Renewable rural electrification: Prediction of sustainability in South Africa

Case study: Wind and solar photo-voltaic with lead acid battery storage

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Abstract

A case study methodology and assessment of renewable energy technology and sustainable development is applied to a DME rural village project. Wind, solar and lead acid battery energy storage technology were used for off-grid electrification. Sustainability was assessed for economic and technological systems. The usable eco-services from wind and solar power have been estimated from projections of wind and solar energy from nature. Capital and operating costs are calculated from project budget. Energy conversion efficiencies and storage capacities are obtained from the specifications and performance of the equipment in use. The outcomes for a renewable energy technology intervention had been predicted by way of a learning model using discipline experts in the fields of economics, sociology, ecosystem sustainability, governance and the physics, and chemistry of energy conversion processes. South African socio-economic commitments for the provision of free basic services have been applied so as to achieve the Millennium Development Goals. The Department of Mineral and Energy (DME) and the National Energy Regulator of SA provide the institutional support and establish the cost based demand for all electricity, including renewable energy consumption.

Comparison of project outcomes with the sustainability model shows that this renewable village grid is not viable within the South African Sustainable Development Framework. The main reason being that charges for electricity supply costs in village grids are too high for the sustainable development subsidy and the economies of scale for renewable energy supply technologies favour national grids. Although there is growing uncertainty in the eventual costs for new coal and nuclear based electricity, the latest estimates indicate that renewable energy is not viable unless a charge is made for the social cost of carbon.

1. General introduction

The South African governance system is developing national and international measures of sustainability. The Millennium Development Goals objective is to reduce widespread poverty between 1990 and 2015 (SA-DoH, 2005). The post-Kyoto 2012 commitments to low carbon technologies to mitigate the effects of climate change (DEAT, 2008), are based on renewable energies that are to be supported by a carbon tax.

Previous reports by the CSIR and the University of Pretoria address the application of technological innovation to meet the objectives of sustainable development and the conditions for sustainability (Rogers et al., 2007; Brent and Rogers, 2008; Brent and Pretorius, 2008).

The methodology approaches used to assess sustainability of technologies are

- Systems thinking, i.e. systems provide feedback loops (Bertalanffy, 1968) and large self correcting systems contain biological and inorganic components (Odum, 1950).
- Learning models for the management of information in the paradigm of sustainable development and sustainability science (Brent and Rogers, 2008).
- Conditions for sustainability to reduce complexity systems by clarifying magnitude of cause and effect on systems, so that priorities can be allocated. (Rogers et al., 2007).
- Technology innovation and what is feasible within constraints of time, finances and institutions (Brent and Rogers, 2008).

Supply of energy for basic needs is an assumption for sustainable development of the DME (DME, 2003). Household electrification and an energy grant of R55 per household is administered to local municipalities by the Department of Provincial and Local Government. In rural areas up to 84% of households can qualify for this grant (Municipal Demarcation Board, 2006). In 2003 the DME embarked on a renewable energy village project that was used to test the viability of renewable energy for locations not accessible to the national grid. This case study was carried out to test the applicability of sustainable science thinking for research in energy technology (Brent and Rogers, 2008). Conditions for sustainability were prioritised by the learning group. The prioritised set of assessable indicators for economic and technology sustainability are given in Table 1.

System	Priority	Indicator
Economic	A	Purchase Power Parity: benchmark to meet basic needs within available resources (MDG)
	A	Gini: share of poorest quintile in national consumption (MDG)
	A	World Bank Model for MDG productivity; 0.4% per 10 years life expectancy (MDG)
	B	World Bank Model for MDG productivity; 0.5% per year at school (MDG)
	B	Energy output of system>energy inputs; ensures viable energy supply
	C	Access to basic services for productivity (SA-MDG)
	D	Energy cost is affordable to users
Technology	E	Ability of energy system to improve productivity

- **Table 1: Prioritised assessable indicators for sustainability for the renewable energy system**

