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Decision aiding in off-grid electrification projects: the role of uncertainty acknowledgement and objectives alignment

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Declaration

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Bernard Bekker

Acronyms

| | |
|-------|--|
| CFL | Compact Fluorescent Lamps |
| DECAS | Department of Environmental and Cultural Affairs and Sport |
| DME | Department of Minerals and Energy |
| EIA | Environmental Impact Assessment |
| ERC | Energy Research Centre |
| ESI | Electricity Supply Industry |
| GSM | Groupe Spécial Mobile |
| IAEA | International Atomic Energy Agency |
| IDT | Independent Development Trust |
| KWEDF | Klipheuwel Wind Energy Demonstration Facility |
| LFA | Logical Framework Approach |
| LPG | Liquid Petroleum Gas |
| NEMA | National Environmental Management Act |
| NEP | National Electrification Programme |
| NER | National Electricity Regulator |
| NERSA | National Energy Regulator of South Africa |
| PCM | Project Cycle Management |
| PV | Photo-Voltaic |

| | |
|-----------|--|
| RAPS | Rural Area Power Solutions |
| RE | Rural Electrification |
| RED | Regional Electricity Distributor |
| REFSA | Renewable Energy For South Africa |
| RES | Renewable Energy System |
| SABRE-Gen | South African Bulk Renewable Energy Generation |
| SHS | Solar Home System |
| SIP | Strategic Infrastructure Plan |
| SMME | Small, Medium and Micro Enterprises |
| SWER | Single Wire Earth Return |
| INEP | Integrated National Electrification Programme |

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Glossary

| | |
|---|--|
| <i>Analyst</i> | The actor supporting or guiding the decision aiding process. |
| <i>Client</i> | The client is the person that requested the decision process, and provides the necessary means to conduct it. The client is not necessarily a stakeholder, and does not have to exist in the process. |
| <i>Constructive decision aiding approach</i> | The constructive approach is based on the hypothesis that a stakeholder can be led by the decision aiding process to modify his or her preferences, either through lack of initial opinions, or through valid arguments presented during the process. |
| <i>Decision aiding</i> | Decision aiding consists of activities, tools and approaches designed to improve the quality of decision making to which it is applied. |
| <i>Decision maker</i> | Belton and Steward [2002:p14] defines the stakeholder that finally has the responsibility for the decision as the decision-maker. |
| <i>Decision quality framework</i> | A framework of criteria against which to measure the contribution of decision aiding tools and approaches to high quality decision making. |
| <i>Descriptive decision aiding approach</i> | With the descriptive approach, the assumption is made that a latent system of preference relations exists in the mind of the decision maker before the decision aiding commenced. This system is however not explicit to the decision maker. The task of decision aiding is to clarify or describe (without influencing) this system of preference relations as exactly as possible. |

| | |
|-------------------------------------|--|
| Energisation framework | A framework of energisation objectives that ultimately leads to sustainable development, against which to measure the project objectives of an energisation project. |
| Energisation objectives | The primary objectives of energisation that ultimately leads to sustainable development. Note that off-grid objectives form a subset of energisation objectives. |
| External uncertainties | Uncertain events that might affect project outcomes but over which decision-makers have little or no control. |
| Hard uncertainty | In hard uncertainty 1) the set of all possible outcomes of an action is unknown and can only be hypothesized, or 2) if all the outcomes are known, the probability distributions of all the outcomes are unknown or not fully definable. |
| High quality decision making | High quality decision making results in decisions that lead to the achievement of the project's primary objectives. |
| Hybrid Mini-grid | See mini-grid |
| Internal uncertainties | Uncertain events that might affect the outcomes of a project and are under the control of the decision-makers. |
| Mini-grid | A hybrid mini-grid distributes energy from a combination of local off-grid generation sources, for example mini-hydro, PV, wind or diesel, to several households located close to each other and the source. |
| Multi-criteria analysis | A multi-criteria analysis " <i>aims to make explicit a coherent family of criteria (not reduced to a single element at the outset) that will serve as an intelligible, acceptable, and exhaustive instrument of communication allowing conception, justification, and transformation of preferences within the decision process.</i> " [Roy 1996] |
| Non-grid | See off-grid |
| Off-grid | Electricity generation and distribution systems that are not connected to the national grid, i.e. either stand-alone or mini-grid systems. Also called non-grid. |

| | |
|---------------------------------|--|
| Off-grid objectives | The primary objectives of off-grid electrification that ultimately contribute to sustainable development. Note that off-grid objectives form a subset of energisation objectives. |
| Project | <i>“a group of activities to produce a project purpose in a fixed time frame”</i> [EC 2002:p3] |
| Project objectives | The ultimate goals towards which a project aims. These objectives do not necessarily have to align with sustainable development. |
| Programme | <i>“a series of projects whose objectives together contribute to a common overall objective at sector, country or even multi-country level.”</i> [EC 2002:p3] |
| Risk | See soft uncertainty |
| Single criteria analysis | In a single criterion analysis, the (possibly very heterogeneous) consequences of each potential action are quantified in the units of a single significance axis chosen beforehand. |
| Soft uncertainty | Soft uncertainty or risk is used to define situations where all the possible outcomes of an action, as well as the outcomes’ probability distributions, are known, |
| Solar Home System | A stand-alone electricity supply system that typically consists of a 100Ah battery, 50Wpeak PV panel and power electronics. |
| Stakeholders | <i>Standard stakeholders</i> impact / are affected by the problem and participate in the process that resolves it, <i>fiduciary stakeholders</i> represent clients and participate in the problem resolution without been directly affected be the problem, and <i>silent stakeholders</i> refer to those that are affected by the problem, but has no control over or participation during the resolution process. <i>Stakeholders</i> refer to all three groups. |
| Sustainable development | <i>“Sustainable development is essentially about improving quality of life in a way that can be sustained, economically and environmentally, over the long term supported by the institutional structure of the country.”</i> [IAEA 2005:p16] |

Abstract

Most completed South African off-grid electrification projects have failed to contribute significantly to the sustainable development of the communities they supply. The hypothesis of this research is that the root causes of these failures can often be found in the pre-implementation decision making (planning) processes, specifically in three areas:

1. Decision aiding approaches and tools, aimed at supporting the decision making process, are either not used or do not support high quality decisions.
2. Uncertainties that can impact the project negatively are often not acknowledged (identified) initially, and can therefore not be addressed proactively.
3. The primary project objectives often do not align with sustainable development objectives, which mean that even if all the project objectives are achieved (i.e. a successful project) the project still does not contribute to sustainable development.

The process of validating this hypothesis results in several outputs aimed at improving the contribution of future off-grid electrification projects to sustainable development:

- A framework of *primary energisation objectives for sustainable development* is developed, which defines what the outcomes of a successful off-grid electrification project should be.
- *High quality decision making* is defined, and a framework of *decision aiding characteristics that support high quality decision making* is developed against which decision aiding approaches and tools can be evaluated.
- The concept of *soft and hard uncertainties* is introduced, and it is shown that most of the social and institutional unacknowledged uncertainties in South African off-grid projects are hard. Hard uncertainties are impossible to represent probabilistically, and are difficult to include in traditional single-dimensional (mostly cost-based) decision aiding approaches and tools.
- A *degree of surprise tool*, based on Shackle's measure of a decision maker's degree of surprise at a future outcome becoming reality, is developed to act as an example of how hard uncertainty can be acknowledged in the decision making process.

- Soft uncertainty in the decision process is quantified for two examples: renewable energy system sizing, where an *adequacy confidence index* is proposed, and renewable energy resource estimation, where the *accuracy and applicability of RETScreen and Homer within a South African climatic context* are analysed.
- Finally, the above outputs are *integrated into an existing decision aiding process and applied* in order to demonstrate the value of decision aiding which includes uncertainty acknowledgement and objectives alignment.

The applicability of the results of this research is not limited to off-grid electrification, and can be of value within any developmental project aligned with sustainable development, especially where social and institutional uncertainties are prevalent.

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1 Introduction

1.1 Non-performance of off-grid rural electrification in South Africa

South Africa has made remarkable progress in widening access to electricity, through a National Electrification Program (NEP) that commenced in the late 1980s and is still active. Prior to 1990, less than a third of South African households had access to electricity, while a decade later that proportion had doubled. At the height of the NEP program in the middle 1990s close to 500 000 new households were being connected per year.

1.1.1 Decreasing annual connection rates

However, since the early 2000s the programme has slowed down as shown in Figure 1-1, with only around 160 000 new connections made in the 06/07 financial year. The growth in total households since 2000, as published by Statistics SA, has however varied between 218 000 and 448 000 households per year, which means that since around 2003 the percentage of total South African households electrified has actually been decreasing [Bekker et al 2008].

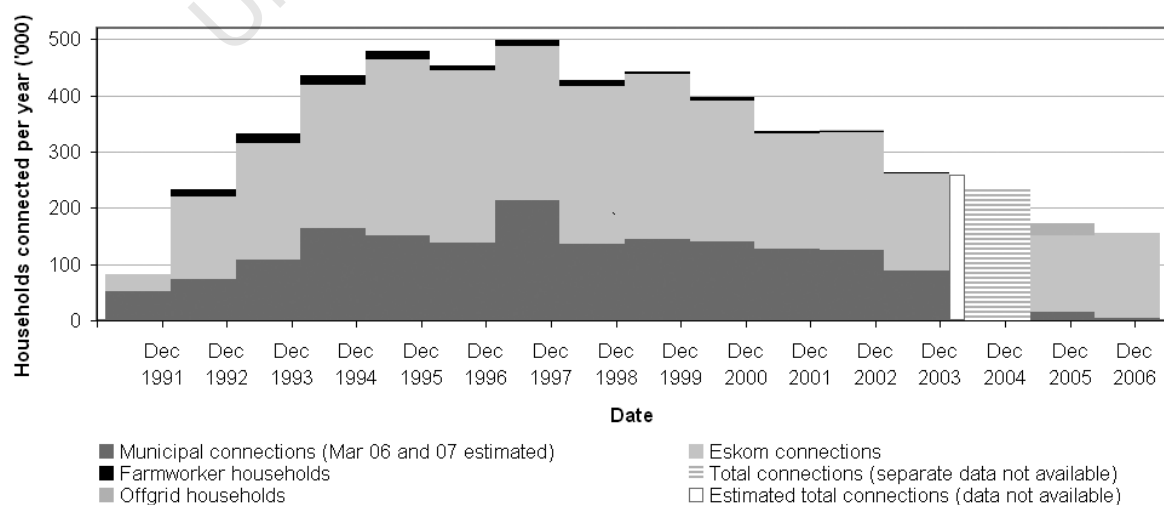


Figure 1-1: Annual new household electricity connections in South Africa [Bekker et al 2008]

What caused this decrease in annual connections? After all, South African government appears to be strongly committed to electrification, as is evident from a number of government statements and publications. President Thabo Mbeki, for example, committed to the goal of universal access to electricity by 2012 in his parliamentary State of the Nation Address in 2004¹:

'...with a strengthened local government working with our state enterprise, Eskom, we will, within the next eight years, ensure that each household has access to electricity' [Mbeki 2004].

More evidence is found in the Department of Minerals and Energy (DME)'s strategic report published in 2006:

"The INEP plans to electrify 500 000 households annually (subject to the allocation of adequate funds) with effect from 2007/8 financial year at an estimated cost of R2.5 billion per annum." [DME 2006:p5]

Electrification stakeholders appear to agree that the explanation for the decreasing connection rates can be found in the fact that all the 'easy' households have already been connected, necessitating an electrification programme focus shift towards less easily accessible households:

"...we continue to progress in the national electrification programme, although this has slowed down due to sparsely populated areas." [DME 2005:p3]

"...the most reachable communities have been electrified and the less accessible communities/households now remain to be electrified, i.e. all the low hanging fruit have been picked." [Scholle and Afrane-Okese 2007]

"The average cost of infrastructure development and the cost per connection will increase as we electrify communities in more remote rural areas." [Eskom 2007:p87]

"Challenges of poor and the absence of bulk infrastructure, especially in rural areas, have put a strain on the performance of the programme. During the year under review, an amount of R282 million had to be channelled from electricity connections towards bulk infrastructure, resulting in a reduced number of connections planned for the year." [DME 2007:p7]

¹ This target was moved to 2014 in Mbeki's 2008 State of the Nation address [Mbeki 2008]

As implied by two of the preceding statements, logically it makes sense that less easily accessible households will predominantly be in rural areas. Urban areas are generally more accessible due to higher household densities and proximity to Eskom's existing grid, created during 'first-wave' electrification².

It is however an over-simplification to position the shift towards less easily accessible household electrification within a general shift from predominantly urban electrification initially towards current rural electrification. As can be seen from Figure 1-2 rural annual connection rates exceeded urban ones during the middle 1990s, only been overtaken by urban connections after 1997 until 2002³.

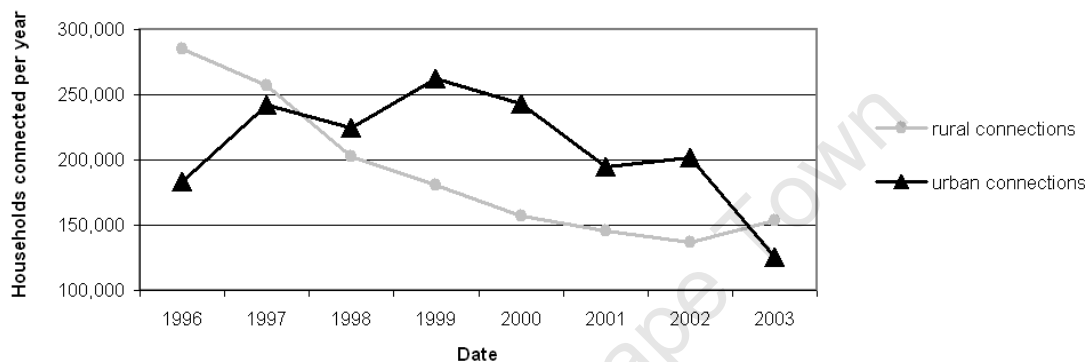


Figure 1-2: Annual number of urban and rural connections [NER 2003]

The challenge of how to increase annual connection rates appears to exist in how to adapt the existing electrification technologies, skills, methodologies and institutional structures to the changing focus of electrification, i.e. from accessible urban and rural communities that could be grid-connected cost-effectively, towards remote low density rural communities that are too expensive to connect to the grid despite innovations like Single Wire Earth Return (SWER) lines, necessitating off-grid electrification solutions.

² The 'first wave' of electrification usually involves the electrification of the economy as a whole. The 'second wave' generally responds to the problem of including areas of national economies that did not meet 'first wave' criteria for electrification (typically financial criteria). For a more complete description within the context of electrification policy refer to [Bekker et al 2008b]

³ After South African municipalities were restructured in 2000 the institutionally defined distinction between rural and urban areas fell away (refer to [Stats SA 2003]), although official electrification statistics continued to distinguish between rural and urban until 2003 (from 1996), when the DME took over from the National Electricity Regulator (NER) as the official source of electrification statistics.

1.1.2 Brief background to off-grid electrification in South Africa

By the early 1990s a significant number of domestic photo-voltaic (PV) systems (in the region of 40 000 to 60 000 systems according to the ERC [2004:p2]) had already been installed in rural South Africa on a commercial basis. The subsequent extension of the grid to rural areas through the electrification programme substantially undermined this market.

In addition a few subsidized off-grid electrification pilot projects occurred in the 1990s, including farmworker household electrification in the Free-State province⁴ and a number of village electrification projects, for example Folovhodwe, Maphephethe and KwaBhaza. Many problems were experienced in these projects, for example at Folovhodwe, where lack of maintenance and other factors resulted in only 13 SHSs out of the original 582 still being in good working condition after six years of operation (Table 1-1).

Table 1-1: The decline in the functionality of the SHSs at Folovhodwe, reproduced from [Bikam and Mulaudzi 2006] (from Appendix B)

| Solar energy facility statistics in Folovhodwe, 1999–2004 | | | | | | | | | | | | | | | | | | |
|---|-------|----|----|------|-----|----|------|-----|-----|------|-----|------|------|-----|------|------|----|------|
| Equipment | Years | | | | | | | | | | | | | | | | | |
| | 1999 | | | 2000 | | | 2001 | | | 2002 | | | 2003 | | | 2004 | | |
| | FC | FP | OU | FC | FP | OU | FC | FP | OU | FC | FP | OU | FC | FP | OU | FC | FP | OU |
| Solar module | 562 | 0 | 0 | 447 | 100 | 15 | 199 | 163 | 200 | 30 | 52 | 480 | 14 | 60 | 448 | 13 | 0 | 549 |
| Battery | 562 | 0 | 0 | 430 | 102 | 30 | 317 | 110 | 135 | 30 | 54 | 478 | 25 | 37 | 500 | 13 | 0 | 549 |
| Lights | 1686 | 0 | 0 | 1500 | 182 | 0 | 855 | 297 | 534 | 135 | 192 | 1359 | 135 | 192 | 1359 | 39 | 0 | 1647 |
| Charge controller | 562 | 0 | 0 | 450 | 100 | 12 | 462 | 85 | 15 | 87 | 75 | 400 | 40 | 42 | 480 | 13 | 0 | 549 |
| Radio adapter | 562 | 0 | 0 | 447 | 100 | 15 | 199 | 163 | 200 | 30 | 52 | 480 | 14 | 100 | 448 | 13 | 0 | 549 |

Source: Authors field data, 2004.

Key: FC: Functioning perfectly, FP: Functioning partially, OU: Out of use completely.

It was only from 1999 that the first programmes and pilot projects aimed at government subsidized, large-scale off-grid electrification were launched in South Africa, notably the Solar Home System (SHS) concession programme, and two hybrid mini-grid system demonstration projects. Figure 1-3 indicates the geographical locations of the off-grid electrification projects that will be discussed in this research.

⁴ Local authorities in the Free-State region subsidised the installation of 1700 farmworker household solar systems by mid 1997 [Banks and Karotki 2000].

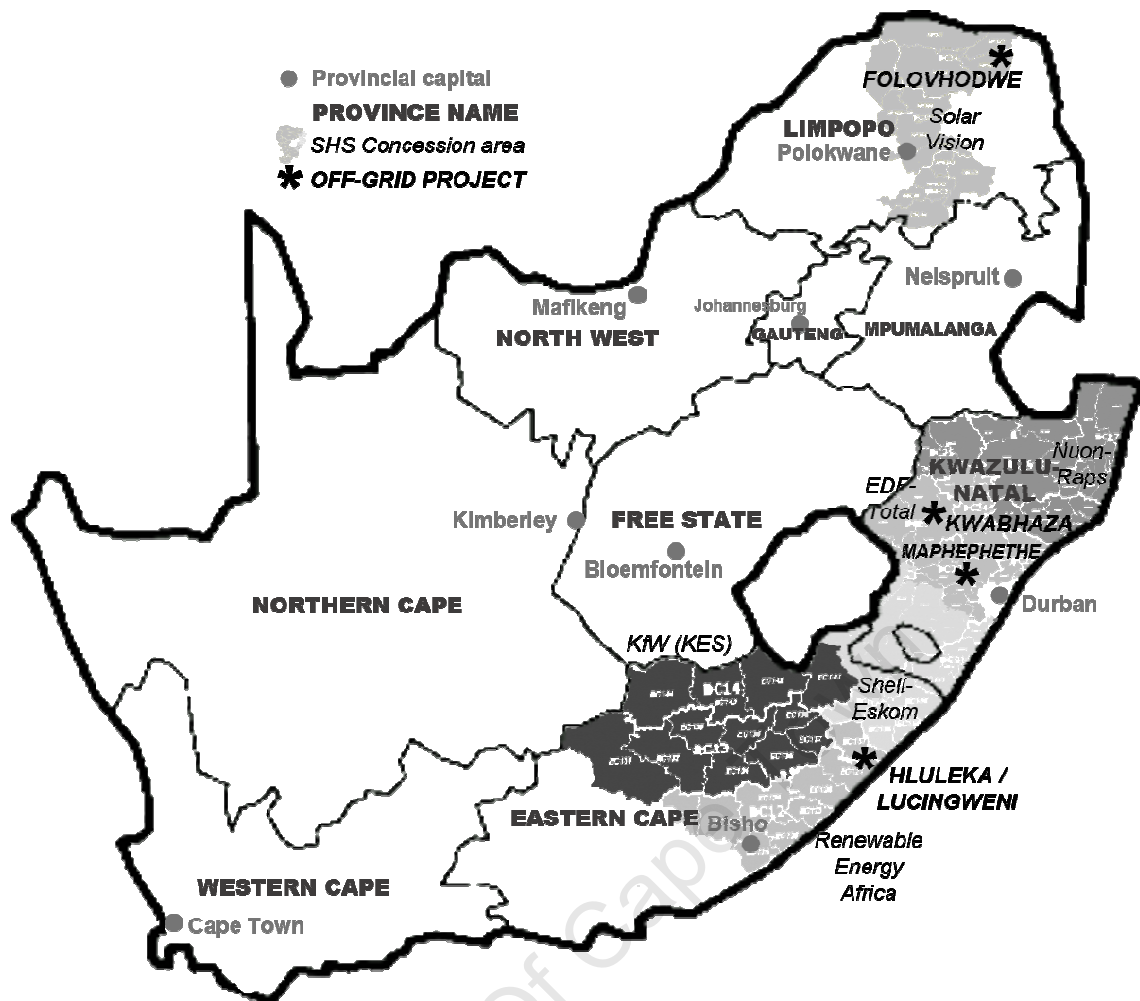


Figure 1-3: The geographical locations of the off-grid electrification projects discussed in this research, as well as the SHS concession areas as originally demarcated by the DME [2002]

1.1.2.1 The SHS concession programme

Towards the end of the 1990s the DME decided to allocate a number of remote rural concession areas to private off-grid service provider companies for subsidised SHS installations.

The first implementation of this concession policy involved a joint venture between Eskom and Shell International Renewables, announced in October 1998 and launched in March 1999, to install SHSs in the Flagstaff region of the Eastern Cape Province. The joint venture undertook to electrify some 50 000 rural households using SHSs over the following 5 years [DME 2001:p94].

The DME invited submissions in January 1999 for additional off-grid service providers, based on which six additional consortia were identified in May 1999. The interim contracts between the consortia and National Energy Regulator of South Africa (NERSA) and Eskom were however only signed in May 2002, after extended institutional delays in finalising the programme structure, the roles of different stakeholders, contract terms and subsidy structures.

This allowed the first phase installation of SHSs to commence in concession areas⁵. Two of the six selected consortia did not start operations, while the remaining four companies were expected to connect 50 000 customers per concession area over an initial period of 5 years [Banks 2007].

In February 2004 subsidy funds were stopped at short notice, halting new SHS installations. Negotiations between stakeholders led to a new agreement that was signed in October 2004 for phase two of the concession program. This new contract ended in April 2006 without a new one in place, again halting new SHS installations. In November 2007, after several meetings, the consortia were informed by the DME that the contract will not be renewed “*at this time*” [Banks 2008]. From May 2006 up to the time of writing (February 2010) no further subsidy funding has been received by the consortia from national Government. The KfW (KES) concession in the Eastern Cape is the exception: the German development bank KfW is funding the installation of SHSs in this concession area via the DME, with installations commencing in January 2009 and numbering around 3000 by February 2010 [Boussard 2010].

The total number of SHSs installed by the consortia between March 1999 and October 2007 are reported in Table 1-2. From this table it is evident that *in total* not even 40 000 SHSs have been installed by October 2007 [Banks 2008], significantly less than the target of 50 000 SHSs per consortium originally aimed for.

Table 1-2: Consortia, concession areas and total number of installations by June 2004 and October 2007

| Consortia | Concession Area | Total installations by June 2004 [Create Acceptance 2007] | Total installations by October 2007 [Banks 2008] |
|--|--|---|--|
| Nuon-Raps (NuRa) | Northern KwaZulu-Natal | 6541 | 10393 |
| Solar Vision | Northern Limpopo | 4758 | 9200 |
| EDF-Total (KES) | Interior KwaZulu-Natal | 3300 | 9000 |
| Renewable Energy Africa | Central Eastern Cape | 0 | - |
| Shell-Eskom (Replaced by the 3 companies below in 05/06) | Northern Eastern Cape and Southern KwaZulu-Natal | 5800 | 5800 |
| Summer Sun | | - | 1600 |
| Shine the way | | - | 1600 |
| Elita Co-op | | - | 1700 |
| Total | | 20399 | 39293 |

⁵ The NuRa consortium started installing SHSs in December 2001, supported by a Programme for Co-operation with Emerging Markets grant by the Dutch government.

A number of studies have been done on the social, economic and environmental impacts that SHSs have made on the South African households where they have been installed. Although a number of positive impacts have been reported, problems exist:

“It is still doubtful if very poor rural people can afford even this highly subsidised service of PV just for lighting and media use.” [Create Acceptance 2007: p6]

“Social changes brought by innovations such as solar power are small and imperceptible and probably only cumulative in the presence of other catalysts.”
[ERC 2004:p vii]

1.1.2.2 The hybrid mini-grid system demonstration projects

The South African Minister for Minerals and Energy mandated the NER to investigate and propose to government an appropriate regulatory framework for off-grid electrification. This mandate included that the NER, along with the Independent Development Trust (IDT), facilitate the piloting of hybrid mini-grid systems in South Africa, with the view to inform a national rollout of these systems.

The Hluleka Nature Reserve and the adjacent community of Lucingweni, in the Eastern Cape Province near Coffee Bay, were chosen as sites to install such pilot hybrid mini-grid energy systems. Implementation of the projects was completed respectively in 2002 and 2004⁶.

By May 2007 the two mini-grid installations were in a serious state of disrepair, as shown in Figure 1-4 for Lucingweni. By this time Hluleka had been using diesel generation (which the hybrid system originally replaced due to its cost and environmental impact) for more than a year, while the Lucingweni community was once again reliant on traditional sources of energy, like biomass and paraffin (for more information, please refer to the detailed off-grid project evaluations in Appendix B).

