HYBRID MINI-GRID SYSTEMS – DISTRIBUTED GENERATION SYSTEMS FOR COMMUNITIES BASED ON RENEWABLE ENERGY RESOURCES

S Szewczuk
CSIR, Built Environment, Pretoria, South Africa

ABSTRACT

To date, the South African electrification programme has been extremely successful from a policy, institutional, planning, financing and technical innovation perspective [1]. The focus on electrification and energisation, though, has moved from chasing numbers of connections mainly in the urban areas, to one of achieving sustainable economic and social benefits mainly in the rural areas.

This paper describes the three-year investigative project in the Eastern Cape Province, the formulation of an integrated energy/economic framework and describes the CSIR's role in the formulation of South Africa's pilot hybrid mini-grids and the lessons learnt.

The hybrid mini-grid systems can also be classified as distributed generation systems.

1. INTRODUCTION

Africa's economic priorities are strongly formed by the need to alleviate poverty. With more than 500 million people currently without access to electricity and with more than 600 million people dependent on traditional biomass for survival on the African continent, Africa has a dire need for safe, affordable and clean forms of energy to enable productive economic activities to generate much needed income. However, the provision of energy must be cognisant of Africa's primary needs of also delivering potable drinking water and sanitation.

Hence, the delivery of new energy services must be based on an integrated and holistic approach where Africa's priorities of potable drinking water, sanitation and poverty reduction are included in any paradigm for development.

Besides the benefits of economic development through the provision of energy services, the long-term goal of the South African Government is also the establishment of a sustainable renewable energy industry with an equitable Black Economic Empowerment share and job market that will offer in future years a fully sustainable, non-subsidised alternative to fossil fuel dependence. Local manufacture of related technologies will need to be encouraged to limit the cost of imported equipment and to benefit from economies of scale as well as creating employment opportunities.

For the rural areas of the Eastern Cape province of South Africa, the Eastern Cape Provincial Government had identified that the sectors likely to contribute to new economic activities are agriculture, forestry and eco-tourism. As part of its integrated energy/economic methodology CSIR identified high-value agricultural products as possible new economic activities for the rural communities. This with a view to ensuring that communities have the ability to pay for services, such as the provision of electricity. To increase the demand for energy and electricity, from not only the rural domestic sector but also from the agricultural sector, high value agricultural crops could be processed further for export out of the region.

The challenge of alleviating poverty through establishing new economic activities can be addressed with various decision-support processes and technologies, within the context of this paper, energy related technologies. The implementation of such technologies will need to be supported by good research and development. Alternative, preferably sensible, energy technologies will need to be developed and implemented to ensure that the South African Government's objective of universal access of energy & electricity to all its citizens is to be achieved. Also, many low income households make use of 'traditional' forms of energy such as dung, paraffin, wood and coal. Many negative consequences arise from the use of these forms of energy such as respiratory problems from combusting coal, denuding of the environment from collecting and burning wood and injuries sustained from accidents in burning paraffin.

The then President of South Africa, President Thabo Mbeki, in his State of the Nation Address on 9 February 2001 stated:

"With regards to the energy sector, among other things,........localised energy grids for rural areas will be developed"

Local small-scale grid, also known as hybrid mini-grid, capabilities need to be developed and implemented. Technologies and methodologies will need to be developed and implemented to 'fast- track' the usage of affordable, safe and 'modern' energy systems by low-income households. Amongst others, these include solar, wind and wave technologies, natural gas and fuel cells, to name a few.

Towards the energisation of Africa, CSIR has gained
experience and first-hand know-how in addressing the developmental issues discussed above. This paper describes some recent technical work undertaken by CSIR in its participation in the conceptualisation and implementation of pilot hybrid mini-grid energy systems. This experience will also provide inputs into identifying appropriate R&D activities that will need to take place.

2. ENERGY/ECONOMIC FRAMEWORK

As a national research institute, changes in national priorities in the early 1990s resulted in CSIR aligning itself with and responding to the challenges of addressing new national priorities. One such priority was the socioeconomic upliftment of South Africa, particularly in the rural areas. An internal CSIR debate was undertaken to determine its role in energy to address these new national priorities. A paradigm shift in thinking resulted in CSIR realising the need for a holistic and integrated approach in that energisation and electrification will be sustainable only where there is economic activity to pay for it.