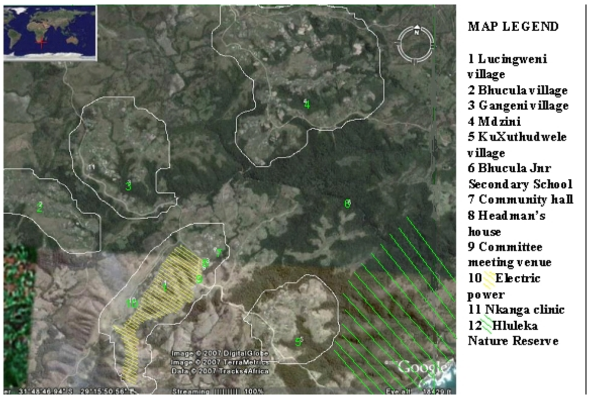
2. Scope of the study

The boundaries of the case study are set at the borders of the three regions in which the OR Tambo Lucingweni Village is located with its four neighbouring villages and the nature reserve (Illustration 1). The time period for the case study is from September 2004 to January 2007. The boundaries and key elements have been described (Rogers et al., 2007) for the following systems:

- Socio political – the five villages and the region that is controlled by the traditional government
- Socio ecological – the area used by the villagers in Lucingweni for their ecological services. This is a subset of the socio-economic system as it includes the Hluleka forest, which is not clearly demarcated from the Hluleka nature reserve.
- Socio economic – the same as the socio-political with the Hluleka nature reserve and the tourist camp that is a source of employment, including the economic services that are provided as part of the non-traditional government system, i.e. a clinic and school, and the Eastern Cape Parks Board.
- Energy system - the area to which the power lines are extended. This is a subset of the Lucingweni village.

Flows across boundaries

Productive capacity is in agriculture. Trade and financial transactions across borders are therefore for production in the village and remittances from government grants, and migrant workers. Energy flows across the boundaries are for fossil liquid fuels for transport, cooking, lighting, refrigeration, and biomass for heat, and cooking, and electricity stored in lead acid batteries for radios and cell phones.

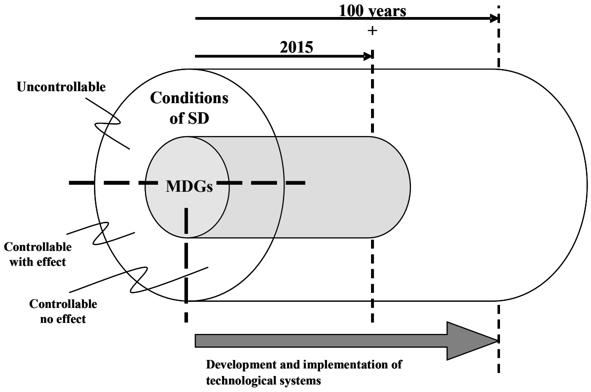


- **Illustration 1: Socio-political map showing the electrical energy system(yellow) located in one of the five villagers controlled by the headman**

Sustainability modelling

The assumptions of the three main sustainability paradigms were used as the starting point for identification of the elements in each of the systems. These are the World Bank Millennium Development Goal (MDG) model (World Bank,

2003) to which South Africa has subscribed for energy consumption per unit GDP, the World Commission on Environment and Development (Brundtland, 1987), which has provided the first and only global consensus on conditions for sustainability (Brent and Rogers, 2008), and the Stern Review (Stern, 2006), which has provided the most widely accepted techno-economic model for mitigation against climate change due to energy consumption. The measured and assessable indicators specified in these paradigms have been used as the initial elements (Illustration 2). Additional sustainability and sustainable development indicators were identified by utilising a learning model (Brent and Rogers, 2008). Prioritisation was included in the model, and this distinguished between those elements that were controllable with no effect. Expert knowledge was obtained by way of review of the sustainability mapping with the University of Pretoria Departments of Economics, Law and Governance, Ecology; the CSIR: Energy Processing, Energy Infrastructure, and Natural Resources and the Environment, the DME: Renewable Energy, and NERSA: project management. Interviews were obtained from the Local Municipality Manager and Council, Ward Councilor, the Ward Council Committee, Head Man and the Headman's Committee. Technology inputs were supplied by the technology contractor, and network of technology suppliers; the District Municipality; ESKOM; and adjacent ESKOM grid consumers. More information on the sustainability model development is available (Brent and Rogers, 2008) and the CSIR project file (Rogers et al., 2007).