⁶ At Hluleka an energy system was installed with two 2.5kW Proven wind generators and a Shell Solar PV array of 56 100W PV modules, with batteries for reserve energy. A diesel generator was retained on site as backup. The Lucingweni energy system consisted of 560 100W solar PV panels, six 6kW wind generators, batteries and control equipment.



Figure 1-4: The Lucingweni hybrid mini-grid system in May 2007. Around 40% of the total PV panels were either stolen or inoperable due to vandalism.

1.1.3 The argument so far

- *Off-grid electrification technologies have the potential to play an important part in reaching South African electrification goals.*

From the published electrification statistics it is clear that South Africa's national electrification program is losing momentum. This is despite the fact that almost a third of the country's households are still without electricity within the context of a government policy goal of universal access to electricity.

A significant reason for this loss of momentum appears to lie in the challenges of electrifying increasingly remote, low household density rural communities. Off-grid electrification technologies like SHSs and hybrid mini-grid systems are potentially well suited to overcome the challenge of electrifying these communities.

- *Up to the present South African programmes and pilot projects aimed at government-subsidised, large-scale off-grid electrification have not been performing: they have clearly failed from a connection target perspective, and have had limited success in providing the benefits of electricity to households.*

From a connection target perspective, the SHS programme, with a 5-year target of providing 50 000 households with SHSs in each of the targeted concession areas, has not even reached 40 000 households in total by the end of 2007, and is currently dormant.

Regarding the benefits, the literature reports that the SHS programme has only been partly successful in extending the benefits of electricity to households.

A visual inspection of the PV arrays at the hybrid mini-grid project at Lucingweni is enough to conclude that this project has failed. The same applies for Hluleka, where 5 years after installation the nature reserve was again using diesel for electricity generation.

1.2 Causes and potential solutions for this non-performance

In the light of the above, two questions now require further analysis:

- Why is off-grid electrification not performing?
- What can be done to increase the likelihood of successful off-grid electrification?

1.2.1 Causes of off-grid electrification project non-performance in literature

A good place to start looking for answers to the first question is in published literature. The almost two decades of electrification experiences in South Africa has resulted in numerous research outputs, many of which touched on the problems that led to failure or lower-than-expected performance of projects in this field.

A wide spectrum of problems is reported. A study of the Eskom-Shell Joint Venture SHS concession's experiences for example identified the long-term integrity of systems from a technical maintenance perspective, the risk of non-payment and theft of system components as important issues [Afrane-Okese 2003:p40].

Addressing the identified problems, for example the problem of system theft, often leads to new problems:

“This technology sophistication (technical security protection against SHS component theft) in deep remote areas has led to many system failures which has aggravated the maintenance requirements beyond the capability of the maintenance service. This has led to much dissatisfaction among end-users,

which has consequently resulted in increased non-payment.” [Afrane-Okese 2003:p41]

Inaccurate load data during the design stage, lack of operation maintenance and human inertia to change were identified as the problems with the mini-grid project at Hluleka:

“It became immediately apparent after the system was installed that the accommodation figures provided by the nature reserve management had been incorrectly calculated”

“Despite repeated training ... The staff (is) reactive in their approach towards maintaining the system.”

“Guests are being allowed to enter the reserve with pump powered portable swimming pools, large freezers, fridges and various other appliances. Distribution boards are bypassed in order to have these appliances function on site.” [NER 2003b:p4-5]

Another problem identified in many projects appears to be that the expectations of the different stakeholders are not managed, and that the importance of stakeholder interaction is often not recognised:

“I am angry at Eskom-Shell because instead of giving us the real thing (grid electrification), they have made us ‘playthings’. Eskom-Shell is just tempting us with this SHS thing and not giving us the full service of what proper electricity should be doing in terms of meeting our needs.” Customer comment reported in [Afrane-Okese 2003:p43]

“The over eagerness of some of the government officials and manufacturers’ representatives in getting the project established, lead to unrealistic presentations and promises.” [Sparknet 2003]

“The service provider does not understand the needs and conditions of the customers and the customers do not understand the technology and the often complicated agreements that go with it.” [Create Acceptance 2007:p11]

The lack of transparency and communication within electrification planning are also often blamed:

“When the concession areas were awarded, the service providers thought that the basis for allocating the concessions was the fact that electrification was not to reach the area in the near future, but some SHS clients were later connected to

the grid. ... When clients are expecting grid electricity they are generally not willing to accept SHSs. [Create Acceptance 2007:p10]

Institutional delays and uncertainties appear to be a serious cause of project failure:

It was therefore a relief that the government increased its pace in [releasing subsidies for the SHS concession programme]. If government and donor funding wait too long, the [Eskom-Shell joint venture] may incur a bad reputation for the technology and it may be too difficult to repair the image damage. [Afrane-Okese 2003:p47]

“The withdrawal of the capital subsidy [SHS subsidy withdrawn in February 2004 and again in April 2006] is a major issue threatening the viability of the business plan and questions government’s commitment to this RE model ... Some impoverished rural municipalities ... were not able to pay the service subsidy and some paid it irregularly, leaving customers stranded. ... This uncertainty of service subsidy also affects the business plan of the service provider.” [Create Acceptance 2007:p10]

A range of other problems, like the often-unsustainable short-term target driven nature of especially donor-driven electrification [WEC 1999:p103], additionally contributes to off-grid electrification non-performance.

1.2.2 The nature of the causes of non-performance

1.2.2.1 Multi-dimensional and interlinked in nature

The preliminary literature survey clearly indicates the multi-dimensional and interlinked nature of the causes of off-grid electrification non-performance. Magilindane [2003] reached the same conclusion:

“...a plethora of individual and mutually inclusive factors constrain the widespread use of SHS.” [Magilindane 2003]

Therefore, an analysis that aims to find solutions to the non-performance of off-grid electrification, and resulting approaches and tools, need to take this multi-dimensional and interlinked nature of the problems into account.

1.2.2.2 In essence unacknowledged uncertainties

It is apparent from the preliminary survey that most of the causes identified are, in essence, project uncertainties that were not acknowledged during the planning stages of the project. If these uncertainties were acknowledged, they could then be managed or addressed in such a way that they did not lead to non-performance.

This last statement is in agreement with the definition of good decision making, as offered in literature. According to Belton and Steward [2002], a good decision should be “*well considered, justifiable and explainable*”. The word “*well considered*” entails comprehensively taking the different uncertainties into account.

The management of uncertainties can be done most easily when these uncertainties can be controlled directly. For example, the uncertainty or risk of non-payment can be addressed by installing prepayment meters, and the risk of technological reliability by implementing adequate maintenance structures and more robust designs.

Even in cases where uncertainties are further removed from the control of the programme / project, they can still be managed: for example the risks of human inertia to change and of unrealistic customer expectations can be managed by better stakeholder interaction and information sharing.

It might be impossible to address uncertainties that fall completely outside the control of the programme / project, for example institutional risks like unstable subsidy provision. However, even in these cases making the uncertainty explicit during the project planning stages will lead to better-informed decisions.

1.2.2.3 Mainly uncertainties of a non-techno-economic nature

What also became apparent from the preliminary survey is that the majority of uncertainties identified are social or institutional in nature, compared to a minority of technological and economic uncertainties.

1.2.2.4 Project objectives were not necessarily aimed at sustainable development

The primary project objectives in both the SHS concession programme and the mini-grid demonstration projects appeared not to directly include sustainable development objectives. So, for example, it appeared that the main objective of the concession programme was to reach connection targets, and for the mini-grid projects to demonstrate the practicality of a mini-grid solution. The underlying assumption in both these examples was surely to contribute towards the sustainable development of the

communities targeted; however, it appears that not formally focussing on sustainable development objectives in projects might undermine their success.

1.2.2.5 Formal decision aiding approaches and tools were not used

The preliminary survey found only very limited evidence of the use of formal decision aiding approaches and tools, which would have supported and structured the decision making (planning) process, potentially avoiding many problem causes like unacknowledged uncertainties and misdirected objectives.

1.2.3 Increasing the likelihood of successful off-grid electrification projects

1.2.3.1 Classification of off-grid project uncertainties as hard or soft

According to Young [2001], uncertainty can only be practically dealt with in the decision making process by recognizing the variations in the nature of the different elements of uncertainty.

Building on work by other authors, Young defines two types of uncertainty, hard and soft. With hard uncertainty the set of all possible outcomes of an action is unknown and can only be hypothesized, or if all the outcomes are known, the probability distributions of all the outcomes are unknown or not fully definable.

Soft uncertainty is used to define situations where all the possible outcomes of an action, as well as the outcomes' probability distributions, are known.

The correlation between hard uncertainties and off-grid non-performance

Most of the social and institutional uncertainties identified in the preceding literature overview, like human behavioural inertia to change or government subsidy stability, can be categorised as hard uncertainty according to this classification.

On the other hand, technological and economic uncertainties are mostly soft uncertainties, for example load characteristics, technical failure rate, and project cost and timing.

A correlation between unacknowledged hard uncertainties and off-grid electrification project non-performance appears to exist, because

- the main causes of off-grid non-performance appear to be unacknowledged uncertainty of a non-techno-economic nature, and

- non-techno-economic uncertainty is typically defined as hard.

1.2.3.2 Improve the alignment between project objectives and sustainable development objectives

Addressing the problem of project objectives not being aligned to sustainable development objectives should also increase the likelihood of successful off-grid electrification projects in South Africa.

1.2.3.3 Encouraging the use of adequate decision aiding approaches and tools

Using adequate decision aiding approaches and tools (where by “adequate” is meant decision aiding that adequately supports all the aspects of a decision that leads to a successful project) will increase the likelihood of successful projects. Such “adequate” decision aiding will have to include the acknowledgement of uncertainties and alignment of objectives, along with other factors like recognising the multi-dimensional and interlinked nature of the causes of problems in projects.

A preliminary literature survey could find no existing tools or approaches explicitly aimed at acknowledging off-grid electrification project uncertainties, or aimed at aligning project objectives with sustainable development objectives within the energisation context. A number of tools were identified that could potentially be adapted to this task, including the RETScreen and Homer renewable resource estimation tools (for soft uncertainty acknowledgement), Shackle’s model as implemented by Young [2001] (for hard uncertainty acknowledgement) and the Logical Framework approach (for objectives alignment).

1.2.4 Concluding the argument

In the light of the above analyses, it is reasonable to argue that,

- assuming that the above-identified nature of the causes of non-performance within South African off-grid electrification projects reported in literature is accurate,

a set of decision aiding approaches and tools with the following characteristics will be beneficial in increasing the likelihood of these projects contributing to sustainable development:

- of sufficient quality to adequately support all the aspects of a decision that will result in a successful project, including the following aspects:

- capable of making explicit the soft and hard uncertainties affecting the project,
 - capable of aligning project objectives with sustainable development objectives, and
 - capable of recognising the multi-dimensional and interlinked nature of off-grid projects
- applicable for use within the context of South African off-grid electrification projects.

1.3 Hypothesis and research questions

Following from the above argument, the hypothesis that this research sets out to test can now be defined in three parts:

There is a strong correlation between failure of South African off-grid electrification projects to achieve sustainable development objectives, and unacknowledged⁷ uncertainties within the initial decision making / planning processes of these projects.

A high quality decision making process that is capable of acknowledging both hard and soft uncertainties will assist off-grid projects in reaching their primary project objectives (but not necessarily sustainable development objectives, unless these two sets of objectives align).

Applying existing high quality decision aiding tools and approaches, with improved uncertainty acknowledgment and objectives alignment capabilities, to off-grid projects will increase such projects' impact on sustainable development.

Several research questions arise from these hypotheses, and will be used to guide the research needed to test their validity. For the first part of the hypothesis the questions are as follows:

⁷ It is important to differentiate between acknowledging uncertainties (i.e. being aware of it) and addressing uncertainties (i.e. doing something about it). The hypothesis in this thesis focus on acknowledging uncertainties – what to do once these uncertainties have been acknowledged is touched on, but is not the core focus of this thesis.

- What off-grid electrification objectives align with the principles of sustainable development?
- What are the factors already identified in literature that inhibited South African off-grid electrification projects from reaching sustainable development objectives?
- What uncertainties underlie the set of objective-inhibiting factors identified earlier, or have been identified in literature specifically relevant in the South African off-grid electrification context?
- What impacts did the early acknowledgement / non-acknowledgement of these uncertainties have on South African off-grid electrification projects reaching their sustainable development objectives?

The second part of the hypothesis will be tested using the following questions:

- What are the advantages of differentiating between soft and hard uncertainties?
- What are the characteristics of high quality decision making?
- What are the criteria of a decision aiding process which supports high quality decision making, and do these criteria include hard and soft uncertainty acknowledgement?
- Is high quality decision making sufficient to ensure that off-grid projects achieve sustainable development objectives, and if not, what are the additional requirements?

The third part of the hypothesis will be tested using the following questions:

- What decision aiding tools and approaches currently exist that will support high quality decision making to a large extent within the context of South African off-grid electrification projects?
- How can the uncertainty acknowledgment and objectives alignment capabilities of these existing tools and approaches be improved?
- Would these improved decision aiding tools and approaches, if applied originally, have increased selected South African case study projects' impact on sustainable development?

1.4 Research methodology / Conceptual map

The testing of the three parts of the hypothesis will be divided between four chapters, each answering two to four research questions, as shown in Figure 1-5. Each chapter will be introduced with a more detailed conceptual map of how the research questions will be answered. This map will also explain how the appendixes link to the main text.

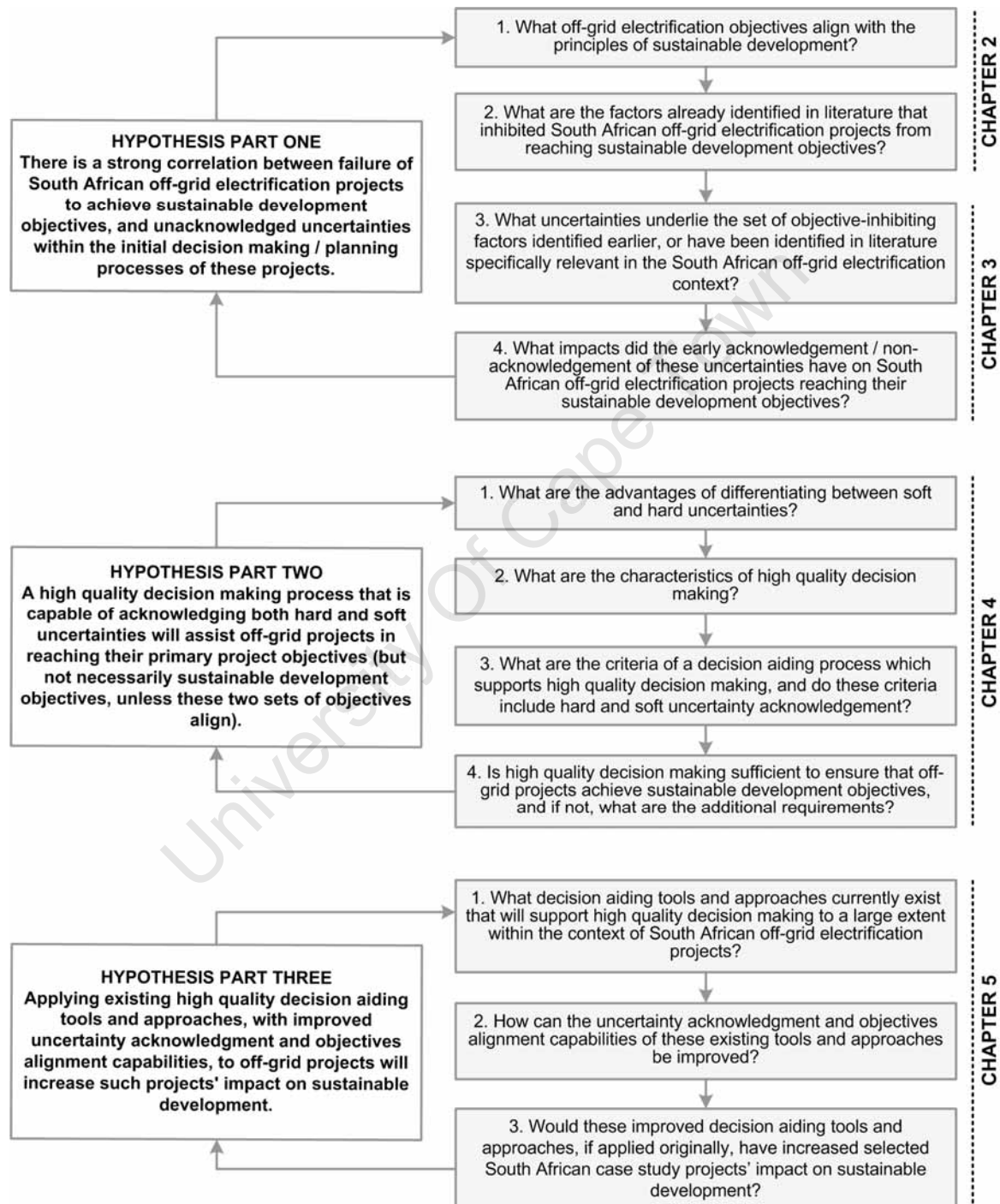


Figure 1-5: A conceptual map of the different parts of the research hypothesis, the research questions related to each part and the chapters where these questions will be answered.

2 Off-grid electrification that aligns with sustainable development

Off-grid electrification projects do not necessarily result in sustainable development. A lack of adequate planning, badly executed project implementation, political or business objectives etc. can all detract from the developmental impact of such projects. In order to evaluate the contribution of off-grid projects to sustainable development, some form of standard is required against which such projects can be compared.

This chapter develops such a standard, in the form of an energisation framework, against which completed South African off-grid electrification projects are then evaluated for their sustainable development impact, as shown in the conceptual map in Figure 2-1.

In this chapter the first two research questions leading towards testing part one of the research hypothesis are answered.

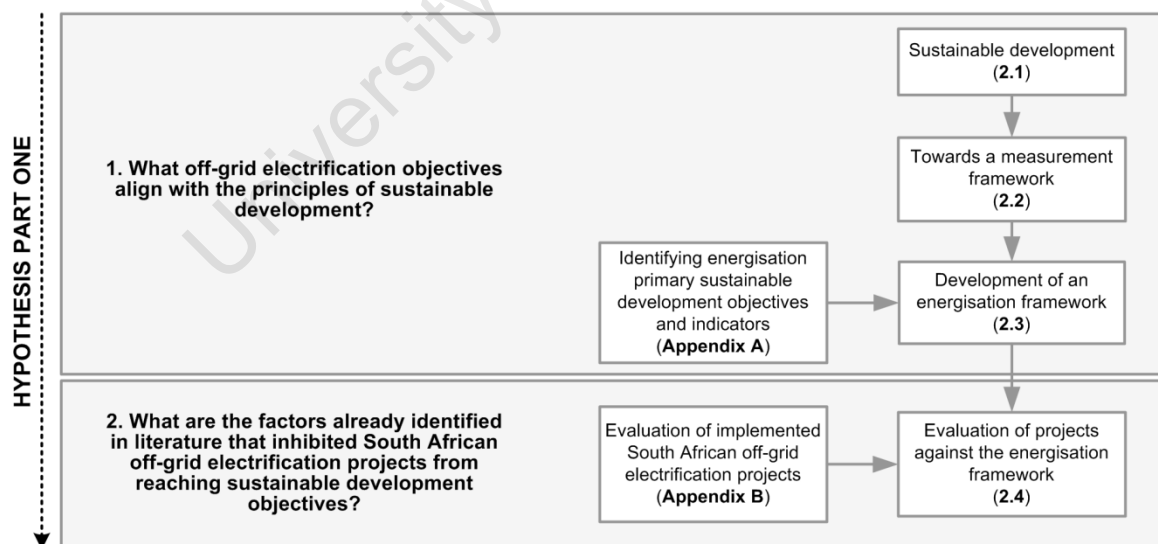


Figure 2-1: Conceptual map showing how the different sections of Chapter 2 and the appendices relate to the research questions and hypothesis.

2.1 Sustainable development

2.1.1 What is sustainable development?

A well-known definition of sustainable development, originally proposed by the UN World Commission on Environment and Development's Brundtland report [Brundtland 1987], is "*development that meets the needs of present generations without compromising the ability of future generations to meet their needs.*"

One of the primary aims of the Brundtland report was to propose measures "*to deal successfully with the problems of protecting and enhancing the environment*" [Brundtland 1987:pix]. However, the outcomes of sustainable development are not restricted only to the environmental dimension, but also include the social and economical dimensions, supported by institutional structures as illustrated by the following quote:

"Sustainable development is essentially about improving quality of life in a way that can be sustained, economically and environmentally, over the long term supported by the institutional structure of the country." [IAEA 2005:p16]

2.1.2 Why use sustainable development as measurement standard?

Sustainable development acts as a general guiding principle within South African policy, as indicated by the fact that the adjective "*sustainable*" is used thirty times in the Energy Policy White Paper [DME 1998], and by the following selection of quotes from the South African constitution:

"... secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development." [SA Gov 1996:section 24]

"... provide municipal services in an equitable and sustainable manner." [SA Gov 1996:section 155]

"... in the interest of balanced and sustainable economic growth ..." [SA Gov 1996:section 224]

As South African off-grid energisation actions typically occur within the context of government policy, it is clear that sustainable development is a valid foundation on which to build a measuring standard such as the proposed energisation framework.

2.1.3 What existing sustainable development frameworks are applicable?

The International Atomic Energy Agency (IAEA), in collaboration with a number of other institutions, developed a set of energy indicators against which the sustainable development impact of activities can be measured, presented in [IAEA 2005].

Although the IAEA's energy themes and their related indicators, summarised in Table 2-1, are aimed at energy-related activities on a national level, they will serve as a starting block from which a sustainable development framework for off-grid electrification will be adapted:

"No set of energy indicators can be final and definitive. To be useful, indicators must evolve over time to fit country-specific conditions, priorities and capabilities."
[IAEA 2005:pv]

Table 2-1: Sustainable development indicators for energy-related activities on a national level, divided into dimensions, themes and sub-themes, as proposed by the IAEA [2005]

| Social dimension | | |
|-----------------------------|----------------------------|---|
| <i>Theme</i> | <i>Sub-theme</i> | <i>Energy Indicator</i> |
| Equity | Accessibility | Share of households (or population) without electricity or commercial energy, or heavily dependent on non-commercial energy. |
| | Affordability | Share of household income spent on fuel and electricity. |
| | Disparities | Household energy use for each income group and corresponding fuel mix. |
| Health | Safety | Accident fatalities per energy produced by fuel chain. |
| Economic dimension | | |
| <i>Theme</i> | <i>Sub-theme</i> | <i>Energy Indicator</i> |
| Use and production patterns | Overall Use | Energy use per capita |
| | Overall productivity | Energy use per unit of GDP |
| | Supply efficiency | Efficiency of energy conversion and distribution |
| | Production | Reserves-to-production ratio Resources-to-production ratio |
| | End use | Industrial energy intensities Agricultural energy intensities Service/commercial energy intensities Household energy intensities Transport energy intensities |
| | Diversification (fuel mix) | Fuel shares in energy and electricity Non-carbon energy share in energy and electricity Renewable energy share in energy and electricity |
| | Prices | End-use energy process by fuel and by sector |
| Security | Imports | Net energy import dependency |
| | Strategic Fuel stocks | Stocks of critical fuels per corresponding fuel consumption |

Table continues on next page...

| Environmental dimension | | |
|-------------------------|---------------------------------------|--|
| Theme | Sub-theme | Energy Indicator |
| Atmosphere | Climate Change | GHG emissions from energy production and use per capita and per unit of GDP |
| | Air quality | Ambient concentrations of air pollutants in urban areas Air pollutant emissions from energy systems |
| Water | Water quality | Contaminant discharges in liquid effluents from energy systems including oil discharges |
| Land | Soil Quality | Soil area where acidification exceeds critical load |
| | Forest | Rate of deforestation attributed to energy use |
| | Solid waste generation and management | Ratio of solid waste generation to units of energy produced Ratio of solid waste properly disposed of to total generated solid waste Ratio of solid radioactive waste to units of energy produced Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste |
| Institutional dimension | | |

2.2 Towards a measurement framework

2.2.1 The scope of the new framework

The measurement standard that will be developed in this chapter will be defined within the context of energisation (i.e. making available energy by using any carrier, be it electricity, biomass, LPG etc.) rather than specifically electrification (i.e. making available energy by using electricity as carrier).

By focussing on energisation, this research acknowledges electrification as part of the broader energisation context. A number of sources in the literature support this perspective, for example in the Renewable Energy White Paper:

“An electrification programme, particularly if it has a strong non-grid component, has to form part of a holistic approach to energy provision, if it is to succeed.”

[DME 2003:p38]

2.2.2 Objectives rather than sub-themes

The sub-themes defined within the above-described IAEA framework will be replaced with project objectives. This aims to improve the clarity of the adapted framework, and increase the framework’s usefulness within the decision aiding tools developed later in this research.

The decision to use objectives is informed by Keeney and Raiffa’s [1976] statements regarding the usefulness of objectives in the decision making process, and Zomers’

[2001] conclusion regarding the importance of clear objectives for electrification project evaluation:

“The identification and structuring of objectives essentially frames the decision being addressed.” [Keeney and Raiffa 1976]

“The results of the majority of the socio-economic studies [on the impact of rural electrification] give rise to the conclusion that the objectives of rural electrification projects should be made very clear for both assessment and evaluation reasons.” [Zomers 2001:p47]

2.2.3 Different types of objectives

At this point it is useful to note that this research differentiates between primary, supportive and ultimate objectives.

Primary objectives are potentially directly impacted by the action of energisation, for example the objective of *decreased indoor air pollution* which is directly impacted by the change from biomass to electricity or gas as cooking energy source.

Supportive objectives are defined as project objectives that need to be met to a lesser or greater extent in order for energisation to reach its primary objectives, for example *access to markets* to support the primary objective of *small and medium enterprises (SMME) development*.

