

GUIDELINES FOR PILOT PROJECT IMPLEMENTATION OF HYBRID SYSTEMS

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Table of contents

1	Piloting hybrid systems	1
1.1	The niche for hybrid systems	1
1.2	Application scenarios for hybrid systems in South Africa	4
1.3	The need for piloting hybrid systems	5
1.4	Experience in piloting off-grid technologies	5
1.4.1	International experience	5
1.4.2	South African rural electrification: experience and outlook	6
1.5	Summary	7
2	Structure and phases of pilot projects	7
2.1	Feasibility assessment	8
2.1.1	Site identification	8
2.1.2	Appraising demand	9
2.1.3	Appraising constraints	10
2.1.4	Appraising resources	11
2.1.5	Market assessment: feasibility assessment versus design planning: a chicken and egg situation?	12
2.1.6	Summary	16
2.2	Planning	16
2.2.1	Costs and benefits in determining electrification options	16
2.2.2	Techno-financial design	17
2.2.3	Sustainability of a hybrid system implementation	21
2.2.4	Summary	22
2.3	Implementation	22
2.3.1	Pre-installation phase	22
2.3.2	Installation	23
2.3.3	Operation and maintenance	24
2.3.4	Project support, monitoring and follow-up	24
2.3.5	Summary	25
3	Conclusions and recommendations	25
4	References	32
5	Appendix A: Techno-financial assessment of different technology options for rural household and centralised electrification of schools, clinics, farms	33
5.1	Techno-financial comparison of household electrification with different technology options	34
5.1.1	Technology options for remote area power supply for households	34
5.1.2	Financial analysis	34
5.1.3	General case study assumptions	34
5.1.4	Grid electricity assumptions	35
5.1.5	SHS assumptions	37

5.1.6	Diesel generator assumptions	40
5.1.7	Hybrid system assumptions	41
5.1.8	Decision ranges	43
5.1.9	Summary	43
5.1.10	References for Section 5.1	44
5.2	Techno-financial comparison of electrification options for centralised applications	44
5.2.1	South African cost and design scenarios	44
5.2.2	PV/wind/battery school/clinic system at Mabibi – coastal region with good wind resources	44
5.2.3	PV/diesel farm systems at Upington – inland region with good solar resources	45
6	Appendix B – Implementation structures: community visits	47
6.1	NGO-driven: CSIR – Lubisi, Eastern Cape	47
6.2	NGO-driven: The Methodist church in Eastern Cape – Kumberstone	47
6.3	SELF-driven: Maphephete, Kwazulu-Natal	47
6.4	Entrepreneur-driven: Kentani, Eastern Cape	48
6.5	ESKOM-driven: Eastern Cape schools electrification	50
6.6	Upgrading diesel? Namaqualand – Lepelfontein	52
6.6.1	Estimate of energy used	52
6.6.2	The diesel desalination plant	52
6.6.3	Future plans	53
6.6.4	Summary	53

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EXECUTIVE SUMMARY

The experience with hybrid systems is very limited and little information exists so far on their performance or impact. However, they have been installed world-wide and have been put to use because of the fuel-saving operation of off-grid systems, supplying domestic use of electricity and also powering some productive activities associated with income generation or improved health and education. Carefully planned strategies are important in implementing such new technologies. It seems that accompanying factors such as the infrastructure provision, training, type of financial arrangements and user involvement may even be more important than the technology itself. Off-grid technology dissemination in South Africa has been hampered so far by unclear grid extension plans, a lack of clearly defined rural electrification responsibilities and unclear distribution criteria for rural electrification funds. In addition, other than for large commercial farms or tourist resorts, the cost of providing rural grid electricity will typically not be recoverable in the near or even longer-term future as consumption take-up in many areas is very low and is not expected to change much in future. Nevertheless, rural grid electricity is presently offered with very low connection fees and rates per kWh consumed.

The possibility is under discussion that Eskom's distribution might be split up into regional electricity distributors (REDs), in addition to the other existing regional distributors which mainly serve urban areas. In this context, the development of a national electrification policy that will address the functions and roles of respective players and how electrification should be funded is desirable. This should include the establishment of criteria for the prioritisation and allocation of funding for grid and non-grid electrification. A national body, such as the National Electricity Regulator (NER) or a national electricity funding body, can then administer funding to competing REDs for projects that meet the defined criteria. The criteria will include whether the chosen technology option and approach for the project has the ability to sustainably contain costs, meet regional needs and increase socio-economic productivity. There is also a desire to link electrification projects with other infrastructure projects such as water, housing and others to optimise the deployment of national resources.

The main difference between the existing system and the future system is that while electrification is now mainly being pursued following micro-economic (Eskom's) interests, it will in future be driven by macro-economic interests which are much more complex and difficult to measure and control.

Eskom might be able to implement off-grid/hybrid technology options in future. So will other implementing agencies once a national electricity funding body is able to distribute funding for rural electrification by raising taxes and funds from Eskom's revenues and other sources. Because new technologies could be implemented through different electricity distributor agencies in future, it is important to pilot new technologies such as hybrid systems to gain experience in planning, implementation and impact assessment. The first pilot projects could be more expensive than more commercialised projects. It is important that the pilots are implemented well because project management failures might lead to a rejection of the technology, regardless of whether the technology is feasible or not. It is also important to pilot a number of projects in order to develop appropriate maintenance support that might not be available for a small isolated project.

Experience in South Africa of piloting off-grid and rural electrification technologies has already yielded useful observations and lessons. The piloting of hybrid systems should follow these observations – both nationally and internationally – and be well prepared in terms of the different technical, financial, social, economic, institutional and environmental factors involved.

Next to planning, pre-installation planning, implementation and follow-up, the feasibility assessment is a decisive part in project development. A feasibility analysis can be carried out for a particular site or be used to actually select a 'feasible looking' site in a certain region. It can be said that the selection of a site or region is often a sensitive and politically-charged issue. Analyses of resources, demand, constraints and market potential are often described separately

but they are very much related. Demand should be seen in relation to the resources accessible by the project, the site, potential users, relevant institutions and other factors. Demand assessments from different sampled regions can feed into a broader market estimate. Often the technical demand assessment in terms of power and energy requirements of an identified application will be a 'looping' process, identifying financial requirements of an application and feeding back discussions and experiences around willingness to pay into the design process.

It can be deduced that a careful community interaction and participation process is essential for yielding conclusive results of the feasibility assessment. However, a detailed participation processes requires time and funds, so much so that, in the case of larger regional feasibility assessments, these are often reduced or taken out altogether. It is recommended that regional assessments use as much locally-surveyed data as possible. Most of the steps of a feasibility assessment could be roughly estimated during the feasibility phase and carried out later in more detail during the planning phase, depending on the resources available.

The planning phase is essential in working out appropriate designs, financial packages, training requirements and long-term management structures for the identified and discussed needs. Liaison with users and other roleplayers is of paramount importance. The designed systems will often have to be integrated with other technology, energy or service options. The costs/service provision of the different technology and service options are determined in the planning phase, as well as how demand is affected by the cost and the service offered. An assessment is also necessary regarding what kind of financial packages will be suitable in terms of the costs which arise and the willingness of people to pay. In addition, the type of infrastructure in place, or which has to be established, is appraised, during the planning phase including requirements such as training and general support. The principal question that will have to be answered is whether the skills and resources necessary for the project can be made available and in such a way that the project can run sustainably and provide the demanded services adequately in the long-term.

Aspects of the planning phase can be covered in the feasibility assessment or can even become pre-installation steps. Whether steps described under planning can already be carried out during the feasibility phase is often a matter of resources. The planning needs to accommodate the different objectives of the roleplayers and find a compromise between expectations and resources. The evaluation of the longer-term impacts and performance of the technology, service provision, infrastructure and market needs to be an integrated part of the planning process.

Pre-installation planning, installation, operation and maintenance, and monitoring and follow-up are part of the practical project implementation after all the feasibility assessment and planning has taken place. It is important that all these phases are well thought through and planned in detail with all roleplayers, especially local participation and local management personnel whether in business, administration, maintenance or any other area. Funding of the evaluation of project impacts is recommended to be able to draw lessons from the projects and disseminate them. Monitoring of the pilot projects will aim to assess:

- User satisfaction.
- Technical performance.
- Financially sound operation.
- Industry operation.
- Institutional operation.
- Environmental and socio-economic impacts.
- Whether these factors can be achieved sustainably.

It is important that a piloted and potentially new technology is monitored in sufficient depth and evaluated adequately to gain insight into how suitable the technology is, and what aspects of the project approach can be improved or changed.

In conclusion, the following points are important consider when planning the piloting of hybrid systems:

- Piloting is important and needs to be carried out in 'clusters'.
- Feasibility depends on resources and demand.
- Planning is important for matching resources and demand.
- Implementation and operation needs trained local personnel and reliable industry delivery.
- Sufficient resources for monitoring and evaluation of pilot projects are important.

The following sections summarise important factors in this process regarding the feasibility of a pilot project, steps that support the piloting process, relevant system designs, and resources needed in piloting new technology options.

Factors relevant for feasibility of a hybrid system project

Weather resources

- Is the region in question a coastal/wind intensive area and/or a radiation intensive inland area?

Financial resources

- Is the present expenditure and willingness to pay on energy services high enough to cover the payments for a financial package of the pilot project?
- Do people want the service to be provided by the pilot project and are they willing to pay deposits and fees?
- Has a body committed itself to finance infrastructure requirements, such as subsidies on interest rates, lobbying for lifting import taxes on relevant equipment, training requirements, facilitation of user feedback, testing of equipment and monitoring?
- Has an institution committed itself to supporting a revolving financial fund?
- Does a cost/benefit analysis and socio-economic assessment indicate a viable project?

Implementation resources

- Has an institution committed itself to carrying out a reliable tendering process?
- Has an institution committed itself to supporting the provision of relevant training sensibly?
- Has an institution committed itself to developing standards and testing equipment for the pilot projects?
- Has an institution committed itself to supporting the monitoring and evaluation of the projects reliably?
- Is an industry available which is committed to deliver low-cost, reliable system hardware with after-sales services?

Local skill resources

- Are committed people available locally who can be trained to manage the project and install, operate and maintain the system?

Business development support resources

- Has an experienced institution committed itself to supporting the development of a business plan for the project?
- Is some economic activity in existence already?

Infrastructure resources

- Is water accessible in the community/near the site?
- Are health services accessible within the community?
- Is the community accessible under all weather conditions?
- Is existing infrastructure sufficient? If not, what additional infrastructure is required?
- Are people well organised in community groups?

Local administrative resources

- Is there a committed support infrastructure available in terms of advice desks, system failure assessment, continued training and others?
- Is there an interest expressed in the project?

Steps for support of pilot projects in order of necessity and importance**Framework**

- Development of electricity provision framework for social equity and economic development needs.

Grid extension plans and off-grid decision criteria

- Determination of national grid electrification plans for the next five, 10 and 20 years.
- The development of criteria for non-grid technology selection at a national level.

Infrastructure

- Determination of nation-wide status of service infrastructure and product availability.
- Determination of infrastructure costs still to be incurred.
- Determination and dissemination of levels of subsidies (lifting import taxes and subsidising interest rates).
- Determination of whether/where/how to establish/subcontract/train local 'advice desks' that can carry out training and tendering, support planning and disseminate information.

Demand assessment

- Surveying of demand.

Sustainability

- Discussing and analysing the:
 - suitability of service
 - sufficiency of existing/planned infrastructure and cost of additional infrastructure
 - socio-economic impacts
 - factors affecting market sustainability.

Integration

- Linking electrification projects with other infrastructure projects such as water provision and others.

Financing and cost/benefit analysis

- Determination of integrated service options and corresponding financial packages. Clear sensitivity scenarios for different:
 - financing packages
 - demand scenarios
 - future growth scenarios.
- Worst/medium/best scenario development for different financing packages (that might include different levels of subsidies) and demand levels.

Assignment of responsibilities

- Determination of partners in financing, training and implementation and their terms of reference.

Standards and tendering

- Determination of standards for off-grid/hybrid systems.
- Determination of tendering procedures.

Monitoring and follow-up

- Determination of monitoring and evaluation procedures.

System designs

Findings of the EDRC-based hybrid project¹ have shown that

- Off-grid systems seem a more cost-effective choice than grid extension in remote areas with low household consumption take-ups and specific power requirements between 2kW_p and 100kW_p (4kWh/day–500kWh/day) The type of system technology, whether single source or hybrid system, will depend on the application.
- Mini-grids powered by hybrid or diesel systems are cost-effective for dense housing, an attractive tariff package and sufficient user demand.
- Hybrid systems are cost-effective for peaky demand profiles, complementary renewable energy resources and long hours of electricity demand per day.
- Wind hybrid systems are recommendable along the coastal areas (wind speeds >3m/s), PV hybrid systems in inland areas (solar radiation >4 500Whm²/day). The systems can have a PV share and a wind turbine share respectively.
- Diesel hybrid systems make sense where:
 - A high reliability of electricity supply is required
 - The required diesel generator runtime/day is short and its required output is relatively constant
 - Certain loads can only be powered by a diesel generator
 - Detailed techno-financial design recommends a diesel generator.
- Off-grid/hybrid system options are especially viable where integrated service provision is taking place and with vendors who have an integrated product provision attitude.

¹ Appendix H: Kailasanathan, A. 1998. *Hybrid systems project: demand analysis and cost benefit analysis*, EDRC report, University of Cape Town.

However, optimising the techno-financial design for an user application should still be done for each project individually.

- Disposable income in areas such as Eastern Cape and Kwazulu-Natal is quite low and therefore rural services other than household lighting and TV/radio might require increased subsidies or a combination with an income/wealth generating entrepreneurial development programme. Such a programme needs to be supported nationally.

Resources needed

Resources are needed for:

- Determining grid extension plans and off-grid technology project selection criteria.
- Subsidising infrastructure (lifting import taxes and subsidising interest rates)
- Establishing advice desks (providing advice, administrative support, support in business plan development, facilitation, overlooking tendering procedure, disseminating information – for example, on available subsidies and support with design advice).
- Surveying and feasibility assessment processes.
- Facilitation of project planning and implementation.
- Facilitation of community/user group planning.
- Training (education in schools about renewable energy, education of technicians to install and operate RAPS systems, education of users, education of entrepreneurs, capacity building and others).
- Defining and testing of standards.
- Capital grant contributions to pilot projects.
- Tendering procedures.
- Training.
- Monitoring and evaluation.

1 Piloting hybrid systems

1.1 The niche for hybrid systems

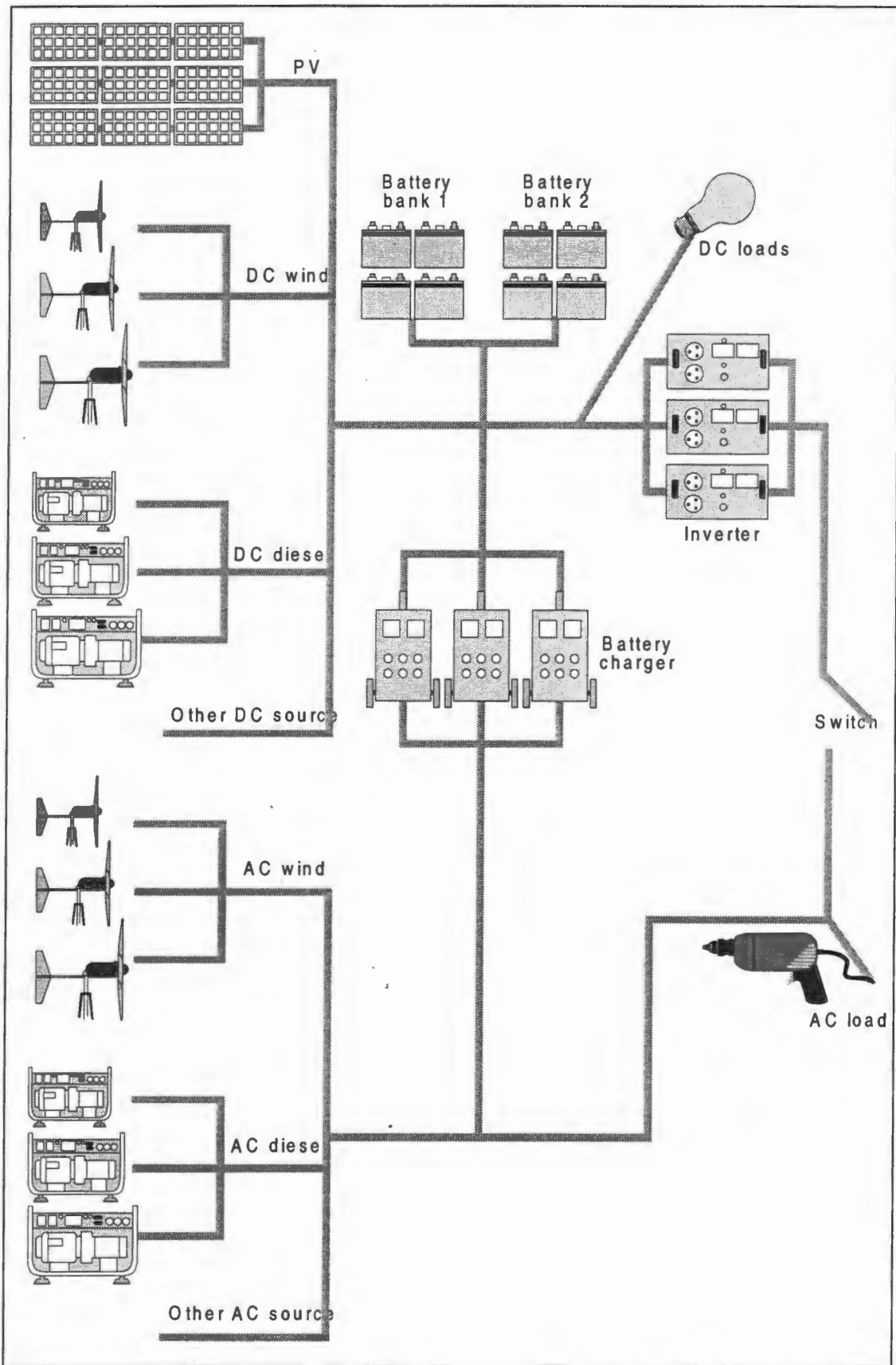
A renewable individual system will often be appropriate for small loads in remote areas, but not necessarily used only for small load requirements depending on the remoteness of the site, and the importance of supplying the load versus the costs involved. A diesel generator system will be attractive through low capital costs, but will incur high operation costs. A renewable hybrid system and diesel-renewable hybrid system will usually have lower capital costs than a renewable-only system and at the same time lower operational costs than a diesel-only system. This combination can in many cases result in lower life-cycle costs (LCCs) than otherwise.

