

RENEWABLE ENERGY SYSTEMS FOR DISTRIBUTED GENERATION IN SOUTH AFRICA

Stefan Szewczuk,

CSIR Built Environment, P O Box 395, Pretoria,0001, South Africa

sszewczuk@csir.co.za, +27 82 453 1383

Abstract

The South African Government is committed to universal access to electricity across South Africa. The South African Cabinet endorsed hybrid mini-grid systems as a potential means for non-grid and rural electrification. This Cabinet decision implies that the hybrid mini-grid demonstration projects are meant to provide the experience and information necessary to inform a nationwide implementation of hybrid mini-grid systems.

In support of hybrid mini-grid systems this paper describes the research undertaken by the CSIR and its international partners, Garrad Hassan of the UK and the Netherlands Energy Research Foundation into the development of an analytical tool that could be used to assist in identifying viable renewable energy opportunities in areas with no prospect of grid electrification in the Eastern Cape Province using wind, hydro and biomass-powered remote area power supply systems. The analytical tool utilises Geographical Information Systems (GIS) and provides the basis to investigate various scenarios.

As a consequence of this multi-national project a site for the pilot hybrid mini-grid demonstrator project was identified at the Hluleka Nature Reserve on the Wild Coast of the Eastern Cape Province. This was followed by the second hybrid mini-grid at Lucingweni village. This paper further describes the CSIR's role that lead to the physical implementation of South Africa's hybrid mini-grid demonstrator systems. This paper also discusses the technical and non-technical lessons that were learnt in implementing hybrid mini-grid projects which can also be classified as distributed generation systems.

Keywords

Renewable energy systems, distributed generation rural energisation.

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1. Introduction

The major role that the access to energy services plays in economic development is generally recognised. However, the linkages between the provision of energy and poverty alleviation through economic development are not fully understood and it can be argued that this lack of understanding contributes to the relatively slow pace of energisation of the African continent.

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 also be cognisant of Africa's primary needs of also delivering potable drinking water and sanitation.

Hence, the delivery of new energy services must be one 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.

It is the South African Government's objective to achieve universal access to energy and electricity for all its citizens. With approximately 80% of the urban areas and approximately 45% of the rural areas being electrified there are approximately 3.7 million households still unelectrified, most of these being in the rural areas. Consequently there is a shift in emphasis towards energising the rural areas of South Africa.

To date, the South African electrification programme has been extremely successful from a policy, institutional, planning, financing and technical innovation perspective as described by 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.

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 that are 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. 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 must be taken up and to assist in this challenge use can be made of 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.

Manders,(undated), discusses a strategic perspective on energy related technologies for Africa's sustainable development, particularly within the context of the New Partnership for Africa's Development (NEPAD) and the priorities identified during the August 2002 World Summit on Sustainable Development (WSSD) held in Johannesburg, South Africa. Given the current lack of coordination of energy research and development (R&D) activities and institutions in Africa, Manders advocates an initial focus on strategy and institutional arrangements rather than listing R&D ideas. This will ensure that the limited R&D resources will focus on activities that achieve the greatest leverage in attaining development goals. Furthermore, a focus on R&D projects, without African based direction and collaboration will likely result in such priorities being addressed by international R&D organisations, without the wherewithal of the transfer and development of the necessary skills and capacity into Africa.

To identify, via a rigorous process, priority areas for energy R&D CSIR and Shell International developed a set of scenarios on how the energy economy may develop in

Africa, CSIR (2003). As part of the scenarios development process three fundamental questions were aired, namely:

- can Africa develop and implement a coherent energy strategy that responds to the need of society;
- what role will NEPAD and the African Union play in the formation of such a strategy; and
- fundamentally, what role can CSIR and/or a co-ordinated national programme of energy R&D play in South Africa, regionally and the continent?

In addition to the drivers identified by Shell previously, two key drivers that were identified as catalysts for change are:

- poverty reduction; and
- making the appropriate technology choices

In the context of this paper one energy R&D priority area that was identified was that of energy for sustainable development.

To reiterate, energy is an essential consideration in development and the choices taken by Africa in the near future with regards to its energy economy will have far-reaching consequences on development, the sustainable use of ecosystems and non-renewable resources on a continental scale.

At a strategic level, Venter and Manders, (2004), discuss the effective supply of energy and its use in a developmental context. Venter and Manders depict the complex nature of the energy economy and its linkages to the various sectors of the economy and the various cross cutting issues as shown in Figure 1. Note must be taken of the cross cutting issues depicted in this figure. In an African context it can be argued that one of the key cross cutting issues relates to that of having access to good and validated information, data and statistics.

Africa is a huge continent with vast areas facing deprivation and to facilitate the many decision support processes that are and will be required in achieving developmental objectives it is vital that attention be paid to generate and give to researchers access to good information, data and statistics.