Ultimate objectives are defined as wider objectives that are supported by energisation primary objectives, often along with non-energisation objectives, for example the ultimate objective of *decreasing rural to urban migration* that is supported by a variety of energisation primary objectives along with non-energisation objectives.

2.2.4 Ensuring a coherent measurement framework

An important question related to the proposed measurement framework, and a question that will surface again later in this research, is how to ensure that the framework of objectives / criteria⁸ being identified is comprehensive or exhaustive, yet useful.

⁸ A criterion is “*some sort of standard by which one particular choice or course of action could be judged to be more desirable than another.*” [Belton and Steward 2002:p1] In the context of this research the concepts criteria and indicators are used interchangeably.

Belton and Steward [2002:p55-58] offers an answer to this question, through their guidelines on building what they call a “*coherent family*” of criteria or objectives. Eight guidelines are proposed:

- **Value relevance** - “*Are the decision-makers able to link the concept to their goals, thereby enabling them to specify preferences which relate directly to the concept?*”
For example, a goal like *health* is too vague to allow direct valuation by decision-makers, and might be specified more clearly as *a decrease in disease caused by indoor air-pollution.*
- **Understandability** - “*It is important that DMs have a shared understanding of concepts to be used in an analysis*”
- **Measurability** - “*... decompose criteria to a level which allows this.*”
- **Non-redundancy** – “*Is there more than one criterion measuring the same factor?*”
- **Judgemental independence** – “*Criteria are not judgementally independent if preferences with respect to a single criterion, or trade-off between two criteria, depend on the level of another.*”
- **Balancing completeness and conciseness**
- **Operationality** – The set of criteria should be “*usable with reasonable effort – that the information required does not place excessive demands on the decision-makers.*”
- **Simplicity versus complexity** – “*... the modeller should strive towards the simplest [set of criteria] which adequately captures the problem.*”

Related to ensuring coherent measurement frameworks, it is important to acknowledge the always-changing nature of reality, which also applies to the principles of sustainable development. So, for example, certain of the IAEA’s themes might become irrelevant with time (e.g. energy security in a future scenario where local energy sources are more than sufficient for the national demand) or be replaced with new sustainable development concerns.

The use of a formal measurement framework allows for this always-changing nature of reality: even though its robustness⁹ might be limited in the face of future changes, it is flexible and can easily be updated to the current context.

2.2.5 Level of detail of proposed framework

The use of energy indicators, rather than just objectives or sub-themes, makes possible detailed comparisons between intra-project pre- and post-implementation conditions, or inter-project outcomes. This chapter's evaluation of South African off-grid electrification projects will however focus only on identifying factors that prevented energisation objectives from being met. For this reason a broad categorisation of objectives, which excludes indicators, will be adequate to serve as measurement standard.

However, indicators and basic associated measurement scales will also be developed in this chapter as part of the proposed framework, as they will be useful in providing a more complete understanding of the objectives, required within the decision aiding processes developed later.

2.2.6 Qualitative rather than quantitative indicators

The IAEA's quantitatively measured energy indicators will be replaced with qualitatively measured indicators wherever possible during development of the proposed framework. This decision is motivated by the following reasons:

- a. *Aim of the framework within the research context:* In the research contained in this research the proposed framework will only be used to compare intra-project pre- and post-implementation conditions. Because of this, basic qualitative measurement scales, for example less / no change / more, will be adequate. Quantitative measurement, although useful especially for inter-project comparison, will be of little value within this research context.
- b. *Availability and relevance of data:* Energy indicators on a national level can in general be measured quantitatively, as national energy statistics are available to some extent. In contrast, very little quantitative data are typically available for off-grid

⁹ "... a robust solution will perform well under a range of unknown futures, while a flexible solution could easily be adapted to changing future conditions at minimal loss of performance in relation to the objectives." [Heinrich 2008:34]

energisation activities, especially during the early stages of an off-grid energisation programme as in South Africa.

The data that are available will also mostly be from localised project evaluations, which are of limited use for inter-project comparisons due to the many local variables that influence the data.

- *Simplicity*: As mentioned earlier, the application of the proposed framework will not be limited to the project evaluation contained in this chapter, but will also be useful within decision aiding processes discussed later. The more data the framework require before it can be used, the less likely it is to be used by actors in these processes. Vincke [1992] supports this perspective, by suggesting that qualitative variables should be preferred over quantitative ones, as decision-makers are often unable to provide answers to the latter.

2.3 Development of an energisation framework

A primary objectives framework for energisation¹⁰ will now be developed, based on the IAEA's energy framework, adapted to the specific context of energisation, and shaped by the discussions in the previous section.

2.3.1 Choice of dimensions

The IAEA divides the objectives framework against which the energy indicators measure into four dimensions: social, economical, environmental and institutional, as shown in Table 2-1. Note also that the IAEA's institutional dimension is not divided further into themes and sub-themes, due to the following motivations:

“First, [the themes within the institutional dimension] tend to address issues that are, by nature, difficult to measure in quantitative terms. ... Second, the variables measured by institutional indicators tend to be structural or policy responses to sustainable development needs.”[IAEA 2005:p20]

This research concludes that institutional objectives are not primary but rather supporting in nature, as the above statement suggests, and will therefore not include an *institutional*

¹⁰ For ease of use, this “primary objectives framework for energisation” will be abbreviated to “energisation framework” – this abbreviation will be used throughout the rest of the research.

dimension in the energisation framework. This dimension will however be important when defining supportive objectives. This same argument applies to a *technical dimension*, as proposed in Ilskog [2008]: once again technical objectives are supporting rather than primary in nature.

According to Zomers [2001:p46], rural electrification objectives can be classified within a political dimension in addition to the economic, social and environmental dimensions. Sebitosi and Pillay [2005:p2047] also identifies cases where the primary objectives of electrification are political:

“... at community level infrastructure and services like electrification are often, erroneously, treated as commodities. In this regard electrification becomes an end rather than a means. In African politics it doubles as the proverbial ‘carrot and stick’: rewarding politically friendly communities and denied to communities that are perceived to be politically hostile.” [Sebitosi and Pillay 2005:p2047]

Electrification solely for political objectives however rarely results in sustainable projects according to Zomers:

“Projects created only for the sake of politicians to score points or for donors to locate suitable funding opportunities, are not likely to be sustainable.” [Zomers 2001:p55]

Yet political objectives do not always result in unsustainable outcomes: outcomes within the political dimension that do align with sustainable development include *increased political stability* and *decreased discontent* (as identified in Mason [1990]). A statement from a teacher at the KwaBhaza energisation project (discussed in Appendix B) illustrates this:

“We like this [energisation] project; it shows that the government has not forgotten about us.” [Kloot 1999:p68]

It can be argued that these outcomes are purely the result of objectives in the social, economic and environmental dimensions being met, in which case an additional political dimension will be redundant. Zomers [2001:p72] suggest that this is not the case, with the above outcomes potentially resulting solely from the fact that rural communities often see electrification as a “*symbol of progress*” or a “*light in the darkness*”, and associate electricity “*in itself*” with well-being.”

Evaluation of South African off-grid electrification projects however shows that, while in the short term electricity “*in itself*” can contribute to decreased discontent and increased

political stability, in the long term only tangible social, economic or environmental benefits will guarantee these outcomes.

In the light of this a *political dimension* is seen as redundant within the energisation framework, and will not be included. Objectives such as *increased political stability* and *decreased discontent* can be seen as ultimate objectives, within which context a political dimension will be useful.

In conclusion then, only three dimensions will be used for the energisation framework: social, economic and environmental.

2.3.2 Choice of themes, objectives and indicators

Themes, objectives and indicators were selected for inclusion in the proposed energisation framework based on the IAEA's indicator framework, and a detailed literature study. In order not to break the continuity of the research' argument, the details of the process that led to the selection is described in Appendix A; only the results of this process are shown in Table 2-2.

Table 2-2: The energisation framework: primary sustainable development objectives and indicators within the context of energisation projects, developed as standard against which to compare project objectives, and intra-project pre- and post-implementation conditions

| Social dimension | | | |
|------------------|---------------------------------------|---|---|
| Theme | Objective | Indicator | Measurement scale |
| Equity | Accessibility of energy | Adequacy of energy from modern sources for basic needs of a) indoor lighting, b) media, c) communication, d) cooking, e) space heating, f) water heating and g) refrigeration | Not available Available but inadequate Available and adequate |
| | Affordability of energy | a) Average customers' ability to pay b) Poorest customers' ability to pay | Not able to pay Able to pay |
| | Addressing disparities | Disparities in access to and affordability of modern energy sources between a) different locations and b) different social groups. | Significant disparities Some disparities No disparities |
| Health | Fuel-use safety | The occurrence of a) paraffin poisoning, and b) fire-related injuries | More than before No change Less than before |
| | Indoor air quality | The occurrence of indoor particulate emission-related illnesses | More than before No change Less than before |
| | Security | Adequacy of exterior lighting | Not available Available but inadequate Available and adequate |
| | Energy-supply related physical labour | The amount of energy-related physical labour | More than before No change Less than before |

Table continued on next page...

| Economic dimension | | | |
|--------------------------------|-----------------------------|---|--|
| <i>Theme</i> | <i>Objective</i> | <i>Indicator</i> | <i>Measurement scale</i> |
| Productive use | Access to information | The use of a) radio, b) TV and c) Internet within the target area of the energisation project | More than before No change Less than before |
| | Increased time availability | The amount of free time daily compared to before energisation | More than before No change Less than before |
| | SMME development | The number of SMMEs within the target area of the energisation project | Less than before No change More than before |
| | Long-term income generation | The average household income within the target area of the energisation project | Less than before No change More than before |
| Environmental dimension | | | |
| <i>Theme</i> | <i>Objective</i> | <i>Indicator</i> | <i>Measurement scale</i> |
| Atmosphere | Addressing climate change | Green house gas contribution from energy sources | Less than before No change More than before |
| Water | Water quality | The impact of the use of modern energy sources on drinking and general water quality | Worse than before No change Better than before |
| Land | Deforestation | The impact of the use of modern energy sources on deforestation | Worse than before No change Better than before |

2.4 Evaluation of projects against the energisation framework

2.4.1 Off-grid electrification as a subset of energisation

This research focuses on off-grid South African electrification projects, which as a rule utilise renewable energy-based electrification technologies (SHSs and mini-grids) that currently produce costly energy compared to grid-connection. This high cost of energy, along with the limited ability of the customer to pay for it, leads to restricted electrical energy allocations per customer, which typically does not allow for high-energy household requirements like cooking, space and water heating and refrigeration:

“The SHS is good but it cannot cook, it cannot provide warmth, it cannot ... It can only power lighting, radio and black and white TV but not all at the same time.”
SHS customer comment recorded in [Afrane-Okese 2003:p46]

These electrical energy restrictions, inherent to the renewable energy-based electrification technologies that are used, limit the potential of these technologies to meet the primary energisation objectives defined earlier. So, for example, the primary objectives of *deforestation* and *air quality* are directly related to the use of firewood, a fuel used mainly for thermal applications like cooking and heating. If the electrification solution does not impact thermal applications, it is clear that firewood use will continue, resulting in these objectives not being fully met.

In the light of this, an evaluation of existing off-grid electrification projects should focus on those primary energisation objectives that the off-grid technologies have the possibility of contributing to, rather than on the complete set of objectives.

As previously stated, this restricted focus implies the realisation that an off-grid electrification program that does not form part of a wider energisation process can be severely limited in its sustainable development contribution.

2.4.2 Criteria for inclusion of projects in evaluation

The following criteria were used to select which South African off-grid electrification projects to include in this section's evaluation:

- The lessons learned from the project should be applicable to large-scale off-grid electrification.
- The project must have included an implementation phase. This evaluation consequently excludes the E7-led mini-grid demonstration project and the KwaZulu-Natal mini-grid study done by NuRa for the NER. The experiences and conclusions from both of these will be commented on in a later chapter.
- The project must be documented comprehensively enough in existing literature to allow accurate identification of factors that prevented primary objectives from being met.
- An attempt should be made to include projects that represented each of the four delivery models generally used in off-grid electrification projects, as categorised in [Nieuwenhout et al 2000:p15]:
 1. Cash sales by commercial dealers
 2. Donations, where users pay at most a small contribution to the total costs
 3. Credit-based schemes
 4. Energy service companies with fee-for-service systems.

2.4.3 Evaluation of projects

Based on the above criteria, the following six projects were selected:

- Maphephethe pilot SHS project

- KwaBhaza energisation project
- Folovhodwe project
- The DME's SHS concession program
- Hluleka nature reserve hybrid mini-grid demonstration project
- Lucingweni hybrid mini-grid demonstration project

A detailed project evaluation was done for each of these projects, focussing specifically on:

- a. the factors which prevented the project from meeting energisation primary objectives as defined in the energisation framework, while acknowledging that off-grid electrification objectives by necessity form a subset of these energisation objectives, and
- b. the lessons that were learned from these projects, as reported in literature and through interviews.

In order not to break the continuity of the research argument, only a brief background to each project will be provided here, along with a summary of the factors that prevented off-grid electrification objectives from being met. For the full project evaluation, please refer to Appendix B.

2.4.3.1 Maphephethe pilot SHS project

Maphephethe is a rural village in KwaZulu-Natal province, characterised by dispersed settlement patterns. The total number of homesteads in the village is estimated at around 2200. Grid electrification was available only at the edges of the village at the time of the project.

Maphephethe was identified as a suitable site for a pilot project which commenced in January 1996, aimed at developing and testing a replicable mode of practice for installing SHSs in South Africa. The Solar Electric Light Fund (SELF), a US-based NGO, initiated the project while Solar Engineering Services (SES) implemented it.

The project was completed within two years, having installed 50 SHSs. A number of additional energisation projects were undertaken in this village, including projects focussed on solar cooking, the use of biogas digesters, and the establishment of a PV/biogas hybrid supply at the Myeka High School, which supported among other the development of a computer centre with internet access.

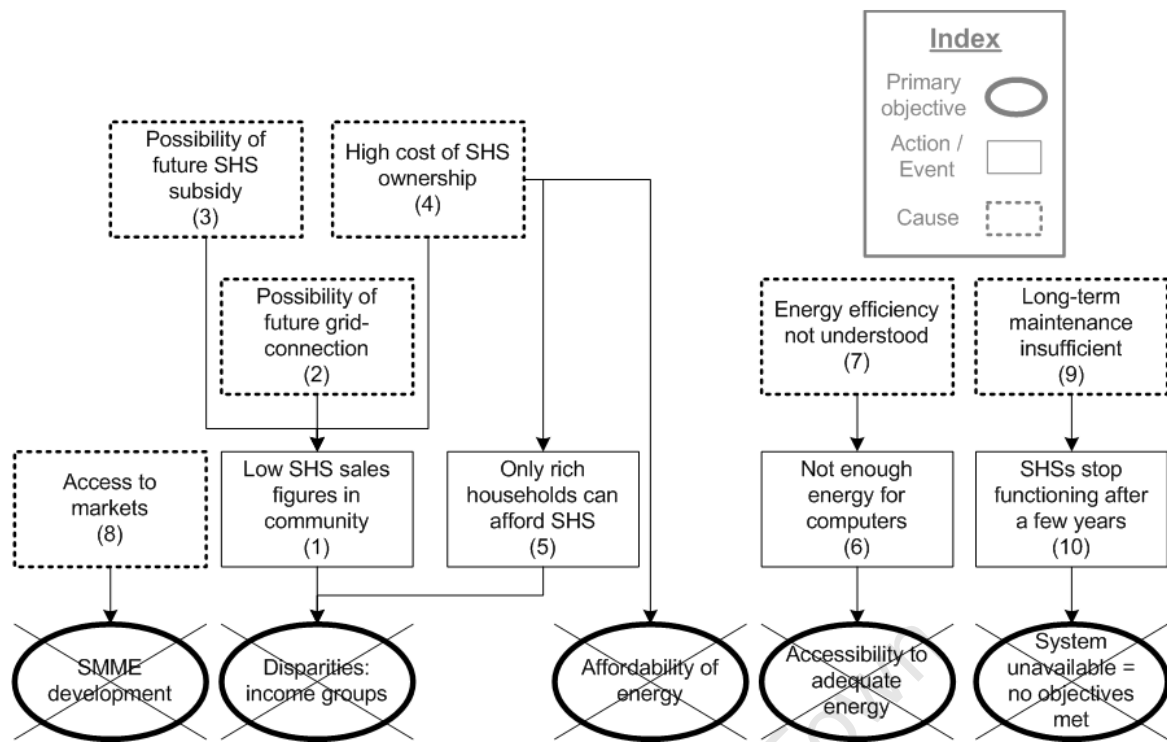


Figure 2-2: Factors identified in literature that prevented the Maphephethe pilot SHS project from meeting certain primary energisation objectives (reproduced from Appendix B).

2.4.3.2 KwaBhaza energisation project

Eskom identified six remote rural sites for energisation within a framework set out in the Energisation Pilot Project Proposal [Eskom 1997], with SHSs provided by Eskom and LPG gas provided by one of a number of South African LPG companies. Due to institutional and financial problems the energisation pilot project was finally only implemented fully at KwaBhaza in KwaZulu-Natal.

A 50Wp SHS for light and media, and a two-plate LPG stove and two 4.5kg LPG cylinders were to be supplied to households as a subsidised energisation package. Installations started in July 1998, and a total of 120 systems have been installed in at KwaBhaza through this energisation project. It was anticipated that the project would eventually form part of the EDF/Total concession area.

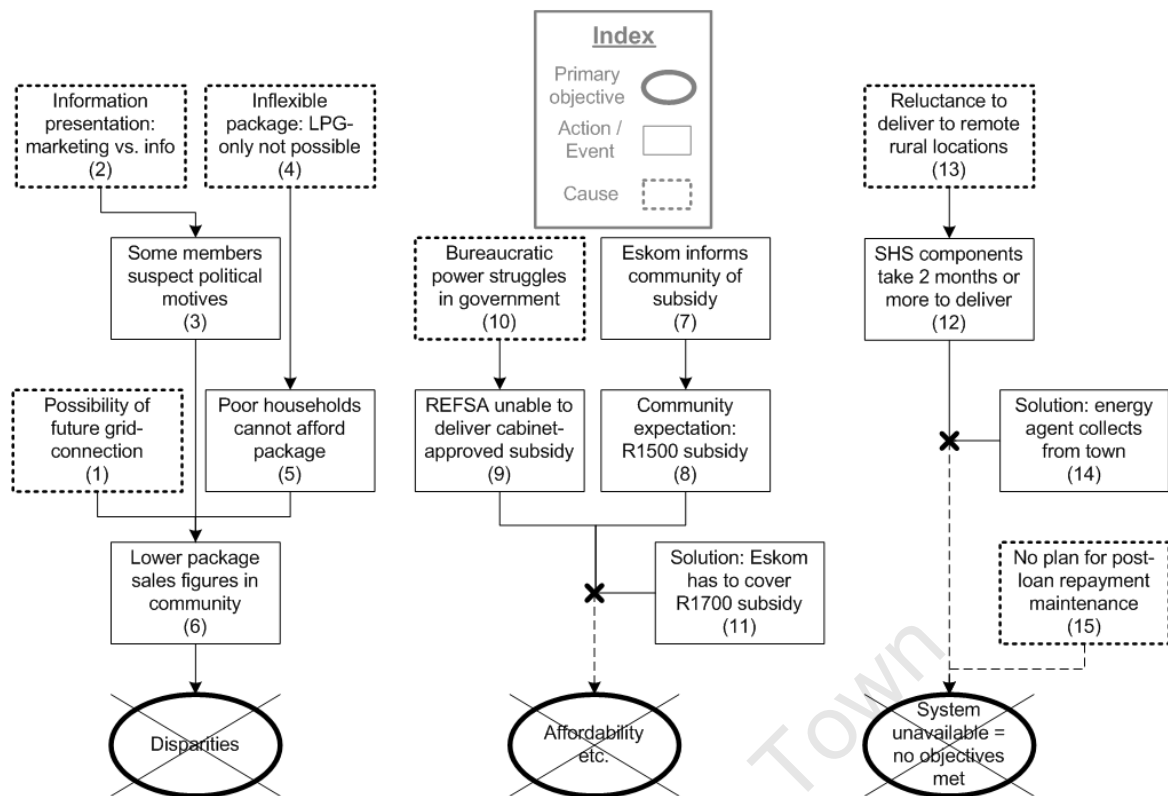


Figure 2-3: Factors identified in literature that prevented the KwaBhaza energisation project from meeting certain primary energisation objectives (reproduced from Appendix B).

2.4.3.3 Folovhodwe project

Folovhodwe is a village in the Limpopo province, which in 1996 contained around 670 households, located around 10 km from the nearest grid. The community was originally approached in August 1995 for interest in participating in a SHS pilot project, but expectation of imminent grid electrification led to the abandonment of the proposed SHS pilot project.

In 1997 the Bavarian government approached the DME with a proposal to establish a demonstration Solar Village using SHS technology. The Bavarian government was to fund most of the hardware, with the DME funding the balance. The Folovhodwe village was identified as a suitable site, as it was (after all) unlikely to receive grid electricity in the short- or medium-term.

By February 1999 the previously electrified local clinic's PV system was repaired and upgraded, and all 582 formally inhabited houses in the village supplied with 50Wp SHSs. No connection or service fees were received from individual households until November 1999, when RAPS, on the request of the DME, tried to solve the problems related to payment for the SHS service.

By the middle of 2004 only 13 SHSs out of the original 582 were still in good working condition, as shown in Chapter 1's Table 1-1.

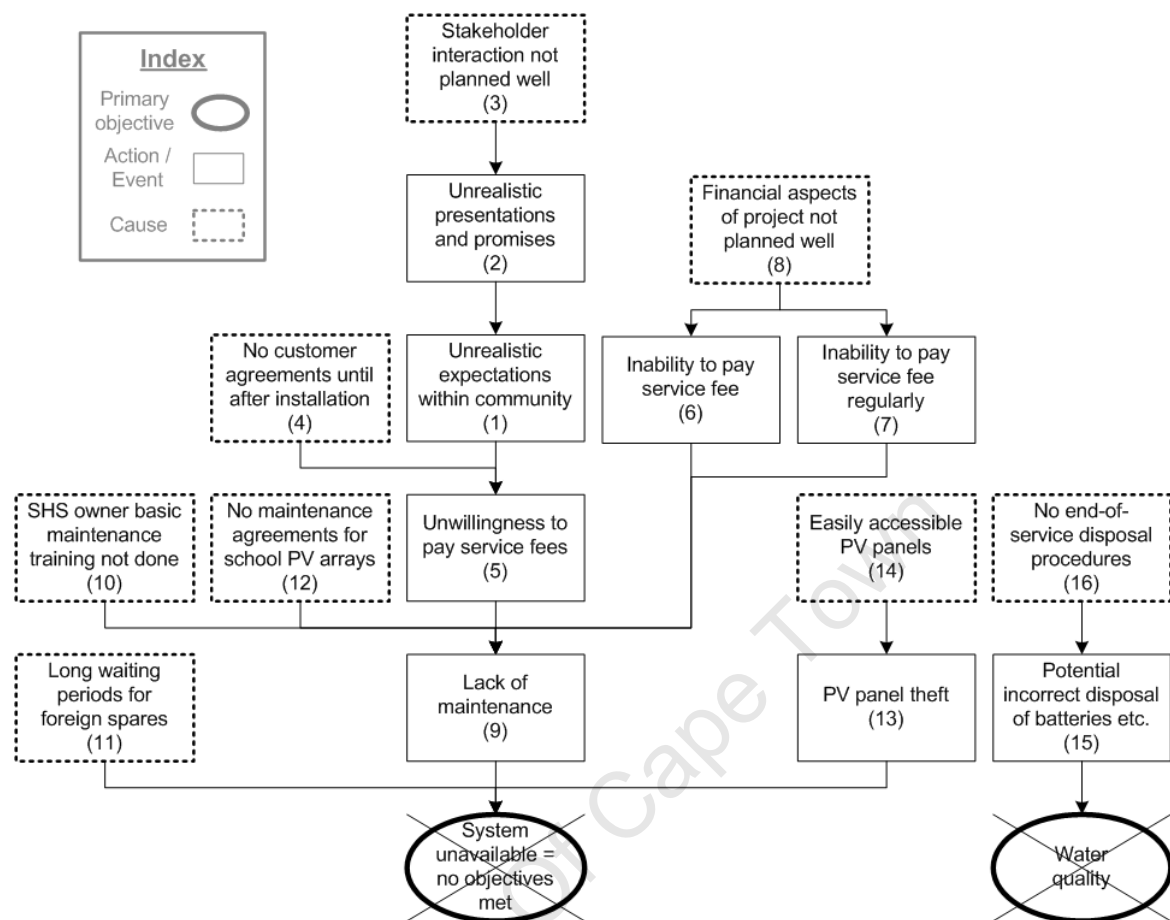


Figure 2-4: Factors identified in literature that prevented the Folvhodwe project from meeting certain primary energisation objectives (reproduced from Appendix B).

2.4.3.4 The DME's SHS concession program

Towards the end of the 1990s the DME decided to allocate a number of remote rural concession areas to private off-grid service provider companies for subsidised SHS installations. The first joint venture was launched in March 1999, with additional consortia identified in May 1999. Interim contracts between the consortia and NERSA and Eskom (operating under a mandate from the DME) were however only signed in May 2002, after extended institutional delays. Each consortium was expected to connect 50 000 customers over the 5-year contract period.

In February 2004 capital subsidy funds were stopped at short notice by the DME, halting new SHS installations. Negotiations between stakeholders led to a new contract signed in October 2004, but subsidies were again stopped in April 2006. By October 2007 less than 40 000 SHSs have been installed in total by all the consortia, against a target of 50 000 per consortium.