Seasonal renewable source patterns also vary substantially, and in a properly designed hybrid system the various sources can complement each other over the year (for example, there might be wind when there is little sun), and a diesel generator can supplement energy when no renewable power is available. This can also cut down on expenses for battery storage which would be fairly high otherwise.

If good renewable energy sources are available in a remote area, a hybrid system option should be analysed, especially when transport of fuel and maintenance on-site are difficult. The different energy sources in a hybrid system can help to bridge the maintenance time for one energy source more easily. Another advantage of a hybrid system is that different energy sources can be combined to optimise the overall life-cycle costs and system performance. In many cases a hybrid system may be the best option, technically and financially. The disadvantages include dependence on the availability of renewable energy sources and the need for more sophisticated control than in the non-hybrid case.

A hybrid system may be particularly effective in cases where electricity is demanded for long periods of time and high peak demands are placed on the system compared to otherwise lower load levels. Another factor to consider in selecting a hybrid system concerns the amount of load placed on the system during daytime or other renewable-intensive time periods, as the renewable energy can be directly supplied to the load and storage losses can be avoided. A production project with high daytime load levels combined with lower load levels in the morning and evening will produce a load profile for which a hybrid system is well suited. It is, however, particularly difficult to develop accurate forecasts of the growth in connections to a system per year or the consumption per connection.

Figure 1: Schematic principle of a hybrid system



The few hybrid systems in South Africa are mainly PV/diesel/battery systems situated on remote commercial farms and tourist facilities. A number of companies are able to install and maintain

hybrid systems and some hybrid system components such as inverters and controllers are manufactured locally. The type of system the mix of life cycle costs will favour, in the face of required electricity supply reliability, depends on the site and application. Life cycle costs in operating a hybrid system to reliably meet a given demand can be lower than for a single-source system if the renewable energy sources, their complementarity and the component capacities are well matched.

In general it can be said that a diesel-generator-only system is suitable for applications which have a very flat demand profile and require electricity supply only for a small number of hours per day. Renewable individual systems are appropriate if the load power requirements can cope with a sometimes unreliable electricity supply. Hybrid systems are suitable for applications with very peaky demand profiles and long hours of daily electricity supply. Table 1 summarises the different design factors.

Table 1: Technology comparison for rural electrification (◦:Low, ●:Medium ◐: High)

<i>Issues</i>	<i>Grid</i>	<i>Diesel-only system</i>	<i>RE individual system</i>	<i>Hybrid-diesel-RE system</i>	<i>Hybrid-RE-only system</i>
1. Need for redundancy sizing	◦	◐/●	●	◦	●
2. Complementarity of resources	●	◦	◦	●	●often
3. Capital costs (\$/kW _p rated capacity)	●	◦	●	◐/●	◐/●
4. Operation costs	◦	●	◦	●	◦
5. Life cycle costs	◦	◐/●	◐/●	◐/●	◐/●
6. Service needs	●	●	◐/●	◐/●	●
7. Component lifetime	●	◦	●	◐/●	●
8. Robustness	●	●	◐/●	◦	◐/●
9. Sensitivity to efficient appliances	◦	●	●	●	●
10. Cost of end-use appliances	◦	◦	◐/●	◐/●	◐/●
11. Availability of end-use appliances	●	●	◐/●	◐/●	◐/●
12. Environmentally friendly	◦	●	◦	●	◦
13. Fuel dependence	●	●	None	●	None
14. Fuel efficiency	●	◐/●	None	◐/●	None
15. Complexity of control	●	◐/●	◐/●	●	◐/●/●
16. Maturity of technology	●	●	◐/●	◦	◐/●
17. Infrastructure complexity	●	◐/●	◐/●/●	●	◐/●
18. Quality of service	●	●	◦	●	◐/●
19. Range of applications for productive users	●	●	◐/●	●	◐/●
20. Training of end users	◦	◐/●	◐/●	●	◐/●
21. End-user safety	●	●	◐/●/●	●	●
22. Metering potential	●	●	◦	◦	◦
23. Affordability	●	◦	SHS: ◦ BCS: ●	◦	◦

SHS: solar home system; BCS: battery charge station; RE: renewable energy

1.2 Application scenarios for hybrid systems in South Africa

Hybrid systems in South Africa can make sense for centralised power applications ($4kW_p$ – $50kW_p$) such as community centres, entrepreneurial development centres, or any other productive and centralised application (Table 2). Hybrid systems will not make sense in many areas for providing power to a mini-grid or micro-grid in a community for household electricity supply. However, if the households are located densely enough, a mini-grid supply can become viable. A techno-financial analysis should be carried out to decide on a suitable option. Typical applications for hybrid systems that were also workshopped by the National Hybrid Working Group of South Africa are listed in Table 2 with applicable power and energy ranges in Table 3.

It is difficult to estimate load scenarios correctly. It seems that domestic farm use, running a school or clinic requires around $2kWh$ – $5kWh/day$ (Rehm 1997). For more extensive farming, such as a diary farm or a cattle farm, estimates of energy consumption are based on, for example, the number of hectares to be irrigated or the number of cattle. A diary with 50 cows, water pumping and other appliances typical for farm use might require up to $10kWh/day$. A mill running 7 hours a day plus water pumping and other typical farm equipment might require up to $18kWh/day$. Chicken farms need gas or electricity for heating incubators, lighting and water. A full-fledged chicken farm with three chicken sheds and a household can require up to $7\ 200kWh/day$. A typical village of 1 000 households might require $40kWh/day$ – $200kWh/day$. A good guideline for energy requirements in agriculture in South Africa is found in Williams (1996).

Table 2: Applications for hybrid systems

<i>Recommendation: Applications for a hybrid system</i>
Technical rural school
Community centre running workshops and courses
Entrepreneurial development centre
Farm
Clinic
Rural trade stores
Water supply and purification
Battery charging station
Expansion of an existing off-grid system
Communication
Tourism facilities (nature reserves)
Village mini-grids?

Table 3: Power and energy requirements applicable for a hybrid system

<i>Policy recommendation: Power and energy range suitable for a hybrid system</i>
Peak power size: $2kW_p$ – $50kW_p$
Energy per day: $4kWh/day$ – $500kWh/day$

Quite a number of factors contribute to the success of a hybrid system pilot project and some of the items listed in Table 4 should be checked before choosing an application and site. These factors will also be dealt with in section 2.1.1.

Table 4: Promising resources for a hybrid system project

<i>Policy recommendation: Promising resources for a hybrid system project</i>
Coastal areas and radiation intensive inland areas
Local ability to pay for services
Financing available (revolving fund, initial cost grant funding and others)
Reliable skills for administration and revenue collection available or easily trainable people
Low-cost, reliable system hardware, preferably no import tax
Reliable technical skills for installation and operation
Transparent tendering, monitoring and subsidy infrastructure

1.3 The need for piloting hybrid systems

The purpose of the pilot projects is to define a detailed preparation process for the successful and sustainable implementation of several selected hybrid system projects that should be clustered in a chosen region. Cost recovery mechanisms of at least the operation costs should be integrated in the implementation process.

Success of the pilot projects should be monitored in terms of:

- User satisfaction.
- Technical performance.
- Financially sound operation.
- Industry after-sales service delivery.
- Institutional operation.
- Environmental and socio-economic impacts.
- Whether these factors are achieved in a sustainable way.

The learning phase of the pilot projects is important for the sustainability of future implementation – experience from these projects should feed into a national implementation strategy. Piloting a new technology is also necessary because the first few ‘learning’ projects will be more expensive than later project implementations. Pilot project failure can indicate that the technology is not suitable for implementation, or that project management was not carried out properly, or both. Because failure might lead to the dismissal of future projects and the technology itself, it is important to have well-prepared pilot project implementations.

1.4 Experience in piloting off-grid technologies

1.4.1 International experience

The implementation of hybrid systems world-wide started just a few years ago. Not much data and information is available on installed hybrid systems regarding factors such as their performance, sustainability, acceptances and potential impacts. However, hybrid systems have been installed in many countries including the USA (Alaska), Indonesia, Thailand, China, Australia, Mexico, India, Argentina, Chile, Morocco, Spain and Greece.

Many hybrid systems have been implemented with a certain amount of grant funding. Some hybrid systems are owned by utilities, others by the government or its local structures. Some hybrid systems were implemented to reduce fuel costs of existing diesel plants (such as in Indonesia), some were built from scratch to use good renewable energy sources and provide electricity in areas remote from the grid. The majority of the applications powered by these hybrid systems are related to the domestic use of electricity as in many South American countries (McAllister 1996). There has been little experience with supplying electricity with hybrid systems to power remote productive activities. Some applications in South America

have been recorded by NREL (Web site: 'Renewables for sustainable village power' <http://www.rsvp.nrel.gov>), National Rural Electric Cooperative Association NRECA (Smith 1995) and World Bank reports (World Bank 1975) as ice-making, shop lighting and commercial refrigeration, wood and metal work, and agricultural uses. NRECA points out the need to design hybrid systems so they can cope with motor loads required for productive and commercial applications. However, as mentioned before, very little information is as yet available on the performance and impacts of these systems. The following highlights some of the experience gained in rural off-grid electrification for which hybrid systems were also used.

1.4.1.1 Mexico

In Mexico's rural electrification programme using renewable energy, solar home systems, PV and hybrid systems have been used to electrify 1 257 communities with around 200 000 people according to Huacuz (1997). The programme was implemented on a large scale at a fast pace using a combined effort of public and private sector enterprises. A variety of socio-cultural conditions were encountered in the different regions of Mexico. The government was involved in the political drive and the planning of funding. The community provided local organisation, support and O&M (organisation and method) services. Industry was responsible for equipment supply, after sales service, installation and training. The electric utility contributed in the areas of technical standards, quality assurance and training. An implementing agency was responsible for planning, project development and administration. The projects were co-ordinated with other infrastructure projects. User involvement and user training was seen to be essential to achieve successful and sustainable project implementation.

1.4.1.2 India

Seventy percent of India's population lives in rural areas. A rural electrification programme that includes renewable energy sources and other off-grid technologies has been in place for the last 25 years. However, the criterion of a successfully electrified village is that an electricity pole has been installed in the village, regardless of whether any households or other buildings are connected to it. In this way, India managed to electrify 90% of its villages and reach 30% of rural households. The electrification programme looks at a basket of options, such as mini-grid systems, hybrid systems and demand-side management measures. The sizing of the technology is a problem for remote areas as no immediate load is there. India's programme focuses on awareness creation, access to finance, involvement of local institutions, availability of components and willingness of users to pay. The utility is state-controlled and demand is outstripping supply of electricity. The market for the technology is not there yet, even so a market for delivery of services is there. This is illustrated by the fact that the use of off-grid technologies in India's rural electrification programme is subsidised, as is its grid extension programme. To convert the present 'market' into a real market would require a number of steps which are very difficult to take. For example, the removal of subsidies is a sensitive issue as it can affect political support.

An integrated energy planning approach has not been carried out in India at a national level, but more has been done at the planning and implementation and grassroots level. Some of the planning has worked, but it is unlikely that it can be replicated elsewhere without local adjustments (Venkata 1998).

1.4.2 South African rural electrification: experience and outlook

In South Africa, the experience of rural off-grid electrification so far is that off-grid technologies are seen by many rural people as second class and expensive and that grid electricity would be the much preferred option. The main player in rural electrification in South Africa is Eskom, which uses cross-subsidies from its urban and industrial revenues to support the rural grid electrification drive. Such cross-subsidies are normally not available for off-grid electrification. Off-grid technology dissemination has been hampered so far by unclear grid extension plans, a lack of clearly defined rural electrification responsibilities and unclear distribution criteria for rural electrification funds. In addition, other than for large commercial farms or tourist resorts,

the cost of providing rural grid electricity will typically not be recoverable in the near or even longer-term future as consumption take-up in many areas is very low and is not expected to change much in future. Nevertheless rural grid electricity is presently offered with very low connection fees and rates per kWh consumed, using a flat tariff structure or prepayment metering. In many cases, users seem to prefer prepayment metering to be able to better control their spending. Prepayment metering is under development for off-grid technology options.

The possibility is under discussion that Eskom's distribution might be split up into regional electricity distributors (REDs), in addition to the other existing regional distributors which mainly serve urban areas. In this context, a national electrification policy is being developed that will address the functions and roles of respective players and how electrification should be funded. This should include the establishment of criteria for the prioritisation and allocation of funding for grid and non-grid electrification. A national body, such as the National Electricity Regulator (NER) or a national electricity funding body, can then administer funding to competing REDs for projects that meet the defined criteria. The criteria will include whether the chosen technology option and approach for the project have the ability to sustainably contain costs, meet regional needs and increase socio-economic productivity. There is also a desire to link the electrification projects with other infrastructure projects such as water, housing and others, to optimise the deployment of national resources.

The main difference between the existing system and the future system is that whereas now electrification is being mainly pursued following micro-economic (Eskom's) interests, it will in future be driven by macro-economic interests which are much more complex and difficult to measure and control.

Eskom might be able to implement off-grid/hybrid technology options in future. So will other implementing agencies once a national electricity funding body is able to distribute funding for rural electrification by raising taxes and funds from Eskom's revenues and other sources. As new technologies might be implemented through the different electricity distributor agencies in future, it is important to pilot new technologies such as hybrid systems.

1.5 Summary

It can be said that experience with hybrid systems is limited and little information exists so far on their performance or impact. However, they have been installed all over the world wide and have been put to use in terms of fuel saving operation of off-grid systems, supplying domestic use of electricity and also powering some productive activities associated with income generation or improved health and education. Carefully planned strategies are important in implementing such new technologies. It seems that accompanying factors such as the infrastructure provision, training, type of financial arrangements and user involvement may even be more important than the technology itself. Implementation of pilot off-grid and rural electrification technologies in South Africa has started and has already brought forward useful observations and lessons. The piloting of hybrid systems should follow these observations – both nationally and internationally – and be well prepared in terms of the different techno-financial, socio-economic, institutional and environmental facets involved.

2 Structure and phases of pilot projects

The different stages of developing an implementation project can be roughly defined as:

- Feasibility assessment for an application, site, area or region.
- Planning.
- Pre-installation planning.
- Implementation and operation.
- Follow-up.

All these stages are very important in implementing a successful pilot project and should be carefully planned and carried through.

During the feasibility stage an investigation into whether a hybrid system could be a relevant option for an application, a site, area or region is carried out. Assessing feasibility includes the identification of sites for pilot projects, and the appraisal of potential demand and resources for, and likely constraints faced by, such a project. Often some sort of market assessment is made. An important step in these feasibility appraisals is liaison with roleplayers such as clients, institutions and NGOs. This should facilitate obtaining information and expertise about perceived needs and priorities, including willingness to pay for services, available products for servicing needs, and available or planned infrastructure and programmes.

If exploring off-grid/hybrid systems in more detail during the planning phase is indicated, the systems have to be designed for the determined needs and compared – and if necessary integrated – with other technology, energy or service options. The cost/service provision of the different technology and service options needs to be determined, as well as how the cost and the offered service affects demand. An assessment is necessary regarding what kind of financial packages will be suitable in terms of the costs which arise and the willingness of people to pay for the service. In addition, the type of infrastructure in place – or which may have to be established – needs to be appraised, including requirements such as training and general support and the outlook on the sustainable market potential of the technology.

The principal question that will have to be answered is whether the skills and resources necessary for the project can be made available, in such a way that the project can run sustainably and provide the demanded services adequately in the long term.

If it emerged from the planning that a hybrid system is suitable for the situation, the pre-installation steps have to be carried out in detail to guarantee timely and smooth installation and system operation. This includes fine-tuning and refining designs; tendering procedures; setting up time schedules and operation procedures, responsibilities and selection of personnel; testing of equipment according to developed standards; and training and other processes.

The actual implementation should be well planned. All equipment, tools, and transport should be ready and in good condition and the specialised people required for installation and operation should be available and trained. The operation of the system needs to be monitored regularly and the local maintenance services administered need to be checked from time to time. In addition, during the project follow-up, technical and socio-economic monitoring and evaluation should take place assessing what kind of lessons can be learned and what kind of impacts could be observed. The evaluations and experiences should be fed into national and other planning activities. The following sections discuss the different phases in more detail.