- **Illustration 2: Time scope of MDG, WCED and Stern conditions for sustainable development**

3. Results of the study

3.1 Sources and quantities of renewable energy

The location of the renewable energy system in the socio-political system is mapped (Illustration 3). The useful energy that can be provided by the six wind turbines (6 kW-peak) and 510 solar panels (0.113 kW-peak) is determined from the available wind and sun at the coordinates (Latitude 31.825 S and Longitude 29.254 E) (NASA_http://eosweb.larc.nasa.gov/sse/, 2007). Table 2 shows the available wind and sun energy per day. This daily energy takes up on average an estimated 25% of the maximum capacity of the wind turbines, and 19% of the photo-voltaic cells.

The strongest local wind is located on the edge of an escarpment, and polycrystalline Si collectors are located adjacent to the wind turbines. The batteries, inverter, and grid controller, are located between the wind and solar electricity supplies. More information is available in the project report (Rogers et al., 2007). No connection to a diesel or ESKOM grid was provided. The quantities of energy nominally available from these two technologies is summarised in Table 2.

WIND	Wind velocity	6.32	m/s (10 year average)
	Turbine output	9.00	kW
	Output/day	147	kWh/day
	Capacity factor	25%	Output power / peak power
SOLAR RADIANCE	Solar radiance	4.67	kWh/m2/day (10 year average)
		3.48	hrs full sun/day
	Efficiency Si PV	11%	Output power/ input power
	Output/day	190	kWh/day
	Capacity factor	19%	Output power/ peak power

- **Table 2: Table 2: Projected average wind and sun energy and capacity factors**

Electrical system conversion efficiencies

The flow of energy through the electrical system is shown schematically in Illustration 1 of the supplementary material document.

The amount of useful energy that can be obtained at the household connections can be determined from the input energy from the turbine and the photo-voltaic and subtracting the energy losses in each of the components of the 220 AC 50 hz distribution system. The energy losses of each component in the system are estimated in Table 3.

Approximately 110 households were connected to the system. The useful energy from the 97 kW peak system that is available at the 110 household connections is about 125 watts continuous (see Table 1 of the supplementary data document). This provides energy per connection of 90 kWh per month. As the average system output is equivalent to 7 electric kettles, the amount of electricity per household is a lot less than is expected by a typical South African family.

Conversion efficiencies of components	
Transformer	99%
Battery	85%
Battery temperature derating	97%
Inverter efficiency	85%
Power conditioning	99%
Line losses	99%
Sum of energy losses	**32%**

Table 3: Conversion efficiency of distribution system components, storage, DC/AC conversion and AC distribution

3.2 Demand vs. production

Observation from the site visit was that average demand exceeded average generation capacity of 3 kWh per day per household connection.

Energy charges and demand in the case study area

A reason for high demand for electricity in the region can be seen from the charges for energy in the adjacent areas. Electricity has the lowest charge by a factor of 2 to 3. For this reason electricity is the energy carrier of choice for high energy services, i.e. cooking and refrigeration. ESKOM (2007b) advises that electricity demand doubles soon after installation when people want stoves and refrigerators. Household connections are provided with a 20 A trip.