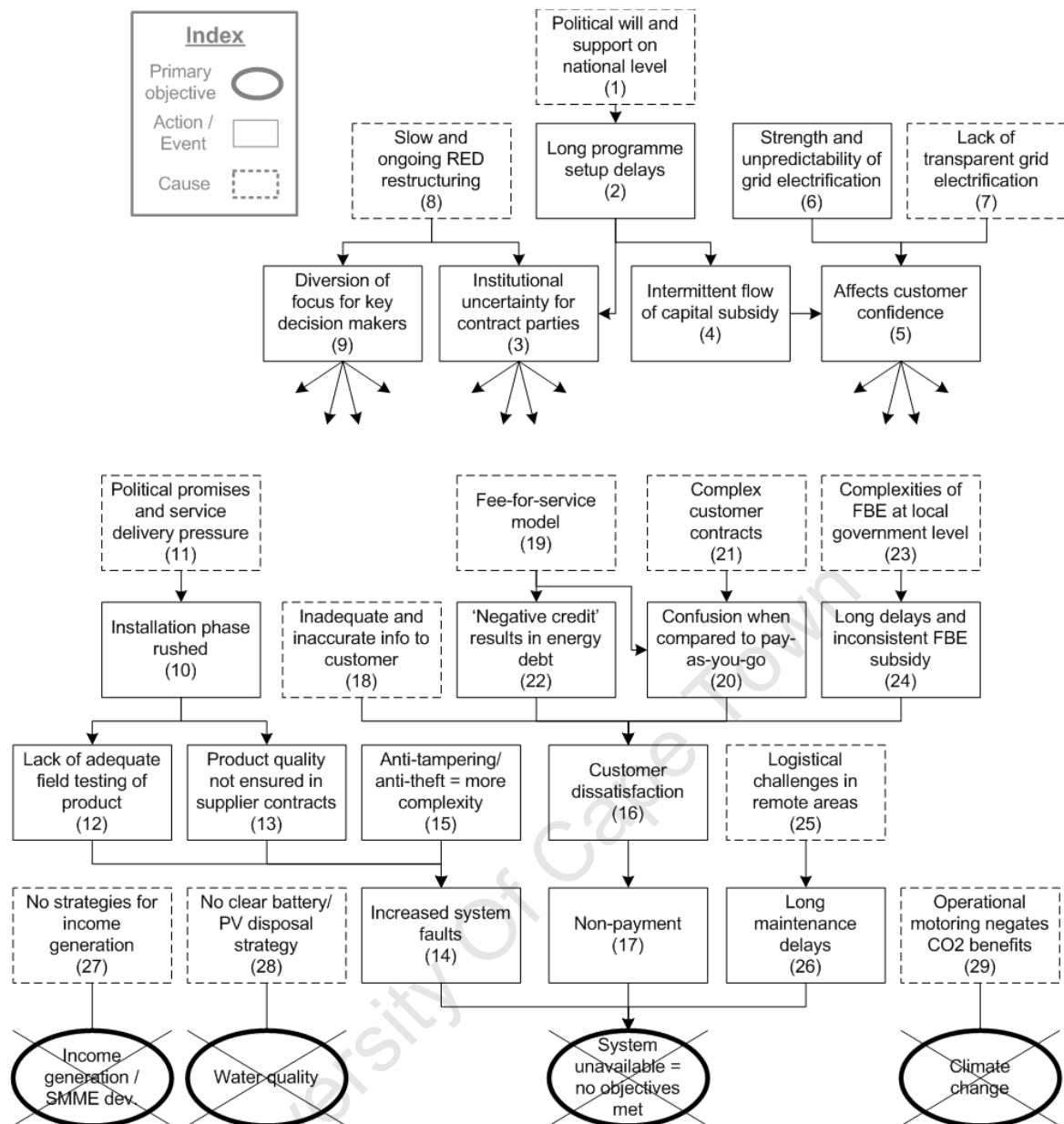


Figure 2-5: Factors that prevented the DME off-grid concession program from meeting certain primary energisation objectives (reproduced from Appendix B).

2.4.3.5 Hluleka nature reserve hybrid mini-grid demonstration project

The Hluleka Nature Reserve along the Wild Coast of the Eastern Cape, along with the adjacent community of Lucingweni, was identified as a suitable hybrid mini-grid demonstration site in a project managed by the NER and implemented by Shell Solar SA.

When identified as a demonstration project location, the Hluleka reserve's 12 guest cottages, offices and guest quarters were already fully reticulated, and connected to two 75 kW diesel generators. The hybrid mini-grid energy system that replaced this system consisted of two 2.5kW wind generators, a 5.6kW PV array, and a 141 kWh battery bank.

The hybrid mini-grid was completed by December 2002 and operated, with a number of often lengthy interruptions due to technical problems, until the reserve closed for renovation in mid 2006, by which time the first PV panels have already been stolen. In May 2007 a new diesel generator was installed at Hluleka.



Figure 2-6: The PV array at Hluleka, photographed in June 2003 (top left), July 2006 (top right) and May 2007 (bottom). July 2006 photograph by C. T. Gaunt (reproduced from Appendix B)

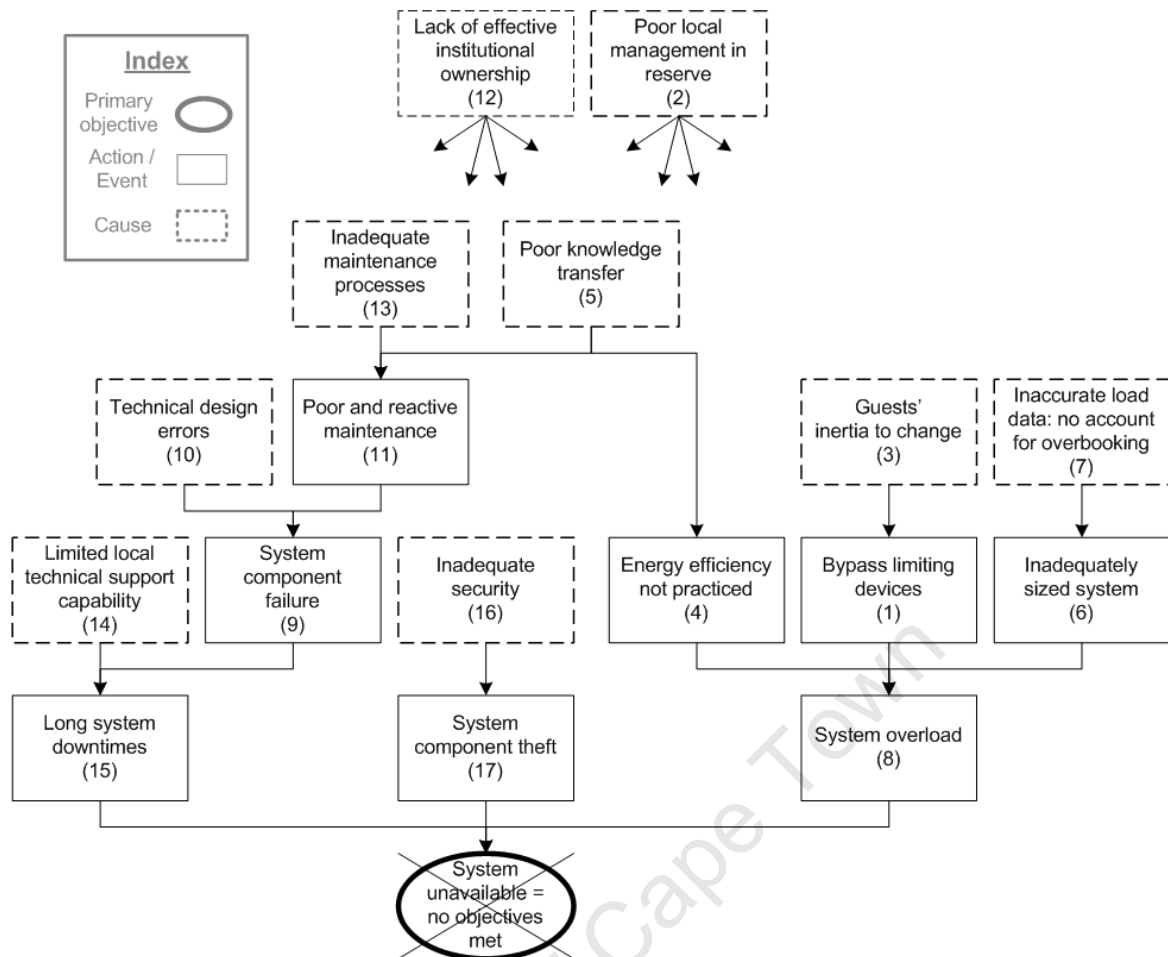


Figure 2-7: Factors that prevented the Hluleka project from meeting certain primary energisation objectives (reproduced from Appendix B).

2.4.3.6 Lucingweni hybrid mini-grid demonstration project

The Lucingweni village in the Eastern Cape was identified as a suitable hybrid mini-grid demonstration site in a project managed by the NER and implemented by Shell Solar SA.

The village, consisting of 220 dwellings, used mostly wood and paraffin as energy sources before the project was implemented. The new hybrid mini-grid system consisted of 56kW PV panels, six 6kW wind generators and a 2.2 MWh battery bank, and was designed to supply 70 street lights, a community centre, water pumping, 4 shop refrigerators, and a radio, TV, decoder, cell phone charger and 4 lights in each dwelling. No energy limiting devices were installed in the dwellings, other than a 2A current limiter.

The Lucingweni mini-grid system was switched on towards the end of 2005, even though the project was not fully completed by that stage. The system operated for a few months, but was quickly overloaded. Theft started at a slow pace in early 2007, and soon afterwards a large percentage of panels were stolen and vandalised in a single evening.

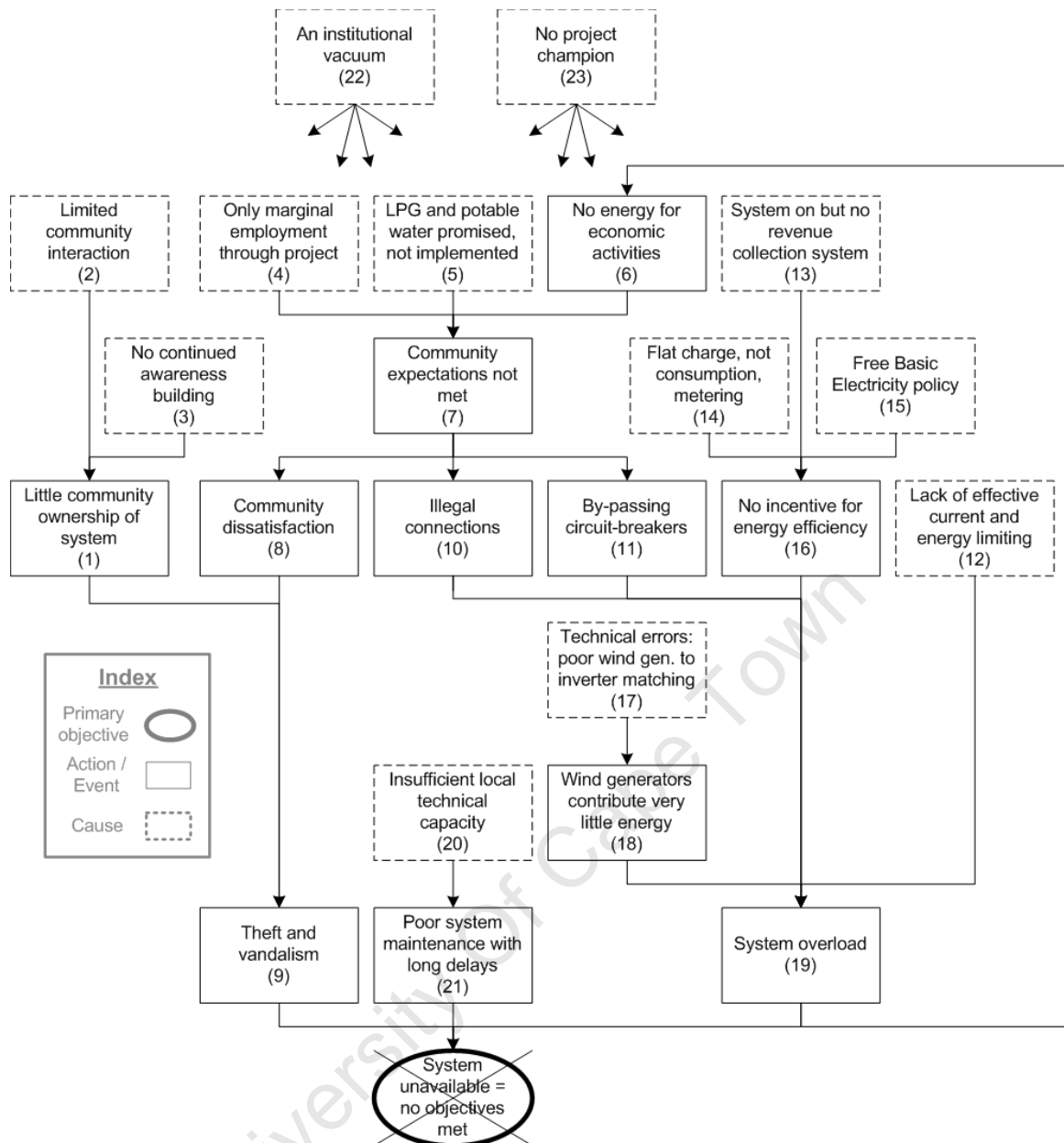


Figure 2-8: Factors that prevented the Lucingweni project from meeting certain primary energisation objectives (reproduced from Appendix B).

2.4.4 Summary of objectives-inhibiting factors

The evaluation done in Appendix B now enables the identification of those factors that prevented South African electrification projects from reaching their objectives.

Categorising these factors into groups will aid later analysis, but identifying suitable categories are challenging due to the interlinked nature of the identified factors. Initially the five sustainability dimensions proposed by Ilskog [2008] were considered: technical, economic, social, environmental and institutional.

These categories were however unsuitable for the identified factors: for example, the factor of grid encroachment has its cause in institutional structures, but its impact is economic (wasted expenditure when off-grid infrastructure is made redundant by the arrival of the grid) or social (customer discontent if the village down the road gets grid while the customer is paying for a SHS). Another example is the factor of lack of community / customer sense of ownership, which is social in cause, yet economic (customer doesn't pay) or technical (system theft or vandalism) in impact.

An electrification context-specific categorisation was found to better suit the identified factors, where the categories are delivery model, tariff policy, community, institutional and technical.

Each of the identified factors will be commented on in detail in the following chapters.

Table 2-3: Factors identified during the project evaluation in Appendix B that inhibited South African off-grid projects from reaching certain primary energisation objectives.

| Delivery model |
|--|
| <ul style="list-style-type: none"> • Lack of disposal strategy • Inflexible system options • Challenging rural logistics • High renewable energy costs • Electrification not part of broader service provision • Lack of sustainable maintenance |
| Tariff policy |
| <ul style="list-style-type: none"> • Efficient energy use not incentivised • Inconsistent subsidies • Subsidy implementation inequality • Inflexible tariff schemes |
| Community |
| <ul style="list-style-type: none"> • Limited understanding of technology • Unrealistic customer expectations • Customer inertia to change • Lack of community / customer sense of ownership |
| Institutional |
| <ul style="list-style-type: none"> • Lack of political will and focus • Lack of institutional home / project champion • Grid planning unpredictability |
| Technical |
| <ul style="list-style-type: none"> • Poor quality load data • System design / configuration mistakes |

2.5 In summary

This chapter set out to answer two of the four research questions that will ultimately test the first part of the research hypothesis. The following answers were found to these research questions:

What off-grid electrification objectives align with the principles of sustainable development?

The primary objectives of energisation that leads to sustainable development were identified through the development of the energisation framework, shown in Table 2-2. It was shown that off-grid electrification objectives form a subset of these energisation objectives, restricted by the energy limits that off-grid technologies impose due to their high cost.

What are the factors already identified in literature that inhibited South African off-grid electrification projects from reaching sustainable development objectives?

A literature study along with the evaluation of completed South African off-grid projects against primary energisation objectives, presented in Appendix B, led to the identification of a list of objective-inhibiting factors, shown in Table 2-3.

This chapter provides evidence of the relevance of this research, which rests on the assumption that South African off-grid projects up to date have not contributed significantly towards sustainable development: of the six completed projects that were evaluated, three projects are no longer operational (Folovhodwe, Hluleka and Lucingweni), one failed to meet its targets by a large margin and have now been stopped until further notice (the SHS concession programme), while the contributions to sustainable development of the remaining two projects were limited by the low uptake among customers (Maphephethe and KwaBhaza).

3 Objectives non-achievement due to unacknowledged uncertainties

A list of factors have now been identified that inhibited sustainable development objectives from being met in off-grid projects.

This chapter will investigate whether a significant number of these factors have as underlying causes uncertainties that were not acknowledged during the decision making process, and could therefore not be addressed.

This correlation (or lack thereof) between the identified objective-inhibiting factors and unacknowledged uncertainties will be sufficient to test the first part of the research hypothesis:

There is a strong correlation between failure of South African off-grid electrification projects to achieve sustainable development objectives, and unacknowledged uncertainties within the initial decision making / planning processes of these projects.

Two research questions will be used to structure this chapter, as shown in Figure 3-1.

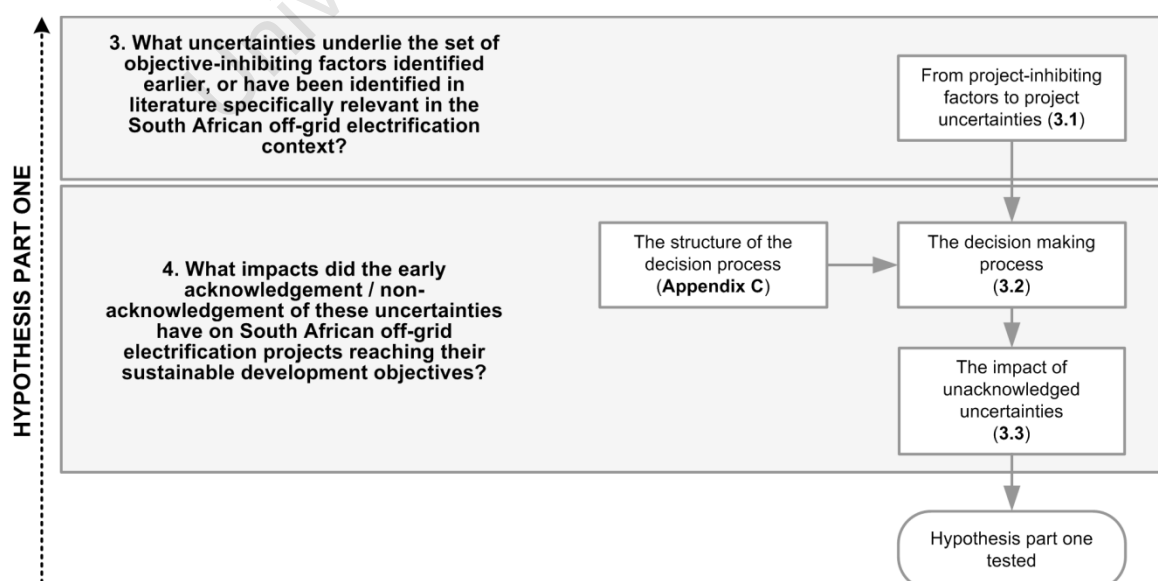


Figure 3-1: Conceptual map showing how the different sections of Chapter 3 and the appendices relate to the research questions and hypothesis.

3.1 From objective-inhibiting factors to project uncertainties

3.1.1 *The scope of uncertainty*

Before project uncertainties are identified, it will be valuable to define clearly what falls within and outside the concept of uncertainty. Loosemore et al. [2006:p8-9] identified four useful criteria to distinguish between what is an uncertainty (or risk), and what is not:

1. Uncertainties imply unpredictable outcomes: “[It is] *the absence of information about future events which makes them unpredictable. A certain future event which is predictable is not a risk but is a problem which needs resolving.*”
2. Uncertainties relate to events, not impacts or consequences. This criterion highlights the danger of focusing on the consequences of risk events rather than on the risk events themselves.
3. Uncertainties relate to the future: “*...past events are not examples of risks, but are actual problems or crises that need to be resolved. Risk management is therefore a proactive process of looking forward and is fundamentally different from crisis management, which is reactive and backward looking.*”
4. Uncertainties are closely linked to project objectives. If a potential future event has no way of affecting the objectives of a project negatively, the future event is not an uncertainty within the context of the specific project.

3.1.2 *Using objective-inhibiting factors to identify uncertainties*

The factors identified in Table 2-3 offer a good foundation from which to derive project uncertainties, but these factors themselves cannot necessarily be defined as uncertainties. Some will fail the first criterion proposed by Loosemore et al. to distinguish between what is an uncertainty and what not, namely the requirement for unpredictable outcomes. Examples of this are the factors of *high renewable energy cost*, *challenging rural logistics* and *lack of disposal strategy*, which are not uncertainties, but rather facts and problems that need to be resolved.

Many of the factors identified will also fail the second criterion defined by Loosemore et al., which states that uncertainties relate to events, not impacts or consequences. The objective-inhibiting factors were summarised from literature, and are often written as causes of problems rather than problem events, for example *efficient energy use not incentivised*.

Although the identified objective-inhibiting factors can assist in the identification of project uncertainties, it is clear that some further analysis is required. A review of literature for already defined uncertainties will inform this analysis.

3.1.3 South African off-grid project uncertainties identified in literature

3.1.3.1 KwaZulu-Natal mini-grid feasibility study

Banks and Aitken [2004:p99-101] identified a set of risk areas related to the establishment of a mini-grid household electrification project in KwaZulu-Natal, which can be useful in informing the development of a set of uncertainties linked to the identified objective-inhibiting factors.

The uncertainties that Banks and Aitken identified included the following:

- *Policy change*. The impact of this event specifically involved long-term maintenance, for example if the concession programme was not able to continue.
- *Demand for power lower than expected*, with the impact being low revenues.
- *Demand for power higher than expected / higher than system capacity*, which will result in overload trips, excessive diesel consumption and rapid aging of batteries.
- *Ability or willingness to pay incorrectly assessed / changed*, which will result in low penetration rate, low consumption, payment defaults, weakened operators financial position, and reduced benefit dissemination.
- *Lower than expected revenues*, caused largely by non-technical losses.
- *Poor acceptance of technology*, both at a utility / decision maker level (causing confusing public messages) and a community level (leading to low uptake and resistance to the service packages offered).
- *Grid encroachment*, resulting in lost customers and revenue and stranded assets.
- *Technical failure* of components in the field.
- *Lightning damage*
- *Theft of components / system*

- *Risks associated with a project with several partners*, for example time required to identify partners, agree on responsibilities and draft contracts, and different motivations.
- *HIV/AIDS*, which can affect customers and repayment rates, and staff turnover and absenteeism.
- *Standard business risks*, for example exchange and interest rate risks and labour unrest.

3.1.3.2 *The e7's renewable mini-grid assessment*

Another study of interest is the e7 renewable mini-grid assessment [E7 2003]. This study was initiated in 2003 by ScottishPower plc, a member of e7 (electricity companies that operate on the national territories of the G7 countries), and investigated the suitability of off-grid hybrid mini-grid systems in South Africa in order to inform future roll-outs.

The study identified two villages in the Eastern Cape as suitable sites for mini-grid systems, and a pre-feasibility study was undertaken, which recommended a feasibility study. This study was however not undertaken due to a change in electrification plans for the identified sites, even though one of the original site-selection criteria was a definite 5-year period of off-grid connection, confirmed through a memorandum of understanding signed with Eskom (but not with the DME) [E7 2003:p27], and meetings with the local role-players. Subsequent to the initial site selection, *“site selection was carried out in several other areas of the Eastern Cape. These were also not taken to a further level of development due to similar uncertainty over future grid electrification.”* [E7 2003:p34]

The uncertainty regarding policy is also highlighted in the e7 report:

“Government support for non-grid rural energy projects was in transition during the timeframe of this work, therefore it was not possible for a new mini-grid initiative to be clearly aligned with national policy and support mechanisms.” [E7 2003:p33]

3.1.3.3 *The DME's Hluleka and Lucingweni evaluation report*

A number of risks that should have been identified earlier in the Hluleka and Lucingweni projects are listed in the draft DME evaluation report on these projects [DME 2007b:p39], divided into market and technical risks. The market risks identified include community dissatisfaction with the level of service provided, *“ownership and maintenance of the*

system ... not thought out at the inception of the project” and “payment and revenue collection ... not put in place at the inception of the project.”

The most relevant technical risks from those identified include that *“maintenance and operation of the system was not put in place, no budget allocated and no local personnel trained to operate and maintain the system”* and that *“the use of wind speed data of Port Elizabeth was very risky.”* Note that maintenance, operation and training is grouped in this research as delivery model rather than technical factors (refer to Table 2-3).

The report concludes:

“A thorough risk analysis should have been undertaken before committing funds to the project [and] a thorough feasibility study should have been undertaken to determine the load and assess available renewable resources. The use of RETScreen alone to size the system was risky [as] the software is intended for rough sizing in the pre-feasibility phase.” [DME 2007b:p39]

Section 5.3.1 explores in detail the question of how “risky” the use of estimation software like RETScreen is.

3.1.4 Developing a set of project uncertainties

The KwaZulu-Natal and e7 mini-grid studies, and the DME’s evaluation report, are similar in their ultimate primary objectives to the evaluated projects from which the objectives-inhibiting factors have been identified. The uncertainties identified in the studies should therefore also apply to the evaluated projects, based on the fourth criterion of Loosemore et al. which notes that uncertainties are closely linked to project objectives.

Uncertainty events can now be identified, based on Loosemore et al.’s criteria of what uncertainties are and the areas of risk identified in literature, and informed by the identified objectives-inhibiting factors. The identified list of uncertainties does not presume to be fully representative, but should rather be seen as a demonstration set of uncertainties, specifically based on the evaluated South African projects. In essence, given a different project context but the same methodology, the identified list might appear very different.