2.1 Feasibility assessment

2.1.1 Site identification

The selection of a village, site, or region is a difficult process, often influenced by the number of potential electricity connections, the information a certain community or interest group has access to, and the level of its ability to communicate its interest. In a similar manner, site or regional selection by a centralised institution depends on the amount of data and information available to that body. Site selection is an important aspect in piloting service options and needs to be given substantial attention. A number of important points need to be made:

- Funding for the site analysis/survey process needs to be secured. Site identification, if carried out properly, can consume a large amount of time and funds. However it is important to be quite certain that the site and its people are really likely to benefit from the project to ensure a high likelihood of a sustainable project.

- Requirements for the pilot site need to be identified. It is useful to determine the requirements for a site by the pilot project – a minimum number of users or a high percentage of local management may be essential.
- Good data sources need to be identified. The better the weather and other relevant data one can obtain for a site, the less time and funds need to be spent on generating these.
- Field experience and contacts of other institutions or activities in the area will be useful for shaping the project and using time and funds effectively.
- The site evaluation process must be identified. In order to gather information that can be effectively used in deciding which site is a likely candidate for a pilot project, it is helpful to have pictured the evaluation process already. It helps to shape questions in such a way as to ease the evaluation of answers and findings.
- The information dissemination process relevant for site selection must be identified. If the selection process also responds to requests made by interested potential user groups, it is important to disseminate enough information to attract a number of potentially promising user groups.

As said before, site selection is a very sensitive and politically charged process. Some of the criteria that could be helpful in selecting a site concern:

- The existence of economic activities.
- The existence of infrastructure and community groups.
- The interest expressed in the service provided by such a project (James 1996).

The following sections on demand, resources, constraints and market potential can feed into the overall site selection process and can, for example, be used to collect data regarding the existence of other economic activities, infrastructure and interest in the services. All four sections impact on the outcome of the feasibility assessment.

2.1.2 Appraising demand

Closely related to site selection is the determination of demand for a service provided by a technology or other service options. Demand appraisal for sample locations often feeds into the broader market assessment described in section 2.1.5. Determining demand technically is done through assessing the kWh/day and kW peak demand required by an application and through incorporating an integrated energy/services approach in which attempts are made to supply electricity inefficient services by more efficient or more highly prioritised energy or service options. However, the technical demand required by an application is highly influenced by its costs and perceived benefits to the potential user. This interdependence is often difficult to specify as it means assessing the willingness to pay for a service in order to model the technical demand incurred by the service. There can be many reasons why willingness to pay can be tricky to assess: people might not want to part with information about their income, as they might think this could reduce their chance of obtaining support. Some household members would not know how much others earn. Income can also be irregular. Committing to being willing to pay for one service option might carry the fear that another service option, perceived to be superior, might not be provided. Clarifying grid extension plans, discussing different options and their financing packages will be a sometimes lengthy but necessary process. In addition, enumerators employed in a local survey and trained in the technology option can often disseminate information effectively about the services offered and the related financial packages.

Appraising demand on a larger regional or even national level becomes more uncertain and in many cases more expensive the larger the region to be covered in the demand analysis (see also section 2.1.5 on market assessment). Often a mixture of interpreting information from databases and from random spot surveys will contribute to forming a regional picture of demand and willingness or ability to pay for service.

In many cases, factors influencing demand and income levels are of general interest and attempts are made to model these to obtain an impression of future growth patterns for demand and income. Often previous experiences in other locations with similar conditions and service provisions are studied and used to help extrapolate demand and income patterns for a particular site. However, care should be taken to incorporate the situation and condition of a particular location using local data from interviews if available.

In appraising demand, the following factors should be investigated adequately:

- General needs, not only need for electricity, but also for water, health, education and other services.
- Potential power and energy requirements for different levels of service provision.
- Necessary additional infrastructure required and the associated costs.
- Options to supply electricity needs, estimate the associated costs and propose financial packages.
- Relation of cost per service and willingness to pay for the service.
- Reassessment of power and energy requirements based on estimated willingness to pay, recalculation of necessary financial packages and re-discussion of options.

2.1.3 Appraising constraints

Having analysed demand for potential sites or regions, it is also important to consider constraining factors that might impact on the success and sustainability of a project. These may include:

- Infrastructure constraints (insufficient infrastructure, insufficient resources to expand infrastructure adequately).
- Insufficient resources for participation.
- Land ownership issues.
- Political stability in a region.
- The amount of future migration.
- Uncertain grid extension plans.
- Insufficient system operation, management and maintenance resources and services.
- Insufficient resources or work on monitoring and evaluation.
- Insufficient financial backing (whether from a financing institution or the users themselves).

Such constraints need to be considered and discussed at length with the roleplayers involved. In some cases, ways might be found to address the constraints. In other cases, however, some constraints might be too overwhelming to carry out a project. No generally valid recommendations can be given as what type of constraint would make a project unviable or not. Constraints should be acknowledged with an open mind and discussed with the roleplayers concerned. In addition, often a cost/benefit analysis, roughly weighing the financial resources against the provided services, is utilised in deciding whether the constraints will weigh too heavily against the success of the project for the project to be recommended. A combined cost/benefit analysis with a qualitative discussion of the relevant social issues can help to facilitate and support the decision. However, the latter will most likely form part of the more detailed planning process, at least if a more detailed level of cost/benefit analysis is done that includes a qualitative analysis of social and environmental constraints for a location and the overall weighting of different factors. Where such an analysis is placed, whether in the feasibility or the planning process, depends largely on available resources. Often a feasibility assessment would benefit from such a detailed analysis. However, often only rough estimates are carried

out in order to decide whether or not to go ahead with planning. Cost-benefit analysis is discussed in more detail in the planning sections.

2.1.4 Appraising resources

Assessment of resources can integrate demand assessment and the analysis of constraints for a project. In general the different appraisal steps are connected. Evaluating resources of a site, several locations or even regions encompasses some of the following factors:

- What are the (renewable) energy sources of the region? Is it a coastal area? Is the solar radiation level quite high? Are there water resources?
- What existing services and infrastructure exist and how can they be accessed (for example, water, education and health)?
- What access does the community/region have to hardware? To support? To finance? To markets?
- What is the availability of technical/management/entrepreneurial skills? What resources exist for training? Can project champions be identified?
- What is the level of disposable income? Willingness to pay for the particular service?
- What is the level of industry products and support available?
- What institutional skills and resources are available (for example, for tendering and monitoring)?

It seems the more of each of these resources is available, the better. However, more specific criteria in assessing resources can be similar to those in Table 5. Criteria in the table answered with 'yes' can indicate a potential promising project in terms of its resources. The criteria in Table 5 are ranked in order of importance.

Table 5: Facilitation of resource identification

<i>Policy recommendation: Promising resources for a hybrid system project</i>	
Weather resources	Is the region in question a coastal/wind intensive area and/or a radiation intensive inland area?
Financial resources	Is the present expenditure and willingness to pay on energy services high enough to cover the payments for a financial package of the pilot project? Are people wanting the service provided by the pilot project and are they willing to pay deposits and fees? Is a body committing itself to finance infrastructure requirements, such as subsidies on interest rates, lobbying for lifting import taxes on relevant equipment, training requirements, facilitation of user feedback, testing of equipment and monitoring? Is an institution committing itself to supporting a revolving financial fund?
Implementation resources	Is an institution committing itself to carrying out a reliable tendering process? Is an institution committing itself to supporting the provision of relevant training sensibly? Is an institution committing itself to developing standards and testing equipment for the pilot projects? Is an institution committing itself to supporting the monitoring and evaluation of the projects reliably? Is available industry committed to deliver low-cost, reliable system hardware with after-sales services?
Local skill resources	Are committed people available locally that can be trained to manage the project and install, operate and maintain the system?
Business development support resources	Is an experienced institution committing itself to supporting the development of a business plan for the project?

Infrastructure resources	Is water accessible in the community/near the site? Are health services accessible within the community? Is the community accessible under all weather conditions?
Local administrative resources	Is there a committed support infrastructure available in terms of advice desks, system failure assessment and continued training?

2.1.5 Market assessment: feasibility assessment versus design planning: a chicken and egg situation?

A market assessment is often carried out to estimate whether certain regions are likely to procure several projects of a similar nature, with similar hardware and management requirements, in the foreseeable future. Often decision-makers are interested in this bigger picture of how many packages of an option can be absorbed in an area, region or nation as opposed to just equipping one project with hardware and infrastructure while no other sales will be expected.

Determining the amount of absorption depends on data that can be collected from existing research and databases, but it also depends on specific needs and circumstances of the people targeted as customers. The assessment of sites, resources, demand and constraints input into such a market assessment. Market assessment can also inform site selection processes.

Data that cannot be gained on a national or regional level from existing research or databases will have to be acquired through sampling demand potential, resources and constraints for different locations and then weighing and extrapolating the obtained data into a more regional and generalised market trend estimate.

This form of data needs to be acquired in the form of surveys and discussions. It is very difficult to carry out surveys for a nation unless one is prepared to spend tremendous amounts of money. In most cases developing a market demand analysis will require all of the following:

- Determination of national grid electrification plans, or at least for the location in question, for the next five, 10 and 20 years (see Figure 2 for status of electrification in 1995 and 1996).
- Determination of nation-wide status of service infrastructure and product availability.
- Determination of infrastructure costs still to be incurred.
- A number of random surveys across regions of interest.
- Worst/medium/best scenario development for different financing packages (that might include different levels of subsidies) and demand levels.

Such estimates can rough at first, and be made more accurate in later planning. To clarify the last point, two extreme rationales when assessing a potential market that are often brought forward are discussed here briefly:

- Assessing the market potential of a technology using conceptual parameters before deciding to go forward with it.
- Assessing relevant designs and financial packages and surveyed demand data and using the results for a comprehensive market assessment.

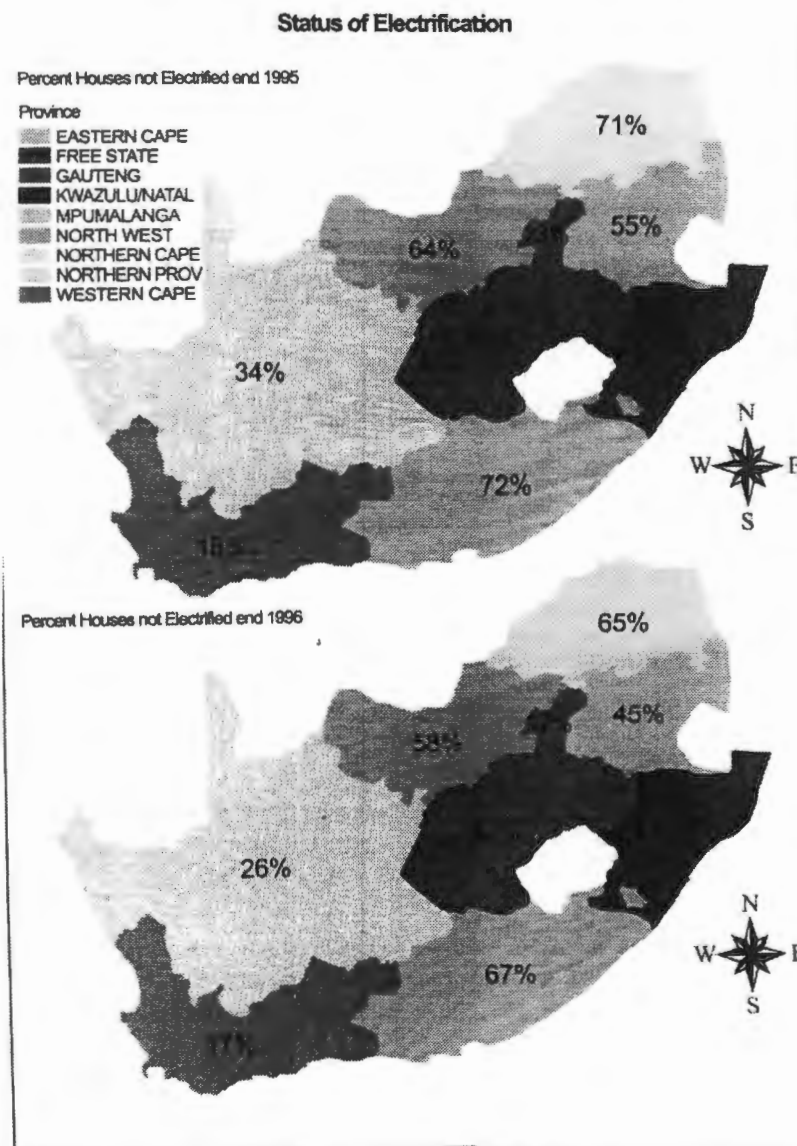
The situation can be broadly compared with trying to obtain a quote from an architect about whether a desired type of construction work will stay within a particular budget. A potential client would like a yes/no answer from the architect to decide whether to go ahead with the construction planning and the employment of the architect herself. However, the architect in this process needs to carry out a complete technical, environmental and social design suitable to the clients' needs, requiring enumeration, before being able to calculate a quote. The client presumably had only wanted a quick low-budget yes/no answer with no design costs involved.

Similarly, with assessing markets and designs, wanting an answer to the question 'Is there a market for the technology?' requires in-depth design and surveying work.

Often it can be suitable to carry out a rough market estimate, compiling data on disposable income, number of potential users, amount of subsidies, number of applications, rough cost estimates of applications and an estimate on a possible financing package. A step like this could be a component in deciding whether to go ahead with a more detailed analysis. The more detailed analysis would involve a more accurate analysis of the applications including roleplayer interviews and discussions, suitable service options and their costs, and the demand for these services as related to type of financing available and the extent to which this meets needs. The evaluation outcome can then be used for a broader market assessment, bearing in mind that the necessary use of local data in a more general analysis might be limited, meaning the estimates have to be considered carefully. For this reason the broader market assessment should include more needs assessments and user feedback.

Section 2.2 on planning outlines steps in devising options for implementation. Such planning exercises can also be carried out for market assessment purposes if enough resources are available to do so.

Figure 2: Status of Electrification 1995 and 1996 (NER 1997)



No such market analysis was carried out within the EDRC-based hybrid systems project. However, as can be seen from the Table 6, areas where hybrid systems could make an impact are Eastern Cape and Kwazulu-Natal. Northern Province and Mpumalanga would be suitable provinces for hybrid system implementations but there are tentative plans by Eskom to grid electrify these areas soon.

As can be seen from the table, disposable income in areas such as former Eastern Cape and Kwazulu-Natal is quite low and therefore rural services other than household lighting and TV/radio might require an increased level of subsidy or a combination with an income/wealth generating entrepreneurial development programme. Such a programme needs to be supported on a national basis. More detailed market assessment is required for specific feasibility assessments or planning exercises.

Table 6: Market parameters (Source: Hochmuth 1996)

Region (rural data)	Amount of electrification (%, 1995)	Grid connection costs (95)	Monthly ave. spent on fuel (95)	Average monthly Income (95)	Monthly expenditure (95)	Population (‘000) (95)	Yearly global Irradiation Whm²/day	Demand?
<i>Eastern Cape</i>	almost entirely unelectrified (6%)	(R4 397)	high (R42)	moderate (R670)	low R692	Large population (4 475)	4 500–5 500	low disposable income, some coastlines
<i>Kwazulu-Natal</i>	small, dispersed HH (14%)	very high (R5 055)	very high (R77)	low (R874)	R1 159	Very large (5 186)	4 500–5 000	low disposable income, some coastlines
<i>Mpumalanga</i>	densely clustered villages (37%)	low (R2 653)	(R59)	high, affluent communities (R1 818)	(R1 256)	High population density (2 081)	5 000–5 500	dense settlements, some disposable income, grid
<i>Free State</i>	Mainly farms, whose majority will not be electrified (33%)	high (R4 088)	R41	high (R1 649)	R969	1 300, mainly white established farmers, many farmworkers	5 500–6 000	high, need interaction farmers – farmworkers
<i>Western Cape</i>	(88%) only very few spots not electrified, few rural areas							only few good wind regimes areas along coast
<i>Northern Cape</i>	Large portion electrified (47%)	high (R4 437)	low (R27)	(R1 099)	(R826)	Not very large (263)	good solar irradiation, 5 500–6 500	
<i>Regions not likely to be chosen for pilot projects:</i>								
<i>North West</i>	21%, but will to be extensively electrified	R3063	R54	R1194	R1 083	2 440	5 000–6 000	will be grid connected
<i>Northern Province</i>	24%	R3 010	R42	low, R743	R835	4 661	5 000–5 500	will be grid electrified

2.1.6 Summary

The feasibility assessment for which some contributing steps were outlined in the last sections is a decisive part in project development. A feasibility analysis can be carried out for a particular site or be used to actually select 'feasible looking' sites in a certain region. It was said that the selection of a site or region is often a sensitive and politically-charged issue. The analysis of resources, demand, constraints and market potential were described separately but it was mentioned that they are very much related. Demand needs to be seen in relation with the resources accessible by the project, the site, potential users, relevant institutions etc. Demand assessments from different sampled regions can feed into a broader market estimate. Often the technical demand assessment in terms of power and energy requirements of an identified application will be a 'looping' process, identifying financial requirements of an application and feeding back discussions and experiences around willingness to pay into the design process. A lack of resources can be a constraint to the project as can be other factors.

It can be deduced that a careful community interaction and participation process is essential for yielding conclusive results of the feasibility assessment. However, a detailed participation processes requires time and funds, so much so that, in the case of larger regional feasibility assessments, these are often reduced or taken out altogether. It is recommended that regional assessments use as much locally-surveyed data as possible. Most of the steps of a feasibility assessment could be roughly estimated during the feasibility phase and carried out later in more detail during the planning phase, depending on the resources available.