Energy carrier	**lpg**	**diesel**	**paraffin**	**OR Tambo DM rural electricity**
MJ/kg	48.55	38.1	37.00	
R/kg	19.00	6.58	7.39	
R/MJ	0.39	0.17	0.20	0.11
R/kW hr				0.39

- **Table 4: Energy charges in the OR Tambo District Municipality (March 2007)**

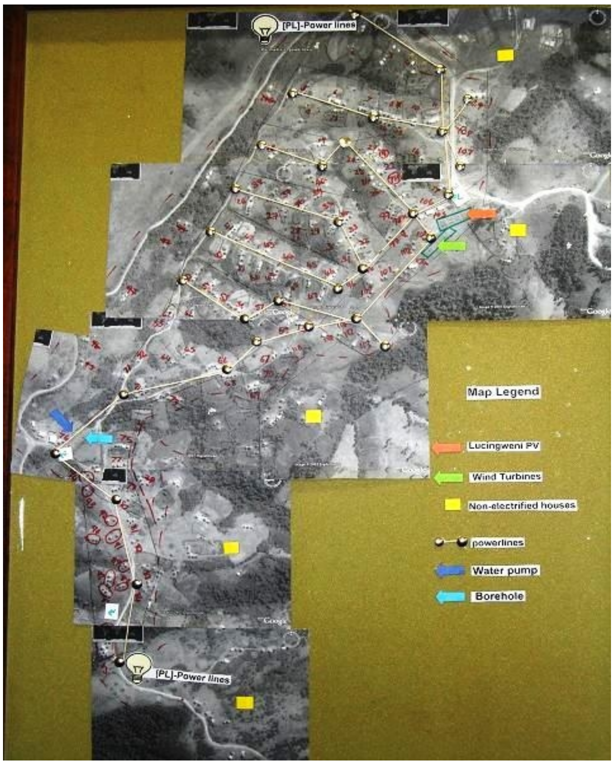


Illustration 3: Main features of the energy system

Municipalities are authorised to derive revenue from the sale of electricity. Municipal electricity charges are typically made up of a municipal levy of R 0.23/kWh plus the ESKOM supply charge of c. R0.16 /kWh (ESKOM,2007a). We have found that electricity sales can be the single largest source of revenue for South African municipalities.

Units	OR Tambo DM charge	ESKOM national average cost	O.R.Tambo DM levy
R/MJ	0.11	0.05	0.06
R/kW hr	0.39	0.16	0.23

Table 5: OR Tambo District Municipality income from electricity at a rural connection (March 2007)

Municipality subsidy from DME

The DME free basic alternative energy policy for off-grid support to indigent households is administered by DPLG (DME, 2003) and was established at R55 per household per month. At the ESKOM electricity charges in the vicinity, the off-grid support is equivalent to either 166 or 359 kWh per household (Table 6), depending on the charge of the levy by the municipality. The indigent subsidy policy for urban households is 50 kWh/connection.

Municipal charge system to DME indigent grant	Cost (1) for electricity R/kWh	Demand (2) from policy kWh AC
Without levy	0.13	359
With levy	0.39	166

Note 1: cost includes VAT

Note 2: demand is based on a CPI + 1.5% escalation of the R 55 grant per annum from 2003

Table 6: Estimated municipality monthly demand using the DME basic grant funding for 2007

Potential offsets for renewable energy projects

Renewable energy projects attract carbon subsidies from SA and international institutions, but for potential project implementers, a determining barrier is often the administrative costs. In order for registration and auditing to be a small fraction of the total project costs, a minimum number of carbon credits are needed. In January 2007 typical incomes that might be obtained are:

- Tradeable Renewable Energy Certificates; R0.12/kWh that has been reported by DME (DME, 2006) and this is equivalent to R 15 000/a.
- A DME Renewable Energy Subsidy of 20% of the capital cost, i.e., R1.04/kWh or R155,000/a was available in early 2007 (DME,2007). (For details of the capital cost components see Table 2 of the supplementary material).
- NERSA household connection subsidy: at about R 4 500 per household this is equivalent to R1.78/kWh (ESKOM, 2007b).
- EU Green House Gas emission trading scheme for 2007 ranged between R 0.04 to R 0.40 /kWh for income between years 2007 and 2014 (Cozijnsen, 2008)

These could provide a total of R 3.34/kWh but the administrative costs would be most cost effective if only the NERSA and DME renewable energy subsidies were claimed at the start of the project, i.e. R2.82/kWh.

Electricity costs for off-grid municipal supply from wind and solar power and ESKOM national grid coal power.