- *Grid encroachment.* The impact of uncertainty regarding the imminent arrival of the grid has caused a variety of problems in the evaluated projects, for example Maphephethe and KwaBhaza, which led to primary objectives not being met. The uncertainty is summarised by Banks and Aitken:

“Planning risks seem to be a generic problem for mini-grids in South Africa, as the strong grid and extensive household and institutional electrification programme mean that mini-grid sites remain vulnerable to grid extension, even after discussions with planners and the utility have clarified that sites are ‘off-grid’.” Banks and Aitken [2004:p130]

The experiences of the e7 project highlight the importance of this uncertainty.

- *Implementation agency non-committal.* A study of existing literature reveals that a lack of commitment from the implementation agency has caused many problems in the evaluated projects. Scholle and Afrane-Okese [2007] links “*a lack of institutional ownership*” to unsustainable maintenance processes at Lucingweni, and then goes further by linking the ultimate failure of that project to a weak institutional framework. According to these authors, the weak framework was caused mainly by lukewarm support from the DME and a lack of an “*institutional home*” and project champion for off-grid electrification.

Banks [2007] identifies the “*slow and ongoing*” RED restructuring process as a cause of institutional uncertainty for all contracting parties and as a diversion of focus for key decision makers in the SHS concession programme. Gaunt [2008] confirms this, when he discusses the “*serious negative consequences*” of indecision and uncertainty in his analysis of the restructuring within the South African electricity distribution industry.

Lack of implementation agency commitment also resulted in significant process delays, for example where the six consortia identified by the DME in May 1999 only received interim contracts in May 2002. This impacted service delivery and the financial sustainability of the consortia: Afrane-Okese [2003] partly blames the slow release of subsidies for the financial problems which led to the ultimate liquidation of the Eskom-Shell joint venture.

Many of the above problems appear to be rooted in the appropriateness of the DME as an off-grid electrification implementation agency, given that the DME’s focus is towards policy rather than implementation, which might sit more comfortably with the DPLG or the DPE. For now, these problems can be grouped under the uncertainty introduced by implementation agency non-committal towards off-grid electrification projects and the technology used.

This uncertainty includes the risk of ‘policy change’ identified by Banks and Aitken [2004] to define specifically the uncertainty of the DME’s concession areas being

withdrawn from the selected concessionaire – an uncertainty that might significantly impact the concessionaires' businesses and the service delivery to their customers.

- *Customers do not accept technology.* The project evaluation highlights the importance of electrification technology acceptance by customers and communities. Factors that negatively influence this acceptance, according to the evaluation, include grid encroachment, high renewable energy costs, inflexible system options, subsidy implementation inequality, inflexible tariff schemes, unrealistic customer expectations, customer inertia to change and a limited understanding of the technology by the customers and community. The evaluation also showed that electrification as part of broader service provision aids technology acceptance.
- *Customers unable to pay.* The financial sustainability of the project (and the utilities implementing it in the case of the concession programme) is to a large extent dependant on the customers' ability (and willingness, as highlighted by the next uncertainty) to pay for the service. The prevalence of HIV/AIDS, along with inflexible tariff schemes, impacts this uncertainty.
- *Customers unwilling to pay.* This uncertainty is closely linked to the customers or community's acceptance of the technology, and is therefore negatively impacted by much the same factors as the *technology acceptance* uncertainty.
- *Low uptake among customers.* The uncertainty regarding how many customers will adopt the off-grid electrification technology has been shown in the evaluation to be influenced by grid encroachment, high renewable energy cost, whether the project is part of a broader service provision strategy, inflexible system options, customer inertia to change and a limited understanding of the technology.
- *Theft and vandalism.* The project's system ownership model impacts strongly on the future occurrence of theft and vandalism. This is clear when the experiences at KwaBhaza (strong customer ownership and no theft) is compared to those at Lucingweni or Folovhodwe (little ownership and significant theft). The link between ownership and theft is widely acknowledged in literature, as shown in the quote below, which also highlights some of the other factors influencing this uncertainty:

"...the major causes of theft and vandalism are the following:

- *Lack of ownership of system by the community*
- *Poor security of the system*

- *Lack of involvement of the community in the planning and implementation of the projects*
- *Non-functioning of the system due to either poor installation or lack of maintenance*
- *Lack of awareness on the use of the system*
- *Poor management by those responsible.” [DME 2007b:p30]*

Subsidy implementation inequality (which might manifest as jealousy against neighbouring communities) and unrealistic (or realistic, but disappointed) customer expectations appears to also play a role in the occurrence of vandalism.

- *Incorrect estimation of system consumption.* The potential inability of the system to provide adequate energy or power to customers is a significant risk when renewable technologies are used, due to the sizing restrictions imposed by the high cost of renewable energy. Factors which impact this uncertainty include whether electrification forms part of a broader service provision strategy and whether efficient energy use is incentivised, which will reduce consumption. Limited understanding of the technology by the customer and poor quality load data also plays a role.
- *Inadequate maintenance.* The experiences at Hluleka and Lucingweni highlight the importance of planning and implementing ongoing maintenance during the initial phases of projects, while Folovhodwe again highlights the impact that non-payment can have on maintenance structures. The challenges associated with rural logistics significantly impact this uncertainty, as do the availability of parts and pre-rollout testing and complexity of the systems, as illustrated in some of the other projects evaluated.

This uncertainty includes what Banks [2007:p122] defined as the risks of a ‘project based’ approach, i.e. “*a high risk of medium/long term failure as project resources fall away after the initial installation phase*”, as maintenance is an important long-term component of the project.

- *Subsidy decrease, discontinuation or inequality.* As illustrated by the SHS concession programme, subsidy instability impacts not only the amount of systems rolled out, but also user satisfaction and confidence in the programme and ultimately the technology.

- *Technical design/configuration errors and component failure.* Failure of the off-grid electrification systems due to factors like component reliability, lightning damage and system design and configuration mistakes prevent all the primary objectives from being met. The evaluation of Hluleka and Lucingweni highlights the impact of such system design and configuration mistakes.
- *Inaccurate estimation of renewable resource availability.* As all the systems considered for off-grid systems, with the exception of diesel, are dependant on renewable energy sources like the wind and sun, the accuracy with which the local availability of these sources are predicted can significantly impact project success.
- *Exchange and interest rate changes.* Although Banks and Aitken [2004] group this uncertainty under 'standard business risks', the impact of exchange and interest rate changes can be severe due to the already high cost of renewable technologies, and the fact that a large percentage of the system cost is made up of imported components, for example the PV panels. This uncertainty is therefore presented as separate from 'standard business risks'.

The identified uncertainties are summarised in Table 3-1 at the end of section 3.3.

3.2 The decision making process

The research hypothesis refers to the concept of the decision making process, which has not yet been defined within the context of this research. Therefore, before this chapter concludes by testing the first part of the hypothesis, a brief description of this concept is required.

3.2.1 The decision making process and the final decision

Decision making theory is the subject of research within a wide range of fields, from the management sciences to robotics. As a consequence perspectives on the decision making process and its relationship to the final decision also vary widely, informed by the specific decision making context.

The perspective of the decision making process held by authors like Roy [1996] and Belton and Steward [2002] appear to be well suited to the context of decision making within electrification projects, which typically involve multiple actors and objectives.

Within this perspective, the **decision making process** can be defined as:

the playing out of “*confrontations and interactions*” between different actors, under a variety of “*compensating and amplifying effects present within the framework of their operating environment*”. [Roy 1996:p4]

According to Roy these different actors can hold diverse value systems¹¹ and informational systems¹², and might not even agree on the definition of the decision problem.

Roy [1996:p31] sees the **final decision** as a “*synthesis of an interconnected web of decisions*” made during the decision making process, and therefore states that “*the concept of a decision cannot be completely separated from that of a decision process.*”

The different stages of the decision making process is not directly relevant to this research, but is included as background context as Appendix C.

3.2.2 Different actors in the decision process

It is important at this stage to define the roles of the different actors in the decision process, in order to provide a basis for later discussions around providing aid to the decision making process.

The general term **actor** referred to above will be defined for the purpose of this research as being an individual or group of individuals that either directly or indirectly influence the decision by his or her value system, or are affected by the decision even though he or she had no influence on it.

Roy [1996:p32] notes that “*for a group of individuals (entity or community) to be considered as a single actor, no distinctions should exist in the value systems, informational systems, and relational networks¹³ of the different members of the group.*”

Roy and Hemmati [2002:p2] both agree that *stakeholders* are those actors that have a strong interest in the decision and can or do influence it directly through the value

¹¹ “... *the somewhat implicit system that underpins the very basis of the value judgements of an individual or group*” [Roy 1996:p31]

¹² The systems that provide the information considered and used during the decision process.

¹³ The “*somewhat solid framework of influences, alliances, coalitions, pressures, ... between a given individual and all the others involved in a decision process.*” [Roy 1996:p31]

systems that they possess. Hemmati however also includes those that have no influence in the decision, but are affected by it, as stakeholders. Roy instead defines these affected actors without influence as *third parties*.

The classification of stakeholders as standard, fiduciary and silent, used by Banville et al. [1998] however offers greater accuracy of description, and will be used in this research: **standard stakeholders** impact / are affected by the problem and participate in the process that resolves it, **fiduciary stakeholders** represent clients and participate in the problem resolution without been directly affected be the problem, and **silent stakeholders** refer to those that are affected by the problem, but has no control over or participation during the problem resolution process (i.e. Roy's third parties). **Stakeholders** refer to the three groups combined.

Belton and Steward [2002:p14] defines the stakeholder that finally has the responsibility for the decision as the **decision-maker**, although this does not imply that the opinions and preferences of other stakeholders are excluded in the decision making process.

The decision process is often aided in some form or another, for example through tools and approaches that provide structure to the process, inform stakeholders, or allow stakeholder preferences to emerge. The actors supporting or guiding this decision aiding process are referred to **analysts** or **facilitators**:

“The term analyst tends to be used when there is a strong emphasis on that person working independently to gather information and to capture expertise; a facilitator is more commonly recognised as someone who also bring the skills of managing group processes.” [Belton and Steward 2002:p8]

Roy [1996] comments on the neutrality of the analyst, pointing out that it is impossible for the analyst to remain completely outside the decision process if he wishes to affect it, and as such he becomes of necessity a stakeholder. *“His role is to explain, to justify, to recommend, but he must do this independently of his own value system.”*

Lastly, the **client** is the person that requested the decision process, and provides the necessary means to conduct it. The client is not necessarily a stakeholder, and does not have to exist in the process.

3.3 The impact of unacknowledged uncertainties

The extent to which the uncertainties identified earlier have been acknowledged within the decision making processes of the evaluated South African off-grid electrification

projects can now be investigated. The aim of this investigation will be to test the correlation between a lack of uncertainty acknowledgement and the failure to achieve sustainable development objectives.

3.3.1 Uncertainty acknowledgement during decision making

Information about the decision making processes that were engaged in during the initial stages of the evaluated projects are scarce, as the emphasis of project literature was mostly on problems experienced during implementation, or post-implementation evaluation.

The literature review however indicated that the decision making process preceding implementation at KwaBhaza was relatively comprehensive, although the perspective was one of marketing rather than social development. The process was guided by Eskom's Project Proposal through three phases: project introduction to the community and market research, community interaction and marketing, and installation.

Literature and interviews further indicated that no systematic decision making process (even in the form of a feasibility study) was followed during the initial stages of the Hluleka / Lucingweni projects [Afrane-Okese 2005]. The following statement confirms this:

“In the two cases of Hluleka and Lucingweni Hybrid System, undertaking pilot projects of these nature [sic], a careful analysis of the risks was not undertaken as suggested. This is demonstrated by the problems that were encountered in the implementation of both projects...” [DME 2007b:p39]

In the cases of the other projects, the information that could however be found have been used below, focusing on the extent to which uncertainties have been acknowledged, and the impact that this acknowledgement had on the achievement of sustainable development objectives.

3.3.1.1 Grid encroachment

Many of the evaluated projects acknowledged the uncertainty of grid encroachment by including a 5-year off-grid window period as part of their site identification criteria (e.g. Maphephethe), and sometimes in addition the criterion that the site must be further than 5km from the existing grid (e.g. KwaBhaza).

As was highlighted by the e7 project, however, such criteria were of little value in the face of a strong and unpredictable grid electrification programme. The Maphephethe project

confirms this: the first SHS household was connected to the grid in 1998 [Green and Zwebé 2006:p13], within two years after the project started.

3.3.1.2 Implementation agency non-committal.

This uncertainty impacted especially the Hluleka and Lucingweni projects, and it is clear from previously reviewed literature that this uncertainty was largely unacknowledged in the initial stages of these projects.

There is too little information to conclude that the uncertainty of institutional non-committal has not been acknowledged in the SHS concession programme. If it has however been acknowledged, its impacts have clearly not been sufficiently addressed, as is shown in the analysis in section 3.1.4.

3.3.1.3 Customers do not accept technology

The project evaluations in literature report that information dissemination, community participation and acceptance of the technology were important initial project aims both at Maphephethe and KwaBhaza (e.g. demonstration houses and an energy day).

The result of this acknowledgement of the customer technology acceptance uncertainty was that in both communities the SHS technology was in general well-accepted (although some members in the KwaBhaza project still suspected political motives in the electrification drive, blamed by Kloot [1999] on the initial strong emphasis on marketing rather than information sharing). Related to the Maphephethe project, Green and Zwebé [2006] reports favourable perceptions towards SHSs within the community even after the grid had arrived.

At Hluleka it is clear that the impact of customer inertia to change, as a part of the customer technology acceptance uncertainty, had not been acknowledged, as no plan other than circuit breakers was in place to accommodate or change the habits of guests that brought their own large freezers and portable swimming pool pumps. This led to the guests bypassing distribution boards and the circuit-breakers, which in turn contributed to the problems related to lack of energy.

3.3.1.4 Customers unable to pay

The uncertainty regarding the customers' ability to pay was apparently acknowledged during the initial stages of the Maphephethe project, as Sparknet [2003] reports that the community was involved in decisions regarding the financing mechanisms and affordability. Whether this acknowledgement was effective is debatable: Green and

Zwebe [2006:p12] report that 13 systems have been removed for non-payment, presumably out of the original installed total of 50 systems.

In contrast, KwaBhaza's acknowledgement of the same uncertainty led to the use of flexible repayment systems which acknowledged the erratic nature of income in rural areas, and resulted in a positive situation where at least 80% of household repayments were up to date, with no SHS having been removed due to non-payment by 2003 [Sparknet 2003].

The difference between the results of the acknowledgments of this uncertainty between the two projects however does not just lie in the effectiveness of the method of mitigation, but also in the fact that a capital subsidy was made available at KwaBhaza.

At Folovhodwe the financial aspects of the project appears to have received very little attention during project planning, as is indicated by the fact that a payment system was only implemented (unsuccessfully) a year after the systems were installed. Bikam and Mulaudzi [2006] reports that many members within the community could not afford the monthly service payments, a fact which ultimately led to total project failure, which might have been avoided had the ability of customers to pay been considered initially.

3.3.1.5 Customers unwilling to pay

Folovhodwe again serves as a good example of the danger of ignoring this uncertainty during the initial decision making process. Although a stakeholder interaction process was engaged in at this project, the literature reports that this process was not well planned, and resulted in unrealistic expectations within the community, for example that the SHSs will be without cost to the customers. When the customers were finally informed that they were to pay a monthly fee, they were unwilling, and this unwillingness (and inability) finally led to project failure.

3.3.1.6 Low uptake among customers

An attempt was made to address this uncertainty at Maphephethe by offering a guaranteed SHS buy-back scheme should grid-electrification occur. Uptake in this project was however still low, as no subsidy was offered to alleviate the high cost of the SHS system.

In subsequent projects like KwaBhaza and the SHS concession programme, the use of a capital subsidy significantly increased the uptake among customers. At Folovhodwe this uncertainty has been addressed completely by donating systems to the whole

community. Unfortunately the lack of a sense of ownership which this donation resulted in, along with other problems, still caused ultimate project failure.

3.3.1.7 Theft and vandalism

The low incidence of PV panel theft at Maphephethe and KwaBhaza is in strong contrast to the widespread theft at Folovhodwe, and is ascribed by Sparknet [2003] to community buy-in in the projects and customer ownership of the systems in the first two projects. Community buy-in is largely a product of inclusion of the community during initial decision making processes, as concluded for example by Woudstra and Zoller [2004], and this inclusion was done at both Maphephethe and KwaBhaza.

Although the NER [2003b] reports that emphasis was placed on stakeholder participation during the planning process at Lucingweni, Scholle and Afrane-Okese [2007] disagrees, and reports that the community had little sense of “*buy-in*” or ownership in the hybrid system, caused by limited community interaction and a lack of continued community awareness building. In addition the community was only marginally involved in the actual project construction work, and was not provided with LPG-based thermal services and potable water from boreholes even though this was originally promised. Dissatisfaction within the community, and little sense of system ownership, appears to be among the main reasons why the community condoned the eventual theft and vandalism of the system.

The delivery model used defines the customers’ sense of ownership to a large extent, and therefore also impacts the theft uncertainty – the acknowledgement of this uncertainty, given the limitations imposed by the delivery model, is clearly illustrated by the NuRa utility: acknowledging the limitations of the fee-for-service model in instilling a sense of system ownership, NuRa implemented a penalty to the customer of R500 to replace a stolen PV panel. This appears to be successful except near the Mozambique border, where other factors than ownership play a role [Aitken 2008].

3.3.1.8 Insufficient energy or power.

The Hluleka and Lucingweni projects can be seen as examples where the uncertainty of insufficient energy and power had been largely unacknowledged.

At Lucingweni, even though the systems sizing were in theory sufficient, insufficient energy resulted from lack of customer energy efficiency practices and the lack of effective current and energy monitoring devices, which made illegal connections and circuit breaker bypassing possible. Technical design and configuration mistakes increased to problems, although this last cause would have been more difficult to

address even had the uncertainty been adequately acknowledged during planning. The fact that the electricity supply to customers at Lucingweni was connected before revenue collection systems had been implemented, and that energy was free until the system failed, in addition took away any incentive for the community to practice energy efficiency.

At Hluleka incorrect load data and overbooking made the system sizing insufficient even if no other problems occurred – most of the above problems of energy inefficiency and technical configuration mistakes however also occurred at Hluleka.

3.3.1.9 *Inadequate maintenance*

At Maphephethe and Folovhodwe the uncertainty of maintenance sustainability was acknowledged and addressed in the short term by training SHS installers. No provision was however made for long-term maintenance: at Maphephethe the installers moved on, leading to a situation where a new project had to be launched 8 years after the project started to try and solve the maintenance issues, and at Folovhodwe the inadequate financial planning, lack of maintenance contracts etc. led to total failure of the project after 4 years.

At Hluleka and Lucingweni the uncertainty of maintenance was acknowledged to a limited extent (the NER made high-level recommendations regarding maintenance responsibilities and agreements), but not addressed. Scholle and Afrane-Okese [2007] reports that the local technical capacity was insufficient, and therefore depended on outside experts, resulting in high costs and long system down-times when faults occurred.

One of the main motivations for using the fee-for-service with utilities model for the SHS concession programme was that it resulted in sustainable maintenance [Banks and Aitken 2004:p97]. This uncertainty was clearly considered before project implementation, and appears to have been addressed successfully.

3.3.1.10 *Subsidy decrease, discontinuation or inequality*

The seriousness of the impact of this uncertainty is illustrated in a number of the evaluated projects.

The first example occurred at KwaBhaza, where the R1500 subsidy (and loan underwriting) from the DME's implementation agency REFSA, promised to the community by Eskom, failed to materialise due to "*bureaucratic power struggles*" [Kloot 1999:p69]. Eskom acknowledged this uncertainty regarding subsidy provision, as

indicated by the fact that “*energisation was going ahead on the understanding that Eskom would ‘crisis manage’ when the time came.*” [Kloot 1999:p56] The crisis management entailed that Eskom finally had to provide the (by then R1700) subsidy to prevent project failure.

As important, the inconsistent availability of the DME’s capital subsidy subsequent to 2002, and the current lack of clarity on the future of the off-grid programme, have seriously impacted customer confidence and production planning and ongoing product improvement by the service providers.

Prasad and Visagie [2005], Banks [2007] and Niemand and Banks [2006] highlight the problems that utilities in the SHS concession programme experienced due to delays and geographical and time-based variations in the application of Free Basic Electricity (FBE)¹⁴ subsidies by local municipalities. These variations led to customer dissatisfaction, and contributed to significant non-payment problems.

There is no indication that these uncertainties were acknowledged in the SHS concession programme. It is however interesting to note that the ongoing operation of the concession utilities is not necessarily impacted by this instability:

“...critically, several of the companies are either big enough, or very close to being large enough to reach operational profitability – so there is reasonable expectation that they will continue to operate and deliver services – irrespective of the outcome of further subsidy deliberations.” [Banks 2007:p119]

3.3.1.11 *Technical design/configuration errors and component failure*

Afrane-Okese [2003:p35] notes that the installation phase of the initial Eskom-Shell joint venture project was rushed due to political and service delivery pressures. The technical uncertainties were therefore inadequately acknowledged, which resulted in inadequate field-testing of the product before roll-out, and little contractual protection of the joint venture against low product quality.

It is also clear in the Hluleka and Lucingweni projects that little attention was given to the impact of technical design/configuration uncertainties, something which should have

¹⁴ South Africa’s FBE policy was announced in 2000, and promulgated in 2002, and specified the provision of a ‘self-targeted’ subsidy consisting of 50kWh per month of free electricity to poor households, identified for example by the willingness of these households to accept a limited supply capacity of 10A or a very low consumption level [SA Gov 2002].

been an important focus especially since new technology was being demonstrated. This lack of uncertainty acknowledgement led to long periods of no power (while the inverter problems were being resolved), reduced energy (from the PV array at Hluleka due to the inverter problems, and the wind generators at Lucingweni due to the wrong inverter being used) and system damage (incorrect integration of the diesel generator at Hluleka).

3.3.1.12 Inaccurate estimation of renewable resource availability, and exchange and interest rate changes

Although the impact of these uncertainties can be large, there are no clear examples in literature related to South African off-grid projects to correlate non-acknowledgement of these uncertainties to project failure.

3.3.2 The first part of the hypothesis tested

The results of the previous section's analysis are summarised in Table 3-1.

From the analysis and this summary it is clear that in all the projects that convincingly failed to achieve their primary sustainable development objectives, uncertainties were not acknowledged during the initial decision making/planning processes.

This result provides sufficient evidence to validate the first part of this research's hypothesis:

There is a strong correlation between failure of South African off-grid electrification projects to achieve sustainable development objectives, and unacknowledged uncertainties within the initial decision making / planning processes of these projects.

The correlation between acknowledgement of uncertainties and achievement of sustainable development objectives is however less clear, as once again illustrated in Table 3-1. The second part of this research's hypothesis will investigate this further.

Table 3-1: Uncertainty acknowledgments in South African off-grid electrification projects.

| Uncertainty largely or totally unacknowledged | Uncertainty acknowledged but inadequately addressed | Uncertainty acknowledged and addressed |
|--|---|---|
| Grid encroachment | | |
| KwaBhaza, Maphephethe | | |
| Implementation agency non-committal | | |
| Lucingweni, Hluleka | SHS concession programme | |
| Customers do not accept technology | | |
| Hluleka | KwaBhaza | Maphephethe |
| Customers unable to pay | | |
| Folovhodwe | Maphephethe | KwaBhaza |
| Customers unwilling to pay | | |
| Folovhodwe | | |
| Low uptake among customers | | |
| | Folovhodwe, Maphephethe | KwaBhaza, SHS concession programme |
| Theft and vandalism | | |
| Folovhodwe, Lucingweni | | Maphephethe, KwaBhaza, SHS concession programme |
| Insufficient energy or power | | |
| Hluleka, Lucingweni | | |
| Inadequate maintenance | | |
| | Maphephethe, Folovhodwe, Lucingweni, Hluleka | SHS concession programme |
| Subsidy decrease, discontinuation or inequality | | |
| SHS concession programme | | KwaBhaza |
| Technical design/configuration errors and component failure | | |
| Hluleka, Lucingweni | SHS concession programme | |
| Inaccurate estimation of renewable resource availability | | |
| Exchange and interest rate changes | | |

3.4 In summary

This chapter set out to answer the final two research questions required to test the first part of the research hypothesis. The following answers were found to these research questions, providing sufficient evidence for the first part of the hypothesis to be confirmed valid in section 3.3.2:

What uncertainties underlie the set of objective-inhibiting factors identified earlier, or have been identified in literature specifically relevant in the South African off-grid electrification context?

The project uncertainties, identified from literature and the set of objective-inhibiting factors, are summarised in Table 3-1.

What impacts did the early acknowledgement / non-acknowledgement of these uncertainties have on South African off-grid electrification projects reaching their sustainable development objectives?

The analysis in section 3.3, summarised in Table 3-1, showed that non-acknowledgement of uncertainties at an early stage negatively impacted the contribution of projects to sustainable development.

The analysis further indicated that when project uncertainties were acknowledged, this did not necessarily guarantee sustainable development objective achievement.

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4 Achieving objectives through high quality decisions

In the previous chapter it became apparent that acknowledging project uncertainties do not necessarily mean that sustainable development objectives will be achieved.

What else, in addition to uncertainty acknowledgement, is necessary to ensure that off-grid electrification projects do achieve sustainable development objectives? This chapter attempts to find an answer, structured as the second part of the research hypothesis:

A high quality decision making process that is capable of acknowledging both hard and soft uncertainties will assist off-grid projects in reaching their primary project objectives (but not necessarily sustainable development objectives, unless these two sets of objectives align).

The chapter is divided into different sections that analyse individual parts of this hypothesis, guided by four research questions, as shown in Figure 4-1.