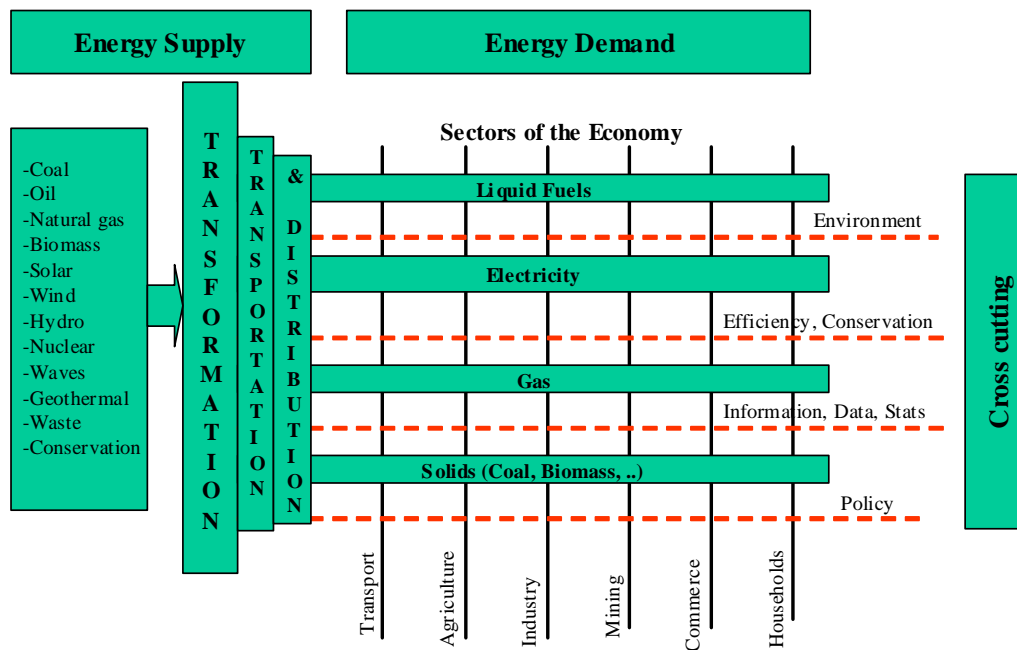


Figure 1: Holistic nature of the energy economy

Furthermore, from Figure 1, note must be taken of the mainly rural household sector of the economy, as represented by the more than 500 million people currently without electricity and the more than 600 million dependent on traditional biomass for survival. This is the sector that must benefit from the various issues discussed above, issues such as poverty alleviation, if the energy economy is to contribute towards achieving developmental objectives.

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, also known as distributed generation systems, as a potential vehicle to contribute to the energisation of Africa. This experience will also provide good input into identifying appropriate R&D activities that will need to be done.

2. The South African Household Energy Context

With 80% of the urban areas and 45% rural areas electrified the emphasis of the South African Electrification Programme is now shifting from the urban to the rural areas of South Africa. Where feasible grid electricity will be extended as far as is possible into the rural areas. However, large numbers of households and communities will not be connected to the national electricity grid for the foreseeable future.

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 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 obtained from accidents in burning paraffin.

The then President of South Africa, President Nelson Mandela, in his State of the Nation Address in 1996 stated:

"We can neither heal nor build, if the rich in our society see the poor as hordes or irritants: or if the poor sit back, expect charity. All of us must take responsibility for the upliftment of conditions and prepare to give our best to the benefit of all".

The current 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, fuel cells etc.

3. Integrated Energy/Economic Framework

Changes in national priorities in the early 1990's resulted in CSIR aligning itself and responding to the challenges of addressing the new national priorities. One such priority was the socio-economic upliftment of South Africa, particularly in the rural areas of South Africa. 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.

The challenge of establishing new economic activities must be taken up and to assist in this challenge use can be made of various decision support processes. Consequently the author developed the Integrated Energy/Economic Framework as a contribution to achieving sustainable socio-economic development.

Figure 2 depicts, in a flow-diagram fashion, 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 methodology outlined in Figure 2 are:

- the linkage, via 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 Mechanisms (CDM) etc