Cost of electricity supply for the DME renewable energy village project using wind and sun projections has been estimated from projections of energy outputs and project the renewable energy village budget (see Table 2 of the Supplementary Material document). In 2007 Rands, the total system cost is R7.76/kWh for 119, 000 kWh/a. The ESKOM cost for 2006-2007 is R0.16/kWh and approximately 50 times lower (ESKOM, 2007a). Reasons for this include:

- Energy conversion losses between the source of electricity and the consumer are higher. About 30% is lost by battery storage, and DC to AC conversion (See Table 3). ESKOM transmission losses are expected to be up to 10% .
- Capital costs battery storage take up 40% of the total costs. ESKOM pumped storage is more like 1% of the capital cost (NERSA,2007)(ESKOM, 2007a).
- Capital costs of renewable electricity generators have low capacity factors, i.e., 25% and 19%. These compare unfavourably with coal fired power stations operate at 87% of maximum rated output (ESKOM,2008).
- ESKOM capital costs are typically based on old and depreciated plant. New renewable energy generators have yet to be written off.

- Connection costs in rural areas can be subsidised by NERSA in a once off payment and are therefore not included in the ESKOM tariff (ESKOM, 2007b).

The DME subsidy system operating in 2007 provided for a once off subsidy of 20% (DME, 2007). This is equivalent to a grant of approximately R1/kWh.

The inclusion of the DME and NERSA subsidies results in a Renewable Village Energy cost about R5/kWh. The R65 household energy grant from DME, provides for a maximum of 12 kWh/month. It is reasonable to expect that the traditional leader, the Nyandeni Local Municipality and the DME would prefer a quantity closer to the indigent allocation of 50 kWh to national grid connections.

3.3 Alternative technological solutions for sustainable development

The DME needs a more economical electricity supply if the indigent grant subsidy scheme is to be used for renewable energies. Alternative technologies options to renewable energy are considered.

Village grid energy storage in lead-acid batteries or diesel?
The DME renewable energy village has battery capacity for storage for up to 100 hours of windless and overcast days, i.e. for approximately 1400 kWh. This storage is provided by about 500 l of diesel. The cost of the 75 kW peak diesel generator is approximately R200 000 and includes a fuel tank. In comparison, a lead-acid battery bank capital cost is R3m (see Table 2 of the supplementary material document). While the running costs of diesel are higher they are not high enough in January 2007 (R5.6/l) to make diesel unaffordable R2.85/kWh (Table 10) compared to renewable energy. This is still a factor of 16 more expensive than ESKOM charge but improves affordability of a stand alone rural village grid by a factor of 2.7.

Village grid storage or national grid storage?
The national grid has a smaller differential between peak and average demand (Table 7) and a lower portion of the supply from pump storage (248 MW and 0.9% of supply capacity (NERSA, 2007)) compared to the lead acid batteries (1400 kWh and 100% of the village supply). Connection to a national grid for renewable energy saves storage costs of R3.15/kWh (see Table 2 of the Supplementary Material).

Low cost extension of the national grid
Technological innovations from the national electrification programme have been attributed to user based standards rather than supplier (old ESKOM) based standards (Bekker et al., 2008). These enabled uniformity in procurement and national up take of successful interventions and shorter times on fault corrections during implementation. These included prepaid meters and low cost grid extension. Single Wire Earth Return (SWER) technology replaced both three phase and single phase grid extension.

Demand	Mini-grid (kWh)	National grid (kWh)
Peak	53	32,000,000
Average	14	22,000,000
Ratio	3.7	1.5

Table 7: Peak and average demand for the village grid and the national grid

An ESKOM cost for a 5000 kW line extension 13 km from the adjacent Mdumbi village using a standard ESKOM grid controller would cost about R40 000 per km and about R0.91/kWh (see Table 3 of the supplementary material). Normal grid extensions require in rural areas are limited by bulk infrastructure capacity but in the case of a small additional load (14 kW) this is not a restriction. The extension would provide 50 kWh per household within the DME grant. If this project were funded as a stand alone project the local municipality would however, have to forgo approximately R0.23/kWh income on sales (see Table 5).

