DISTRIBUTED GENERATION SYSTEMS FOR SOUTH AFRICA BASED ON RENEWABLE ENERGY RESOURCES

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Abstract

The hybrid mini-grid systems at the Hluleka Nature Reserve and Lucingweni on the Wild Coast of the Eastern Cape Province of South Africa were implemented to provide the experience necessary to develop a nation wide rollout plan for hybrid mini-grid energy systems. These two mini-grids made use of local solar and wind resources to generate electricity. This paper describes the technical lessons that the CSIR learnt in its experiences with the design and implementation of these hybrid mini-grids.

This paper will also discuss the research into results of a Geographic Information System (GIS) that was developed to generate, analyse and present combinations of supply-side, demand-side and financing data so that the locations and characteristics of renewable energy systems could be identified.

Research into above two concepts provided the foundation on which an integrated energy and economic framework was developed and will be discussed as a basis for providing guidance towards sustainable development.

The lessons learnt from the hybrid mini-grids and additional research on energy generation technologies identified a gap for research into a concept known as Distributed Generation (DG). Recommendations on DG for South Africa based on renewable energy resources to compliment bulk generation of electricity will be presented. A brief description will also be provided of HomerGIS, a rural electrification planning tool that is being developed by the CSIR, Eskom and the DoE.

1. INTRODUCTION

To date, the South African electrification programme has been extremely successful from a policy, institutional, planning, financing and technical innovation perspective (Bekker et al, 2008). 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.

Besides the benefits of sustainable economic and social 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 sustainable 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 and sustainable 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 is 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.

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.

Such energy systems can be categorised as distributed generation system.

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 has also provided inputs into identifying appropriate Research and Development 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 socio-economic 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