2.2 Planning

Some of the planning process could be part of the feasibility assessment. For example, when deciding on financial packages and establishing the demand for a service, the detailed planning steps as outlined in this section can be used as part of the feasibility assessment. However, it is also important that once the feasibility of a site or region is determined, the project is planned in detail for a particular application. This might have been already carried out in a feasibility assessment if it was very much focused on a specific community and carried out in great detail. In other cases, the feasibility assessment might be a very rough analysis requiring more detailed planning later.

The following sections describe the contributing steps of the planning process. User interaction and discussions are assumed with regard to the users' needs, priorities and willingness to pay in all the following sections when mentioning data on demand, load profiles and particular financing packages. The described data is taken to obtain a design and finance proposal which then has to be redefined according to needs and levels of comfort expressed in user and other role player discussions. The actual techno-economic design based on the collected data and the redefining and adjusting process are described in more detail in section 2.1.5. In many cases the desired user involvement process to adjust technology design might become neglected due to financial constraints in the planning of the project. Even then, obtaining as much local information and feedback as possible needs to be made a priority within the financial constraints for the planning and design process.

2.2.1 Costs and benefits in determining electrification options

Determining the required service and its load profile is the first step to design an appropriate rural technology option. This can be a very difficult assignment, especially in areas where no prior experience in using electricity exists. It is also a resources-intensive, but important, task to survey and discuss service requirements with potential users. The better the information available on load requirements and general constraints, the better an initial cost-benefit analysis for different off-grid/hybrid service options can be carried out.

The costs of providing the required electricity service have to be assessed for the different available technology options. The provision of electricity will also produce benefits such as income generation and improved standards of living.

In designing remote area power supply systems (RAPS), there is a need to trade off costs and benefits. The costs and benefits of a RAPS system depend on the design of the system and the type of application. Over-designing a system ensures a low probability of loss of load, that is, a high level of reliability or a large number of services offered, but causes an excessive capital cost. Under-designing a system minimises the capital cost but allows frequent loss of load and decreases potential services and supply reliability. Loss of load might not matter in some cases, depending on the application, but in others it might cause significant problems.

Benefits can include measurable impacts such as an increase in income from a particular project or improved health services offered. Other benefits are often more difficult to assess – for example, improved access to services, satisfaction gained from having a service or indirect effects such as stimulated growth, income and wealth generation. Such benefits or impacts should be analysed in a discussion paper apart from a very mathematical cost/benefit analysis. Similarly, external costs can arise, not showing up on project cash flow sheets, but noticeable at some point for somebody – for example, costs for removing pollution and reforestation. Again, it is difficult to account for and model these external cost estimates.

Because of the difficulty of defining benefits, these are often treated in terms of quantifying system reliability and counting income generated from the particular project. That means the designer will select a threshold for reliability and then develop a least-cost system for that threshold. In a more detailed cost study, costs can be also traded off against offered system reliability. The income generation stimulated by the particular project is then estimated in the financial project analysis.

The net present value (NPV) of costs and NPV of benefits can be combined into a single measure of worth for the design process. The objective is then to either maximise or minimise the developed measure of worth to obtain a recommendable design. Often computer simulations have to be used for that process due to the design complexities involved (Marrison & Seeling-Hochmuth 1997). Such simulations balance operational and financial performance of the systems under investigation

2.2.2 Techno-financial design

2.2.2.1 The need for a sophisticated design process

Even though the technical part is a small piece of the overall implementation puzzle, it is still important that the design be carried out adequately. The design can constitute:

- Full technical design for a researched application, demand and financial resources.
- Limited design of a pre-packaged system whose package size needs to be determined to fit application, demand and financial resources.

A full design is recommendable, especially in a pilot phase. Cost pressures could lead to only handling pre-packaged systems because they consist of a limited number of components in only a number of sizes, thereby saving on design costs, enabling economy-of-scale savings, easing the stocking of spare parts and the provision of maintenance services. However, it is important that before packaged systems are employed, appropriate package sizes have been tested and discussed with communities, users and owners.

The quantification of the NPV of costs and benefits of the electrification service can be used to optimise or guide the selection and the design of the electrification technology option² (Marrison & Seeling-Hochmuth 1997; Seeling-Hochmuth 1997a, 1997b, 1997c).

For industrial revenue generating applications, it is generally possible to describe the benefits of a reliable electricity supply in techno-financial terms to a large degree. This can be done in terms of the price that the commercial application is willing to pay to obtain reliable power,

² Corresponding design software (Hybrid Designer) has been developed at the EDRC with support from the DME

which in turn is influenced by the operating revenues. The effects of an unreliable electricity supply can be quantified by the economic loss, of revenues for example, or by the expense of installing back-up systems.

For domestic 'quality of life' applications, the quantification of benefits of a reliable system supply can become more complicated as it involves determining how much the users estimate they are willing to pay (Hochmuth 1996; Seeling-Hochmuth 1996) for a certain degree of reliability. In general, the benefit should increase with the total amount of energy supplied but with a decreasing marginal benefit. The benefit should also increase with the reliability of the supply.

Generally, it can be said that benefits have to be measured and discussed on an ongoing basis with the potential users and considered in the techno-economical analysis. Often technical design and user feedback are distinct and different phases due to the desire to use resources efficiently. For this reason, preliminary planning is carried out based on preliminary user data, and the design and financing is adjusted with feedback from the users.

Due to increased demands on design and project management, pilot project implementations can be more expensive than more commercialised implementations in many cases. Nevertheless it is important that the pilot implementations are carried out to pre-test this new technology by planners, implementers and users if it is required to improve the process. It is also necessary to carry out the pilot projects in clusters – only one pilot project may fail due to difficulties in providing maintenance, monitoring and repair infrastructure for just a single remote project. An experience of failure in a single pilot can lead to a bad name for the technology.

2.2.2.2 Principles of software design

Hybrid systems can be designed using trial and error approaches, rule-of-thumb methods or spreadsheet analysis. However, these methods are not very accurate, especially regarding operational requirements and performance of a hybrid system. Software tools can simulate a given hybrid system and help in analysing its performance. A proper optimisation software tool such as Hybrid Designer, developed for the EDRC hybrid project, can optimise the system configuration, the sizing and the operation control. This enables a faster, more accurate design process than manual methods alone or manual methods supported by software performance analysis that has to be repeated a substantial number of times.

The developed software-based design strategy in Hybrid Designer sizes a hybrid system for a stated electricity demand and for given site conditions using renewable energy sources as well as storage elements and fuel or gas powered generators. The design also incorporates choosing a suitable system operating strategy. The inputs to the design tool are demand and site conditions like weather resources, costs and available sizes of components, costs of transport and labour, and specification of component characteristics.

The cost function consists of the present values of purchase costs and operating costs (Figure 3-1). It is minimised by an optimisation routine that uses genetic algorithms. During the minimisation the values of the component sizes and choice of operating strategy are changed according to the optimisation strategy until the design converges to the least-cost and best performance system (Figure 3-2).

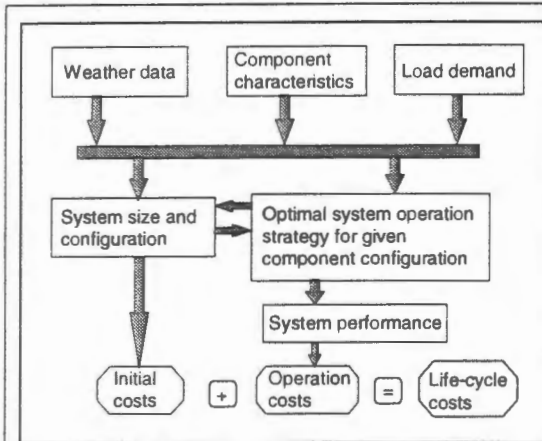


Figure 3-1: Interdependence between system sizing and operation

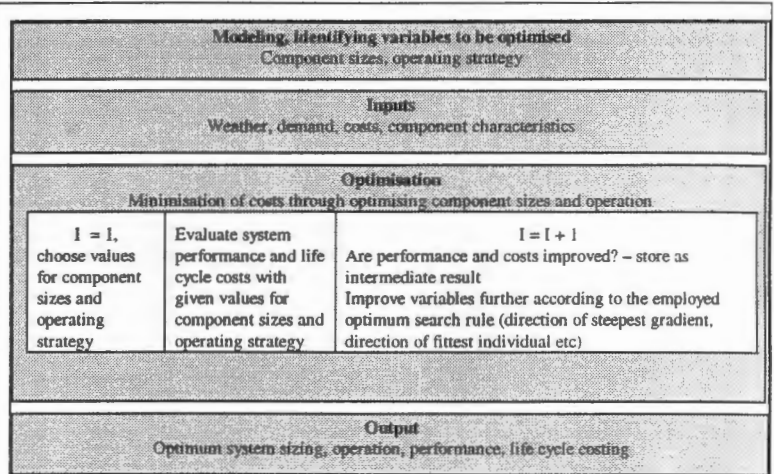


Figure 3-2: Optimisation of hybrid system costing, sizing and system performance

The operating costs consist of discounted costs for fuel consumption, overhaul and maintenance, and replacement of equipment. These costs depend on how the equipment is operated and what equipment sizes are installed. The equipment costs depend also on how the system is operated because this influences the required sizing of the equipment. The system performance is measured by the overall system efficiency, that is, energy supplied over energy generated, by the difference between electricity demanded and electricity supplied, and by the average diesel capacity factor and average battery cycling ratio. A penalty or cost is introduced in the cost function when the demand is not covered. Oversupply of electricity is dumped to secondary loads like heating elements. A penalty for oversupply is reflected in the electricity generating costs.

The algorithm then provides numerical results and graphic displays. The output files store the values of component sizes, operating strategies and system performance. The diagrams display the sizes and numbers required of each component type with the corresponding costing. The life cycle costing is given for each equipment type and for fuel consumption separately. In addition, the operating time series are given for all relevant operating parameters such as battery current, battery state of charge, diesel output power, renewable energy outputs, wasted electricity or not covered demand and component efficiencies and switch positions.

2.2.2.3 Financial analysis

When making decisions regarding the electrification of a rural area the following need to be assessed:

- Different technology options.
- Possible financial packages.
- The willingness to pay for different options.
- The corresponding cash flows.

The difficulty in doing this lies in:

- the different services and cost per services offered by the different technologies which also influences the initial user demand for a connection to such a technology
- the initial consumption rate as well as future variations in demand for a connection and in demand per connection.

One rationale which can be followed is assigning different technology options for a given load profile, calculating the corresponding cash flows based on people’s expressed willingness to pay, then comparing the technologies and obtaining feedback from user groups.

However, because the technologies are different, the demand and take-up rates will also be different. Therefore the other approach is estimating the load demand given a certain technology and the demand for a connection to this particular technology, including the likely growth patterns, with the input of relevant user groups. Then the financial cash flows can be calculated and compared. Based on the cash flow analysis, decision ranges can be identified which will enable planners to make informed proposals and hold informed discussions with customers as about which technology is useful for a certain electrification project.

Summarising, it can be said that both rationales need to be considered in a unified approach. When an application and its load profile has been identified, determine different options that can serve it, compile a number of financing packages³ that seem feasible for the options, estimate the actual load demand for a certain option including the likely growth patterns, calculate corresponding cash flows and impacts, and then compare the options and obtain feedback for refinements from the users.

It can be seen any such approach needs data to back up its estimates of

- Cost/service of a technology.
- Demand for a technology.
- Growth in demand for a technology (that is, for its service as well as its percentage of penetration in an area).

This requires:

- Setting up and user discussion of different financing packages.
- Trend analysis before and after introducing the technology of other regions with similar characteristics, and extrapolating analysis onto similar regions
- Surveys in targeted areas regarding disposable income for the service, the attitude towards the technology, need and demand for the service and other factors.

It needs to be noted that the set up of the financing packages will influence outcomes of trend analysis and survey analysis as they impact on the demand for a service option. Therefore the financial analysis needs to have clear sensitivity scenarios for different financing packages, demand scenarios and future growth developments, among other factors.

The determination of financial packages and the financial analysis need to be carried out in connection with an integrated services and energy planning approach, as some energy or other services options are of higher priorities or cheaper to the user, thereby influencing the demand/affordability picture. The financial analysis will compile initial and future discounted operation costs as well as future discounted revenues to determine whether the given project will break even at all or early enough to implement the project and repay money borrowed from financial institutions or markets. Examples of techno-financial analysis for household and school/clinic electrification are given in the Appendix A of this report.

Findings (Appendix A, EDRC report 'Policy guidelines for implementing off-grid hybrid electricity support systems to support productive activities in rural areas', EDRC report 'Hybrid systems project: demand and cost-benefit analysis') of the EDRC-based hybrid project have shown that

- Off-grid systems seem a more cost-effective choice than grid extension in remote areas with low household consumption take-ups and specific power requirements between 2kW_p and 100kW_p (4kWh/day–500kWh/day) The type of off-grid technology, whether single source or hybrid systems, will depend on the application.

³ 'Financing package' here refers to the amount of deposit, monthly instalments and length of payback period that users have to commit themselves to and that can cover at least life cycle/operation costs and cost of finance.

- Mini-grids powered by hybrid or diesel systems are cost-effective for dense housing, an attractive tariff package and sufficient user demand.
- Hybrid systems are cost-effective for peaky demand profiles, complementary renewable energy resources and long hours of electricity demand per day.
- Wind hybrid systems are recommendable along the coastal areas (wind speeds >3m/s), PV hybrid systems in inland areas (solar radiation >4 500Whm²/day). The systems can have a PV share and a wind turbine share.
- Off-grid/hybrid system options are especially viable where an integrated service provision is taking place and where vendors are supported with, and are supporting, an integrated product provision infrastructure.

Some very general recommendations are given in Table 7, extrapolated from the work in Appendix A of this document and work by Kailasanathan 1998. However, optimising the techno-financial design for an user application should still be done for each project individually.

Table 7: Design recommendations

<i>Policy recommendation: Choice of technology for a hybrid system project</i>	
<i>Coastal areas:</i> Wind/battery Wind/PV/battery Wind/diesel/battery	<i>Use of diesel generator if:</i> High reliability of electricity supply required The required diesel generator runtime per day is short and the required diesel generator output is relatively constant
<i>Radiation intensive inland areas:</i> PV/diesel/battery	Certain loads can only be powered by a diesel generator Detailed techno-financial design recommends a diesel generator

2.2.3 Sustainability of a hybrid system implementation

A technology/service option needs to fit priority needs, whether in terms of social equity needs or in terms of what people are willing to buy. It is important that expressed and prioritised needs are accommodated in order to achieve an acceptance of a technology/option (whether in terms of fulfilling social equity needs or in terms of gaining market shares). At the same time, the sustainability of a technology / option is important. This includes whether a service can be provided on a long-term basis, and whether people will be able to subscribe to it sustainably.

In this regard, the following questions should be addressed

- Is the service option suitable?
- Is the infrastructure sufficient?
- What are the socio-economic impacts?
- Is there a market?

2.2.3.1 Suitable designs

A suitable design is often a trade-off between needs and available finance. For this reason, important aspects of designing a service option are often not the technical specifications but whether the potential users/customers are able to feel that the service is acceptable and useful to them. This requires user-oriented interviews and meetings as well as follow-up evaluations and help desks, and reliable operation and maintenance services.

2.2.3.2 Sufficient infrastructure

A service requires a certain amount of infrastructure to be effective and sustainable. It needs to be assessed and discussed with the potential users/clients as well as participating institutions

whether the existing infrastructure is sufficient, or whether it needs improvements first before the provision of the service in question will be rendered useful.

2.2.3.3 Socio-economic impacts

Any impacts of a service are difficult to assess and forecasting of future impacts is subject to estimates. Some analysts recommend very short-term estimates of 2–3 years, because technology is changing fast. Any sustainable impact from a service requires that a number of other services or conditions are in place, which are difficult to specify and difficult to reproduce from location to location. This should be kept in mind when implementing a service option to achieve a particular impact. Therefore impacts such as an increase in social equity, income or wealth generation need to be evaluated carefully and in an integrated participatory manner.

2.2.3.4 Market sustainability

A final planning check will be to see whether the targeted suitability of the design, sufficiency of the planned infrastructure and relevance of socio-economic impacts will also support the sustainability of the envisaged market. However, it will be difficult to plan the sustainability of a market with certainty. Estimates will have to suffice and a thorough evaluation and monitoring procedure has to be designed addressing the technical, socio-economic and market factors.

2.2.4 Summary

The planning phase is essential for working out appropriate designs, financial packages, training requirements and long-term management structures for the identified and discussed needs. Liaison with users and roleplayers is of paramount importance. The designed systems will often have to be integrated if necessary with other technology, energy or service options.

The costs/service provision of the different technology and service options are determined in the planning phase, as well as how the cost and the offered service affects demand. An assessment is also necessary regarding what kind of financial packages will be suitable in terms of the costs which arise and the willingness of people to pay. In addition, the type of infrastructure in place, or which must be established, is appraised during the planning phase, including requirements such as training and general support. The principal question that will have to be answered is whether the skills and resources necessary for the project can be made available, and in such a way that the project can run sustainably and provide the required services adequately in the long-term.

Aspects of the planning phase can be covered in the feasibility assessment or can even become pre-installation steps. Whether the steps described under planning can already be carried out during the feasibility phase is often a matter of available resources. The planning needs to accommodate the objectives of different roleplayers and find a compromise between expectations and resources. The evaluation of the longer-term impacts and performance of the technology, service provision, infrastructure, market and other aspects needs to be an integrated part of the planning process.

2.3 Implementation

2.3.1 Pre-installation phase

After planning a project it is often necessary to go back to the potential clients and roleplayers and refine the overall planning, design, financing and management of the project. It is also necessary to do a detailed field design at this point, including specifications of wiring sizes and equipment. A circuit diagram needs to be worked out and lighting and surge protection features need to be detailed. Selection of the installation site at the location is also required. Getting local building plans and maps is a good idea if they are not already available.