INTEGRATED ENERGY ECONOMIC FRAMEWORK

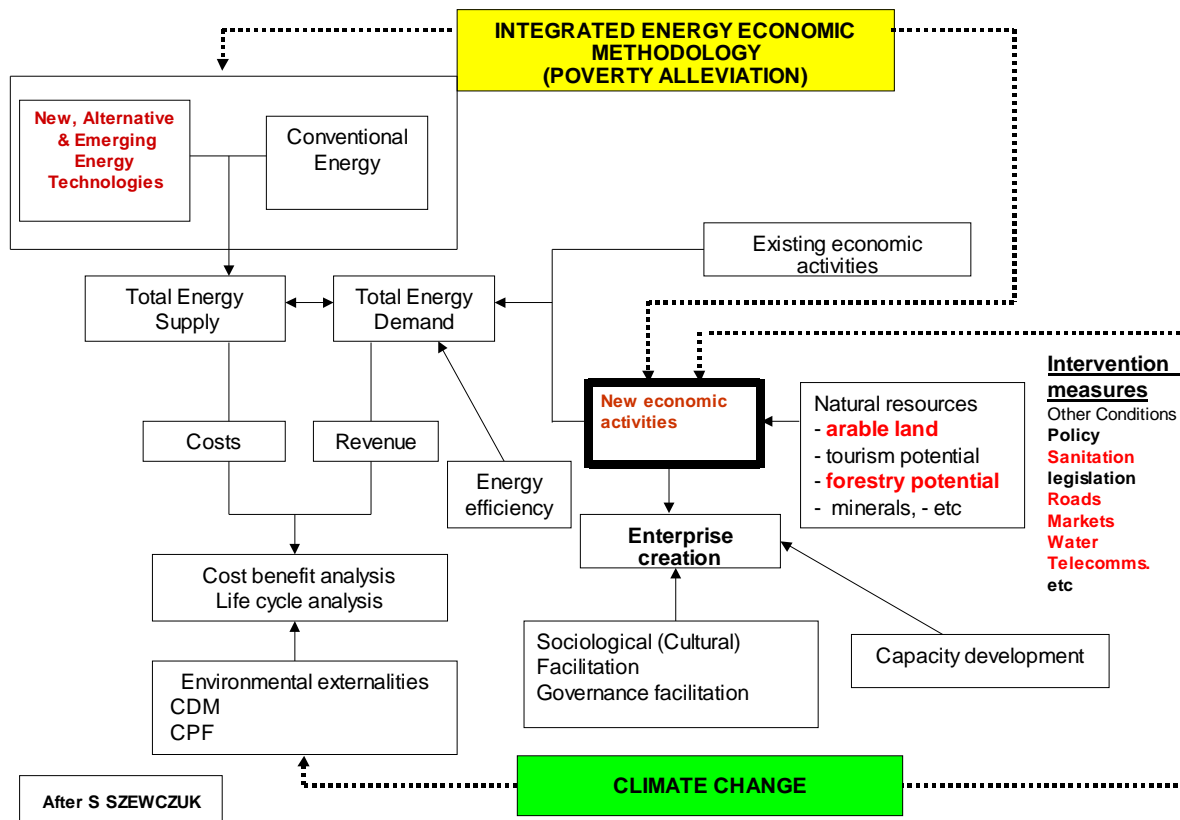


Figure 2: Integrated Energy/Economic Framework

4. Renewable Energy Systems for Rural Electrification in South Africa

4.1 Introduction

Szewczuk et al (2000) undertook a three-year investigative project entitled “*Renewable energy sources for rural electrification in South Africa*”. The aim of this project was to obtain first hand 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.

This chapter will provide a summary of this project and will provide insight into the value of the use of information and communication technologies as a basis for decision support. 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. It was decided to harmonise the approach used for wind, hydro and biomass and local electrical networks by concentrating on four orders of magnitude of rated capacity in the range envisaged for RAPS projects in the Eastern Cape Province, namely: 10 kW, 100 kW, 1 MW and 10 MW to establish benchmark capital and unit costs.

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.

All areas in Eastern Cape Province which are not electrified at present nor expected to be in the foreseeable future and are more than 10 km from the existing grid were found to be within the former Transkei. ESKOM, the South African utility, is planning to electrify fully the Ciskei in the short to medium term.

To further its understanding of the role of energy in socio-economic development as well identifying the associated barriers Szewczuk et al, (2001), developed an action plan to accelerate the penetration of renewable energy into South Africa. This was done in the context of poverty reduction and linking renewable based energy systems to new economic activities.

4.2 Supply Side Analysis

4.2.1 Wind Energy

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 windflow modelling techniques. The discussion below concentrates on the 60 m results shown in Figure 3.

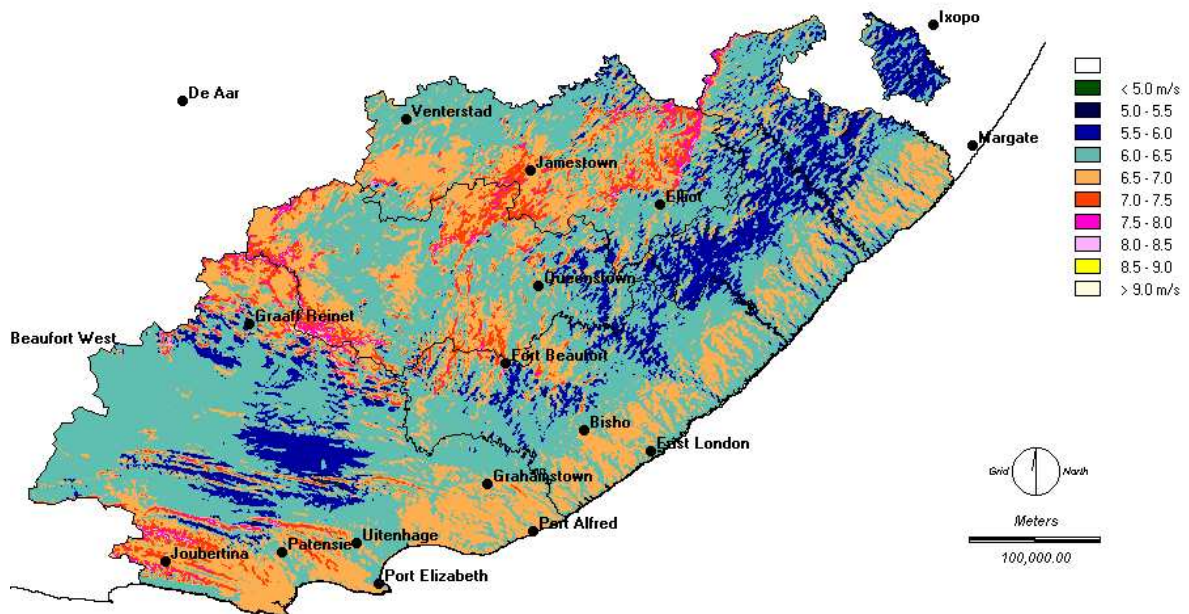


Figure 3: Estimated mean wind speeds at 60 m for the Eastern Cape Province

Of the total area of the Eastern Cape Province (169,899 km²), 148,056 km² have estimated 60 m 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 detailed analysis of wind energy technology and economics established cost curves for electricity generated as a function of both installed capacity and hub height annual mean wind speed. These are presented in Figure 4.