Consequently the author developed the Integrated Energy/Economic Framework as a contribution to achieving sustainable socio-economic development in the rural areas of South Africa, as shown in Figure 1. The framework shows the linkages between energy, the economy and the environment with the focal point being the creation of new enterprises and new economic activities.

Key factors to note in the framework outlined in Figure 1 are:

- the linkage, between Cost Benefit Analysis (CBA) and Life Cycle Analysis (LCA), of economic activities (demand side) to energy (supply side)
- intervention measures to stimulate new activities
- these intervention measures must take into account other conditions such as markets, water, infrastructure, telecommunications etc
- sociological facilitation to ensure community ownership and sustainable enterprise management.
- environmental externalities such as Green Certificates, Clean Development Mechanism (CDM) and
the linkage to bridge the gap between Climate Change and Poverty Alleviation

3. RENEWABLE ENERGY FOR RURAL ELECTRIFICATION

3.1 INTRODUCTION

A three-year investigative project entitled "Renewable energy sources for rural electrification in South Africa" was undertaken [2]. The aim of this project was to obtain firsthand understanding of the complexity of sustainable socio-economic development as well as identify any projects that could be implemented. Due to its impoverished state, particular attention was given to the Eastern Cape province of South Africa in this project.

The primary objective of this project was to identify the commercially viable opportunities for rural electrification in the Eastern Cape Province (ECP) of South Africa using wind, hydro and biomass - powered Remote Area Power Supply (RAPS) systems.

A geographical information system (GIS) was used to generate, analyse and present combinations of supply-side, demand-side and financing data so that the locations and other characteristics of RAPS system development opportunities are shown.

Socio-economic conditions and rural electrification rates are closely related and vary widely throughout the Eastern Cape Province. The Transkei region of the Eastern Cape Province was known from the outset of the project to be the most deprived on both scores and this was confirmed through GIS analysis of various province-wide demographic and electrical infrastructure datasets. On the supply side, resource maps were generated for the whole of the province and further attention then focused on the former Transkei. The demand side analysis increasingly concentrated on this area.

Wind, mini-hydro and biomass were the three renewable resources which were used as the basis for the investigation. In this paper the wind energy resource will be presented and will provide a good overview of the kind of results that were obtained for the mini-hydro and biomass based investigations.

To further its understanding of the role of energy in socio-economic development as well identifying the associated barriers an action plan was developed to accelerate the penetration of renewable energy into South Africa [3]. This was done in the context of poverty reduction and linking renewable based energy systems to new economic activities.

3.2 WIND ENERGY ANALYSIS

The long term wind resource at 60 m and 25 m above ground level (possible hub heights of large and small wind turbines respectively) has been estimated to 1 km² spatial resolution throughout the Eastern Cape using a combination of wind flow modelling techniques. The discussion below concentrates on the 60 m results shown in Figure 2.

Figure 2: Mean wind speeds at 60 m

Of the total area of the Eastern Cape Province (169,899 km²), at a height of 60m, 148,056 km² has been estimated to have an annual mean wind speeds greater than 6 m/s, 11,787 km² greater than 7 m/s, 581 km² greater than 8 m/s and only 32 km² greater than 9 m/s.

A geographical information system (GIS) was used to generate, analyse and present combinations of supply-side, demand-side and financing data so that the locations and other characteristics of RAPS system development opportunities are shown.

An example of a GIS based output will be presented below to indicate how such information technology based systems could potentially be used for planning and decision support purposes.

(Note: due to the unavailability of complete and validated input data it was nevertheless decided to make assumptions so that the analytical process could be developed. Consequently this project highlighted the need for good information, data and statistics. In many instances data and statistics was found to be out of date.)

For the rural areas of the Eastern Cape Province the provincial government had identified, based on available natural resources, the following sectors as providing the basis for new economic activities, namely:

- Eco-tourism
- Agriculture
- Forestry

A number of supply-side/demand-side scenarios were investigated. Supply side options were based on electricity generated from wind, mini-hydro and biomass.
For example, one demand-side option, namely, eco-tourism with one supply-side option, namely, wind generated electricity was investigated. For this combination of eco-tourism and wind based energy systems realistic assumptions were made to estimate the lifetime production costs (unit electricity costs). A 12% discount rate and a zero NPV (Net Present Value) were assumed to generate Figure 3.