4. Comparison with targets for SA low carbon technologies

SA's response to the high cost of carbon, climate mitigation, and energy shortages has so far been to commit to a long-term policy of power expansion based on renewable energy and nuclear power with high carbon tax (DEAT, 2008a). The first response by ESKOM (ESKOM, 2008) is the largest project proposal in SA's history, and latest indications are that the cost for electricity will be in the range of R 1/kWhr

(Eberhard, 2008) assuming a growth of consumption at 6% pa. There is high uncertainty in the cost , with estimates increasing rather than falling. This can be compared with the social cost of carbon which the Stern Review has estimated to be in the range USD 85 to USD 25 per tonne of CO_2 (Stern, 2006). This is equivalent to additional cost between R0.7/kWh and R2.6/kWh, for the ESKOM average coal with 21 MJ/kg and ash at 31% with power station efficiency of 34%.

Expectations are that higher world energy prices will make renewable energies more affordable. For example, the cost of export coal has increased three times since 2002. At current prices it is R0.07/MJ (Business_Day-Nov04, 2008)(BP, 2008). However, as is shown in Table 4, SA electricity price has been kept lower than paraffin and LPG. At energy parity coal generation should cost closer to R0.70/kWh. Such a comparison neglects the energy input costs to the renewable technology, which is not included here.

As this renewable energy village case study shows, renewable energy is more practical when connected to a large grid. For 2007 prices the village wind electricity is about R1.70 R/kWh and solar PV about R2.45/kWh. These costs are the same range as the latest new costs of coal and nuclear electricity added to the lower social cost of carbon, i.e. R 2/kWh. Renewable energy requires a carbon tax to bring into cost competitiveness with coal. A summary of the costs for three options in Table 8 shows that renewable energy is not affordable for local municipalities.

5. Comparison with the national electrification programme and the African Millennium Villages Project

One finding from the national electrification programme is that cost-driven technical innovations and changes in technical standards can be used to meet developmental objectives (Bekker et al., 2008). Can similar a approach can be used for renewable energy for sustainable development in rural settings?

The African Millennium Villages Project is in central Africa. Seventy-eight impoverished villages are receiving external funds to support the application of the MDG economic model (World Bank, 2003) through targeted public-sector investments to raise rural productivity and, thereby, to increase private-sector saving and investments (Sanchez et al., 2007). The external support includes training in healthcare, farming skills and access to finance for trade and fertiliser. The South African application of the MDG model for rural households is on public sector investments in healthcare and education, and improved domestic services for water, sewage that are linked to health. In contrast the focus is on service quality and household electrification. The linkage with rural productivity has not been made. One criticism that can be made of this approach is that it follows an earlier developmental model for Africa (Hyden, 2007), i.e. Modernist Theory, where minimum consumption standards are taken as measures of development, rather than per capita GDP growth. Under the MDG model electrification by connection to large scale grid has been assigned a low priority in the African Millennium Villages Project (Sanchez et al., 2007). One of the reasons for this is the relatively high cost compared to its benefits.

Option		R/MJ	R/kWh
National Grid/ ESKOM	ESKOM national average cost	0.05	0.16
	OR Tambo DM levy	0.06	0.23
	OR Tambo DM charge	0.11	0.39
Village grid	Renewable energy village	2.02	7.76
National grid/ renewable	Wind and solar with NERSA and DME subsidies	0.48	1.83

- **Table 8: Comparison of options**

Improved economic performance was one of the objectives of the DME Renewable Energy Project (Szewczuk in this Conference) where an economic development model was linked to energy availability. Growth of herbs and oranges has been piloted and as in the case of the African Millennium Villages Project, commercial activity has been in selection of crops for cash sales, increasing productive use of limited amount of land, and access to markets.