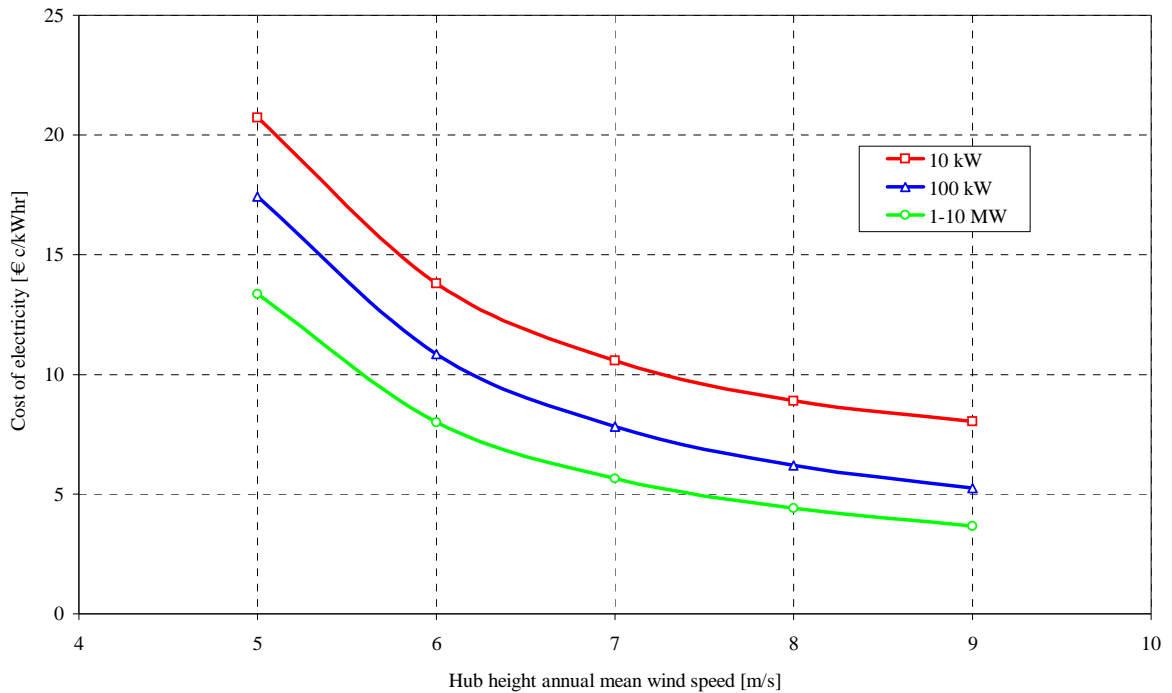


Figure 4: Cost of electricity from wind energy

4.2.2 Small Hydro

Hydroelectric potential has been assessed through GIS modelling for all rivers in the Eastern Cape Province and ranked in bands from 10 kW to 2000 kW and is presented in Figure 5 below.

This study concluded that projects that appear to warrant further investigation include Fraser Falls, Horseshoe, Indwe Poort, Lubisi Dam, Tsitsa Falls, Umtata Dam and Xonxa Dam.

A detailed analysis of small hydro technology and economics in the context of ECP identified typical configurations and associated parameters, including capital costs, for rated capacities from 10 kW to 10 MW. These are presented in Table 1 below.