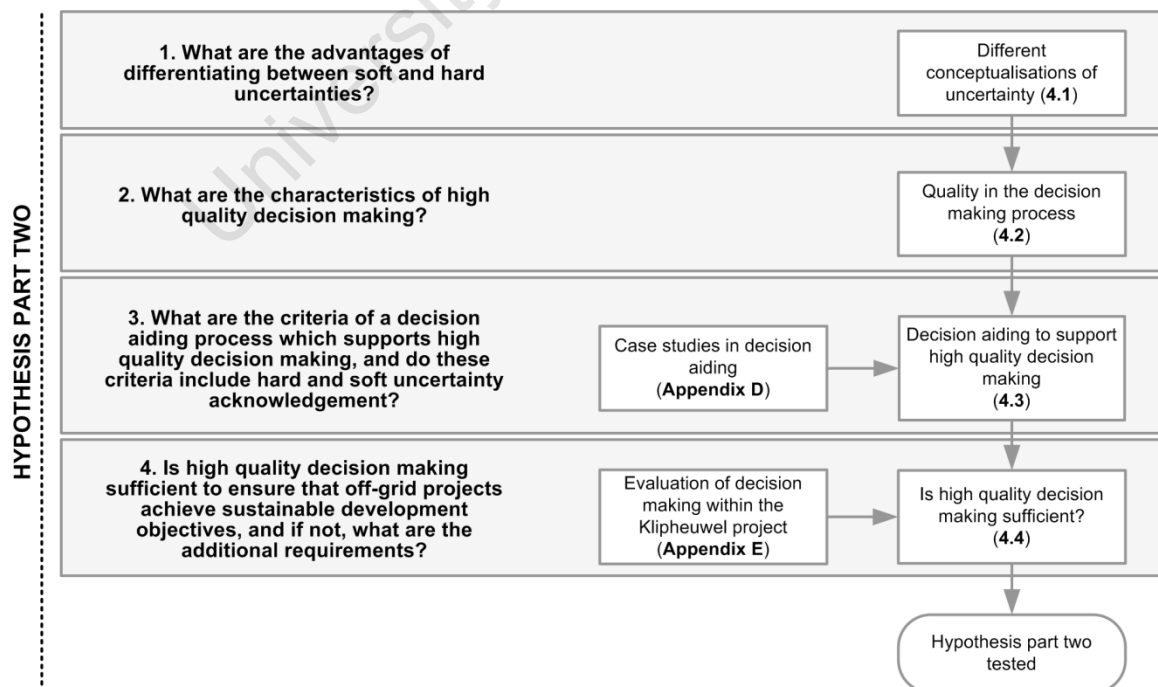


Figure 4-1: Conceptual map showing how the different sections of Chapter 4 and the appendixes relate to the research questions and hypothesis.

4.1 Different conceptualisations of uncertainty

Uncertainty in the decision making process can most efficiently be dealt with if the sometimes-subtle variations in the nature of this uncertainty are acknowledged, as noted by Young [2001] within the context of environmental decision making:

“...many decisions surrounding the environment are conditioned by the presence of uncertainty. The recognition that there are a number of different modes of uncertainty radically alters the way in which environmental uncertainty can be dealt with both on an epistemological¹⁵ and practical level...” [Young 2001:p1]

This section explores different conceptualisations or modes of uncertainty, and highlights the concepts of hard uncertainties and soft uncertainties (or risks), as defined by Young, which this research propose to be potentially valuable within the decision making processes of off-grid electrification projects.

4.1.1 Internal and external uncertainties

The first variation that will be presented within the concept of uncertainty is the split between those uncertainties that are internal to a project (i.e. uncertain events that might affect the outcomes of a project and are under the control of the decision-makers) and those external to a project (i.e. uncertain events that might affect project outcomes but over which decision-makers have little or no control).

Examples of internal uncertainties include whether the product will fulfil market needs, whether the project time and cost requirements will be met, or whether the product is ready for market use in terms of reliability and ease of use. External risks might include actions by competitors, government, customers and the weather.

In order to avoid potential confusion, note that the concept of internal and external uncertainties not only relates to projects, but can also be applied to decision making processes, as used by Belton and Steward [2002:p61]. Internal decision making process uncertainties in this case relate to factors like imprecise data or ambiguity of meaning within the decision aiding model, while external decision making process uncertainties might include both internal and external project uncertainties.

¹⁵ *“The branch of philosophy that studies the nature of knowledge, its presuppositions and foundations, and its extent and validity”*, from The American Heritage Dictionary of the English Language, 2000.

The split between internal and external uncertainties are not specifically useful within the context of this research, which focus on uncertainty acknowledgement, as it is crucial to acknowledge both internal and external uncertainties. The two types of uncertainty are however dealt with very differently when attempting to address project uncertainties, and are therefore included here for completeness.

4.1.2 The nature of reality underlying uncertainty

In moving towards a more accurate distinction between the different conceptualisations of uncertainties, it is informative to review Davidson [1996]. The paper defines two distinct conceptions of the nature of reality underlying uncertainty within economic theory, and offers a basis for a distinction between different types of uncertainty, as used by Young [2001].

The first conception is that of an immutable reality, with the future predetermined (ergodic¹⁶) and thus known or knowable, even if sometimes “*in the short run, the future is not completely known due to some limitation in human information processing and computing power.*” [Davidson 1996:p485].

As Young [2001:p40] notes, “*this concept of reality lends itself to a solely probabilistic interpretation of uncertainty, in which all future outcomes are captured either by an objective probability distribution or a subjective distribution*” This immutable reality dictates that the objective and subjective probabilities will tend to converge in the long term even if they differ initially. In essence, therefore, “*uncertainty only exists because of the failure of humans to process information which, while not known, is knowable.*” [Young 2001:p40]

The second conception is that of a transmutable and non-ergodic reality, where “the future can be permanently changed in nature and substance by actions of individuals, groups (e.g. unions, cartels), and/or governments, often in ways not completely foreseeable by the creators of change. It is also possible that changes that are not predetermined can occur even without any human economic action.” [Davidson 1996:p482]. A probabilistic interpretation of uncertainty within this second reality is meaningless.

¹⁶ “... the assumption of a predetermined – ergodic – reality permits the modeller to assert that sampling from past and present market data is the same thing as obtaining a sample from the future.” [Davidson 1996:p481]

4.1.3 Modes of uncertainty within an immutable reality

Young [2001] notes that the modes of uncertainty identified in literature is generally confined within the first conception of reality: **risk**, which has an objective probability distribution, and uncertainty, which in this context refer to subjective probabilities.

A number of post-2001 examples confirm his statement:

- Reneke and Wiecek [2002:p1] summarizes the definition of risk as “*the randomness of [a] system caused by stochastic variability resulting from inherent fluctuations that the system experiences with respect to time, space, or its individual characteristics*”.

Uncertainty, on the other hand, is the randomness in a system arising when the system cannot be described with complete confidence due to a lack of understanding or limitation of knowledge. Note the emphasis on the failure of humans to process information which is in essence knowable, i.e. both risk and uncertainty in this context are founded in an immutable reality.

- Loosemore et al. [2006] presents a distinction between risk and uncertainty which is also restricted to the perspective of an immutable reality, as shown by the fact that both risk and uncertainty are defined by probability (see Figure 4-2 below).

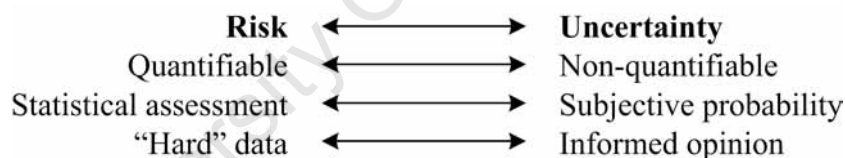


Figure 4-2: The risk-uncertainty continuum, based on [Loosemore et al 2006: figure 1.1]

4.1.3.1 The disadvantage of restricting uncertainty only to the immutable reality

Young [2001:p41] argues that restricting the different modes of uncertainty within decision making to the immutable reality is problematic, especially in cases where “*the system is so transmutable and fundamentally uncertain that uncertainty can never be reduced to situations of probabilistic risk.*”

This view differs fundamentally from that held by Loosemore et al. [2006:p10], which proposes using only one word for all the modes of uncertainty: “*the distinction between risk and uncertainty is not one of substance, it is one of degree ... and distinguishing between them serves academic rather than practical purposes.*”

The use of a single conceptualisation of uncertainty as proposed by Loosemore et al. might indeed simplify project risk-management. However, this research holds that such a

single conceptualisation can lead to non-probabilistic uncertainties being ignored as they do not fit into standard decision making approaches, even though these uncertainties might have a large impact on project objectives.

For this reason, the conceptualisation of uncertainty as presented by Young (which include both immutable and transmutable reality) will now be explored.

4.1.4 Acknowledging a transmutable reality: hard and soft uncertainty

Young [2001] defined two types of uncertainty, hard and soft, based on Davidson's conceptions of reality and previous work by a variety of authors. He then applied these definitions within the context of environmental policy decision making, using a non-probabilistic decision aiding approach developed by Shackle¹⁷.

In **hard uncertainty** 1) the set of all possible outcomes of an action is unknown and can only be hypothesized, or 2) if all the outcomes are known, the probability distributions of all the outcomes are unknown or not fully definable. The definition of hard uncertainty encompasses both the subjective probability area of immutable reality and transmutable reality, as shown in Figure 4-3.

Soft uncertainty or risk is used to define situations where all the possible outcomes of an action, as well as the outcomes' probability distributions, are known, and are therefore falls within the area of immutable reality.

This recognition of uncertainty as occurring both within the immutable and transmutable realities, through the concepts of soft and hard uncertainty, potentially allows a much wider range of uncertainties to be modelled (and therefore acknowledged in the decision making process) than if only probability-based uncertainties were included.

4.1.4.1 Hard and soft uncertainty classification framework

Young [2001:p43-46] develops a framework within which hard and soft uncertainty can be classified using six criteria, as shown in Figure 4-3.

¹⁷ Shackle proposed using *degree of surprise* rather than probability as a measure of uncertainty, thereby making it possible to include uncertainties in both the immutable and transmutable realities. The Shackle model will be explored in detail in Chapter 5.

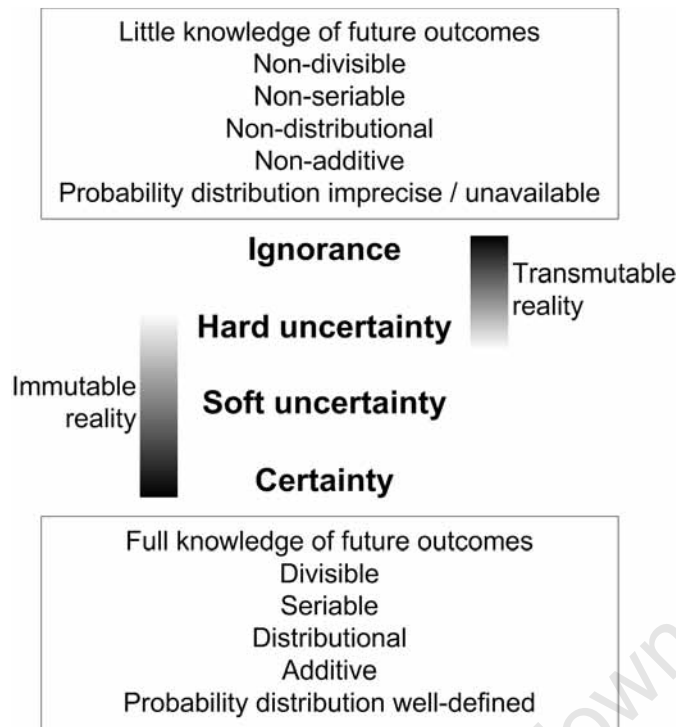


Figure 4-3: The types of uncertainty and their relation to Davidson's concepts of reality, as proposed by Young [2001], along with the criteria used for classification.

The six criteria are defined as follows:

- **Knowledge of future outcomes** – if all the future outcomes of an action are fully known it is defined as a soft uncertainty, otherwise as a hard uncertainty.
- **Divisibility** - A divisible action, typical in soft uncertainty, is repeatable under the same underlying conditions, while a non-divisible action, typical in hard uncertainty, is unprecedented or non-repeatable.
- **Seriability** - Some non-divisible actions can be pooled with similar actions, and the uncertainties redistributed among the group, for example life expectancy used by insurance companies. Seriable actions can be addressed using soft uncertainty.
- **Distributionality** - In a distributional action, typical in soft uncertainty, the complete set of events is known and adds up to unity.
- **Additivity** - With an additive event it is possible to add together the probabilities, while the number of outcomes will affect the probability of each outcome. Additivity does not apply in hard uncertainty.
- **Probability distribution** – If the probability distribution of an action is known, it can be defined as a soft uncertainty. If the distribution is imprecise or unknown it can be defined as a hard uncertainty.

4.1.5 *Classifying off-grid electrification project uncertainties*

It will be informative to classify the set of project uncertainties identified in the previous chapter in Table 3-1 as soft or hard, utilising Young's classification framework described above. If the majority of the identified uncertainties are soft uncertainties, which can typically be acknowledged within existing decision aiding approaches, little motivation remains to add complexity to the decision process by differentiating between soft and hard uncertainties.

When the criteria of knowledge of future outcomes, divisibility, seriability, distributionality, additivity, and probability distribution is applied to the list of uncertainties, only the following uncertainties are not clearly hard uncertainties:

- *Technical design/configuration errors and component failure*: if this uncertainty was only impacted by the reliability of the system components, it would clearly have been a soft uncertainty. System design and configuration mistakes however plays a significant role especially in demonstration projects, and cannot be precisely modelled by a probability distribution. It can therefore be concluded that *technical failure* is a hard uncertainty during initial demonstration projects, and becomes a soft uncertainty as experience of the system grows.
- *Inaccurate estimation of renewable resource availability*: this uncertainty can be divided into three different parts, related to the three sources of data from which the renewable resource is estimated: measured historical data at the project location, measured historical data at a site which is in some ways similar to the project location, and estimated data from software programs like RETScreen which typically use generalised satellite-derived data.

The uncertainty of the first type of data relates to the randomness that the renewable source experience due to inherent fluxuations in it, and falls within the domain of probability and therefore soft uncertainty. The uncertainty of the second and the third sources of data include the not-knowable-until-measured differences between the resources at the project location and at the site on which the available data is based. This uncertainty includes an unknowable component, and can be categorised as a hard uncertainty.

It can therefore be concluded that where historical data at the same site as the project is available, the uncertainty introduced is soft. Where no historical data is available, the uncertainty will be hard.

- *Exchange and interest rate changes*: exchange and interest rates are influenced by macro-economic indicators and events, but also by human perceptions, which result at best in an imprecise probability distribution of future rate actions. For the purpose of this research it is therefore considered as a hard uncertainty.
- *Incorrect estimation of system consumption*: When historic consumption data is available for a group of customers with very similar characteristics to the customers currently being electrified, this uncertainty becomes soft – as historic data becomes less applicable, the uncertainty will move into a hard classification.

It can be concluded that the majority of the identified uncertainties are hard during initial demonstration projects, with only *technical failure*, *resource estimation* and *consumption estimation* becoming soft uncertainties when adequate data exists.

It is worthwhile noting that most of the identified uncertainties are defined as hard uncertainties because of the large impact of social or political factors on them. Scholle and Afrane-Okese [2007:p107] alluded to this when they noted within the context of socio-economic realities within mini-grid projects that “*Many of these issues are neither formal nor predictable*”. A central aim of the development of the concept of hard uncertainties within off-grid electrification projects is that many of these issues will ultimately become more formal and, if not predictable, at least manageable.

4.2 Quality in the decision making process

The focus of this chapter now shifts towards decision making, and finding a useful definition of the characteristics of a high quality decision making process.

4.2.1 Preliminary definition of high-quality decision making

Decision making is the activity of reaching a decision, which results in actions and ultimately in results. These results can be used to measure the quality of the decision making. Within the context of a project, decisions should help achieve the project’s primary objectives, and a measure of the quality of decision making will be how well the results align with the project’s primary objectives. A preliminary definition of what a high-quality decision making process is can therefore be formulated as:

High-quality decision making results in decisions that lead to the achievement of the project’s primary objectives.

However, this preliminary definition is limited in that the quality of a process can only be measured once the project has been completed and it is clear whether the primary objectives have been achieved. For the above definition to be useful *during* the decision process, a more detailed characterisation of a high-quality decision making process is needed.

4.2.2 Characteristics

4.2.2.1 Characteristics of high-quality decision making in literature

A review of decision making literature was undertaken to inform the development of an adequate, non-redundant set of characteristics of high quality decision making. Although a large volume of research is available on decision making in general (on UCT's electronic journal catalogue eight journals has "*decision making*" in their title, while many more relate to the subject through for example operational research or psychology), in only a small number of texts was the quality of decision making explicitly analysed.

One of these texts, by Herek et al. [1987:p204] writing within the context of presidential decision making during times of international conflict, defines high-quality decision making as characterised by a "*relative absence*" of Janis and Mann [1977]'s seven symptoms of "*defective decision making in executive groups*":

- "*Gross omissions in surveying alternatives*
- *Gross omissions in surveying objectives*
- *Failure to examine major costs and risks of the preferred choice*
- *Poor information search*
- *Selective bias in processing information at hand*
- *Failure to reconsider originally rejected alternatives*
- *Failure to work out detailed implementation, monitoring and contingency plans*"

In a more recent text, Belton and Steward [2002:p5] defines a "*quality decision making process*" as resulting in "*better considered, justifiable and explainable decisions*" that provides an audit trail for the final decision. Note that in their writing the word *quality* equates to the concept of *high quality* used in this research; the equivalent of their *lack of quality* will be *defective quality* in this research.

The above writings on quality in a decision making process offer a basis for further exploration in literature on what characterise quality decision making processes.

Objectives, alternatives and risks should be well-considered

The first three of Janis and Mann's symptoms of defective decision making are avoided if the objectives, alternatives and risks of a decision problem are well-considered.

A set of South African Government guidelines for integrated environmental management, based on the National Environmental Management Act (NEMA) of 1998, confirms the importance of all reasonable alternatives being well-considered:

"The [decision making] process must identify and define all reasonable alternatives and provide the decision-makers with an understanding of the trade-offs that will result from the alternative options." [DEAT 2004:p9]

An important part of making a well-considered decision lies in acknowledging the multi-dimensional nature of the decision making problem, as highlighted by Belton and Steward's [2002:p2] statement that *"Every decision we ever take requires the balancing of multiple factors ..."*. This acknowledgment of multiple dimensions is also a central part of the definition of sustainable development offered in NEMA:

"Sustainable development means the integration of social, economic and environmental factors into planning, implementation and decision making so as to ensure that development serves present and future generations." [NEMA 1998:section 1]

From the above, a preliminary characteristic of high quality decision making can now be defined:

- ❖ Objectives, alternatives and risks should be well-considered, acknowledging the multi-dimensional nature of most decision making problems.

The process should be informed

According to Janis and Mann's fourth and fifth symptoms of defective decision making, high quality decision making cannot depend on poor or biased data.

The South African Government guidelines for integrated environmental management [DEAT 2004:p9] offers a definition of what the opposite of poor and biased data entail, by stating that data should be *"sound and useful"*, and that *"Decisions must take into account ... all relevant forms of knowledge, including traditional knowledge."*

In essence the data used in decision making should therefore be accurate (“*sound*”), adequate (both “*useful*” and inclusive of all “*relevant forms of knowledge*”) and unbiased. This leads to the next preliminary decision-making characteristic:

- ❖ The process should be informed with accurate, adequate and unbiased data.

The process should result in justifiable and explainable decisions, with an audit trail

In the above text Belton and Steward identified “*justifiable and explainable decisions*”, with an audit trail, as important characteristics of high quality decision making. These characteristics are closely linked to the concept of accountability, i.e. where the decision makers are held accountable for their decisions by the rest of the stakeholders.

Alexander [2000] states that accountable decision making tend to result in more sustainable outcomes, because:

- the decisions are more likely to be consistent, instead of arbitrary, since they are open to challenge, and set precedents,
- a wider range of views and experiences are typically taken into account, and
- mistakes are reduced because decision-makers will typically think harder before acting.

But what are the characteristics of accountable decision making that are closely linked to “*justifiable and explainable decisions*”? Two characteristics are especially of interest in literature: *inclusiveness* through stakeholder participation, and *transparency*. Two references in particular comment at length on these subjects: Hemmati’s [2002] work on multi-stakeholder processes, and Kovach et al.’s [2003] works on the accountability of large inter- and non-governmental organisations and trans-national corporations.

Inclusiveness

Kovach et al. [2003:p1] states that greater inclusiveness of all stakeholders in the process (especially the silent stakeholders, as defined in section 3.2.2) results in greater ownership, which “*tends to lead to more relevant decision making and better implementation.*”

This perspective is shared by Hemmati [2002:p3], who states that “*a lack of inclusiveness has resulted in many good decisions for which there is no broad constituency, thus making implementation difficult.*” Stakeholder participation, according to Hemmati [2002:p40], requires a “*process of dialogue and ultimately consensus-*

building of all stakeholders as partners who together define the problems, design possible solution, collaborate to implement them, and monitor and evaluate the outcome.”

Transparency

Regarding the transparency of decision making towards the outside, Hemmati [2002:p57] notes that a “*lack of disclosure of information of any of the aspects, decisions or steps related to [the process] will decrease its credibility and, consequently, its effectiveness.*” The risks of an obscure decision making process include that these processes can be abused, or can be perceived to have been abused. An audit trail will improve the transparency of the process to the outside, as suggested by Belton and Steward in the context of justifiable and explainable decisions.

Kovach et al. [2003:p1] links stakeholder satisfaction to transparency, by noting that greater transparency is an important part of effective accountability mechanisms, resulting in people that are more likely to feel that their needs are taken into account.

Heinrich [2008:v], while commenting on how poor environmental performance within the Electricity Supply Industry (ESI) can be reduced by using a transparent methodology, notes how transparency assists in aligning different stakeholders: “*The more transparent the decision making methodology, the closer the gap between the policy maker and society.*”

From the preceding review and discussion two preliminary high quality decision making characteristics can be identified:

- ❖ The process should be inclusive, taking a wide range of stakeholder opinions into account.
- ❖ The process should be transparent, with an audit trail to ensure that the decisions can be explained and justified.

The process should allow for adaptation and iteration

Janis and Mann introduced the subject of an adaptive and iterative process by identifying “*failure to reconsider originally rejected alternatives*” as a symptom of defective decision making.

Further literature reviews indicate that the quality of decision making is increased by willingness among decision makers to adapt and learn, both from their mistakes and from interaction with other stakeholders.

Kovach et al. [2003:p1], for example, recommend that feedback loops are build into the decision making process “so that decision-makers can learn from communities affected by their decisions and, in particular, learn from their mistakes in order not to repeat them”.

The South African Government guidelines for integrated environmental management lends further support to the statement that the decision making process should incorporate past lessons learned, and recommend that the process be flexible / adaptive:

“The process should be flexible and adjust to the realities, issues and circumstances of the activities under review, without compromising the integrity of the process; and be iterative, incorporating lessons learned throughout the activity life cycle.” DEAT [2004:p9]

Lastly, Hemmati [2002:p53] recommends a balance between a process with an “agreed, foreseeable agenda” and “the ability to respond flexibly to changing situations”.

From the preceding review two preliminary high quality decision making characteristics are identified:

- ❖ The process should be flexible and able to adapt to the context of the process.
- ❖ The process should incorporate lessons learned, both in the past and during the current process, through build-in iterative feedback loops.

The process should result in detailed implementation, monitoring and contingency plans

The last of Janis and Mann’s symptoms of defective decision making highlights the importance of detailed implementation, monitoring and contingency plans. It can be argued that detailed implementation and contingency plans are unlikely unless the decisions have been well-considered. However, well-considered decisions does not automatically lead to detailed plans, therefore this characteristic has been identified as separate:

- ❖ The process should result in detailed implementation, monitoring and contingency plans.

4.2.3 Building a comprehensive set of characteristics

From the preceding literature review the following preliminary characteristics of high quality decision making were identified:

- ❖ Objectives, alternatives and risks should be well-considered, acknowledging the multi-dimensional nature of most decision making problems
- ❖ The process should be informed with accurate, adequate and unbiased data
- ❖ The process should be inclusive, taking a wide range of stakeholder opinions into account.
- ❖ The process should be transparent, with an audit trail to ensure that the decisions can be explained and justified.
- ❖ The process should be flexible and able to adapt to the context of the process.
- ❖ The process should incorporate lessons learned, both in the past and during the current process, through build-in iterative feedback loops.
- ❖ The process should result in detailed implementation, monitoring and contingency plans

Before a final set of characteristics is decided on for further use in the research, the above preliminary set of characteristics should be viewed from the perspective of Belton and Steward's guidelines on formulating a coherent family of criteria, which was presented in Section 2.2.4: value relevance, understandability, measurability, non-redundancy, judgemental independence, balancing completeness and conciseness, operationality, and simplicity versus complexity.

The preliminary set of criteria agrees with Belton and Steward's guidelines except for a lack of judgemental independence between the *flexible process* and *lessons learned* criteria: an iterative process that incorporates lessons learned while underway is also flexible and adaptive. Additional criteria to increase the independence between the two (e.g. differentiating between whether the process takes into account lessons learned in the past versus during the current process) will however add complexity to the criteria set.

It was decided to rather move the *past lessons learned* part of the *lessons learned* criterion into the *informed process* criterion, and combine the remaining parts of the *flexible process* and *lessons learned* criteria, with the results shown in the definition in the next section.

4.2.4 Definition of a high quality decision making process

Following from the above-identified preliminary definition and characteristics of high quality decision making, a definition can now be offered that will inform the rest of the research:

High quality decision making results in decisions that lead to the achievement of the project's primary objectives. The characteristics of such decision making include that:

- *Objectives, alternatives and risks should be well-considered, acknowledging the multi-dimensional nature of most decision making problems*
- *The process should be informed with accurate, adequate and unbiased data, and take past lessons learned into account*
- *The process should be inclusive, taking a wide range of stakeholder opinions into account*
- *The process should be transparent, with an audit trail to ensure that the decisions can be explained and justified.*
- *The process should be flexible and able to adapt to the context of the process through build-in iterative feedback loops.*
- *The process should result in detailed implementation, monitoring and contingency plans*

It is worthwhile noting that the above set of decision making characteristics are not necessarily complete – due to the extent of the subject analysed that is unlikely. The process that led to the identification of this set of characteristics did however attempt to follow high quality decision making characteristics, i.e. well-considered, informed, transparent etc.