Having verified and finalised the designs and financial packages, it is necessary to agree on follow-up obligations. An implementation time schedule needs to be set up and agreed upon to guarantee timely and smooth installation and system operation. It has to include the

procurement time frame, testing of standards and communication and feedback procedures as well as the actual implementation steps and their timing. Operation, maintenance and emergency procedures need to be developed and project support procedures need to be finalised.

Discussions with the users need to be continued or renewed and contracts have to be agreed upon. Any earlier promised support has to be finalised and a detailed tendering procedure should be entered in accordance to tested national standards. Selection of people who will be responsible for the administration, implementation and maintenance of the programme need to be prepared and finalised. Training needs to be prepared and started according to the identified training and awareness needs

Moving closer to the implementation stage, it can be useful to verify and update the implementation schedule.

2.3.2 Installation

The actual implementation should be well planned. All equipment, tools, and transport should be ready and in good condition and the specialised people required for installation and operation should be available and trained. In addition, in many cases it has proven useful to start training users already during the installation phase. Holz (1998) compiled a well-written list of essential installation, operation and safety procedures that have been gathered from hybrid system installations around the world. Some of his recommendations are listed here. For more detail the reader is referred to his chapters in Green, Seeling-Hochmuth, Flowers 1998).

When installing a hybrid system:

- Think safety first.
- Be well prepared.
- Co-ordinate all installation work.
- Develop site plan and site specifications.
- Use environment-friendly practices and materials when possible.

In terms of site accessibility, it is important to know:

- What size of truck or special equipment can be taken to the site?
- Can a truck be hired somewhere at reasonable cost?
- Does site access depend on weather conditions?
- How close is the site to a major population centre?

Getting equipment through customs often requires time and knowing the 'tricks of the trade', so being well prepared can save time. Inspect the equipment before taking it to the site, preferably by testing its operation. Equipment in hybrid systems can be easily damaged, so careful handling is necessary.

Special care needs to be employed when installing wind turbine towers. The tower installation procedures need to be carried out carefully to be safe and to yield a robust set-up with efficient energy outputs. Similarly the installation of PV mounts has to be worked out carefully. Engine generators need an appropriate site with ventilation, as do batteries, The storage of fuel has to be safe to prevent accidents with spilled fuels. The installation process is a good opportunity to employ and train local people in installing and operating the technology. Metering and monitoring equipment needs to be installed and tested. The overall system performance has to be tested before commissioning and handing over the system. The installation should be followed by final training workshops.

2.3.3 Operation and maintenance

The following items need to stay with the installed system:

- O&M manual.
- O&M logbook.
- Spare parts inventory.

The manual should contain start-up and shut-down procedures and other operational information. Data collection procedures at the site are important especially for monitoring the system performance. A proper maintenance schedule needs to be kept and be ready by the local maintenance person for inspection by an outside maintenance company. Similarly, trouble shooting and repair tables need to be kept for inspections. Proper tools and safety equipment is essential and need to be available for maintenance. Remote operations monitoring can help reduce the need for outside maintenance personnel to drive out and check for reported system failures as telephone directions could be given to someone on site on how to correct a certain system failure.

Experience in operation and maintenance of renewable energy systems in South Africa shows that the users of a small renewable system often do not receive enough training to be able to maintain the system. In addition, in some cases there may be no regular professional maintenance service organised. Established farms using diesel generator or hybrid systems are often given a lot of information on how to maintain and operate their system and improve its performance. Many farmers try following these guidelines. It seems that the best maintenance results and electricity theft reductions are obtained when the users and community feel a sense of ownership and responsibility for the system, including their involvement in its planning and operation. Therefore, training of local users and recruiting technicians from the local community is important. Another point that was considered important in the PV school electrification programme is to have clustered projects so that these can create a full-time job for a maintenance person, which contributes to creating a reliable maintenance infrastructure. Running single and isolated projects might contribute to a failure of the overall programme. Projects with similar service and maintenance needs (such as clinic or school PV systems) should also be clustered.

Table 8

<i>Policy recommendation: Installation and operation of a hybrid system project</i>
<p>Contract awarded to tendering industry and technicians with best mix of:</p> <ul style="list-style-type: none"> • Project management skills. • Good and experienced skills of communication. • Adherence to defined technical standards. • Good technical implementation skills. • Good warranty specifications. • Monitoring skills.

2.3.4 Project support, monitoring and follow-up

After the installation of the system and training in its operation, there is still a need for ongoing support, monitoring and follow-up processes. Apart from the local technician(s), another contractor might be required to check the system and the set up processes regularly. The project might need ongoing support in business management. There might be problems associated with theft and vandalism that have to be dealt with. Users might need more information on, for example, which appliances use what amount of energy and how problems with the metering system can be addressed. The financial bookkeeping requires updating, fees need to be collected, spare parts need to be ordered, repairs carried out and any emergencies, difficulties or unclarities, whether technical or non-technical, need to be dealt with. During the project

follow-up, technical and socio-economic monitoring and evaluation should take place assessing what kind of lessons can be learnt and what kind of impacts could be observed. The evaluations and experiences should be fed into national and other planning activities.

2.3.5 Summary

Pre-installation planning, installation, operation and maintenance, and monitoring and follow-up are part of the practical project implementation after all the feasibility assessment and planning has taken place. It is important that all these phases are well thought through and planned in detail with all roleplayers, especially local participation and local management personnel, whether in business, administration, maintenance or any other occupation. It is recommended that the evaluation of project impacts be funded to be able to draw lessons from the projects and disseminate them.

3 Conclusions and recommendations

The experience with hybrid systems is very limited and little information exists so far on their performance or impact. However, they have been installed all over the world and have been put to use for the fuel saving operation of off-grid systems, supplying domestic use of electricity and also powering some productive activities associated with income generation or improved health and education. It seems that accompanying factors such as the infrastructure provision, training, type of financial arrangements and user involvement may even be more important than the technology itself. Off-grid technology dissemination in South Africa has been hampered so far by unclear grid extension plans, a lack of clearly defined rural electrification responsibilities and unclear distribution criteria for rural electrification funds. In addition, other than for large commercial farms or tourist resorts, the cost of providing rural grid electricity will typically not be recoverable in the near or even longer-term future as consumption take-up in many areas is very low and is not expected to change much in future. Nevertheless rural grid electricity is presently offered with very low connection fees and rates per kWh consumed.

The possibility is under discussion that Eskom's distribution might be split up into regional electricity distributors (REDs), in addition to the other existing regional distributors which mainly serve urban areas. In this context, the development of a national electrification policy that will address the functions and roles of respective players and how electrification should be funded is desirable. This should include the establishment of criteria for the prioritisation and allocation of funding for grid and non-grid electrification. A national body, such as the National Electricity Regulator (NER) or a national electricity funding body, can then administer funding to competing REDs for projects that meet the defined criteria. The criteria will include whether the chosen technology option and approach for the project has the ability to sustainably contain costs, meet regional needs and increase socio-economic productivity. There is also a desire to link the electrification projects with other infrastructure projects such as water and housing to optimise the deployment of national resources.

The main difference between the existing system and the future system is that whereas now electrification is being mainly pursued following micro-economic (Eskom's) interests, it will in future be driven by macro-economic interests which are much more complex and difficult to measure and control.

Eskom might be able to implement off-grid/hybrid technology options in future. So will other implementing agencies once a national electricity funding body is able to distribute funding for rural electrification by raising taxes and funds from Eskom's revenues and other sources. As new technologies can be implemented through the different electricity distributor agencies in future it is important to pilot new technologies such as hybrid systems.

Piloting is important and needs to be carried out in 'clusters'

Piloting new technologies is essential to gain experiences in their planning and implementation and assess impacts. The first pilot projects can be more expensive than more commercialised projects. It is important that the pilots are implemented well as project management failures can lead to a rejection of the technology whether it is a feasible technology or not. It is also important to pilot a number of projects in order to obtain appropriate maintenance support that might not be available or created for a small isolated project. The experience with hybrid systems is very limited indeed and little information exists so far on their performance or impact. However, they have been installed world-wide and have been put to use because of the fuel saving operation of off-grid systems, supplying domestic use of electricity and also powering some productive activities associated with income generation or improved health and education. Carefully planned strategies are important in implementing such new technologies. It seems that accompanying factors such as the infrastructure provision, training, type of financial arrangements and user involvement may even be more important than the technology itself. Piloting of off-grid and rural electrification technologies is starting in South Africa and has already brought forward useful observations and lessons. The piloting of hybrid systems should take into account what has been learnt, both nationally and internationally, and be well prepared in terms of the different technical, financial, social, economic, institutional and environmental facets involved.

Feasibility depends on resources and demand

Next to planning, pre-installation planning, implementation and follow-up, feasibility assessment, is a decisive part in project development. A feasibility analysis can be carried out for a particular site or be used to actually select a 'feasible looking' site in a certain region. It can be said that the selection of a site or region is often a sensitive and politically-charged issue. The analysis of resources, demand, constraints and market potential is often described separately but they are very much related. Demand needs to be seen in relation to the resources accessible to the project, the site, potential users, relevant institutions and other aspects. Demand assessments from different sampled regions can feed into a broader market estimate. Often the technical demand assessment in terms of power and energy requirements of an identified application will be a 'looping' process, identifying financial requirements of an application and feeding back discussions and experiences around willingness to pay into the design process. A lack of resources can be a constraint to the project as can other factors. It can be deduced that a careful community interaction and participation process is essential in yielding conclusive results of the feasibility assessment. However, a detailed participation processes requires time and funds which, for larger regional feasibility assessments, is often reduced substantially or omitted altogether. It is recommended that as much data locally surveyed on communities be used as possible. Most of the steps described in the feasibility assessment could be estimated roughly during the feasibility phase and investigated in more detail during the planning phase, depending on the resources available for feasibility analysis.

Planning is important in meeting resources and demand

The planning phase is essential in working out appropriate designs, financial packages, training requirements and long-term management structures for the identified and discussed needs. Liaison with users and roleplayers is of paramount importance. The designed systems will often have to be integrated if necessary with other technology, energy or service options. The costs/service provision of the different technology and service options are determined in the planning phase, as well as how the cost and the offered service affects demand. An assessment is also necessary regarding what kind of financial packages will be suitable in terms of the costs which arise and the willingness of people to pay. In addition, the type of infrastructure in place, or which must be established, is appraised during the planning phase, including requirements such as training and general support. The principal question that will have to be answered is whether the skills and resources necessary for the project can be made available and in such a

way that the project can run sustainably and provide the demanded services adequately in the long-term.

Aspects of the planning phase can be covered in the feasibility assessment or can even become pre-installation steps. Whether steps described under planning can already be carried out during the feasibility phase is often a matter of available resources. The planning needs to accommodate the different objectives of roleplayers and find a compromise between expectations and resources. The evaluation of the longer-term impacts and performance of the technology, service provision, infrastructure and market needs to be an integrated part of the planning process.

Implementation and operation needs trained and local personnel and reliable industry delivery

Pre-installation planning, installation, operation and maintenance, and monitoring and follow-up are part of the practical project implementation after all the feasibility assessment and planning has taken place. It is important that all these phases are well thought through and planned in detail with all roleplayers, especially local participation and local management personnel, whether in business, administration, maintenance or any other occupation. It is recommended that the evaluation of project impacts be funded to enable drawing lessons from the projects and disseminating them.

Sufficient resources for monitoring and evaluation of pilot projects are important

Monitoring of the pilot projects will aim to assess:

- User satisfaction.
- Technical performance.
- Financially sound operation.
- Industry operation.
- Institutional operation.
- Environmental and socio-economic impacts.
- Whether these factors can be achieved sustainably.

It is important that a piloted and potentially new technology is monitored in sufficient depth and evaluated adequately to gain insight into how suitable the technology is, and what aspects of the project approach can be improved and what should be changed.

The following sections summarise important factors in this process regarding the feasibility of a pilot project, steps that support the piloting process, relevant system designs, and resources needed in piloting new technology options.

Factors relevant for feasibility of a hybrid system project

Weather resources

- Is the region in question a coastal/wind intensive area and/or a radiation intensive inland area?

Financial resources

- Is the present expenditure and willingness to pay on energy services high enough to cover the payments for a financial package of the pilot project?
- Do people want the service to be provided by the pilot project and are they willing to pay deposits and fees?
- Has a body committed itself to finance infrastructure requirements, such as subsidies on interest rates, lobbying for lifting import taxes on relevant equipment, training requirements,

facilitation of user feedback, testing of equipment and monitoring?

- Has an institution committed itself to supporting a revolving financial fund?
- Does a cost/benefit analysis and socio-economic assessment indicate a viable project?

Implementation resources

- Has an institution committed itself to carrying out a reliable tendering process?
- Has an institution committed itself to supporting the provision of relevant training sensibly?
- Has an institution committed itself to developing standards and testing equipment for the pilot projects?
- Has an institution committed itself to supporting the monitoring and evaluation of the projects reliably?
- Is an industry available which is committed to deliver low-cost, reliable system hardware with after-sales services?

Local skill resources

- Are committed people available locally who can be trained to manage the project and install, operate and maintain the system?

Business development support resources

- Has an experienced institution committed itself to supporting the development of a business plan for the project?
- Is some economic activity in existence already?

Infrastructure resources

- Is water accessible in the community/near the site?
- Are health services accessible within the community?
- Is the community accessible under all weather conditions?
- Is existing infrastructure sufficient? If not, what additional infrastructure is required?
- Are people well organised in community groups?

Local administrative resources

- Is there a committed support infrastructure available in terms of advice desks, system failure assessment, continued training and others?
- Is there an interest expressed in the project?

Steps for support of pilot projects in order of necessity and importance

Framework

- Development of electricity provision framework for social equity and economic development needs.

Grid extension plans and off-grid decision criteria

- Determination of national grid electrification plans for the next five, 10 and 20 years.
- The development of criteria for non-grid technology selection at a national level.

Infrastructure

- Determination of nation-wide status of service infrastructure and product availability.
- Determination of infrastructure costs still to be incurred.

- Determination and dissemination of levels of subsidies (lifting import taxes and subsidising interest rates).
- Determination of whether/where/how to establish/subcontract/train local 'advice desks' that can carry out training and tendering, support planning and disseminate information.

Demand assessment

- Surveying of demand.

Sustainability

- Discussing and analysing the:
 - suitability of service
 - sufficiency of existing/planned infrastructure and cost of additional infrastructure
 - socio-economic impacts
 - factors affecting market sustainability.

Integration

- Linking electrification projects with other infrastructure projects such as water provision and others.

Financing and cost/benefit analysis

- Determination of integrated service options and corresponding financial packages. Clear sensitivity scenarios for different:
 - financing packages
 - demand scenarios
 - future growth scenarios.
- Worst/medium/best scenario development for different financing packages (that might include different levels of subsidies) and demand levels.

Assignment of responsibilities

- Determination of partners in financing, training and implementation and their terms of reference.

Standards and tendering

- Determination of standards for off-grid/hybrid systems.
- Determination of tendering procedures.

Monitoring and follow-up

- Determination of monitoring and evaluation procedures.

System designs

Findings of the EDRC-based hybrid project⁴ have shown that

- Off-grid systems seem a more cost-effective choice than grid extension in remote areas with low household consumption take-ups and specific power requirements between 2kW_p and 100kW_p (4kWh/day–500kWh/day) The type of system technology, whether single source or hybrid system, will depend on the application.
- Mini-grids powered by hybrid or diesel systems are cost-effective for dense housing, an attractive tariff package and sufficient user demand.
- Hybrid systems are cost-effective for peaky demand profiles, complementary renewable energy resources and long hours of electricity demand per day.
- Wind hybrid systems are recommendable along the coastal areas (wind speeds >3m/s), PV hybrid systems in inland areas (solar radiation >4 500Whm²/day). The systems can have a PV share and a wind turbine share respectively.
- Diesel hybrid systems make sense where:
 - A high reliability of electricity supply is required
 - The required diesel generator runtime/day is short and its required output is relatively constant
 - Certain loads can only be powered by a diesel generator
 - Detailed techno-financial design recommends a diesel generator.
- Off-grid/hybrid system options are especially viable where integrated service provision is taking place and with vendors who have an integrated product provision attitude.

However, optimising the techno-financial design for an user application should still be done for each project individually.

- Disposable income in areas such as Eastern Cape and Kwazulu-Natal is quite low and therefore rural services other than household lighting and TV/radio might require increased subsidies or a combination with an income/wealth generating entrepreneurial development programme. Such a programme needs to be supported nationally.

Resources needed

Resources are needed for:

- Determining grid extension plans and off-grid technology project selection criteria.
- Subsidising infrastructure (lifting import taxes and subsidising interest rates)
- Establishing advice desks (providing advice, administrative support, support in business plan development, facilitation, overlooking tendering procedure, disseminating information – for example, on available subsidies and support with design advice).
- Surveying and feasibility assessment processes.
- Facilitation of project planning and implementation.
- Facilitation of community/user group planning.
- Training (education in schools about renewable energy, education of technicians to install and operate RAPS systems, education of users, education of entrepreneurs, capacity

⁴ Appendix H: Kailasanathan, A. 1998. *Demand analysis and cost benefit analysis for hybrid systems*, EDRC report, University of Cape Town.

building and others).

- Defining and testing of standards.
- Capital grant contributions to pilot projects.
- Tendering procedures.
- Training.
- Monitoring and evaluation.