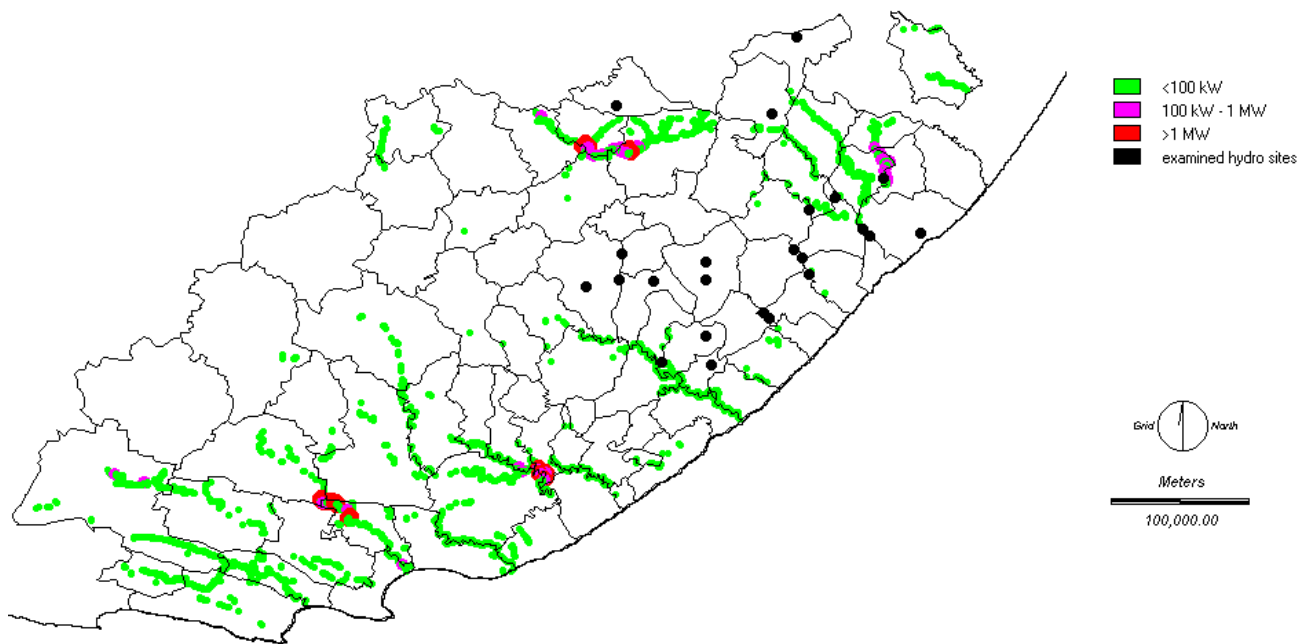


Figure 5: Small hydro sites

Table 1: Generic characteristics of 10 kW to 10 MW hydro schemes

Capacity	10 kW	100 kW	1 MW	10 MW
Turbine type	Reverse pump	Pelton wheel or local design	Crossflow or Pelton wheel	Francis or Pelton wheel
Head, m	5-20	5-50	20-50	50-300
Housing	Platform	Shed	Shed	Concrete + substructure
O & M	Automatic	Supervisor	Supervisor	Team
Eskom grid	No	No	Local	Possible
Machines (€/kW)	925 ----- 370			
Installed (€/kW)	3,700 ----- 1850			
Civils: dam, access (€)	0	370,000	3,700,000	7,400,000
Generic (€ c/kWh)	37.0	18.5	5.5	3.7

4.2.3 Biomass

Existing forest and the potential for eucalyptus and pine in the Eastern Cape Province has been mapped in the GIS model.

The potential energy wood resource from 147,157 ha of industrial forest plantations in the Eastern Cape Province is 18,000 oven dried tonnes per annum, including bark. However, external and internal pressures are creating opposition towards the expansion of industrial forest plantations. Changing plantation use from industry to energy production is unlikely as a result of strong industry demand for fibre.

The sector that provides the greatest opportunities for the production of energy wood is community forestry. The largest factor that will determine the success of the use of energy wood will be the conversion system adopted. For wood as a fuel to be successful, combination needs to take place at a centralised plant with distribution of the energy element in its final form being delivered to the rural community. The final form will be dependent on the conversion technologies that can obtain financial backing.

Using the available technology of a steam cycle generator set (minimum size of 10 MW) the only source of biomass that could meet the required quantity is the community forests. However, both community forests and mill residues could be utilised at the same plant, allowing the mill to benefit from the waste heat associated with the electricity production.

If pyrolysis becomes a viable technology, a large centralised conversion plant, situated next to an existing mill, could become commercially acceptable as community forests from a large area could supply the plant and pyrolysis oil could be returned to those communities for local generation.

A detailed analysis of biomass technology, fuel cycle and economics in the context of ECP identified typical configurations and associated parameters, including capital costs, for rated capacities from 10 kW to 10 MW. Figure 5 shows the range of possible electricity costs, including variability of the cost of wood, together with the range of capacities over which the various generating technologies can be deployed at present. It can be seen that there is a

strong correlation between these two factors resulting in a highly non-linear reduction of unit costs with increasing capacity.