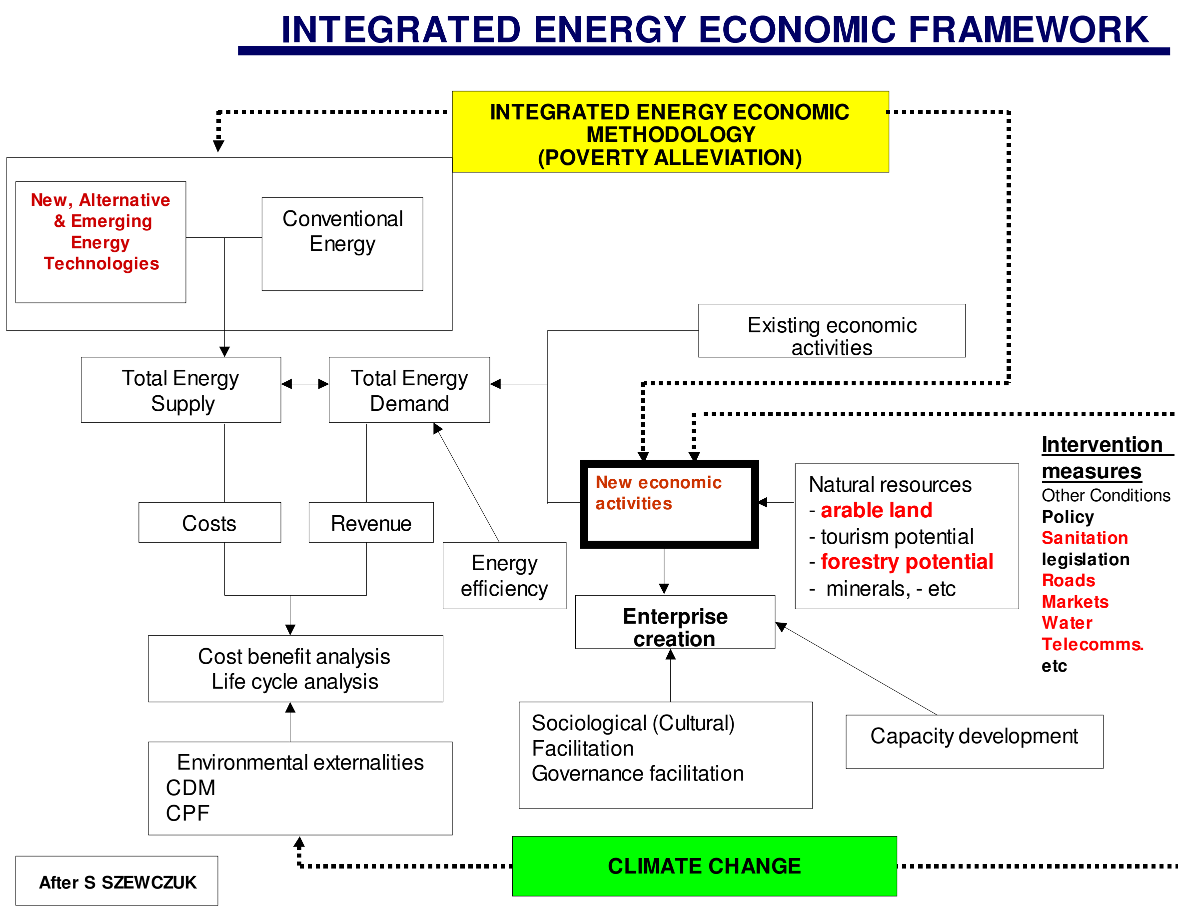

Figure 1: Integrated Energy Economic Framework

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 (Szewczuk et al 2000). 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 (Szewczuk et al 2001). 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 km^2 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.

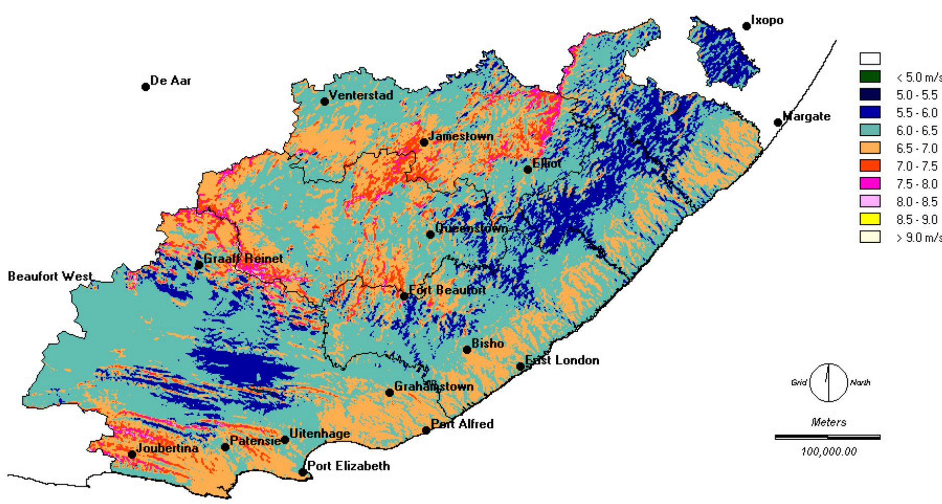

Figure 2: Mean wind speeds at 60m

Of the total area of the Eastern Cape Province (169,899 km2), at a height of 60m, 148,056 km^2 has been estimated to have an annual mean wind speeds greater than 6 m/s, 11,787 km^2 greater than 7 m/s, 581 km^2 greater than 8 m/s and only 32 km^2 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 and 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.

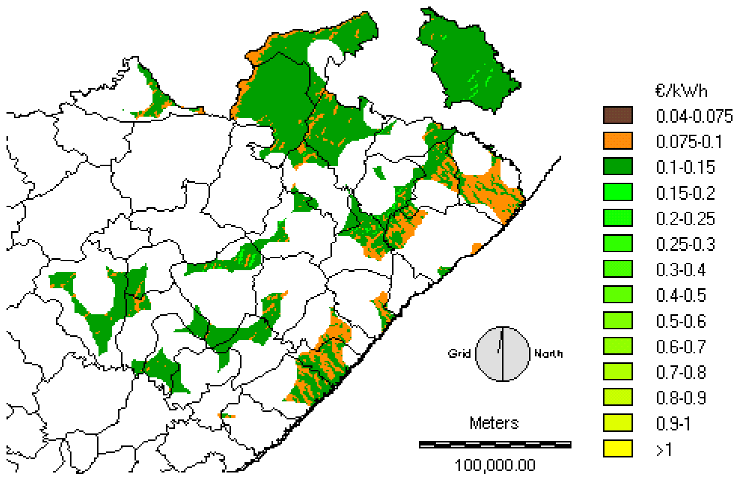

Figure 3: Cost of electricity from wind for eco-tourism 10km either side of the transmission grid

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 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 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.