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5 Appendix A: Techno-financial assessment of different technology options for rural household and centralised electrification of schools, clinics, farms

5.1 Techno-financial comparison of household electrification with different technology options

5.1.1 Technology options for remote area power supply for households

Some integrated off-grid systems have the capability to supply a mini-grid in a rural village. These systems, so-called hybrid systems, consist of a combination of one or several renewable energy sources such as PV, wind, micro-hydro, storage batteries and fuel-powered generators. Hybrid systems can power a mini-grid and, under certain circumstances, provide electricity to households at a relatively economic price. This is especially the case when the demand also includes the supply of a productive activity which often has a predictable and higher load demand than households and additionally generates income. On the other hand, if a productive use such as occurring at a farm, workshop or rural centre is to be supplied with a hybrid system, it could also be possible to connect households to this electricity supply.

Another possibility for supplying electricity to remote households is the use of solar home systems (SHS). They have the advantage that they can provide decentralised electricity at a rural household, independent of a mini-grid, grid extension, or the accessibility of fuel for fuel-powered generators. A SHS will often need some amount of redundancy to achieve a certain level of reliable service provision. In some cases the cash flows of disseminated SHSs on a grid-tariff type basis might not be as favourable as can be achieved under some circumstances with a diesel-powered or hybrid-powered mini-grid supply. Diesel-only powered mini-grids exist in many areas of the world. However, their fuel consumption and economics can often be improved by adding renewable energy sources.

5.1.2 Financial analysis

In order to assess the feasibility of the hybrid technology for a mini-grid type of application, a financial analysis and comparison of the different technology options (grid, SHS, diesel-only, hybrid) is carried out in the following sections. This is based on a cash flow analysis (Davis & Horvei 1995; Horen & Davis 1996), taking into account the relevant growth scenarios.

5.1.3 General case study assumptions

The comparison and evaluation is based on one village assumed to have 2 000 households and an annual household growth rate of 2%. The village is in a 'Rural 2' area, that is, possessing a housing density of 70–100 households/km² (Randall 1997)⁵ Based on that housing density, the material costs of a local mini-grid are assumed to be R1 000 per household. The dwelling type is 80% traditional housing and the average income is R500–R1 000 per month. For a mini-grid type or SHS application, maintenance and operating costs are included. Depending on the costs incurred by the users, the initial percentage of households wanting to be connected to a certain electricity supply (grid, SHS, diesel-only, hybrid) varies, as does the increase in number of new household connections to a certain electricity supply option over the number of years considered in the project life cycle. The length of the project life has been assumed to be 20 years.

For the same reason, namely the costs incurred by the user, the increase of electricity consumption per household will vary with the different electricity supply option. The increase in households connected to an electricity supply option and the increase in household demand on that electricity supply option can be modelled with S-curves (Hochmuth 1996), taking the household growth rate, the initial number of connections and the estimated number of connections at the end of the considered project life into account.

⁵ Rural 1: 110–150 households/km², Rural 2: 100–70 households/km², Rural 3: 0–70 households/km²

Table 9: General case study assumptions

<i>Factor</i>	<i>Value</i>
Area	Rural 2 [70-100 households/km ²]
Distance to grid	10km
Stand size	1 0000m ²
# households	2 000
Type of households	90% traditional
Household income	R500-R1 000/month
Household growth rate	2%
Increase in consumption levels per household	modelled with S-curves ⁶
Increase in households connected to a electricity supply option	modelled with S-curves
Cost of mini-grid	R1 000/household
Discount rate	8%
Interest rate	15%
Project length	20 years

For the same reason, namely the costs incurred to the user, the increase of electricity consumption per household will vary with the different electricity supply option.

The increase in households connected to an electricity supply option and the increase in household demand on that electricity supply option can be modelled with S-curves (Hochmuth 1996), taking the household growth rate, the initial number of connections and the estimated number of connections at the end of the considered project life into account.

5.1.4 Grid electricity assumptions

There are high expectations and hopes among remote communities that the national electricity grid will reach every one of them soon. The advantages for the user in obtaining grid electricity supply are twofold. Presently the costs for the user of grid electricity are much lower than with any other electricity supply form. In addition, the power obtainable from the grid can often supply higher power appliances which is often is not possible with other off-grid technology systems. The village's distance to the existing national grid is assumed to incur electrification costs to the grid supplier of R3 800. The amount of R3 800 is presently the average cost of connection above which electrification of the community might not be financially viable. Grid extension costs can go up to R7 000 and higher for very remote and isolated areas.

The grid tariff is assumed to be 28.8c/kWh, with generation and distribution costs of 6c/kWh, both for a 20A supply⁷. The latter cost of generation and distribution is an underestimate and is higher in reality. In addition, costs are incurred by Eskom due to revenue collection, maintenance and operation of around R22/month/household (communication: Doug Banks, EDRC). Therefore the calculations for a grid extension based on the given figures will give grid technology a slight advantage. Nevertheless, even with these 'positive' grid extension figures, in

⁶ S curve measures the increase in yearly consumption levels per household (hh) in kWh/year/HH and the number of HHs connected per year based on:

- the consumption (# connections)/y/HH in year 1 as percentage of initial consumption (# connections), and
- on the end value of level of consumption (#connections) at final project year.

⁷ There are pilot projects testing 2.5, 5 and 8A supplies. However, this has not been investigated here. It should be noted that this paper does not claim to be a complete assessment of all techno-economic issues, but rather a general overview.

some cases off-grid technologies become more cost-effective, as can be seen in the following sections.

Table 10: Grid electricity assumptions

Factor	Value
Supply	20A
After diversity maximum demand	1.2
Consumption	a) 70kWh/m b) 20kWh/m
Tariff	28.8c/kWh
Connection fee	R 200
Initial # of connected households	11%
# households connected after 20 years	80%
Generation costs	6c/kWh
Connection costs	R3 800

Disadvantages for the grid supplier will often include high electrification costs for the remoter communities. In addition, demand in the remote areas often does not pick up according to forecast estimates which worsens the cost calculations for the grid supplier even more (Table 11). The related growth scenarios can be seen in Table 12.

If a loan was taken out at 15% interest payments to finance the electrification of this community then the grid supplier needs an internal rate of return (IRR) greater than 15%. In case of 70kWh/month of average household consumption and the depicted growth scenarios, the IRR reaches nearly 16% after 20 years. For the case of 20kWh/month average household electricity consumption the IRR doesn't reach any positive value.

Table 11: NPV and IRR analysis grid extension

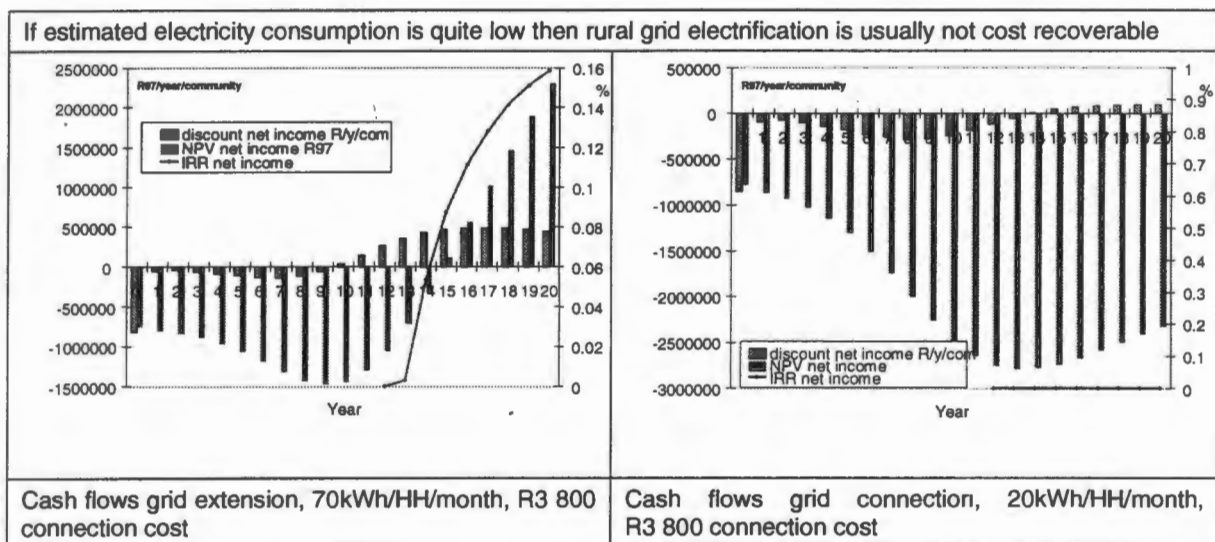
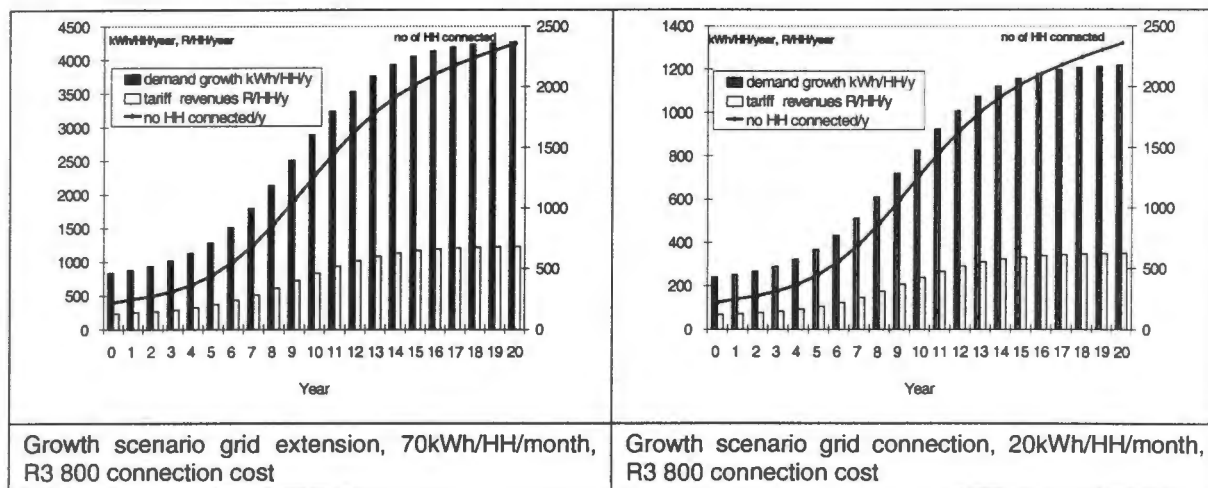


Table 12: Growth scenarios



5.1.5 SHS assumptions

In case the electricity grid will not reach a certain community, solar home systems (SHS) will be an option to provide lighting and a few hours runtime of television and radio. One advantage of a SHS is its possible decentralised installation as compared to the expensive grid extension infrastructure or mini-grid type infrastructure. In addition, monthly instalments for a SHS could be less than the present expenditure of a household on candles, paraffin, gas and car battery charging for lighting and television.

Disadvantages include the limited electricity service obtainable with a SHS (e.g. cooking, heating, ironing is not possible) and the higher costs per service, such as for lighting, TV/radio, compared to the costs of the same services when powered by the grid. In addition, SHS owners need to be their own small 'utility' operator and manage maintenance and component replacements.

The battery lifetime is assumed to be three years, the size of the panels to be 50W_p and costs of the SHS to be R2 500. The monthly instalment is assumed to be R50 which represents subsidised⁸ a moderate growth scenario (Hochmuth 1996). The length of the repayment periods is set to three years and four years. The corresponding cash flows can be seen in Table 14. A repayment period of three years is often practised by financing institutions as batteries need replacement after that time. In addition, a utility-based SHS scenario has been investigated and compared to the grid extension case (Table 16) with SHSs being provided by the utility on a quasi-tariff basis.

When assuming a constant monthly instalment of R50 over either three or four years, then the cash flows of the four-year repayment period are more advantageous for the supplier than the ones of a three-year payback period. However it is likely that less households will increase their demand for a SHS in the four-year payback scheme than in the three year payback scheme.

The increase in number of SHSs due to increased electricity demand and increase in number of households with user-owned or utility-owned SHS can be seen in Table 15. The underlying S-curves for the growth process contain estimates for the number of households with a SHS in years 1 and 20, as well as estimates for the electricity demand in kWh/month in year 1 and 20. Based on this growth process the acquisition of an additional SHS, in addition to one or several operating ones, can be estimated.

⁸ Type and structure of this subsidy are not considered here.

When considering a grid-utility implemented SHS scheme, where households pay a monthly fee per SHS based on a mixture of grid electricity costs for the same services and current amount of expenditures by the rural household for these services (here R20/month), it can be seen that the IRR after 20 years will be very low. However, the incurred debts will be much lower than for the grid connection cases with 20kWh consumption per month per household.

Table 13

SHS	
System	50W _p panel, 100 Ah battery
ADMD	1
Monthly energy supply	6kWh/month/hh
Battery lifetime	3 years
Panel lifetime	20 years
Payback period	User is owner, Case a) 3 years, Case b) 4 years
Tariff-type SHS	Utility is owner
Current expenditure of household on SHS-type services	R20
Battery replacement costs	R3 00 (3 & 4 years pay-back) R50 (Eskom tariff-type system) with battery cost to Eskom R200
Initial # of connected households	1% (4 & 3 years pay-back) 3% (Eskom tariff-type system)
# households connected after 20 years	20% (4 & 3 years pay-back) 50% (Eskom tariff-type system)
Cost of SHS	R2 500 (3 & 4 years pay-back) R2 200 (Eskom tariff-type system – bulk buying)
Deposit	R 200 (3 & 4 years pay-back) R 0 (Eskom tariff-type system)
Maintenance costs	R 60/system/year (3 & 4 years pay-back) R1 200/month salary + R100/month hardware (Eskom tariff-type system)
Monthly instalment	R50 (moderately subsidised, 4 & 3 years pay-back) R 20 (Eskom tariff-type SHS)

Table 14: NPV and IRR analysis, user owned SHSs with 3 and 4 years pay-back periods. Payback period is decisive

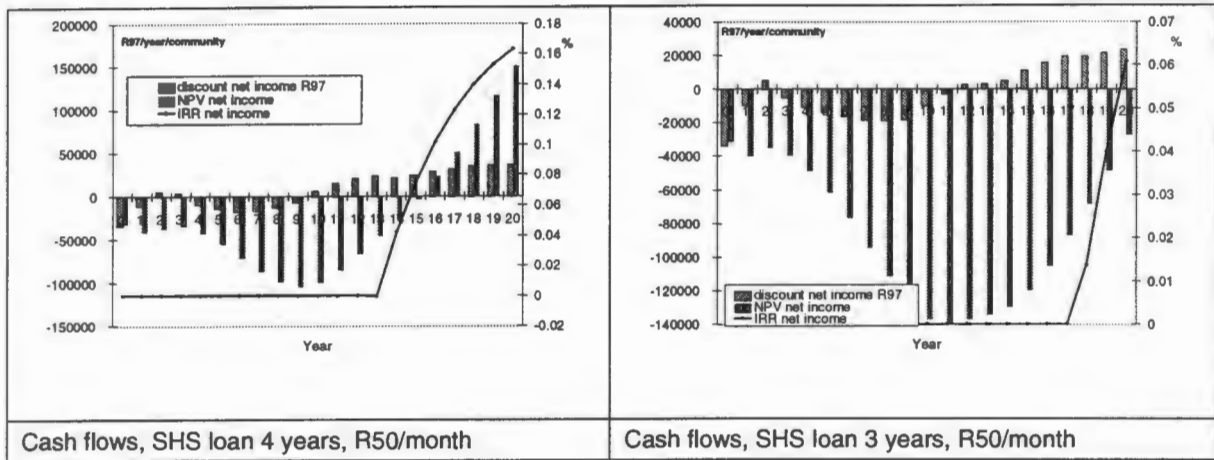


Table 15: Growth scenarios: user or utility owned SHSs

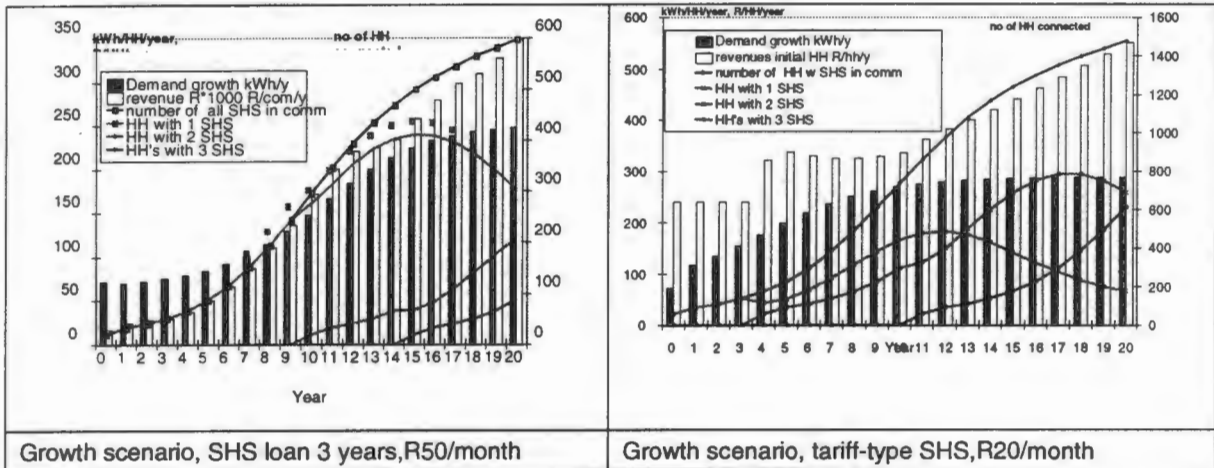
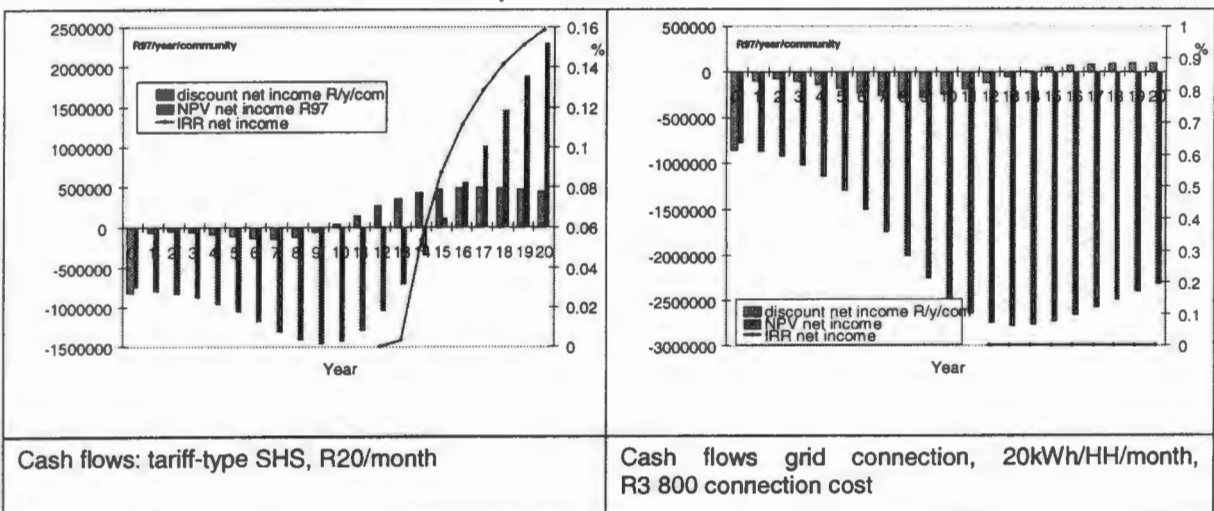


Table 16: NPV and IRR analysis utility-type implemented SHS vs grid extension. SHS can save on expenditures compared to grid extensions



5.1.6 Diesel generator assumptions

Diesel powered applications such as water-pumping, clinic electricity supply, household supply with a mini-grid have been widely implemented around the world. The advantages lie in the fact that grid-type electricity supply is available independent of the national grid and that thereby the often very high grid extension costs to these remote areas are avoided. Disadvantages include long-distance transport of fuel, need for maintenance and repair on-site, sometimes low diesel capacity factors and pollution caused by diesel fumes and diesel noise.