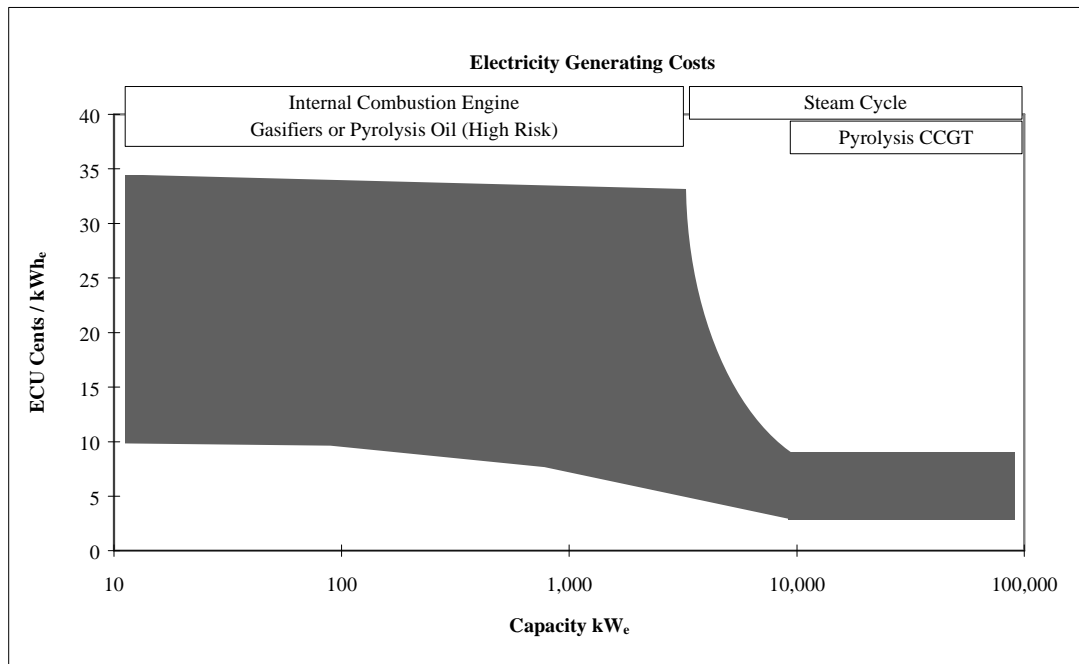


Figure 5: Cost of electricity from wood

If steam cycle generator sets were used, the electricity would cost between 3.1 and 7.4 € cents/kWh to produce. In order to meet the fuel requirements of a 10 MW_e steam cycle power station, a community forest of 10,000 ha would be needed. If distributed pyrolysis or gasifier generator sets prove reliable in the future, the estimated cost of electricity would still be two to six times higher than the local ESKOM supply tariff determined during the first study visit. The economics of biomass generation may be enhanced significantly if productive use can be made of the waste heat (e.g. for sugar beet processing) and if value is assigned to the associated potential for rural employment generation.

4.2.4 GIS presentation of cost of electricity production

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 6.

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 6.

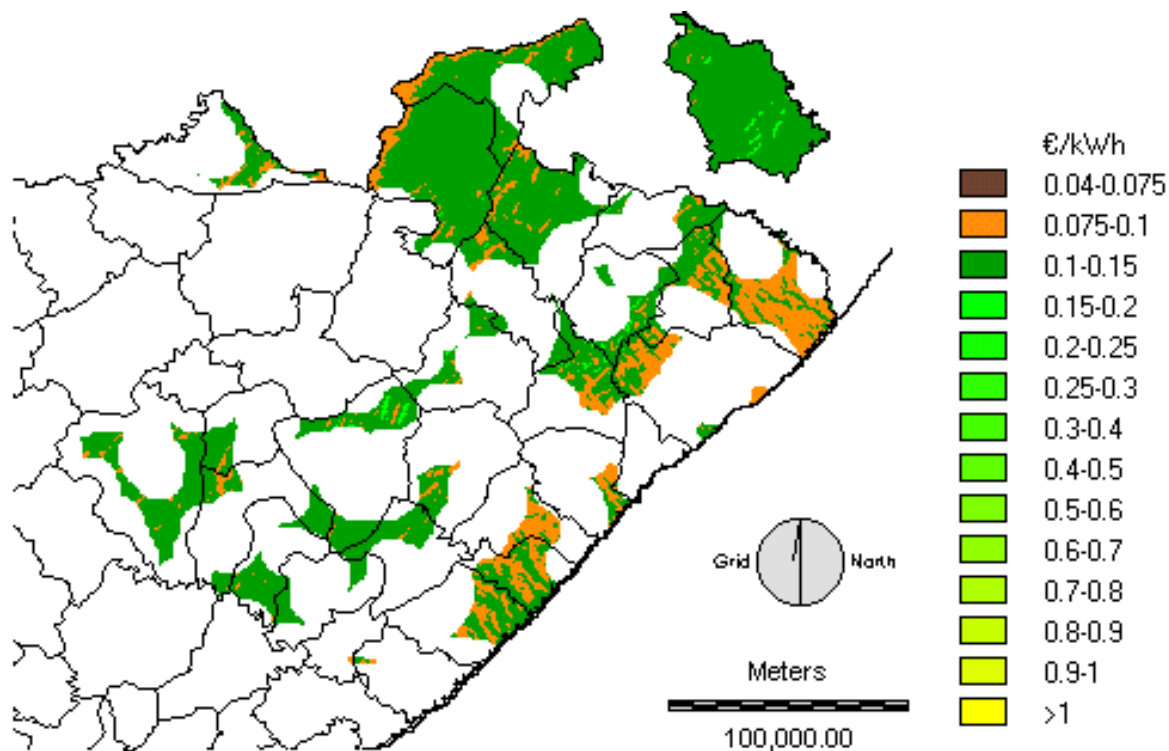


Figure 6: Cost of electricity from wind for eco-tourism 10km either side of the transmission grid

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.

4.3 Demand-Side Analysis

4.3.1 Introduction

Electricity demand was forecasted up to the year 2020 in 5 year intervals for each magisterial district in the former Transkei for the domestic, agriculture, manufacturing and commercial sectors. Population growth, grid electrification rates and household consumption coefficients were used to derive projections for the domestic sector

Projections for the three non-domestic sectors, namely agriculture, manufacturing and commercial sectors, were derived from sector-specific Gross Geographical Products (GGPs)

and electricity consumption coefficients. Because they are indexed to GGP (future trends of which are extrapolated from historical trends) the demand forecast for the agricultural, manufacturing and commercial sectors represents estimates of economic activities that might be expected to occur if historical trends continue.

