

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

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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

INTEGRATED ENERGY ECONOMIC FRAMEWORK

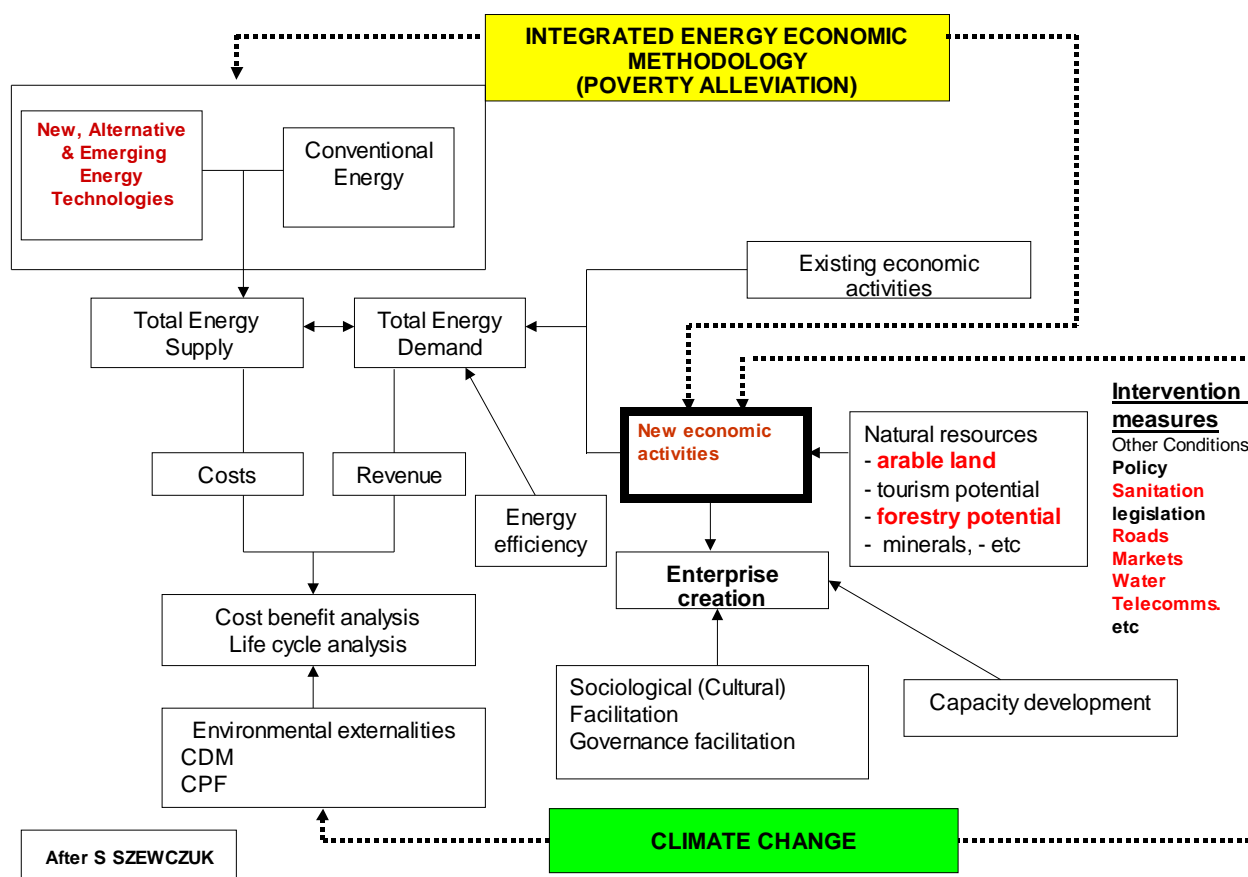


Figure 1: Integrated Energy Economic Framework

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

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.

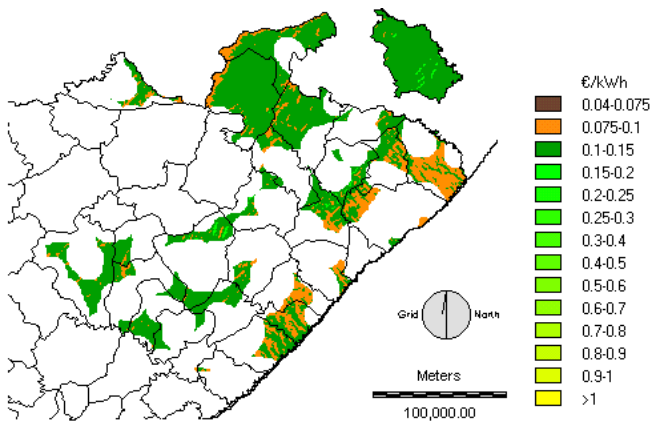


Figure 3: Cost of electricity from wind for eco-tourism 10km either side of the transmission grid

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 pilot hybrid mini-grid project.

A hybrid mini-grid energy system can be defined as an independent, or grid inter-tied community energisation service employing 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 can 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.

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

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.



Figure 4: Wind, PV array at Hluleka



Figure 5: Solar water heaters and LPG bottles

4.3 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 220 households.

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.



Figure 6: 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 6Kw 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.

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 in 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 digester 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 its 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 digester can be used for cooking and heating and consequently be included as part of a distributed generation system.

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