Figure 3: Cost of electricity from wind for eco-tourism 10km either side of the transmission grid

To further identify potential RAPS opportunities a certain distance from the electricity transmission grids it is possible to eliminate regions a certain distance either side of the transmission grid. If, for example, 10kms either side of a the transmission grid is eliminated then based on the eco-tourism/wind options discussed above then the GIS results can be pictorially represented as in Figure 3.

Such pictorial representation of information can assist in any planning activities or any decision support process. Having access to good quality information, data and statistics in electronic form such analysis as described above could readily be applied across Africa to facilitate the many decision support processes that will be required in achieving developmental objectives.

4. PILOT HYBRID MINI-GRIDS

4.1 INTRODUCTION

During the course of the above described project an opportunity was identified for a renewable energy based project at the Hluleka Nature Reserve in the Transkei region of the Eastern Cape Province. This energy project formed the basis of 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 then 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 4) Included in the electrical generation system is a control grid. This then allows for standard 220V appliances can to be used.

Hybrid mini-grid energy systems could be an option that can be implemented in the off-grid rural areas of South Africa.

The Minister of Minerals and Energy extended the mandate of the 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.

4.2 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.
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 5 shows three solar water heaters as well as the LPG bottles outside three of the twelve chalets in the nature reserve.

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

- 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.

The mini grid consists of: Power Generation, Reticulation, and Premises Equipment components. Figure 6 shows a picture of the mini-grid at Lucingweni village.

As part of the integrated approach that included the provision of potable water an existing disused water reticulation system was refurbished.

5. NEW ECONOMIC ACTIVITIES

Many farmers in the rural areas of South Africa rely on subsistence farming for a livelihood. As part of its integrated energy/economic methodology CSIR identified high value agricultural products as the basis for new economic activities for the communities adjacent to the Hluleka Nature Reserve and Lucingweni village. To increase the demand for energy and electricity, from not only the domestic sector from the various villages but also from the agricultural sector, high value agricultural crops could be processed further for export out of the region.
The CSIR and the Agricultural Research Council applied its resources into encouraging local entrepreneurial farmers to adopt new farming techniques as well as gaining experience to propagate and grow high value crops that are suited to the area. Crops introduced were citrus, macadamia nuts, mango and various herbs such as fenugreek and parsley. These herbs were planted in between the rows of citrus trees, Figure 7. Harvesting of herbs takes place a few months after planting and can provide income while the trees grow to maturity.

A nursery was also established to propagate the trees and herbs.

Figure 7: Agricultural based new economic activities, planting herbs in between rows of citrus trees

6. DISTRIBUTED GENERATION

Distributed generation refers to an emerging evolution of the electric power generation systems, in which all the generating technologies available in a given centralised or decentralised region are integrated in the power supply system according to the availability of their respective resources – including renewable energy resources. These resources are known as distributed energy resources. [4].

At present, the bulk of the world’s electricity is generated in centralised power stations. This approach, one of ‘economy of size’, generates electricity is large power stations and delivers it to load centres via an extensive network of transmission and distribution lines. An alternative approach, that of distributed generation, which can be described as ‘economy of mass production’, generates electricity by many, smaller power stations located near to the load centres, [5].

Even although the two hybrid mini-grids at the Hluleka Nature Reserve and Lucingweni are stand alone systems, one of the future possibilities is that these mini-grids could be connected to the electricity grid as part of a distributed generation system.

The Department of Minerals and Energy recently evaluated the mini-grid for the viability and replicability, [6]. 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.

7. WATER TREATMENT AND BIOGAS

As discussed previously, the implementation of the hybrid mini-grid energy systems at Hluleka Nature Reserve and at Lucingweni included the provision of potable water via a water reticulation system.

With a water reticulation in place, consideration can be given to a small scale water treatment facility based on the anaerobic digestion of wet organic waste. Wet organic waste can be sourced in the form of human waste, animal slurries and food waste.