4.3 Decision aiding to support high quality decision making

Now that a useful set of characteristics of high quality decision making have been identified, the focus will shift towards how decision aiding can help realise these characteristics during the decision making process, ultimately assisting in the achievement of a project's primary objectives.

Literature will firstly be reviewed on the philosophy underlying decision aiding. This review, along with three decision aiding case studies in appendix D, will inform the identification of a decision quality framework against which to judge the contribution of existing decision aiding tools and approaches to high quality decision making.

4.3.1 The philosophy underlying decision aiding

4.3.1.1 Definition of decision aiding

Decision aiding definitions tend to focus on integrating stakeholders' value systems / preferences into the decision making process, while maintaining clarity and objectivity, as is illustrated by the following:

“Decision aiding is the activity of the person who, through the use of explicit but not necessarily completely formalised models, help obtain elements of the responses to questions posed by a stakeholder of a decision process. These elements work towards clarifying the decision and usually towards recommending, or simply favouring, a behaviour that will increase the consistency between the evolution of the process and this stakeholder’s objectives and value systems.” [Roy 1996]

“[Decision aiding is] a process which seeks to integrate objective measurement with value judgement [and] make explicit and manage subjectivity” [Belton and Steward 2002:p3]

Decision aiding as described by the above definitions improves the quality of the decision making process in a number of ways, including that:

- by focusing on the need to *“make explicit and manage [the] subjectivity”* which exists in the various stakeholders' objectives and value systems, the likelihood of well-considered and informed decisions is increased.
- by using *“explicit but not necessarily completely formalised models”* decision aiding provides a flexible structure to the decision making process.
- by trying to *“obtain elements of the responses to questions posed by a stakeholder”* decision aiding helps to clarify the decision problem, and increases the likelihood of a feeling of process ownership amongst the stakeholders, identified as important during the preceding discussion on inclusively and transparency.

However, although the above definitions are valuable they do not directly relate to all the characteristics of high quality decision making (e.g. detailed implementation and monitoring plans). A more general definition will therefore be used in this research:

Decision aiding consists of activities, tools and approaches designed to improve the quality of decision making to which it is applied.

Before the characteristics of decision aiding tools and approaches aligned to this definition are identified, some important decision aiding concepts first require further introduction.

4.3.1.2 Multi- versus single-criteria decision analysis

Literature within the field of multi-criteria decision analysis (MCDA) comments at length on the importance of making explicit within the decision making process the multi-dimensionality of the factors influencing a decision problem:

“The very nature of multiple criteria problems is that there is much information of a complex and conflicting nature, often reflecting different viewpoints and often changing with time. One of the principle aims of MCDA approaches is to help decision makers organise and synthesise such information in a way which leads them to feel comfortable and confident about making a decision, minimising the potential for post-decision regret by being satisfied that all criteria or factors have properly been taken into account.” [Belton and Steward 2002:p1]

At this point it is informative to explore the difference between a single- and a multi-criteria analysis. In a **single criterion analysis**, the (possibly very heterogeneous) consequences of each potential action are quantified in the units of a single significance axis chosen beforehand.

Economic evaluation during the decision making process, proposed in numerous references including Khatib [2003] and Willis and Scott [2000], is essentially a single-criterion approach, where all characteristics of the project are presented in terms of one criterion, usually financial costs or benefits.

The limitation of such a single-criterion approach is that the uncertainties around non-financial factors are often difficult to quantify into financial costs or benefits. The uncertainties around these factors are therefore not made explicit and addressed during the decision making process, and might only be revealed as problems later on in the project's life.

A **multi-criteria analysis**, on the other hand, “*aims to make explicit a coherent family of criteria (not reduced to a single element at the outset) that will serve as an intelligible, acceptable, and exhaustive instrument of communication allowing conception, justification, and transformation of preferences within the decision process.*” [Roy 1996]

The site selection process used for the Klipheuwel wind energy demonstration farm is a good example of a well-executed multi-criteria analysis process (discussed in detail in Appendix E). This analysis acknowledged the multi-dimensionality of the decision problem through the use of a family of criteria which covered a wide spectrum of impacts, from financial (e.g. wind speed and land ownership), technical and social (e.g. proximity to residential areas) to ecological.

The two approaches must sometimes be combined, for example so that existing single-criteria tools can be used, as was done by Heinrich [2008] in his proposed *Approach to electricity investment planning for multiple objectives and uncertainty*. During the first phase of his approach, where decision alternatives are generated, Heinrich integrates multiple objectives into an existing single-objective modelling process by including non-cost objectives (e.g. environmental) in the form of cost penalties, in effect reducing multiple performance measures into a single dimension: cost. However, in the next stage where decision makers have to choose between the generated alternatives, Heinrich propose the use of a value function-based multi-criteria decision aiding process.

4.3.1.3 *The spirit of recommendation*

Two distinct decision aiding approaches (or spirits of recommendation as defined by Roy [1996]) become apparent in literature: the descriptive and constructive approaches towards making explicit stakeholder values and preferences.

With the **descriptive approach**, the assumption is made that a latent system of preference relations exists in the mind of the decision maker before the decision aiding commenced. This system is however not explicit to the decision maker. The task of decision aiding is to clarify or describe (without influencing) this system of preference relations as exactly as possible.

The descriptive approach is based on utility (value) theory and the assumption of a rational person: a rational person is intrinsically consistent, will always choose to

maximise utility, and will make transitive¹⁸ choices (Keeny and Raiffa [1976]). Psychological studies however proved that the assumption of the rational person is often unrealistic, thereby also shedding doubt on the existence of a single utility function representing a decision maker's preferences.

The **constructive approach**, on the other hand, is based on the hypothesis that a stakeholder can be led by the decision aiding process to modify his or her preferences, either through lack of initial opinions, or through valid arguments presented during the process. Roy [1996] is a strong supporter of this perspective.

An example of the differences between the two approaches is in how statistical and structural dependence between two decision criteria are handled. In a descriptive approach the analyst might consider replacing two dependant criteria with a new single criterion. In the constructive approach the analyst might again prefer to keep both criteria separate in the model, as more complete or effective bases for guiding the decision process.

Belton and Steward [2002:p336] strongly advocate an integrated approach that incorporates both approaches, allowing the analyst to choose which paradigm is more applicable for the particular problem. The approaches and tools developed in this research align with this view, although later sections will illustrate that a constructive spirit of recommendation is typically better suited to this research's context.

4.3.1.4 Optimal vs. compromise solutions

It is worthwhile noting that decision aiding, within a constructive spirit of recommendation, in many cases will only be able to support a compromise solution to the decision problem rather than an optimal solution:

"[The solution to a] decision problem is therefore not searching for some kind of hidden truth ... but rather helping the decision-maker to master the (often complex) data involved in his problem and advance towards a solution." [Roy 1996]

Mathematics-based decision aiding tools should be seen within this perspective of optimal vs. compromise solutions, as stated by Vincke [1992]:

¹⁸ For example the "greater than" operator is defined as transitive, therefore if $A > B$ and $B > C$, then $A > C$.

“In general, it is impossible to say that a decision is a good or bad one by referring solely to a mathematical model. The organisational, pedagogical and cultural aspects of the entire decision process that lead to a given decision will also contribute to its quality and success.”

Vincke also quotes Scharlig [1985], who states that decision aiding is about *“putting an individual at the centre of the problem, with mathematics around him as peripheral instruments, rather than putting mathematics in the centre and reducing the individual to what they are capable of understanding of him.”*

Differentiating between an optimal and compromise solution leads to the question of how an iterative decision making process should end: a convergence test would not be suitable, as this assumes an optimal solution. Rather, the process should end when the decision-makers are satisfied with the solution or makes the decision that they have enough information about the problem. [Belton and Steward 2002]

4.3.1.5 Decision aiding that acknowledges uncertainty

Decision aiding should support the central theme in this research: acknowledgment of both the soft and hard uncertainties that might occur in projects. As discussed earlier in this chapter, the assumption of the applicability of probability is flawed when dealing with hard uncertainty, and the use of only probability to model project uncertainties during decision aiding should therefore be avoided.

4.3.1.6 To which actors are decision aiding given?

The form of the decision aiding tool or approach might differ according to the actors to which decision aiding is given.

The context of rural electrification decision making is often similar to that of land use planning described by Belton and Steward [2002:p23], where *“decisions are ultimately take at a political level, but this is typically preceded by a process of consultation with interested groups, and of analysis and screening of options by consultants and / or state officials.”* In this research the “political level” referred to in this quote is interpreted as representing both government and donor organisations.

In this context, decision aiding is typically given to one or more of the following three groups:

1. individual interest groups, to assist them in formulating their own preferences,

2. group forums with representatives from different individual interest groups, to “*facilitate the reaching of consensus*” [Belton and Steward 2002:p23],
3. consultants or analysts who wish to identify and present the most suitable alternatives to the decision makers at the political level.

In their discussion of land use planning decision aiding, Belton and Steward highlight the importance of an audit trail documenting the rationale behind the preliminary decisions to be presented to the political decision makers.

4.3.2 Lessons learned from three decision aiding case studies

The author was involved in a number of projects where tools and approaches were developed and used to aid decision making. A selection of case studies based on these experiences has been presented in Appendix D, to clarify and confirm decision aiding concepts introduced in the preceding section on decision aiding philosophy, and to inform the identification of a decision quality framework.

In this section only the lessons learned from these case studies will be presented: for details, refer to Appendix D.

- *Multi-criteria analysis greatly improves information transfer between different shareholders, and provides a useful framework for discussions.*
- *Using qualitative rather than quantitative measurement scales during early project stages makes the process more efficient, and avoids the distraction of shareholder disagreements about quantitative details that are irrelevant at this stage of the decision process.*
- *Valuable information is maintained within the decision making process by not aggregating criteria ratings too early in a decision process.*
- *Information sources / methodologies should be transparent.*
- *The choice of criteria family is highly context specific.*
- *Even in the case where one alternative is clearly superior to all the rest, the runner-up alternative and the process that led to their identification should still be clearly communicated. This gives the decision maker confidence in the process, and informs the construction of his/her preferences.*

- *The sustainability of a project often depends on non-technological factors which appear to over-ride the technical preferences of the project initiators.*
- *Sharing accurate information and highlighting uncertainties during the problem structuring phase of decision aiding can significantly alter the preferences of decision makers.*
- *Including previous experience / lessons learned in the decision aiding process offer significant benefits.*

4.3.3 Criteria to measure the quality of decision aiding tools and approaches

The preceding decision aiding literature review and case studies provide a background from which a framework of criteria can now be identified, against which to measure the contribution of decision aiding tools and approaches to high quality decision making. This framework will be referred to as the “decision quality framework” for the remainder of this research.

This decision quality framework is shown in Table 4-1 below, and attempts to incorporate the lessons learned through previous decision aiding experiences, along with important concepts that were noted during the literature review, while trying to keep the set of criteria usable. The identified framework is basically an extension of the characteristics of high quality decision making identified in section 4.2.4, and aligns with Roy [1996]’s idea of developing “*explicit but not necessarily completely formalised models*” to support the decision making process.

For reasons of simplicity and usability the measurement scale chosen in this framework indicate whether the criterion applies to the specific tool or approach, and if so, the level of contribution to high quality decision making.

Table 4-1: Decision quality framework to measure the contribution of decision aiding tools and approaches to high quality decision making.

| <i>High quality decision making characteristics</i> | <i>Criteria of tools and approaches that aid high quality decision making</i> | <i>Contribution of the tool/approach (Negative, None, Limited, Strong, Not Applicable)</i> |
|---|---|---|
| Well considered | Decision problem structured (i.e. objectives, criteria and alternatives clearly defined)? | |
| | Multi-dimensionality acknowledged? | |
| | Soft uncertainties acknowledged? | |
| | Hard uncertainties acknowledged? | |
| Informed | Incorporate past lessons learned / experiences? | |
| | Accurate, adequate and unbiased data? | |
| Inclusive | Stakeholder inclusive? | |
| Transparent | Transparent data sources / methodologies? | |
| | Audit trail? | |
| Flexible and adaptive | Process can adapt to context through iterative feedback loops? | |
| Implementation plans | Detailed implementation plans as outcome? | |
| | Post-process monitoring plans as outcome? | |

4.4 Is high quality decision making sufficient?

The decision quality framework developed in the previous section now allows the final research question to be addressed. This question in essence asks whether a high quality decision making process (which has been shown to include uncertainty acknowledgement) is sufficient to ensure the achievement of sustainable development objectives.

This section will answer the question by testing the sustainable development contribution of what has been identified in Appendix E as a high quality decision making process: the site selection process leading to the establishment of the Klipheuwel Wind Energy Demonstration Facility (KWEDF).

4.4.1 Case study: site selection project leading to the KWEDF

Although the KWEDF project itself falls outside the off-grid electrification context considered in this research, the site selection that lead to this project is used as case study for the following reasons:

- The use of renewable energy, and the decision problem addressed (site selection for renewable energy technologies) is relevant to the off-grid context.

- A large body of information exists in the public sphere on the decision making processes that took place in this project.
- The comparative abundance of available information, along with the high quality of decision making employed in this project, offers a unique opportunity to study a successfully completed electrification decision making process in South Africa in detail.

4.4.1.1 Evaluation of decision making quality

The decision aiding process underlying the site selection process was consistently of high quality, as shown in the summary of the evaluation (Table 4-2; for details of the full evaluation, refer to Appendix E). In this evaluation the decision quality framework identified in the previous section served as benchmark against which to compare the process.

Table 4-2: Summary of the contribution of decision aiding to high quality decision making during the site selection project leading to the KWEDF (see Appendix E for details)

| High quality decision making characteristics | Criteria of tools and approaches that aid high quality decision making | Contribution of the tool/approach (Negative, None, Limited, Strong, Not Applicable) |
|--|---|--|
| Well considered | Decision problem structured (i.e. objectives, criteria and alternatives clearly defined)? | Strong |
| | Multi-dimensionality acknowledged? | Strong |
| | Soft uncertainties acknowledged? | Strong |
| | Hard uncertainties acknowledged? | Limited |
| Informed | Incorporate past lessons learned / experiences? | Strong |
| | Accurate, adequate and unbiased data? | |
| Inclusive | Stakeholder inclusive? | Strong |
| Transparent | Transparent data sources / methodologies? | Strong |
| | Audit trail? | Strong |
| Flexible and adaptive | Process can adapt to context through iterative feedback loops? | Strong |
| Implementation plans | Detailed implementation plans as outcome? | Strong |
| | Post-process monitoring plans as outcome? | |

4.4.1.2 Achievement of primary project objectives

According to the definition of high quality decision making developed in the previous sections, if the quality of the decision aiding process during a project was high, the decisions made should have resulted in the project achieving its primary objectives. In the site selection project this definition can be shown to hold true:

- In essence, the primary project objectives of the site selection project was to recommend two or three suitable sites, on which to erect six to ten wind turbines

rated at around 10 MW in total, for an Environmental Impact Assessment (EIA), and ultimately to get one of these recommended sites approved by the EIA.

- The Oliphantskop and Klipheuwel sites were recommended to be most suitable for the EIA process, with the Philadelphia site kept in reserve. Klipheuwel was ultimately approved by the EIA.

It is clear that the site selection project's primary objectives have been achieved.

4.4.1.3 Contribution to sustainable development

It appears from the literature that no attempt was however made to align the site selection process's primary objectives with sustainable development objectives.

It can be argued that in selecting the location of the (K)WEDF, which the site selection project defined, sustainable development was irrelevant given that the ultimate objectives of the project were technology demonstration and testing. Yet a sizable amount of money was spent on sustainable development activities (in the form of local community development), which is clearly a function of the location of the site:

- Eskom committed R1 million into a trust towards building a new school closer to the community. [Smit et. al. 2004]
- Two large containers, donated by Maersk, were converted into an additional classroom for the Klipheuwel Primary School, situated 3km from a poor community. Eskom and Partners International funded the material and labour.

Although sustainable development was clearly a part of the outcomes of the project through the community development funding described above, it was excluded from the formal site selection process primary objectives.

The impact of this exclusion is difficult to judge after the fact, but the literature reviewed up to now supports the likelihood that inclusion (e.g. through the use of a "community development opportunities/costs" criterion [Bekker and Gaunt 2005]) might have resulted in a greater sustainable development impact for the same expenditure than that which actually occurred.

Excluding community development as an initial project objective also makes the decision making process vulnerable to the accusation that the community development expenditure was not motivated by a desire for sustainable development, but was driven by marketing or political motivations.

4.4.2 Alignment between primary and sustainable development objectives

The above KWEDF site selection project illustrates that even though high quality decision making occurred, sustainable development objectives were not explicitly considered during the formal decision process. This potentially decreased the sustainable development impact of the project, and opened it up to criticism. In essence, these problems were caused by non-alignment between the primary project objectives and sustainable development objectives.

Even though this alignment of objectives can easily be added as an additional criterion within the decision quality framework developed earlier, in this research it will be kept separate. The motivation for this is purely academic, based on the definition of high quality decision making as resulting in the achievement of primary *project* objectives, and not specifically sustainable development objectives.

4.4.3 The second hypothesis tested

The KWEDF case study highlights that high quality decision making by itself is not sufficient to achieve sustainable development objectives: alignment between such objectives and the project's primary objectives is also required.

This chapter also reached three other conclusions:

1. differentiating between soft and hard uncertainties offer advantages within the context of South African off-grid electrification projects,
2. high quality decision making per definition leads to primary project objectives achievement, and
3. uncertainty acknowledgement forms an important part of the decision aiding that supports high quality decision making.

The above conclusions provide enough evidence to validate the second part of the research hypothesis:

A high quality decision making process that is capable of acknowledging both hard and soft uncertainties will assist off-grid projects in reaching their primary project objectives (but not necessarily sustainable development objectives, unless these two sets of objectives align).

4.5 In summary

This chapter set out to answer four research questions. The following answers were found to these research questions, allowing the second part of the hypothesis to be validated:

What are the advantages of differentiating between soft and hard uncertainties?

The analyses in section 4.1 highlighted that a single conceptualisation of uncertainty risks ignoring those uncertainties that often can't be represented in decision aiding approaches due to their non-probabilistic nature, i.e. hard uncertainties.

An analysis of significant off-grid electrification project uncertainties (identified in the previous chapter) showed that almost all of these uncertainties were hard. This fact offers a strong motivation for differentiating between soft and hard uncertainties within off-grid electrification decision aiding, thereby acknowledging the hard uncertainties that previously might have been ignored within the decision making process.

What are the characteristics of high quality decision making?

A literature review defined high quality decision making, and its characteristics (see section 4.2.4).

What are the criteria of a decision aiding process which supports high quality decision making, and do these criteria include hard and soft uncertainty acknowledgement?

The criteria of a decision aiding process that supports high quality decision making are listed in Table 4-1. It became apparent that hard and soft uncertainty acknowledgement forms a part of these criteria.

Is high quality decision making sufficient to ensure that off-grid projects achieve sustainable development objectives, and if not, what are the additional requirements?

No, in addition to high quality decision making, alignment between primary project and sustainable development objectives is also a requirement.

5 Improving decision aiding approaches and tools

The research has, up to this point, identified that uncertainty acknowledgment forms a crucial part of high quality decision making, alongside alignment between sustainable development and primary project objectives. This chapter will now apply these findings towards improving existing high quality decision aiding tools and approaches, especially in three areas: objective alignment, and soft and hard uncertainty acknowledgement, with the aim of testing the final part of the research hypothesis:

Applying existing high quality decision aiding tools and approaches, with improved uncertainty acknowledgment and objectives alignment capabilities, to off-grid projects will increase such projects' impact on sustainable development.

Three research questions will guide this chapter, as shown in Figure 5-1.

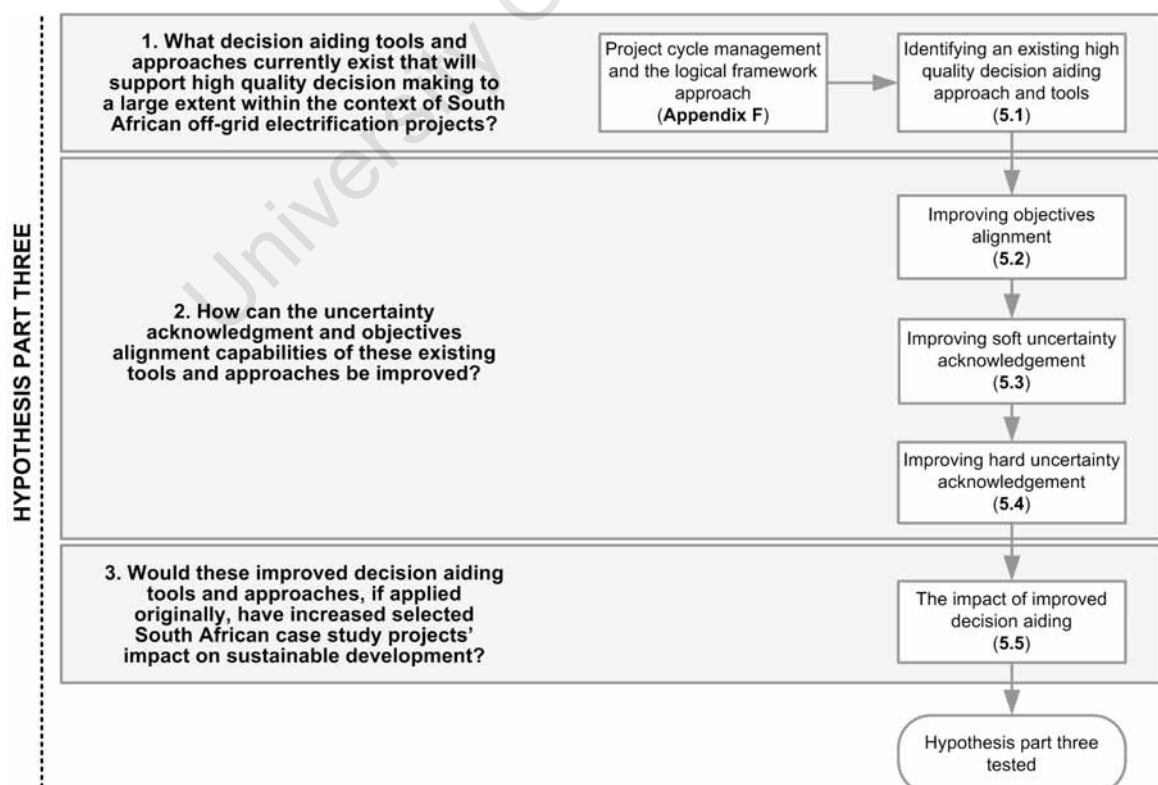


Figure 5-1: Conceptual map showing how the different sections of Chapter 5 and the appendices relate to the research questions and hypothesis.

5.1 Identifying an existing high quality approach and tools

Ideally the “existing high quality decision aiding approach and associated tools” mentioned in the research hypothesis should be chosen from those that have already been used within South African electrification projects. Unfortunately, as shown in Appendix B, no formal use of decision aiding approaches or tools could be identified in any of these projects, with the following exceptions:

- *The Homer and RETScreen renewable energy resource estimation tools, used at Lucingweni and Hluleka.*

The Excel-based RETScreen Clean Energy Project Development software [RETScreen 2009] can estimate RES-based energy production for a specified location, and also offers cost, emissions, financial and risk analyses.

The Homer Micropower Optimisation Model software [Homer 2009] can optimise system component sizing in RES-based projects, either grid-connected or off-grid, can do basic cost and financial analyses, and allows some risk analysis by allowing the user to specify restraints like “maximum annual capacity shortage (%)”.

These tools are updated often, and are widely used internationally in off-grid electrification projects. They also support high quality decision making to a large extent, as shown in Table 5-1, and will therefore be used as example tools within this research.

Table 5-1: Analysis of the quality of the decision aiding process used in Homer and RETScreen.

| <i>High quality decision making characteristics</i> | <i>Criteria of tools and approaches that aid high quality decision making</i> | <i>Contribution of the tool/approach (Negative, None, Limited, Strong, Not Applicable)</i> |
|---|---|---|
| Well considered | Decision problem structured (i.e. objectives, criteria and alternatives clearly defined)? | Not Applicable |
| | Multi-dimensionality acknowledged? | Strong: RETScreen and Homer both acknowledge the main dimensions of the decision problem they aim to aid: technical (energy output), financial (capital and ongoing costs and economic viability) and, in the case of RETScreen, environmental (emissions). |
| | Soft uncertainties acknowledged? | Limited: RETScreen includes a financial sensitivity and monte carlo risk analysis component, which evaluates the sensitivity of important financial indicators in relation to key technical and financial parameters. Homer includes a powerful sensitivity analysis, evaluating the impact on system size and cost for a wide range of varying inputs, including climate, technical and cost parameters. Neither software, however, address uncertainties related to the accuracy of the energy estimation models on which their calculations are based. A number of assumptions are made in these models which, while |

| | | |
|-----------------------|--|---|
| | | potentially valid for North American climatic conditions, might result in significant accuracies in a South African context. These assumptions include the use of monthly rather than hourly / 5 minute climatic data, simplified electrical models, and diffuse radiation estimation models. |
| | Hard uncertainties acknowledged? | Not Applicable |
| Informed | Incorporate past lessons learned / experiences? | Not Applicable |
| | Accurate, adequate and unbiased data? | Strong: RETScreen and Homer were specifically developed to inform decision making processes. The results from the programs are however only as accurate as the inputs into them (rubbish in, rubbish out), and can at worst mislead the decision process (negative contribution). If the assumption is however made that external uncertainties (e.g. the accuracy of the weather data) are managed, the research presented by Bekker [2008:p7] indicates that the impact of internal uncertainties on accuracy is less than 10% for the South African locations that were investigated, indicating that these two tools can offer strong contributions to the decision process. |
| Inclusive | Stakeholder inclusive? | Not Applicable |
| Transparent | Transparent data sources / methodologies? | Strong: The methodologies used in both software programs, as well as the default data sources used by the programs (e.g. NASA SSE satellite weather data), are well documented and fully transparent. |
| | Audit trail? | Strong: RETScreen and Homer both allow the user to save the input parameter data that was used in the project, enabling future reruns of the estimation. Homer can also output the input parameters in html format, while RETScreen is Excel based, allowing effortless inclusion of the simulation inputs and results in the project documentation. These factors contribute to a high quality audit trail. |
| Flexible and adaptive | Process can adapt to context through iterative feedback loops? | Strong: The tools are software-based, and therefore the effects of input parameter changes can easily be confirmed. |
| Implementation plans | Detailed implementation plans as outcome? | Not Applicable |
| | Post-process monitoring plans as outcome? | |

- *Banks' electrification planning tool, used within the SHS concession programme, as described in Banks et al [2000].*

Unfortunately little information exists in literature on the application of this tool.