The diesel 'power station' option to supply a number of households in a community can be a viable option with a positive IRR at the end of 20 years (Table 18). The viability will also depend on the cabling needs for a mini-grid. The tariff rates per kWh are assumed 3 times higher than charged for grid-supplied electricity and therefore the initial demand for a connection, initial electricity consumption and the growth in number of connections and demand per connection is likely to be lower than with the electric grid (Table 19). In this case the initial electricity consumption is assumed 50kWh/month/HH with 8% of the community connected initially.

The diesel power station will be expanded around year 8 with a diesel generator double the size of the initial one. It needs to be noted that the hourly electricity demand profile of the community is decisive in the design, as the diesel generator will be sized to cover the peak demand plus a tolerance margin. Therefore if certain electricity demands can be shifted during the day to lower the overall peak demand then diesel capital costs can be reduced as well as diesel wear and tear through the improved diesel capacity factor. The initial diesel generator runtimes are 8 hours, whereby the smaller and larger diesel generator will be running around 11 and 13 hours respectively in the year 20.

It has been found during this analysis that the diesel-only 'power station' is suitable in cases of 5–8 hours of runtime per day with a demand profile as flat as possible. Long diesel runtimes like up to 20 hours per day, a very high peak demand compared to a load profile with otherwise low load levels can deteriorate the financial viability even if the same average number of kWh per month per household is assumed.

Table 17

<i>Diesel</i>	
Diesel system	150kW
ADMD	1.2
Monthly energy consumption	50kWh/month/hh
Diesel lifetime	30 000 hours
Capital costs	R150 000 (150kW Diesel) R 270 000 (300kW additional Diesel from year 8)
Daily runtime	a) 8h/day, b) 24h/day
Fuel	R2/l + 10% for oil changes and other tasks
Owner	Utility
Tariff	70c/kWh
Generating and transmission costs (incl. O&M)	65c/kWh R2 000/m salary and spare parts Maintenance costs: 20% of capital costs per year
Initial # of connected households	8%
# households connected after 20 years	50%
Cost per connection for DC mini-grid infrastructure	R1000
Connection fee	R200

Table 18: NPV and IRR analysis diesel only system
 Diesel mini-grids' cost-effectiveness (same kWh/year electricity demand) depends on load

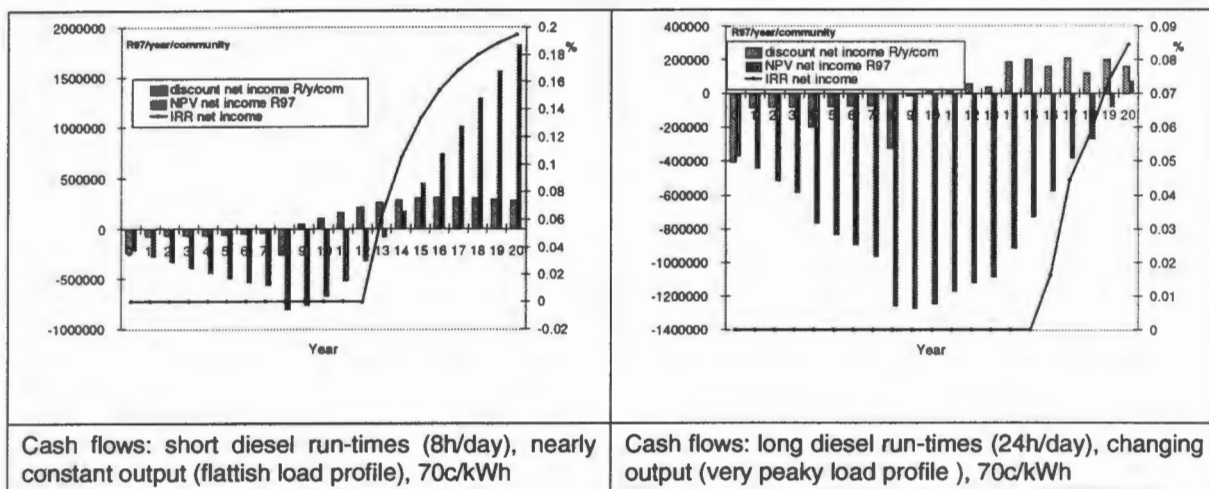
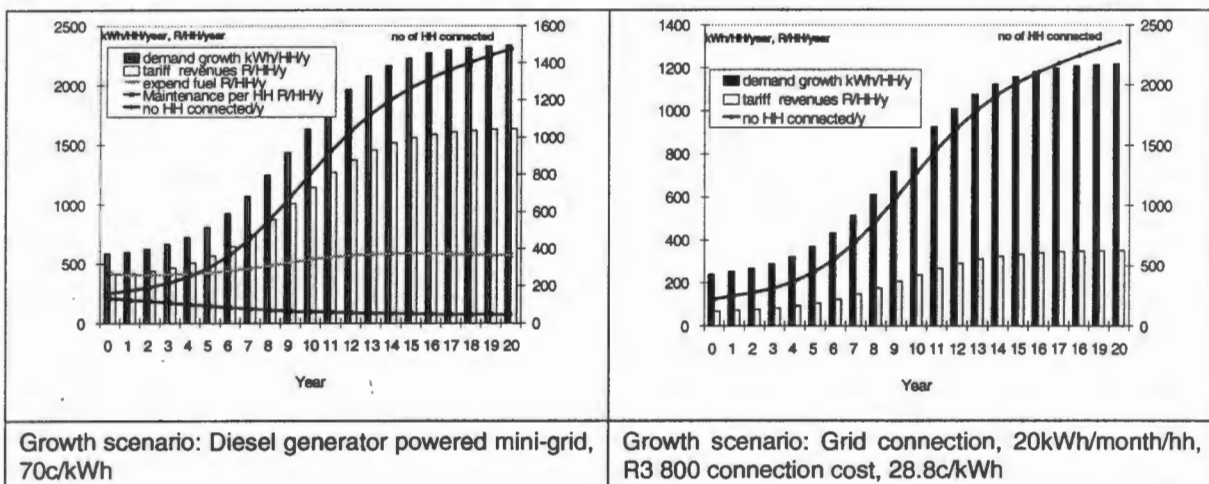


Table 19: Growth scenarios: Diesel generator powered mini-grid versus grid extension



5.1.7 Hybrid system assumptions

If good renewable energy sources are available in a remote area, a hybrid system can be considered, especially when transport of fuel and maintenance on-site are difficult. The advantages of a hybrid system are that the availability and costs of different energy sources can be combined in such a way that the overall life-cycle costs and overall system performance are optimised (Marrison & Seeling-Hochmuth 1997; Seeling-Hochmuth & Marrison 1997). A hybrid system can in some cases be a better option technically and financially.

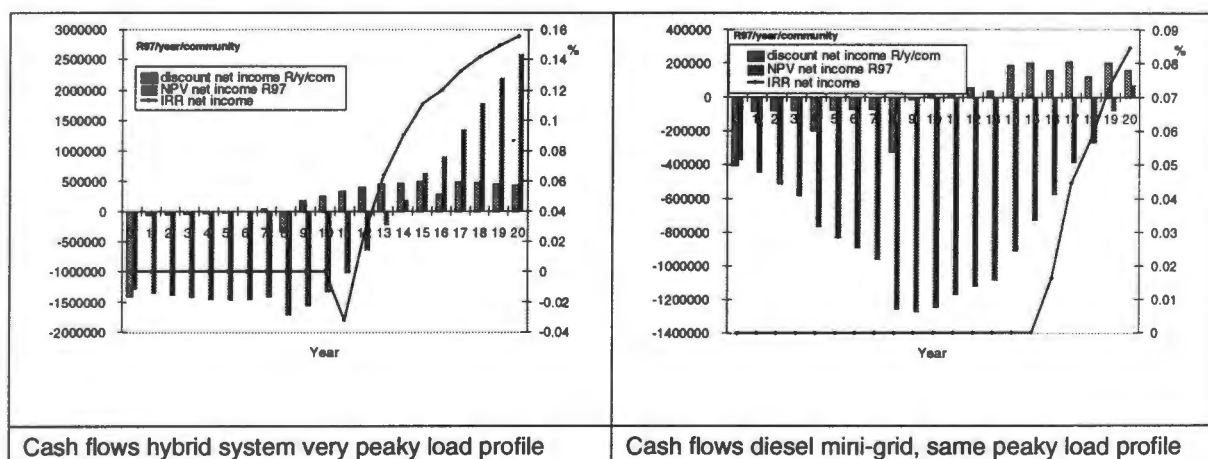
The disadvantages include dependence on the availability of the renewable energy sources and the possible requirements of more sophisticated control than in the non-hybrid case. A hybrid system is especially suitable in cases where on average electricity is demanded for long periods of time and high peak demand is placed on the system compared to otherwise lower load levels as was assumed for Table 21. Another factor in selecting a hybrid system concerns the amount of load placed on the system during daytime or other renewable-intensive time periods, as then the renewable energy can be directly supplied to the load and storage losses can be avoided. In

this regard the inclusion of a productive activity with high daytime load levels and lower load levels in the morning and evening will produce a load profile for which a hybrid system can be well suited. In case of a local productive activity or income generation, the growth scenarios of number of households connections per year and average demand increase per household might be affected. When sizing an off-grid system specifically for a load profile of a productive activity type of application where no cabling need to be considered, see Marrison & Seeling-Hochmuth 1997; Seeling-Hochmuth & Marrison 1997.

Table 20

Hybrid	
Hybrid system	50kW Diesel, 1000Ah batteries (48 in series, 6 in parallel), 12kW _p PV, 20kW _p Wind
ADMD	1.2
Monthly energy consumption	50kWh/month/hh
Diesel lifetime	30 000 hours
Capital costs	R 50 000 (50kW Diesel) R 50 000 (50kW additional Diesel from year 8 and year 14) R20/PV W _p , R8/Wind W _p , R2/ Bat Ah
Daily runtime	6h/day
Fuel	R2/l + 10% for oil changes and other tasks
Battery life	6 years
Owner	Utility
Tariff	70c/kWh
Generating and transmission costs (incl. O&M)	65c/kWh R1 000/month salary & spare parts 20% of initial costs per year
Initial # of connected households	8%
# households connected after 20 years	50%
Cost per connection for DC mini-grid infrastructure	R1 000
Connection fee	R200

Table 21: NPV and IRR analysis diesel only versus hybrid system
Hybrid systems can be more cost-effective than diesel systems (same kWh/year electricity demand)



5.1.8 Decision ranges

The following decision regimes can be deduced from the preceding analysis:

- If the IRR for a grid extension project is strongly positive, that is, higher than the interest rate to be paid on the loan taken out for the electrification project, then the grid extension should be chosen
- If the IRR for a grid extension does not meet the necessary value, and if the initial monthly electricity demand is high enough, the chosen electricity tariff is affordable, the housing is dense enough, and initial demand for a connection is high enough, then a mini-grid can be considered:
 - a diesel-only powered mini-grid with few hours of run-time per day and a load profile as flat as possible
 - a hybrid powered mini-grid if long periods of electricity supply are required and high peak loads occur in comparison to otherwise low load levels, preferably during day-time.
- Otherwise a SHS scheme, either utility or payback type, can be suitable depending on institutional infrastructure.

5.1.9 Summary

A techno-financial approach has been explained and applied to a case study. However, this analysis needs to be taken further by carrying out an explicit sensitivity analysis, evaluating further case studies and identifying broad decision ranges and guidelines.

A comparison and financial analysis of the different technology options (grid, SHS, diesel-only, hybrid) for rural electrification was carried out for a case study taking into account the relevant growth scenarios. The results of the different scenarios have been described and summarised in decision regimes to show the potential for deriving such regimes to guide rural electrification decision-making. The decision regimes indicate when the supply of rural households with a mini-grid, powered by a diesel-only set-up or a hybrid system, is financially viable in comparison to extending the national grid, or a SHS supply scheme. A mini-grid can be an economic option in case of sufficient density in housing. In some cases the cash flows of disseminated SHSs on a grid-tariff type basis might not be as favourable as could be achieved with a diesel powered or hybrid powered mini-grid supply. The fuel consumption and economics of diesel-only powered mini-grids can often be improved by adding renewable energy sources, especially when the electricity demand is placed on the system for more than 14–20 hours a day, if high load peaks compared to otherwise lower load levels are expected and if intensive electricity use occurs at an renewable energy intensive time, such as often happens with a productive activity.

5.1.10 References for Section 5.1

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5.2 Techno-financial comparison of electrification options for centralised applications

5.2.1 South African cost and design scenarios

Design simulations for two case studies are presented using hybrid system design approaches. The two case studies describe typical rural applications in different areas of South Africa, namely Upington and Mabibi. The area around Upington in the Northern Cape province was chosen, a) because the solar irradiation there is highest due to Upington being near the Kalahari desert region and b) because there are already quite a number of established farms using PV/diesel hybrid systems. Some profile data was based on measurements in [Rehm 1997] taken at a farm near Upington. Mabibi was chosen because there has been a development project with a PV/wind hybrid school/clinic system and some logged data is available from there. In addition, Mabibi, being a coastal area, has very good wind resources. The school/clinic systems at Mabibi delivers power for lighting to a school and a visiting point of the local clinic service. In addition, a fridge is powered and the installation of a water pump was planned. The estimated full load operation is 4.2kWh/day. Simulations were carried out for both cases using the prototype of the developed optimisation software 'Hybrid Designer' (see the accompanying manual by Kuik).

5.2.2 PV/wind/battery school/clinic system at Mabibi – coastal region with good wind resources

The existing system at Mabibi is a 36V DC bus system, with all AC appliances. A 2.5kW LMW wind turbine is installed and 450W_p of PV. Next to a 5kW inverter there is a battery bank of 650Ah or 23.4kWh. The initially estimated load was 4.2kWh/day or 1 534 kWh/y. Rule of thumb sizing for this demand level actually yields a 2.5kW_p–3kW_p wind turbine. The system operation data is averaged for logged data from 1 June to 9 August 1995. Looking at the measured data it can be seen that the renewable energy current often has to be dumped during the daytime because the battery is sometimes already full by midday. The simulation run to find a wind/PV/battery design for the Mabibi site with an energy requirement of around 4–5kWh/day resulted in a wind/battery system (2kW_p wind turbine and a 9.6kWh battery). The simulation runs show that the existing Mabibi system is designed well with quite a large battery storage. The additional PV array does not seem to be necessary, which is confirmed by the logged data that shows that most of the PV current gets dumped. The large battery storage, which is 2.5 times as big as the size recommended by the simulation, increases the system costs but also gives a back-up in times of increased demand or component failures. This is important, as Mabibi is very remote and not easily accessible.