The above discussion should be referenced to the Integrated Energy/Economic Methodology presented in Figure 2 where the above statistics are based on existing economic activities. As indicated in Figure 2 it is obvious that intervention measures need to be applied to increase the economic activity in the rural areas of the Eastern Cape Province.

4.3.2 Domestic Sector

The potential demand for RAPS generated electricity in the Transkeian domestic sector is expected to grow over the 20 years of analysis at an annual growth rate of 1.6%. The factors that influence this growth are the grid electrification rate and the electricity use per household. The more households are connected to the grid, the less potential demand for RAPS generated electricity will remain. The more electricity is consumed per household, the more RAPS electricity will be in demand. The potential demand for RAPS generated electricity in the domestic sector is therefore the product of both factors.

4.3.3 Agricultural Sector

In the near future, farming is unlikely to increase its production although there are examples where more rapid results can be expected. Currently, the main energy requirement in the Transkei is draft for ploughing and electricity for water pumping. Water pumps are required for boreholes to provide water for livestock, particularly in the more arid regions where reliable surface water resources are lacking. Food processing, especially milling, requires energy as well.

The electricity requirements will obviously depend on the agricultural operations involved in the particular crop. Electricity may be used for the different types of appliances:

- Refrigeration to store veterinary materials and preserve perishable products
- Water pumping to irrigate crop fields and to supply water for livestock in areas where surface water resources are inadequate
- Processing of agricultural products e.g. threshing and milling

- Heating to obtain warm water for dairies, heat incubators, dry certain crops, sterilise dairy products and weld metals
- Lighting in poultry units, in agricultural extension and organisational development
- Audio-visual equipment for training courses and information distribution.

In order to be able to estimate the future electricity demand of the agricultural sector, an electricity use coefficient has been estimated for agriculture based on ESKOM sales of electricity to agriculture in the and total GGP for this sector. The electricity use coefficient is estimated at 0.952 kWh per € value added unit (GGP).

4.3.4 Manufacturing Sector

In the former Transkei, most manufacturing industries consist of small-scale commercial enterprises such as carpenters, bakeries, brick making and clothing. The main manufacturing products are food and beverages products (e.g. bread, meat, maize and beer), textile products (e.g. clothing, leather shoes), building materials (e.g. cement and cement products), furniture (e.g. school and office furniture), chemical products and metal products (e.g. iron sheeting).

The growth projections for the manufacturing sector show an increased rate of growth in the medium and long term. It is expected that the manufacturing sector in the former Transkei will only grow significantly in the medium and long term once the South African economy has recovered from its current instability. Furthermore, it is assumed that Umtata and Butterworth will remain the core manufacturing areas. It is expected that small-scale service industries will continue to develop in the other towns of the former Transkei.

Energy is mainly required for lighting, heating and cooling. If unelectrified, these enterprises use gas from a cylinder, paraffin, diesel or wood to meet their energy needs. However, these enterprises are very keen to get access to electricity because it is more efficient (and therefore cost efficient) and it poses less health hazards compared to the use of wood or paraffin. Electricity is also affordable to most enterprises.

To determine the potential electricity demand of the manufacturing sector, an electricity use coefficient has been assumed of 0.952 kWh per € value added. This figure is based on

actual ESKOM sales figures and on a number of case studies whereby micro enterprises in rural areas have been interviewed to assess the energy needs and energy expenditures.

4.3.5 Commercial Sector

The commercial sector in the former Transkei is also expected to grow in the long term. This growth is closely related to the growth of the national economy since the disposable income and expenditure of the households in the former Transkei are heavily reliant on wages earned in the mines and factories in the rest of South Africa.

Within the commercial sector, tourism is expected to develop rapidly in the medium to long term. The developments are mostly expected along the coast where the most attractive tourism services are to be found. Despite their high potential, tourism opportunities are not being developed yet to their full potential due to the inaccessibility of many of the areas, the lack of infrastructural services, the restrictions of the existing land tenure system and the lack of local capital. Existing tourism activities currently consist mainly of hotels, campsites, hiking trail huts and caravan parks. In 1994, 14 hotels and 24 hiking trail huts were already spread out along the coast of the Transkei.

The commercial sector comprises mainly retail activities such as shops, general dealers, bottle stores and commercial services such as transport activities, motorcar repairs and hair salons. Electricity is used in these establishments for lighting and powering electrical equipment. The electricity use coefficient for the commercial sector has been determined based on the same sources that were used for the manufacturing sector. A coefficient of 0.136 kWh per € value added has been assumed for the demand projections.

5. South Africa's First Hybrid Mini-Grid Energy System

5.1 Introduction

During the course of the above described project an opportunity was identified for a RAPS 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.

To reiterate, it is the South African Governments objective to achieve universal access to energy and electricity for all its citizens by 2012. To date approximately 7million households have access to electricity. With approximately 80% of the urban areas and approximately 45% of the rural areas being electrified there approximately 3.7million households still unelectrified, most of these being in the rural areas.