The linkage between energy provision and sustainable development *via* increased productivity in rural areas has not been shown in either SA or central Africa. If a national renewable electrification programme was initiated along the same lines as the national electrification programme then the policy commitments in the Long Term Mitigation

Strategy (LTMS) (DEAT, 2008a) can be seen as the starting point with a large scale implementation commitment in 12 to 17 years. One starting point in cost reduction is the connection to national grid for renewable electricity. In the case of the DME Renewable Energy Village, the location has been shown to be comparatively better with a high wind availability. But it is not the general case for other under developed areas in South Africa (Citation Steve's paper).

6. Comparison with indicators from the sustainability learning model

The project outcomes are compared with the prioritised set of assessable indicators (Rogers et al., 2007) for economic and technology sustainability in Table 9. The renewable energy system is not sustainable within the SA MDG framework.

7. Conclusion and summary

Renewable energy for off-grid rural electrification does not meet the South African Millennium Development commitments for poverty reduction because the return in productivity is uncertain and the cost is too high for the institutional support from DME.

If the approach to renewable energy is to be linked to sustainable development goals then national grid connection is required.

System	Met objectives?	Indicator
Economic	yes	Purchase Power Parity: benchmark to meet basic needs within available resources (MDG)
	yes	Gini: share of poorest quintile in national consumption (MDG)
	no	World Bank Model for MDG productivity ; 0.4% per 10 years life expectancy (MDG)
	no	World Bank Model for MDG productivity ; 0.5% per year at school (MDG)
	yes	Energy output of system>energy inputs; ensures viable energy supply
	no	Access to basic services for productivity (SA-MDG)
	no	Energy cost is affordable to users
Technology	no	Ability of energy system to improve productivity

- **Table 9: Sustainability outcomes compared against objectives**

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Eastern Cape Parks, ESKOM, Department of Mineral and Energy Affairs, Lucingweni Village Traditional Leader, National Energy Regulator for SA, Nyandeni Local Municipality, PowerTech, Sungrid, Transcape NPO, University of Pretoria, Vortex

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	Diesel grid	**Value**
a	Capacity kW-peak	75
b	Installation cost/R	633,504
c	Installation cost R/kW-peak	8,447
d	Equipment operation/ supervision costs pa	49,470
e	Routine service pa	26,204
f	Depreciation/capital replacement pa	66,980
g	Fuel costs and infrastructural charges	197,234
h	Sum of costs R pa (Sum d+e+f+g)	339,889
i	System losses (% power generated)	est <1%
j	Scheduled Service down time (% time)	3.00%
k	Capacity for generation (% time meeting peak)	> 95%
l	kWh AC/an sold	119,420
m	kW AC cont	14
	(R/ kWh AC) (h/l)	2.85

Note 2: labour costs 1.24% of capital cost and service costs 0.78% of capital. Depreciation periods as advised by equipment service engineer.

Table 10: Diesel generator alternative to the renewable energy generators and battery (2007 prices)

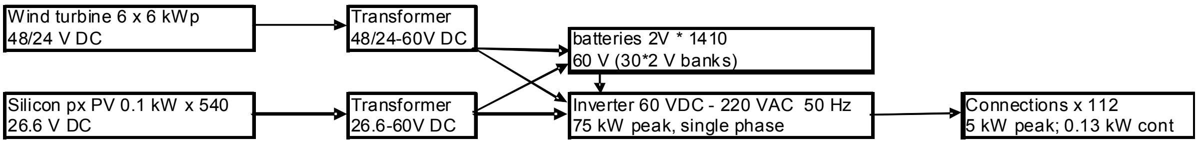

Illustration 1: Energy flows from generators to users

Energy generators	**Power peak**	**Capacity factor (1)**	**Conversion losses**	**Usable power in grid (2)**		**Usable power/ Peak power**	**power per household per day**	
	kW DC	% of kW DC Peak	% kWp	kWh AC/ day	kW cont.	kW-AC/ kW-DC	kWh AC	kW AC
wind turbines	36	25%	32%	146.9	6	17%	1.311	0.055
Si pc PV	61	19%	32%	190.4	8	13%	1.700	0.071
Total wind & solar	97			**337.3**	**14**	**15%**	**3.012**	**0.125**