Figure 4: Different system configurations for the 4.5kWh/day school load at Mabibi

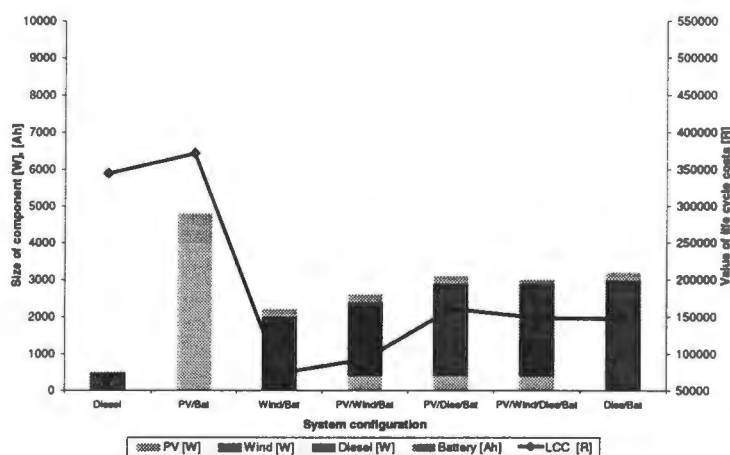
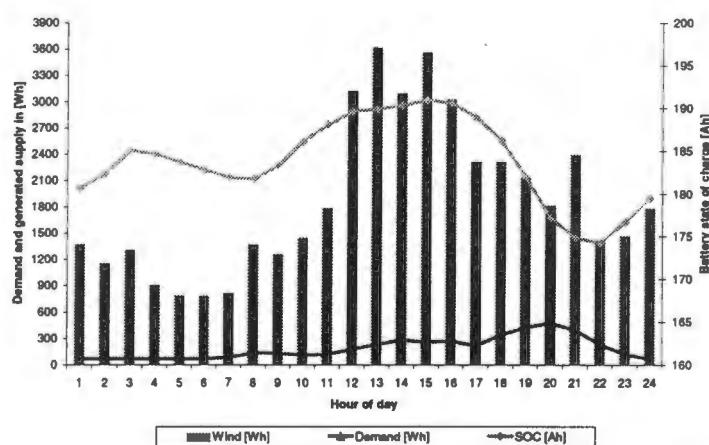


Figure 5: Averaged system operation of the simulated Mabibi wind/battery system



As can be seen in Figure 5, the averaged system operation obtained from the simulated designs is quite similar to the averaged system operation based on the logged system data. A general recommendation based on the simulation results is to try a smaller battery size in the Mabibi system. The simulations confirm that the chosen wind/battery system with PV back up is the right system combination and the sizing of the wind turbine was confirmed. It was also suggested that the PV array might be unnecessary for the Mabibi system.

5.2.3 PV/diesel farm systems at Upington – inland region with good solar resources

A few PV/diesel/battery systems exist around Upington in South Africa. Some of these systems are retrofits of existing diesel generators. A typical system consists of a 36V DC bus with 1.8kW_p PV, 1 000Ah battery that is 36kWh. A switched inverter of 2.5kW–3.5kW is operated next to a 3kW–5kW diesel generator. The switching is done manually and the diesel generator is often only run for 2 hours/day or so a few days during the week. While running the diesel generator, the batteries are also being charged. Seldom is a wind generator used and, when it is used, only with a few hundred Watts. In the simulated system design it was confirmed that a PV/diesel/battery system is indeed the lowest life-cycle cost system choice for the region (Figure 5 and Figure 6). The suggested operation strategy is to use the inverter output instead of the diesel generator whenever the inverter output can cover the load, and only run the diesel generator through the inverter if the battery state of charge is below 64%, that is, very seldom. This confirms the actual running of farm systems near Upington, where most of the time the inverter output is used to supply the loads.

Figure 6: Different system configurations for the 4.5kWh/day farm load in Upington

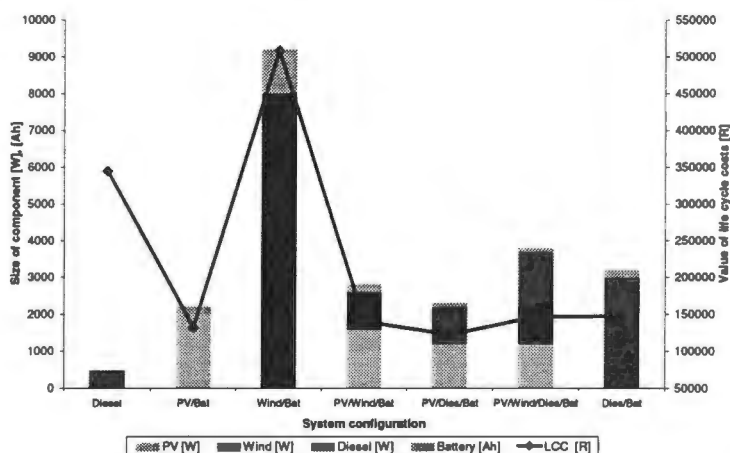
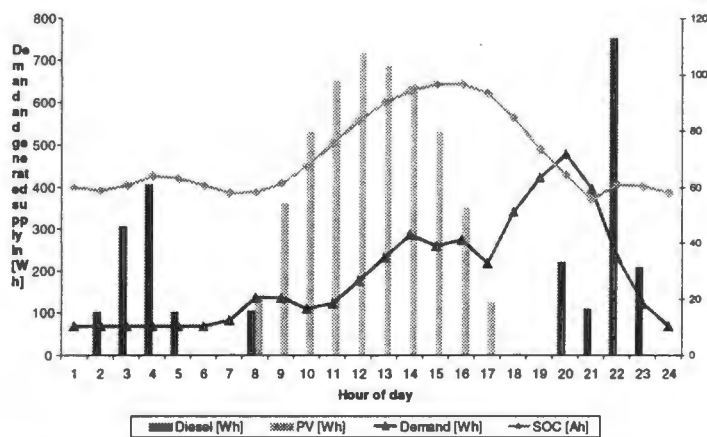


Figure 7: Averaged system operation of the simulated Upington PV/wind/battery system



In summary, the simulation results suggest that the Upington system configuration of a PV/diesel/battery system is the recommendable set-up. A smaller battery size could be tried, however this might result in increased diesel generator runtimes which might not be suitable for the users.

6 Appendix B – Implementation structures: community visits

6.1 NGO-driven: CSIR – Lubisi, Eastern Cape

There is no electricity available in Lubisi, except for privately owned SHSs and Eskom PV-electrified schools and clinics. A hybrid systems installation is planned by the Council for Scientific and Industrial Research (CSIR) some time in future. One person said he does not like SHSs because there is no electricity in winter (his family owns one) and they want grid electricity. CSIR has provided extensive support through sending in social scientists over the last three years to help the community organise itself in planning committees to be able to voice its demands and plans effectively. One such project is a tourism project to which the response of the local authorities seems slow. The local sewing group could use electrical sewing machines to sew faster and with better quality. There are plans for wider irrigation schemes as the area has access to rivers and dams. Job opportunities are few and young people are migrating. People said that there are a number of skills in the community, such as welding and carpeting, but this was not confirmed. Quite a few cows and sheep are owned by people in Lubisi and wool is sold in Port Elisabeth. The people plant mainly maize, animal feed, carrots and potatoes. Some community gardening is taking place. The most ambitious project so far seems a PV-powered schooling-by-video programme for 5–10 grade programmes to be held in any of the five community centres to be established. One community centre is now fenced, as two video cassette recorders have been stolen, allegedly by children now living in towns when they came to holiday at home.

6.2 NGO-driven: The Methodist church in Eastern Cape – Kumberstone

A local battery charging project was promoted by the local Methodist church which seems to exert a substantial influence on its members. It also seems to place emphasis on people being united by the community project and overcoming the difficulties. There is also a wood-fired bakery, a community garden with a tank to collect rain water and wind-water pumping on the church premises. The maintenance person for the project, a long-term member of the church, was chosen by the church. However, the services he delivered seemed to be inadequate, and too few people were utilising the battery-charging station for it to make economic sense. In addition, a lack of clarity arose as to who owned the system – the church believed it was a gift, the company concerned was led to believe that the church would pay for it by a facilitator.

6.3 SELF-driven: Maphephete, Kwazulu-Natal

The Solar Electric Light Fund (SELF), through its regional representative Will Cawood, started a community liaison project in Kwazulu-Natal which led to the first SELF SHS project in South Africa. The revolving financial fund is supported by the KwaZulu Financing Corporation (KFC) and so far around 30–50 systems have been installed. The liaison process included a number of visits, talks, revisits etc. A donated PV system was installed in the court-house of the community for demonstration purposes. This was followed by an in-depth surveying process (Hochmuth 1996, Seeling-Hochmuth 1996) analysing people's needs, present use and expenditures on energy, willingness to have/pay for different SHS packages, and financing preferences. Seven female enumerators were trained for the process and the functioning of the SHS was explained to them. This led to the enumerators explaining to their community members during the surveying process what an SHS does and what it costs. This was an additional unexpected marketing effect. Local people were trained to carry out installation and maintenance of systems and the SELF representative found that women were more reliable technicians than the men he had employed before. In June 1998 a hybrid system was installed

at the local school in order to power several computers with Internet facilities that were received as a gift by IBM.

6.4 Entrepreneur-driven: Kentani, Eastern Cape

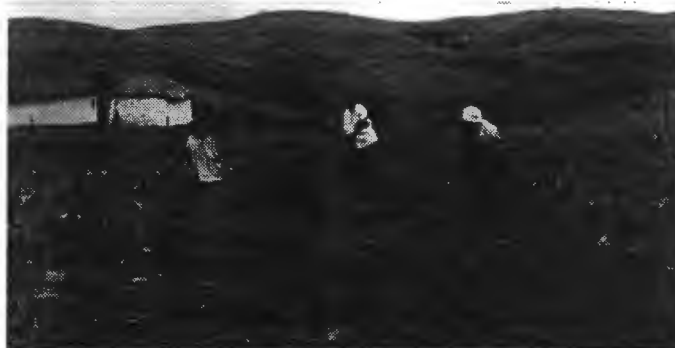
The region around Kentani has no electricity and water needs to be carried for many hours by women and children. Maize is often planted and in several harvests on plots the size of roughly 0.5–0.25ha per homestead. There are some tractors, but most ploughing seems to be done manually by women. Some people have cows, chicken, goose, sheep, horses or bulls.

Figure 8: Typical Eastern Cape village density



Figure 9: Water collection



Figure 10: Manual field work by women

A rural shop owner and his wife started charging batteries with their own 7kVA diesel generator for customers at a fee. When their diesel generator broke down they took the batteries to the nearest grid-powered charging stations. The shop owner's wife said that some people were expecting the Reconstruction and Development Programme (RDP) to provide lighting for everybody, and for free. So when they started selling batteries for home lighting, some people thought they could get the batteries in her shop for free. A battery charging dealer has franchised the shop owner and is delivering equipment to him and his wife. As the husband is working during the day away from the shop, his wife is managing the shop and customer support for the battery charging activities. She also manages the money some people bring to the shop so it can be saved there until an amount for a certain purchase is reached.

Figure 11: Franchising local shop owner

6.5 ESKOM-driven: Eastern Cape schools electrification

According to available information there are 27 698 schools in South Africa, of which 11 011 (41%) are electrified and 16 057 (59%) not electrified. The use of solar systems for the provision of electricity to schools increased dramatically during 1996. Almost 26% of the schools that were electrified during 1996 received solar systems. This was mainly due to funds made available by the RDP (R30-million), Eskom's Community Development (R15-million) and NORAD (R0.9-million). It is evident that for the electrification of the majority of schools in South Africa that still need to be electrified, non-grid technology will have to play a significant role, since many schools are located in remote areas (NER 1997).

Technical senior secondary schools could make use of hybrids. Up to 5kW can cover basic needs for a secondary school as an estimate. Schools said they would like electricity for the use of photocopiers and for the support of handcraft classes.

Figure 12: Eskom test hybrid system with container for storage of batteries, diesel generator, balance of system components and control, at Technology Research Institute, Eskom



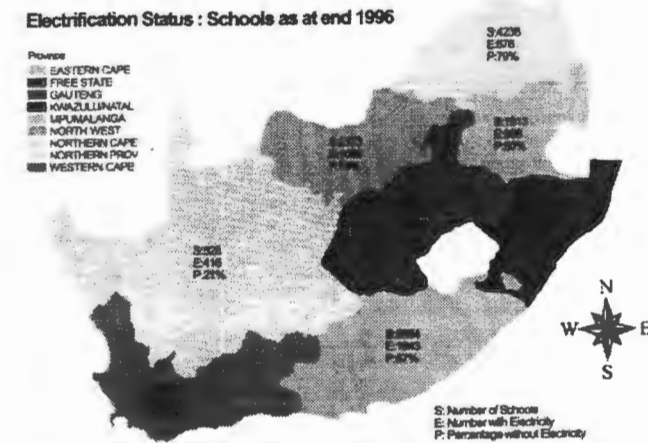
Figure 13: PV electrified secondary school



Figure 14: PV electrified primary school



Figure 15: School electrification status 1996



The system at the government built secondary school visited carried 18 PV panels ($50W_p$ each, together $900W_p$), connected to yield a 24V DC bus system. Some of the panels showed corrosion and some parts of the panel array was shadowed by a nearby tree. The 12V batteries have a capacity of 100Ah each and there were 16 batteries in the system yielding together a storage capacity of 800Ah which is capable of providing system autonomy for several days. A 600W inverter can power an overhead projector and a video cassette recorder, the latter had not been delivered yet at the time of visit. The lights in the system come with their own inverter. Because three out of four classrooms had had lights installed, the school was able to now offer evening classes.

The responsibility for maintenance lies with the Department of Education. Eskom checks the system during the first year which is a guarantee phase. However, the Department of Education encountered difficulties in maintaining the systems due to restructuring and shortage of capacity.

The visited primary school had 12 PV panels installed and even though it wasn't using the lighting yet, it had plans to possibly establish evening classes at some point in future.

6.6 Upgrading diesel? Namaqualand – Lepelfontein

Lepelfontein is located in Namaqualand between Kotzerus and Rietpoort, near Bitterfontein. There are around 70 households, a Roman Catholic Church with a priest and a primary school.

A mobile clinic makes visits to the church premises every second Wednesday. There are some problems with gastromites most likely resulting from water standing for too long in the hot sun. There are some cases of burns caused by open fires using paraffin. The visiting nurse can often only deal with a limited number of the patients waiting for treatment. Some illnesses have to be reported to a doctor and his or her diagnosis might not reach the village for another two weeks. Travel costs to the nearest hospital are around R100, so enough money for medicines if often not available. The local school caters for children up to standard 3 level. After that, pupils need to go to Rietport which provides for children up to standard 6. Further education must be obtained in Vredendal. Regarding the general literacy level – a few people have matric, more in the younger generation, but many adults only have a level of education between standards 2 and 6.

A mobile shop comes through Lepelfontein. A payphone has been installed and there are more than 15 phones used by households which are billed from Pieterfontein post office. The sound level of the phones is quite low. There are some brick ovens for baking. The buildings are mainly rectangular and built with bricks. A few TV aerials can be seen. A nearby farm uses two wind turbines, other farms are using wind water and solar pumping and have installed some PV panels on the farm house.

Apart from the limited opportunities for employment, mainly on nearby commercial farms, there are no employment opportunities whatsoever.

6.6.1 Estimate of energy used

According to Eskom, the area will not obtain the electricity grid for the next 20 years at least (unless a nearby Anglo-American project is developed earlier). When interviewing the wife of the local councillor, she said that wood is used to cover some energy needs. Gas can be obtained when deliveries come from Kotzerus and Rietport. Candles are used for lighting, and so are oil lamps and paraffin which is also used for cooking. Car batteries are employed to power TVs. Charging a battery costs R10, and can be done in Vredendal. The batteries are transported to Vredendal by someone who owns a car and who collects the batteries when he or she is going to the town. Gas costs R90 and can last between 2 weeks and one month, depending on the family. The church has its own diesel generator which the visiting clinic can use for lighting.

6.6.2 The diesel desalination plant

There are two water taps operated by a local operator who also maintains the diesel-powered desalination system. One tap supplies brackish water free of charge which is mainly used for washing, the other tap supplies the desalinated clean water for which a fee is charged. The two different kinds of water taste significantly different. The clean water can be obtained on Mondays, Wednesdays and Fridays.

200 litres of water per hour can be produced. R1 is charged for a big drum (25l) of water. The big drums are often left near the water taps as they are quite heavy, and households collect their water from the drums when they need it. However this leads to the drums and the water becoming very hot in the sun. A 10kVA Hatz diesel was installed in June 1993. The powered desalination motor is an EBERLE motor, 5A, 20V, 1.1kW. The fuel is delivered by NLK Namaqua Land Corporation, and around 100l/month are used.

Every third or fourth day the diesel generator is started and runs for around an hour. Every month the diesel is inspected by the contracted maintenance company. The local maintenance person does the oil servicing, and changing of filters. He went on a training course for three months before starting his job.

6.6.3 Future plans

The regional services council has planned to install another diesel and provide 50 water taps in households (maybe even flush toilets?)

6.6.4 Summary

Only few sites could be visited due to time and budget constraints. In addition, not many hybrid systems installations exist in South Africa, especially not in a rural development setting. In spite of this, the few site visits communicate some of the important points mentioned throughout the report. These can be roughly summarised as:

- Community facilitation is a long and necessary process.
- Questions of ownership and project management are important.
- A local surveying process is important. It can be very effective to deal with local women for community liaison, project management and maintenance services.
- Marketing and supporting technology with the help of local shops through franchising agreements seems to be a possibility, especially for industry.
- Proper agreements for maintenance support are essential.
- The provision of clean water, health services, and the creation of jobs are important objectives.
- There are sites that could profit from upgrading diesel generators to a hybrid system.

The experience gathered from these site visits needs to be extended substantially when preparing actual pilot projects.