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.

5.2 Hluleka Nature Reserve Pilot Hybrid Mini-Grid Energy System

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 1.5 kW machine, and a photovoltaic array consisting of 48 X 100 W solar panels. (Figure 7). The electricity generation system has a nominal capacity of 11kW. 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 7 shows three solar water heaters as well as the LPG bottles outside three of the twelve chalets in the nature reserve.



Figure 7: Solar water heaters and LPG bottles installed in Hluleka Nature Reserve

Energy efficiency was addressed by installing high efficiency chest freezers, compact fluorescent lights and the use of LPG for cooking.

5.3 Lucingweni village 86 kW hybrid mini-grid energy system

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 of 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.

The mini grid consists of: Power Generation, Reticulation, and Premises Equipment components. Figure 8 shows a picture of the mini-grid at Lucingweni village.



Figure 8: View of Lucingweni 86 kW hybrid mini-grid energy system

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 mast mounted wind generators (6m tall), an array of 560 solar photovoltaic panels mounted on steel structures and an equipment cabin/shelter constructed on a concrete base.

Reticulation Components consist of ground mounted creosote poles carrying overhead power lines to each individual dwelling. This is the acceptable and preferred method of distribution in many rural and urban areas. Due to the density and distribution of the dwellings in the village, reticulation is distributed from a backbone running below the summit

of the headland, with spur take-offs to the undulations below. Street-lights are installed on appropriate poles. As part of the integrated approach that included the provision of potable water an existing disused water reticulation system was refurbished.

6. New Economic Activities Linked to Hybrid Mini-Grid Energy Systems

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 possible 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.

With facilitation from CSIR 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, parsley etc. Figure 8 shows the community participating in the first plantings of herbs. These herbs were planted in between the rows of citrus trees. Harvesting of herbs takes place a few months after planting and can provide income while the trees grow to maturity.



Figure 8: Agricultural based new economic activities, planting herbs in between rows of citrus trees

7. 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 as discussed by Risø (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 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 as discussed by Pointon and Langan, (2002).

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 (now the Department of 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.

8. 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 Szewczuk (2008).

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 digesters

9. Decision Support Technologies

9.1 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 9 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/m²) 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.

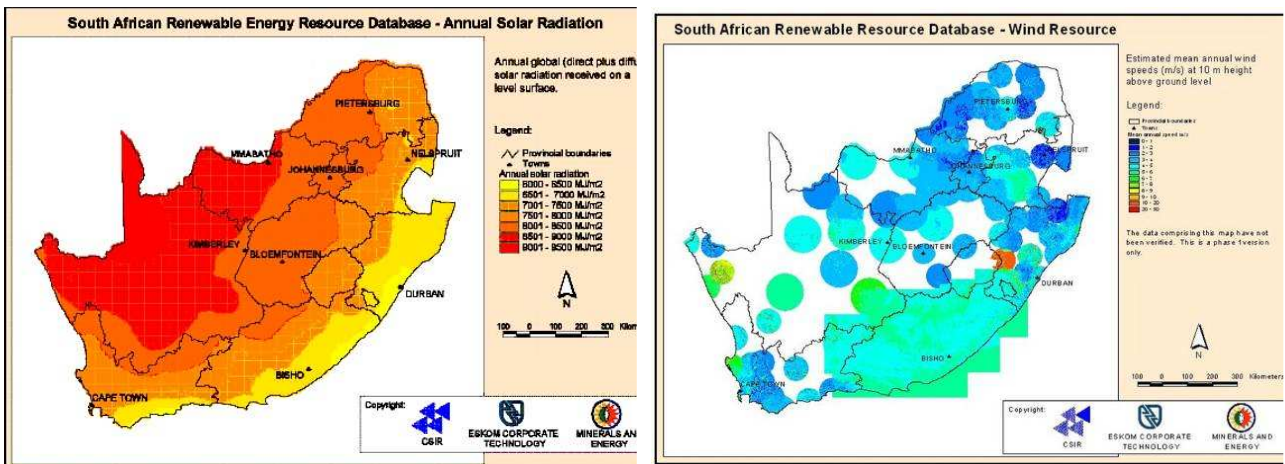


Figure 9: Current solar and wind resource database for South Africa

9.2. 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 SARERED 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.

10. Conclusions

In evaluating the contribution of sustainable energy systems 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 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) As far as the pilot hybrid mini-grid systems are concerned a number of future activities would still need to be done to validate the effectiveness of such energy systems. A

thorough understanding of the impact that these energy systems have on the communities would need to be established. Furthermore, the perceptions of these communities to these energy systems would need to be established. From a technical perspective a thorough understanding of the energy usage patterns would need to be quantified as well as quantify the consumption of electricity, LPG and solar radiation for the solar water heaters.

- e) From an environmental impact perspective an understanding of what role greenhouse gas emission abatement credits may have on any transaction costs would need to be established to reduce the cost of implementing hybrid mini-grids.

The information provided from the above activities could be used in any cost benefit analysis and life cycle analysis to establish the applicability of hybrid mini-grid energy systems in any roll-out and development plan.

- f) 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.
- g) 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, in particular energy related 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.
- h) 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.
- i) 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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