in regions with severe water problems, which nevertheless are fortunate to have renewable energy resources.

There are several techniques for desalinate saltwater (Figure 6), mostly the use of membrane techniques by the principle of reverse osmosis and distillation techniques are used. While membrane techniques are using high pressure to get fresh water through the membrane, distillation needs high temperatures. Both principles need much energy. While reverse osmosis needs electric energy, distillation systems can use both kinds of energy electrical (generating thermal) and thermal (e.g. from thermal solar panels). solution. The most common option adopted in Autonomous Desalination Units Based on Renewable Energy Systems ADU-RES systems accounts for 42% of installed applications based on Small Photovoltaic Reverse Osmosis Systems PV-RO (ADU-RES WP2, 2005).

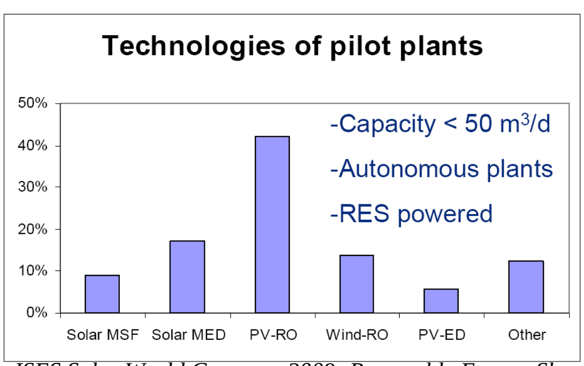

Fig. 6: The most common thermal processes are Multi-Stage Flash Distillation (Solar MSF), Multi-Effect Distillation (Solar MED). Membrane processes make use of semi-permeable membranes to selectively separate water from the saline solution. Reverse Osmosis power with Photovoltaic generator (PV RO), power with wind turbines (Wind-RO) and Electro dialysis power with PV generator (PV ED).

PV water supply desalination dystem: The case of INETY system in Portugal

Background

The Renewable Energies Department of INETI in Portugal has developed a small pilot PV-RO unit for brackish water desalination in order to examine its operation and performance. The system developed around the year 2000 within the project named "Improved Processes for the Production of Water for Human Consumption in Rural Communities" in the framework of the CYTED Ibero-American programme.

Technical system design

The feed water is brackish water having a conductivity ranged from 2000 to 5000μS/cm (at 20oC). The feed water passed through a pre-filter (20μm), and then through a carbon filter to remove any amount of chloride. (see Fig 13). The RO unit has a daily production of 100-500 lt, and functioning with low pressure at the order of 5 bar. The RO membrane used is spiral wound, MP-TA50-J4. The produced water has a conductivity of less than 500 μS/cm. The RO unit is driven by PV modules of 50 -150 W_p (3 modules of 50 W_p each). No batteries are used. The year of installation and operation was in 2000.

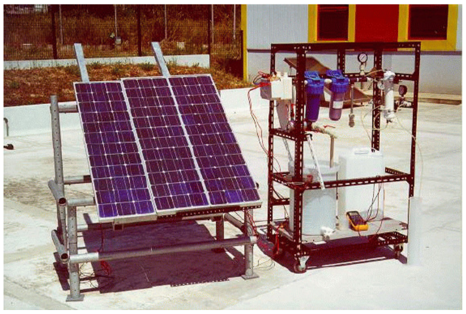

Fig. 7: The PV-RO experimental pilot unit INETI, Portugal, brackish water Desalination

Lessons learned

Small desalination units can be powered from solar energy (PV modules) combined other with other resources like wind offering autonomous operation suitable for rural, isolated communities. ADU-RES are technically feasible and, depending on the local situation, economical attractive. Some important issues for the success of a RES desalination installation are: the selection of the proper RES, Desalination technologies and their combination, the system design and equipment selection and the control system.

The main problem of ADU-RES is the fluctuation in power supply, both in course of the day as well as the year. Most of the renewable power driven RO units have no possibility of a partial load operation. This has direct implications for the quality and the availability of fresh water as well as the lifetime of the systems and their parts. Dealing with intermittency, either through energy storage or intermittent operation of the desalination plant, is central to the development of the use of renewable energy for desalination.

4. Results and conclusion

Barriers

Main barriers for PV hybrid systems are in general the high up front cost and investment needed in renewable energy technologies. During the operation phases, financial, capacity and maintenance constraints often result in a reduced quality of supply to rural consumers, typically known as "weak" electricity. Maintenance of such installations is problematic due to the demographics, infrastructure limitations, rampant tampering, fraud and corruption, not to mention the shortage of staff with knowledge and experience. Furthermore, electricity and water supply has to be developed directly by rural consumers and therefore it is needed to develop and educate new local operators, which also gives chances for social conflicts to come out. Therefore it is important to "empower" rural population for improving rural areas, by awareness of population, transparent information and specially by inclusive participation.

There is a lack of long-term programmes and projects in order to invest for adapting off-grid supply systems as cost-effective solutions for supplying electricity and water services in rural areas and to sett-up a " Business Models" based on rural areas conditions. Successful schemes and experiences are needed for South Africa to scale-up hybrid systems for none electrified populations and to multiply the capacity and benefits of electricity and water services to the neighboured rural regions.

Experiences

The South African Department of Minerals and Energy recently evaluated the mini-grid for the viability and replicability, (DME, 2008). The report concluded that the Hluleka mini-grid should not be replicated in its current form. For the Lucingweni village system it was concluded that there is insufficient information to make a decision on whether the model is either replicable or viable. However, replication of the Lucingweni model in its current form is not viable.

Consequently, if the Lucingweni energy system is re-designed to be optimised from a viability and replicability point of view then the Lucingweni energy system could form the basis of a distributed generation system that will contribute towards South Africa's electricity generation pool.

Potential benefits

Off-grid energy and water supply address priority areas on: (1) people's livelihoods and food security, (2) adaptive capacity of the rural poor, (3) natural resources and long-term adaptability, (4) capacity building and adaptation of appropriate technologies.

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