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 4 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 and solar water heaters and LPG bottles at Hluleka Nature Reserve

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 110 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.

Figure 5 below shows a picture of the resultant 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 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.

5. DISTRIBUTED GENERATION

Distributed generation (DG) 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 (Larson et al, 2005).

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, (Pointon and Langan, 2002).

It appears that there is no consensus on precise definitions of DG as the concept encompasses many technologies and applications (Pepermans et al, 2005). When referred to as small-scale electricity generation it is obviously understood as consisting of small size generation units only, but when referred to as large-scale electricity generation it is usually understood as containing a high proportion of distributed or decentralised generation units regardless of their size. Thus large-scale DERs would in this understanding encompass technologies ranging from e.g. Stirling engines in small, decentralised CHP type generation to large wind farms.

Consequently, 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, (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.

7. DECISION SUPPORT TECHNOLOGIES

7.1 SOUTH AFRICAN RENEWABLE ENERGY RESOURCE DATABASE

The CSIR, Eskom and the DME collated the South African Renewable Energy Resource Database (SARERD). The renewable energy resources that comprise the current SARERD are solar, wind, hydro and biomass. The energy potential of each resource is modelled within a geographical information system (GIS), at a spatial scale of one square kilometre.

Figure 7 shows the two of these resources namely the solar and wind resources. The mean annual and monthly solar energy received per horizontal square metre (MJ/m^2) has been calculated for South Africa. Solar duration and solar radiation data, collected over a 40 year period at 130 sites by the South African Weather Bureau, were used to create and verify the various components of the model.

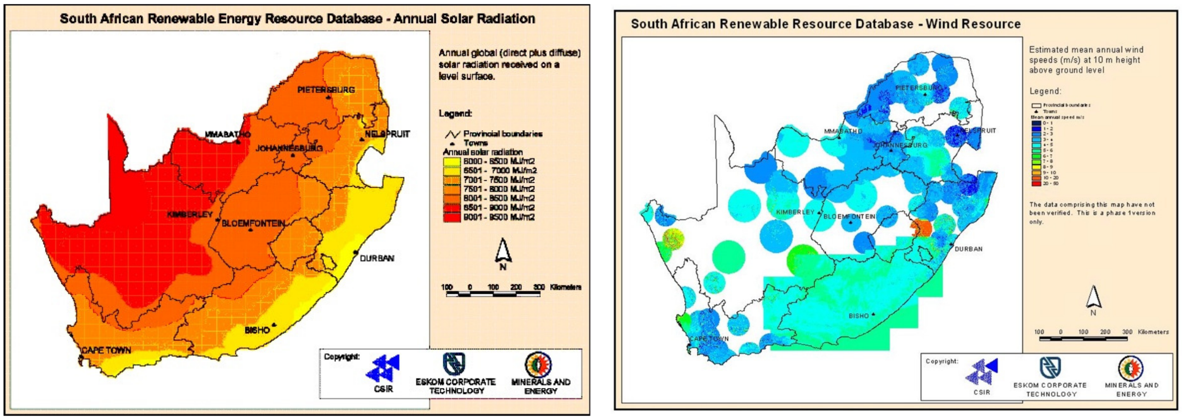

Figure 7: Current solar and wind resource database for South Africa

7.2 HOMERGIS ELECTRIFICATION PLANNING TOOL

The CSIR, Eskom and the DME undertook a project to link the SARERED to a renewable energy optimisation model called HOMER (Hybrid Optimization Model for Electric Renewables). The HOMER model is the development of the National Renewable Energy Laboratory (NREL) of the USA. This model allows users to compare various options for off-grid electrification using combinations of available renewable energies.

The HomerGIS tool uses the SARERD database, component costs, village data to calculate load values, and other inputs which are then sent to Homer for manipulation.

HomerGIS has been demonstrated as a tool that can be used to identify renewable energy based projects in the non-electrified areas of South Africa. However final development of the tool has been put on hold until the wind resource atlas for South Africa is updated.

8. CONCLUSIONS

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

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?"
- "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.
- 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.
- 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.

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.

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.

HomerGIS has been developed as an electrification planning tool for the rural areas of South Africa and essentially identifies renewable energy based distributed generation systems. However final development of HomerGIS has been out on hold until the wind resource map for South Africa has been updated

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