Hybrid mini-grid systems – electricity for communities not connected to the national electricity grid based on renewable energy resources

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Abstract
One of the South African Government's objectives is to have universal access to electricity for all of its citizens (Mbeki, 2004). 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 to one of achieving sustainable economic and social benefits. However, energisation and electrification can only be sustainable where there are economic activities to pay for it.

To obtain first-hand understanding of the complexity of this issue, CSIR undertook a three-year investigative project, focusing on the Transkei area of the Eastern Cape province of South Africa. The primary objective of this project was the identification of electrification opportunities using renewable energy linked to existing and new economic activities.

A holistic and integrated approach is required to achieve sustainable development and an integrated energy/economic framework was developed during the course of the above-mentioned project. CSIR's experience and knowledge was utilised in coordinating the development of an implementation plan for South Africa's first hybrid mini-grid energy system at the Hluleka Nature Reserve on the Wild Coast of the Eastern Cape province of South Africa.

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.

1. Introduction

The major role 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 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.

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. 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.

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, Shell International 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 needs 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

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.

Africa is a huge continent with vast areas facing deprivation. 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 sound information, data and statistics.

Furthermore, from Figure 1, note must be taken of the mainly rural household sector of the economy, as 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.

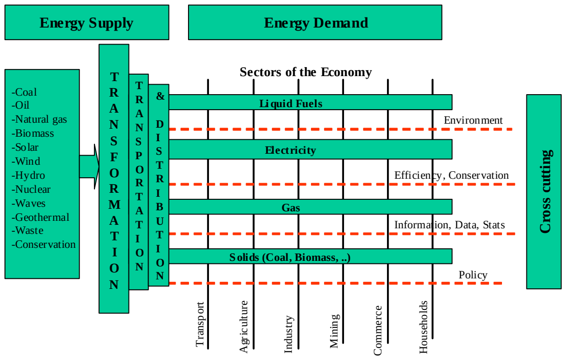

Figure 1: Holistic nature of the energy economy

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 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 'fasttrack' the usage of affordable, safe and 'modern' energy systems by low-income households. Amongst others, these include solar, wind and wave technologies, natural gas and fuel cells, to name a few.

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

2. Energy/Economic Framework

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 2.

In a flow-diagram fashion, Figure 2 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 2 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 Mechanisms (CDM) and
- the linkage to bridge the gap between Climate Change and Poverty Alleviation

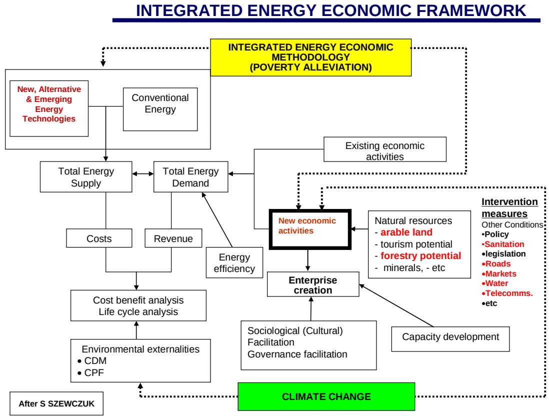

Figure 2: Integrated Energy/Economic Framework

3. Renewable Energy Sources 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 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.

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.

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 Supply side analysis

3.2.1 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 km^2 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.

Of the total area of the Eastern Cape province (169,899 km^2), 148,056 km^2 have estimated 60 m 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.

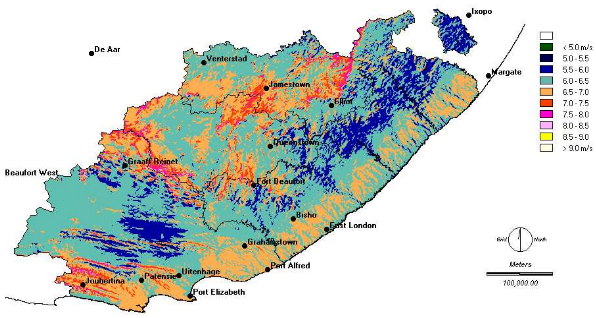

Figure 3: Mean wind speeds at 60 m

3.2.2 Small hydro

Hydroelectric potential had 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 4 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.

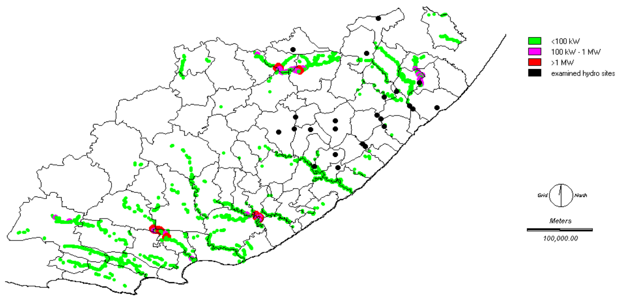

Figure 4: Potential small hydro sites

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

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

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 above

3.2.3 Biomass

Existing forest and the potential for eucalyptus and pine in the Eastern Cape province had 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.