Note 1: Capacity factor = % equivalent of time that the renewable energy converter operates at peak capacity over 10 years sun and wind conditions with equipment operating at delivery specifications
Note 2: Usable power estimate has a zero down time (i.e., batteries supply power during maintenance and the supply is > than demand)

Table 1: Net system power availability for the 97 kW DC system is 125 W AC per household

Row	Item	Wind	PV	Batteries	converters and controllers	Total
a	**Capacity kW-peak**	**36**	**61**	**75**	**75**	**75**
b	**Installation cost/R**	1,108,175	2,071,068	2,758,943	3,705,210	**9,643,396**
c	**Installation cost R/kW-peak**	30,783	33,941	36,657	49,229	**150,609**
d	**equipment operation/supervision costs R pa**	14,235	26,603	35,439	47,593	**123,870**
e	**routine service R pa**	8,693	16,247	21,643	29,066	**75,649**
f	**depreciation/capital replacement R pa**	55,409	103,553	275,894	185,261	**620,117**
g	**Fuel costs, and infrastructural levies**	-	-	-	-	**-**
h	**Sum of costs R pa (Sum d+e+f)**	78,337	146,403	332,976	261,920	**819,635**
i	**System losses (% power generated)**	est <1%	est <1%	18.4%	13.6%	**32.0%**
j	**Scheduled Service down time (% time)**	3.0%	3.0%	3.0%	3.0%	**3.0%**
k	**Capacity for generation (% time meeting peak capacity)**	25.0%	19.1%	97%	97%	**97%**
l	**kW hr AC/an sold**	52,004	67,417	119,420	119,420	**119,420**
m	**kW AC cont**	6	8	14	14	**14**
n	**Contribution to cost (R/ kW hr AC) (divide h/l) (note 1)**	**1.51**	**2.17**	**2.79**	**2.19**	**6.86**

Note 1: StatsSA deflator Dec 2003 to January 2007 is 1.13. The 2007 total cost is therefore R 7.76/kWh

Note 2: labour costs 1.24% of capital cost and service costs 0.78% of capital. Depreciation periods as advised by equipment service engineer.

Table 2: Analysis of capital, running, service and depreciation costs for the generation, storage and distribution of electrical energy for the 14 kW AC continuous and 75 kW-peak at the village grid (data collected in March 2007 and discounted to Rand December 2003 values; excl VAT)

Item	Eskom Power	Eskom Power
Capacity kW-peak	National Grid extended 13 km; no municipal service charge, 14 kW demand	National Grid extended 13 km; no municipal charge; 53 kW demand
Capacity kW-peak	5000	5000
Installation cost/R	1,236,000	1,236,000
Installation cost R/kW-peak	247	247
equipment operation/supervision costs pa	15,876	15,876
routine service pa	9,696	9,696
depreciation/capital replacement pa	61,800	61,800
Fuel costs and infrastructural charges	21,645	83,357
Sum of costs R pa (Sum d+e+f+g)	109,017	170,728
System losses (% power generated)	est <1%	est <1%
Scheduled Service down time (% time)	3.00%	3.00%
Capacity for generation (% time meeting peak capacity)	97%	97%
kW hr AC/an sold	119,420	459,902
kW AC cont	14	53
R/ kWh AC (divide h/l)	**0.91**	**0.37**

Note 1: Installed demand of 14 kW is the same as the renewable supply on average. 53 kW demand is a projected maximum demand for businesses, services and households.
Note 2: StatsSA deflator Dec 2003 to January 2007 is 1.13. The 2007 total costs for basic needs charge is R 1.01 and R 0.35 kWh
Note 3: labour costs 1.24% of capital cost and service costs 0.78% of capital. Depreciation periods as advised by equipment service engineer.
Note 4: Energy costs at ESKOM national average of R 0.1589 (VAT incl) for 2006-7 (ESKOM, 2007)
Note 5: An approximate comparison with 2003 costs is made with the deflator of 1.13, ie, R 0.81/kWh and R 0.33/kWh.

Table 3: Connection to the national grid for planned demand and an estimated maximum demand (2007 Rand costs)