Such a small scale water treatment facility could not only provide recycled potable water and also process organic waste to generate biogas that could be used as an additional form of fuel. The biogas generated can form part of a distributed generation systems where not only electricity is generated but biogas can also be generated for cooking and heating purposes.

To reduce the amount of fossil fuels being used and to treat wastewater and organic waste at source the CSIR is investigating the optimisation of methane production from the anaerobic digestion process, [7].

The application of anaerobic digestion for the treatment of waste-water sludge has been applied in many South African municipal waste-water treatment works where digesters had been in operation as early as in the 1930s. Although anaerobic digestion is a well recognized waste treatment technology, the process has unfortunately been neglected in many South African treatment works.

Since anaerobic digestion is a (micro) biological system, the operation of a digester requires dedicated, skilled staff which is involved with the daily monitoring of the operational parameters of the process inside the reactor. When the digester functions well at a temperature of 35°C one kg volatile solids destroyed over a period of approximately 20 days can yield 1 m³ biogas.

Since an anaerobic digestor operates at its optimum point when it has dedicated and trained staff to operate
and maintain it the CSIR is currently undertaking research into the use of monitoring and control systems to assist the operators of digestors.

8. CONCLUSIONS

In evaluating the contribution of sustainable energy systems and distributed generation to poverty alleviation the following conclusions can be drawn:

a) To alleviate poverty and create gainful employment requires that the correct and appropriate questions would have to be asked and answered and the following questions can be asked:

“What intervention measures, what policies, what strategies would need to be put in place to increase productive economic activities in the rural areas?”

“Can modeling techniques and Geographic Information Systems (GIS) be used to assist in energy and economic planning?”

“What are the necessary conditions for the Lucingweni energy system to be viable and replicable?”

In an attempt to develop an understanding of how to answer these questions CSIR developed it’s Integrated Energy/Economic Framework.

b) Via CSIR’s participation in the conceptualization and implementation of South Africa’s pilot hybrid mini-grid energy systems an attempt has been made to obtain practical know-how and experience towards developing appropriate integrated energy systems, such as distributed generation systems, that will contribute towards the energisation of not only South Africa but Africa is general.

c) One of the major barriers to implementation of energy systems in rural areas is the sociological dimension of introducing new technologies to communities who are not aware of the benefits that such technology can provide. This sociological dimension is understood to be an extremely complex issue but is not yet fully investigated.

To address the above issue the following drivers have been identified:

- Energy & economic development are linked and the application of renewable energy in rural areas should be integrated into local economic planning activities.
- Poverty and lack of capacity in rural communities and their governance structures requires that such energy introduction be integrated with community development and training programs.
- An Integrated, support based systems approach is required, with emphasis given to relentless measurement of all processes.
- An approach should be dynamic, systematic, subject to standards, responsive, and able to be duplicated throughout Africa.

d) In integrating analytical tools into development planning, much information is readily available in electronic format, information such as natural resource data, demographics, water supply etc it is quite feasible to integrate analytical tools into any development planning process. This has been demonstrated in the Eastern Cape Province by the use of GIS based systems.

e) However, the use of analytical planning tools for the various decision support processes that are required is dependent on having access to good and validated input information, data and statistics. Furthermore, access to a portfolio of technologies, based on distributed generation technologies, will contribute to the alleviation of poverty in Africa. The implementation of such technologies will need to be supported by good research and development.

f) Since hybrid mini-grid energy systems generates electricity located near to their load centres, these types of energy systems can be included into the overall definition of distributed generation systems.

g) Since the provision of energy must also be cognisant of Africa’s primary needs of also delivering potable drinking water and sanitation, a water treatment and recycling facility should be included into the overall design of a distributed generation system. Such a water treatment and recycling facility can include an anaerobic digestion system. The biogas that can be generated from an anaerobic digestor can be used for cooking and heating and consequently be included as part of a distributed generation system.

8. REFERENCES


**Author:** Stefan Szewczuk holds an MSc degree in Mechanical Engineering from the University of the Witwatersrand and an MBA from the Herriot-Watt University in Scotland. At present he is the Research Group Leader for the Rural Energy & Economic Development group in the Built Environment at the CSIR. Stefan’s primary interests are in wind energy, distributed generation and conversion of organic waste to biogas.