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.

3.2.4 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 decided to make assumptions so that the analytical process could be developed. Consequently, this project highlighted the need for good information, data and statistics. In many instances, data and statistics was found to be out of date.)

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

- Eco-tourism
- Agriculture
- Forestry.

Supply-side/demand-side scenarios were investigated. Supply side options were based on electricity generated from wind, mini-hydro and biomass.

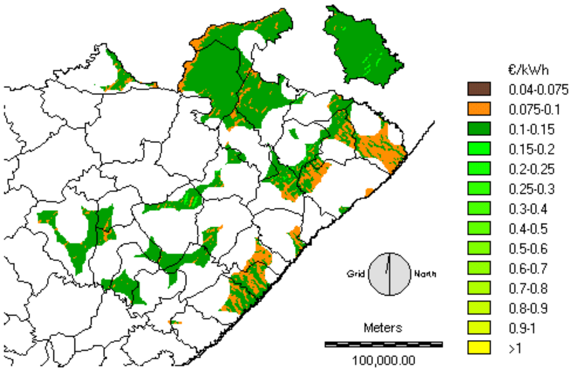

Figure 6: Cost of electricity 10 km either side of grid

One scenario investigated comprised a demand-side option, namely, eco-tourism with one supply-side option, i.e. wind generated electricity. 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 above.

To further identify potential RAPS opportunities a certain distance from the electricity transmission grid 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, the GIS results can be pictorially represented as in Figure 6.

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.

3.3 Demand Side Analysis
3.3.1Introduction
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.

For example, this study forecasted that, for the Transkei, the rural sectoral electricity demands in 2010 would be as follows:

- Domestic: 95% of total
- Agriculture: 2% of total
- Manufacturing: <3% of total
- Commercial: <<1% of total

This forecast indicates the importance of economic activities for poverty alleviation. Similar projections are expected for rest of rural South Africa.

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

3.3.2 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.

3.3.3 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 are:

- 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 and total GGP for this sector. The electricity use coefficient is estimated at 0.952 kWh per € value added unit (GGP).

3.3.4 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 beverage 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 liquid petroleum gas, paraffin, diesel or wood to meet their energy needs.

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 their energy needs and energy expenditures.

3.3.5 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.

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.

4. South Africa’s First Hybrid Mini-Grids

4.1 Introduction

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 is 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 to be used.

Hybrid mini-grid energy systems are 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 then National Electricity Regulator to facilitate the implementation of pilot hybrid mini-grid energy systems with a view to use these pilots projects to gain experience and understanding of such energy systems so that a national roll-out plan can be developed. CSIR was contracted to co-ordinate the development of an implementation plan with Shell Solar Southern Africa being the implementation company.

4.2Hluleka 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 is the responsible body for the nature reserve
- The then National Electricity Regulator who was 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 was the implementing organisation and
- CSIR who co-ordinated the development of an implementation plan

As part of the Integrated Energy/Economic Framework approach 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 consists of two small wind turbines, each being a Proven 1.5 kW machine, and a photovoltaic array. The electricity generation system has a nominal capacity of 11kW. Included is a control system, batteries for electricity storage and a diesel generator as a backup.

A separate set of photovoltaic panels was installed 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 highly variable 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

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 resulted in the identification Lucingweni village, 10kms from the Hluleka Nature Reserve, as a site for a hybrid mini-grid system.

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

- Adequate population density to optimize system employment.
- Community profile, suitability and acceptance.
- Most efficient use of natural resources available.
- Project sustainability measured by:
    - 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 system includes: power generation, reticulation, and a building that contained a large bank of batteries for electricity storage and a control system. Figure 8 shows a picture of the mini-grid at Lucingweni village.

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.

Figure 8: Lucingweni 86kW hybrid mini-grid

5. New economic activities linked to the RAPS energy systems

Many farmers in the rural areas of South Africa rely on subsistence farming for a livelihood. The Integrated Energy/Economic Framework was applied to identify 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.

The CSIR and the Agricultural Research Council identified and implemented applied new farming techniques to propagate and grow high-value crops suited to the area. Citrus, macadamia nuts, mango fenugreek, parsley were piloted. 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.

6. Conclusions

In evaluating the contribution of sustainable energy systems to poverty alleviation the following is concluded:

a) To alleviate poverty and create gainful employment, the forecasted rural sectoral electricity demands for the Transkei in 2010 requires that the correct and appropriate questions would have to be asked and answered. In the context of the Transkei the following questions can be asked:

   "*What intervention measures, policies and strategies would need to be put in place to increase the demand for electricity for productive economic activities from, say, 5% to 10% in 2010 in the Transkei?"*

   "*Can Information and Communication Technologies, such as Geographic Information Systems (GIS) be used to assist in energy and economic planning?"*

   Similar questions can be asked of the vast rural areas of Africa.

   In an attempt to develop an understanding of how to answer these questions an Integrated Energy/Economic Framework was developed.

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 in 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 require that such energy introduction be integrated with community development and training programmes.
- 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 take place 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 of 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 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

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