A potential limitation of the tool is that it quantifies important factors like distance from existing grid and accessibility of the area, and then applies a weighted sum of these quantities to arrive at electrification priorities for different areas. This mathematical process is not transparent, leading to a lack of trust among decision makers about the validity of the results of the tool, as stated by a decision maker involved in a process where the tool was used [Anonymous 2007]. The developer of the tool, Douglas Banks, regrettably passed away in early 2009, resulting in uncertainty about

the continued development and support of the tool. For the above reasons this tool will not be studied further in this chapter.

- *The multi-criteria approach used for the grid-connected Klipheuwel project.*

This approach was embedded in South African EIA legislation. As this EIA process is only required for projects resulting in individual generators above 1MW, it is not applicable for most off-grid electrification projects and will therefore not be used as a demonstration approach here. The lessons from this approach have however been incorporated into the research in Chapter 4.

South African academic literature and post-implementation project evaluations offer further potential sources for the identification of decision aiding approaches and tools. Two approaches from these sources are potentially of interest:

- *Heinrich's proposed ESI investment planning approach for multiple objectives and uncertainty.*

As part of his PhD research, Heinrich [2008] developed a framework that policy makers and planners can use to analyse and plan for investment in the electricity supply industry (ESI). This framework aims to address the decision problem around the choice of future power generation technology on a national level.

An adaptation of Heinrich's approach might be of value within off-grid electrification planning, in the manner in which it integrates multiple objectives into the decision making process while acknowledging underlying uncertainties.

The approach however integrates multiple objectives into an existing single-objective modelling process by including non-cost objectives (e.g. environmental) in the form of cost penalties, in effect reducing multiple performance measures into a single dimension: cost.

It will be difficult to integrate hard uncertainty acknowledgement into this single-objective modelling process, and for this reason this approach is considered unsuitable for the requirements of this research.

- *The logical framework approach, as used in the evaluation of the National Electrification Programme [DME 2001b].*

The logical framework approach (LFA) was used retrospectively to evaluate the South African National Electrification Programme (1994-1999). This approach is well suited to the aims of this research, as it focuses strongly on project objectives, and potentially offers a flexible framework into which uncertainty acknowledgement and objectives alignment can be integrated.

In addition, the LFA is popular internationally in developmental projects, with large donor organisations like AusAid and EuropeAid mandating the use of this approach in many of their projects.

An evaluation was done in Table 5-2 of the well-documented European Commission's Project Cycle Management (PCM) and LFA [EC 2002], and this indicates that these approaches to a large extent support high quality decision making.

For the above reasons PCM and LFA will be used as the example decision aiding approach in this research. For a more detailed description of PCM and LFA, please refer to Appendix F.

Table 5-2: Analysis of the decision aiding quality of the European Commission's PCM and LFA approach

| High quality decision making characteristics | Criteria of tools and approaches that aid high quality decision making | Contribution of the tool/approach (Negative, None, Limited, Strong, Not Applicable) |
|--|---|--|
| Well considered | Decision problem structured (i.e. objectives, criteria and alternatives clearly defined)? | Strong: PCM uses LFA during the project design stages to structure the decision problem in detail, according to different levels of objectives, with outcomes and indicators. |
| | Alignment encouraged between project primary objectives and sustainable development objectives? | Strong: The Integrated Approach used in PCM encourages alignment between the overarching national/sectoral objectives (policy objectives of the EC within this context) defined during the programme phase of the project cycle, and the Logframe-defined objectives and results-based workplans and budgets defined during the planning and appraisal phases. |
| | Multi-dimensionality acknowledged? | Strong: PCM and LFA encourage the identification of "cross-cutting issues" and multiple objectives, and the LFA is structured in such a way that the multi-dimensionality of the decision problem remains clear, for example through indicators that need not be reduced to one dimension (e.g. cost). |
| | Soft uncertainties acknowledged? | <p>Limited: A number of mechanisms encourage decision makers to acknowledge the risks involved in the project. These include:</p> <ul style="list-style-type: none"> • a PCM-required section in all project documentation on "Assumptions and risks"; • the inclusion of risk in the quality criteria/questions lists used during the programming, identification and appraisal phases to ensure well-considered decisions, for example the questions "What are the assumptions and risks underlying the objectives? How critical to the programme's success are they and how likely is it that they will be achieved?" [EC 2002:10] within the programming phase; • the Assumptions column in the Logframe encourage the DM to focus on assumptions or risks outside his/her control; • these Assumptions/Risks can be monitored in the same way as Results, through the use of Indicators and Sources of Verification <p>In all the above mechanisms the risk exist that uncertainties critical to the success of the project are not identified during the planning stages, or not at all. The EC [2008:51] recognise this risk when it list eight Quality Factors which, from experience, has been found to be critical to the longer-</p> |
| | Hard uncertainties acknowledged? | |

| | | |
|-----------------------|--|---|
| | | term sustainability of project benefits: ownership by beneficiaries, policy support, appropriate technology, socio-cultural issues, gender equality, environmental protection, institutional and management capacity, and economic and financial viability. The EC suggest that these factors “should be kept in mind from the planning stage onwards.” |
| Informed | Incorporate past lessons learned / experiences? | Strong: An evaluation study is required by PCM at the end of a project. The lessons learned in this study are available to inform later programming and identification stages. The standardised documentation required by PCM has a section that should include “lessons from past experience, and linkage with other donors’ activities” [EC 2002:5] The list of eight Quality Factors is also an attempt to inform the process with past lessons learned. |
| | Accurate, adequate and unbiased data? | None: PCM and LFA do not include any mechanisms to ensure the quality of the data used in the decision process. |
| Inclusive | Stakeholder inclusive? | Strong: PCM requires consulting and involving key stakeholders as much as possible. The first activity during the analysis phase of the LFA is also a stakeholder analysis to identify and characterise different stakeholders. Although stakeholder participation is strongly encouraged by the PCM and LFA, in the end it is in the hands of the analyst / decision makers. |
| Transparent | Transparent data sources / methodologies? | Strong: The methodologies on which PCM and LFA are based is easy to understand and follow, and is well suited to a transparent process. The standardised documentation required by the PCM also provides a well-documented audit trail of the decision process. |
| | Audit trail? | |
| Flexible and adaptive | Process can adapt to context through iterative feedback loops? | Strong: Monitoring and reporting are two of the three major principles (along with planning) that are applied throughout the implementation phase of the project cycle. This is achieved through the Logframe by defining “Objectively Verifiable Indicators” and “Sources of Verification” for each objective, and is a required section in the standardised reporting documentation required by PCM. This standardised reporting forms the based of the PCM’s integrated approach: “The key principle of reporting is that attention is paid to the same important and critical elements from the early preparation until the very end, project completion” [EC 2002:86] |
| Implementation plans | Detailed implementation plans as outcome? | Strong: The Logframe generates clearly defines Results and Activities, which is then integrated into Results-based Activity and Resource schedules for the implementation phase. |
| | Post-process monitoring plans as outcome? | Strong: The PCM includes an evaluation phase with an evaluation study as outcome. The standardised documentation required by PCM also includes a “monitoring and evaluation” section under the heading of “implementation arrangements” |

Additional decision aiding approaches and tools might exist that will also be useful within this research. The identified approach (the PCM/LFA) and associated tools (RETSscreen and Homer) should however adequately serve the requirements of this research: of acting as examples into which uncertainty acknowledgement and objective alignment can be integrate. For this reason, additional decision aiding tools and approached will not be explored.

5.2 Improving objectives alignment

The analyses of Klipheuwel highlighted the impact of a lack of alignment between sustainable development and project objectives. This section will look at ways in which to address this problem, by utilising the PCM / LFA approach and improving it where required to better suit the context of off-grid electrification projects.

5.2.1 Objectives and the PCM / LFA approach

One of the core strengths of the PCM / LFA is that it focuses the decision maker's attention on project objectives, from the initial programming stages of the project lifecycle up to implementation:

- During the programming stage of the PCM the focus is on the situation at a national or sectorial level, with a Country Strategy Paper defining the main objectives of the program in order to offer a relevant and feasible framework within which projects can be identified and prepared. Note that the structure of the Country Strategic Paper, and all other documentation generated during the PCM process, is informed by a standardised PCM document structure as shown in Figure 5-2 (the structure is presented in Figure 5-3)
- During the identification phase the relevance of project ideas are explored within the programming framework, with pre-feasibility studies leading to Project Identification Sheets. These project ideas are required to align with the framework of programme objectives. The focus during this identification phase is largely on project objectives, as shown by the fact that the objectives areas of the Logframe (the framework generated by the LFA, as explained in Appendix F) need to be completed in full during this stage, while the rest of the Logframe only needs to be completed in full during the next appraisal stage.
- During the appraisal phase the project ideas generated earlier is developed into project plans as part of a feasibility study.

5.2.2 Integrating energisation sustainable development objectives

The standardised structure of all documentation within the PCM offers a useful mechanism to ensure alignment between project and sustainable development objectives: it is proposed that the energisation framework, developed in section 2.3, be integrated into this standard document structure (as originally proposed in [Bekker and Gaunt 2007]), to inform the programming and identification stages (as shown in Figure 5-3). This integration can be done in the form of an additional section within the document

structure which specifically deals with the manner in which project objectives align with sustainable development objectives – the energisation framework will be included in this additional section.

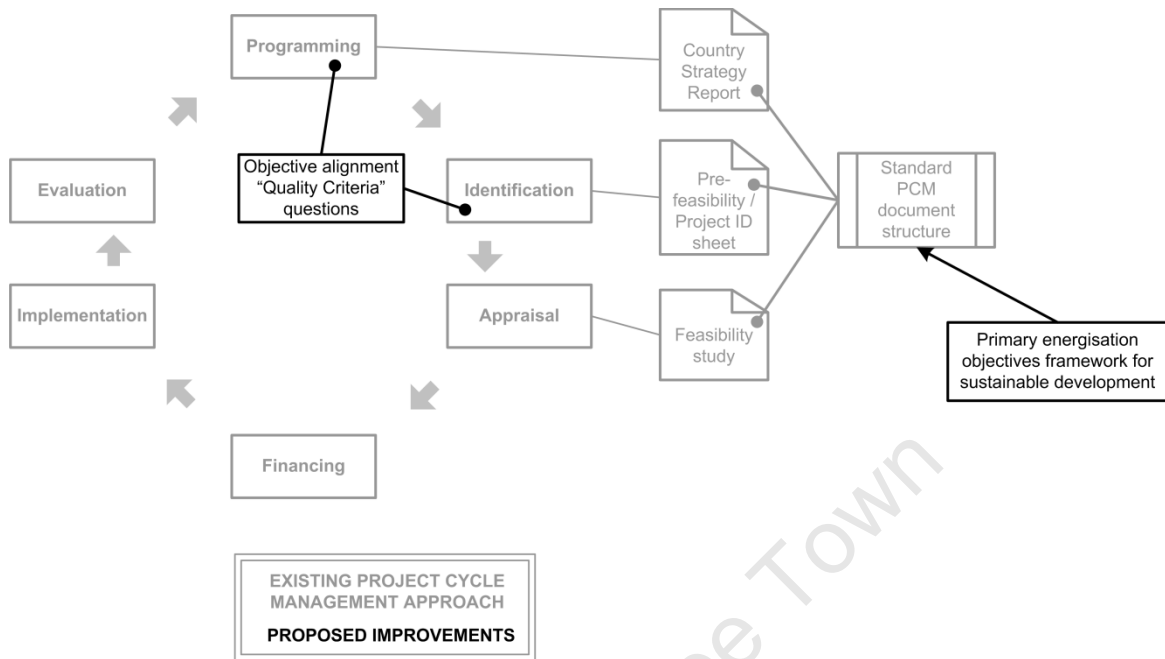


Figure 5-2: The proposed improvements of the PCM approach in order to ensure primary project and sustainable development objectives alignment.

| | | | | | |
|---|-----------------------------|---|---------------------------------------|---|---------------------------|
| <p>1. Summary</p> <p>2. Background: Overall EC and Government policy objectives, and links with the Commission's country programme or strategy, commitment of Government to overarching policy objectives of the EC such as respect of human rights</p> <p>3. Sectoral and problem analysis, including stakeholder analysis and their potentials</p> <p>4. Project / programme description, objectives, and the strategy to attain them ⇒ Including lessons from past experience, and linkage with other donors' activities ⇒ Description of the intervention (objectives, and strategy to reach them, including Project Purpose, Results and Activities and main Indicators)</p> <p>5. Assumptions, Risks</p> <p>6. Implementation arrangements ⇒ Physical and non-physical means ⇒ Organisation and implementation procedures ⇒ Timetable (work plan) ⇒ Estimated cost and financing plan ⇒ Special conditions and accompanying measures by Government / partners ⇒ Monitoring and Evaluation</p> <p>7. Quality factors ⇒ Participation and ownership by beneficiaries ⇒ Policy support ⇒ Appropriate technology ⇒ Socio-cultural aspects ⇒ Gender equality ⇒ Environmental protection ⇒ Institutional and management capacities ⇒ Financial and economic viability</p> <p>Annex: Logframe (completed or outline, depending on the phase)</p> | <p>← Integrated into</p> | Social dimension | | | |
| | | Theme | Objective | Indicator | |
| | | Equity | Accessibility of energy | Adequacy of energy from modern sources for basic needs of a) indoor lighting, b) media, c) communication, d) cooking, e) space heating, f) water heating and g) refrigeration | |
| | | | Affordability of energy | a) Average customers' ability to pay b) Poorest customers' ability to pay | |
| | | | Addressing disparities | Disparities in access to and affordability of modern energy sources between a) different locations and b) different social groups | |
| | | Health | Fuel-use safety | The occurrence of a) paraffin poisoning, and b) fire-related injuries | |
| | | | Indoor air quality | The occurrence of indoor particulate emission-related illnesses | |
| | | | Security | Adequacy of exterior lighting | |
| | | | Energy-supply related physical labour | The amount of energy-related physical labour | |
| | | | | | Economic dimension |
| Theme | Objective | Indicator | | | |
| Productive use | Access to information | The use of a) radio, b) TV and c) internet within the target area of the energisation project | | | |
| | Increased time availability | The amount of free time daily compared to before energisation | | | |
| | SMME development | The number of SMMEs within the target area of the energisation project | | | |
| | Long-term income generation | The average household income within the target area of the energisation project | | | |
| | | | Environmental dimension | | |
| Theme | Objective | Indicator | | | |
| Atmosphere | Addressing climate change | Green house gas contribution from energy sources | | | |
| Water | Water quality | The impact of the use of modern energy sources on drinking and general water quality | | | |
| Land | Deforestation | The impact of the use of modern energy sources on deforestation | | | |

Figure 5-3: It is proposed that the energisation framework be integrated into the existing documentation structure required by the PCM approach, under a new section titled "Alignment with sustainable development".

The advantages of this integration into the standard structure includes that analysts / decision makers are required in the documentation / audit trail to justify their choice of project objectives against a energisation framework which clearly summarise what is meant by sustainable development within the context of energisation.

It should be noted that the framework that is proposed here for integration relates to energisation, not off-grid electrification: this decision was made in the light of the discussion in section 2.4.1, where the limitations of off-grid electrification outside a wider energisation strategy was acknowledged.

5.2.3 Verification through “Quality Criteria” questions

EuropeAid’s PCM / LFA documentation recommends that the analyst asks specific “Quality Criteria” questions during each stage of the PCM process, to ensure that essential requirements of that stage have been addressed. A question within the identification phase that is relevant in this research context is: “*Are the project objectives in line with the overarching policy objectives of strengthening good governance, human rights and the rule of law, and poverty alleviation?*” [EC 2002:p13] Objectives alignment is already a focus of the PCM approach through questions like this one, which verifies the alignment of the identified project’s objectives within the overarching programme objectives.

It is proposed that a similar “Quality Criteria” question is additionally included in both the programming and identification stages, specifically relating to sustainable development: “*Does the programming / project objectives align to the primary sustainable development objectives of energisation?*” as shown in Figure 5-2.

5.3 Improving soft uncertainty acknowledgement

During the analyses of the uncertainties within completed South African off-grid projects it became clear that the majority of the uncertainties could be classified as hard using Young [2001]’s definition. There was however a few unacknowledged soft uncertainties within these projects: how to acknowledge them will be the focus of this section.

The “*Inaccurate estimation of renewable resource availability*” and “*Incorrect estimation of system consumption*” project uncertainties (in the context where they are classified as soft – see section 4.1.5) will be used here as examples to illustrate how existing soft uncertainty acknowledgement tools can be improved.

Specifically two sets of tools will be discussed:

- The first set of tools is the existing Homer and RETScreen renewable resource estimation software: these tools will be used to illustrate how the soft uncertainty around renewable resource estimation tools can be acknowledged. This section will

analyse the accuracy of the estimations produced by these tools and more generally the uncertainty introduced by using various South African weather data sets, and propose ways in which these findings can be incorporated into the PCM approach.

- The second tool will be developed as part of this research, and aims to address the impact of load and resource estimation uncertainties on the final renewable energy system sizing. It is proposed that this uncertainty be managed through the introduction of an adequacy confidence index, once again incorporated into the PCM approach.

5.3.1 The applicability and accuracy of resource estimation

Homer and RETScreen are well suited to estimating the renewable resource availability within South African off-grid projects, as described earlier. The accuracy of these tools is however crucial: an inaccurate estimate will result in under- or over-designed systems, which will either not supply rural households with enough energy, or will cost more than is really required (leaving a smaller budget for additional electrification).

This section reports on the results of a modelling and simulation process that explored the impact of various uncertainties on the accuracy of these programs, using as example PV systems installed in various climatic regions of South Africa. Only a brief background to the process and results will be presented in this section: full details can be found in [Bekker and Gaunt 2008]

A method is also proposed of integrating the results from this process into the example decision aiding approach selected for this research, the PCM / LFA approach.

5.3.1.1 Background to the modelling and simulation process

Uncertainties impacting PV array energy output estimation can be split into those arising from the historical weather data used in the estimation process, and those arising from the models used to simulate PV array energy production, as shown in Figure 5-4. This section focus on those soft uncertainties whose impacts can be simulated or modelled, and is guided by the following research questions:

- Historical weather data
 - What influence does the use of averaged monthly and hourly, rather than 5-minute irradiation data sets have on PV array energy output estimation?
 - What uncertainty is introduced when only global solar irradiation data sets are used, and diffuse irradiation is estimated?
- PV array energy output model

- How does the type of electrical model used to calculate PV array energy output impact the accuracy of the estimates?
- How applicable to the South African climatic context is the type of model that is used to calculate the diffuse irradiation on a tilted PV surface?
- What is the combined impact of these uncertainties on the accuracy of using RETScreen and Homer software within the South African climatic context?

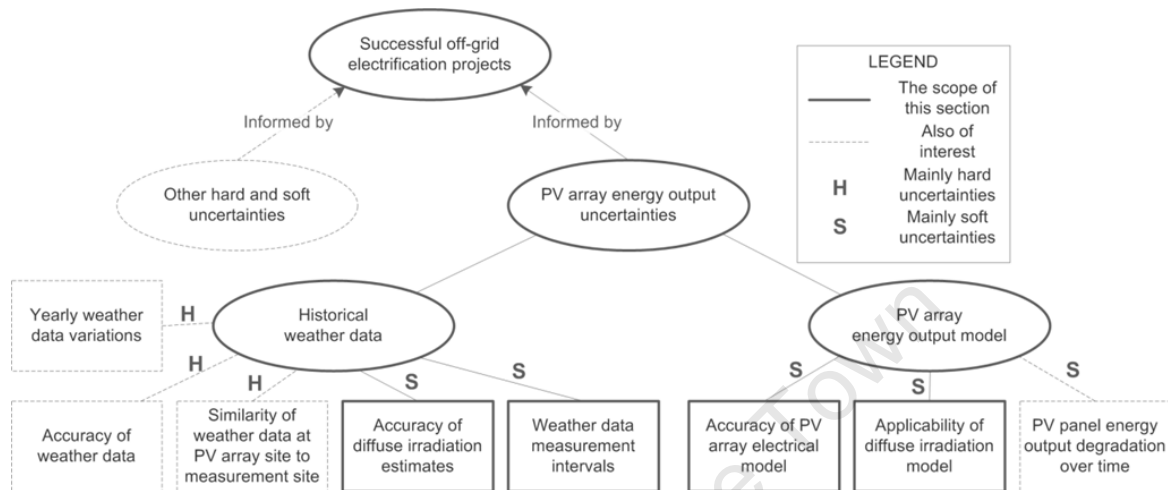


Figure 5-4: Indication of what uncertainties, relating specifically to PV array energy output estimation, are included within the scope of the modelling and simulation process described in this section.

Homer and RETScreen uses hourly or monthly global irradiation data sets as inputs, estimate the diffuse irradiation component, and also use simplified electrical models, and diffuse radiation models developed for North America / Europe (as shown in Figure 5-5). For this reason they are well-suited to answering the above research questions, when compared to a “best case” MATLAB-based software package called SunSim, that was developed for this research and uses 5-minute global and diffuse irradiation as input, a complex electrical model, and a diffuse radiation model applicable to the South African climatic context. SunSim’s user interface is shown in Figure 5-6.

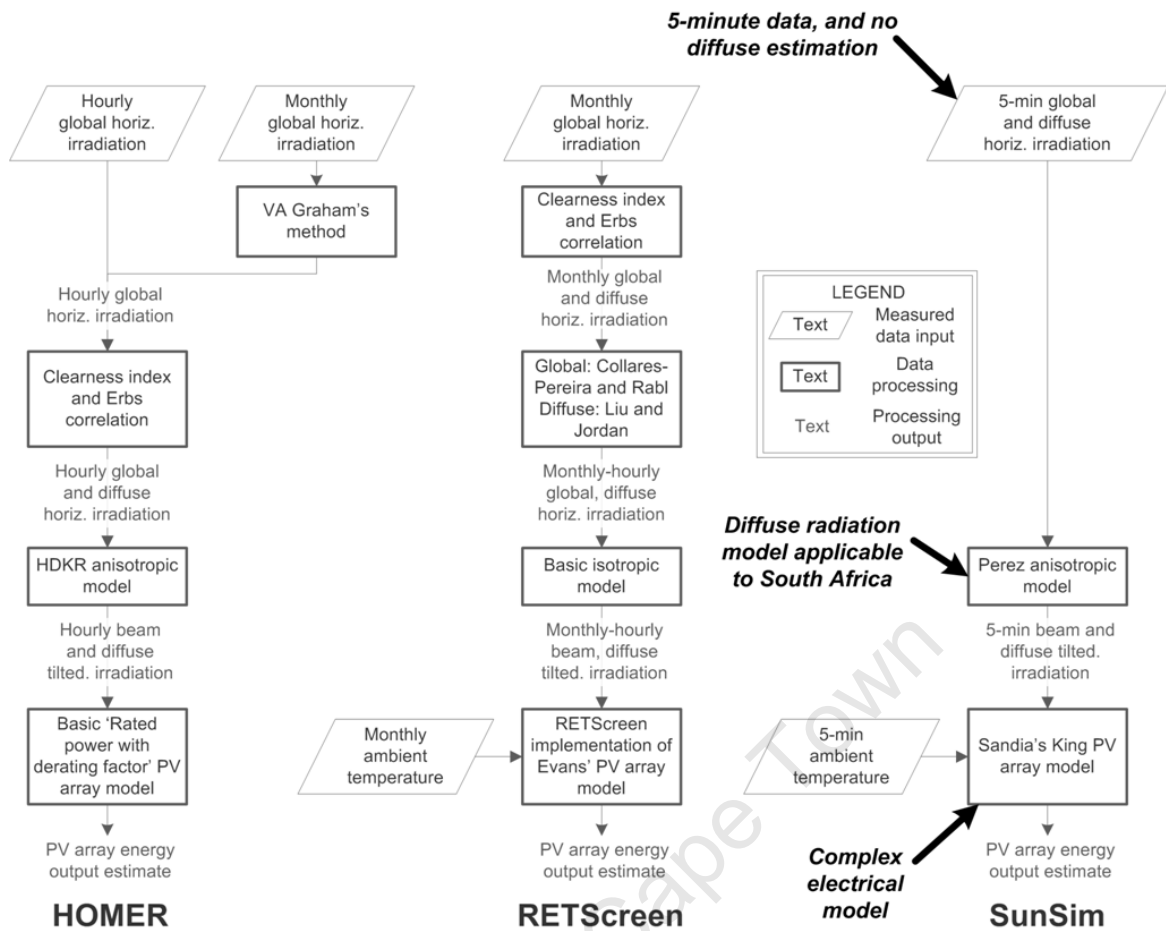


Figure 5-5: Diagrammatic layout comparing the methodologies used in the Homer, RETScreen and SunSim software packages

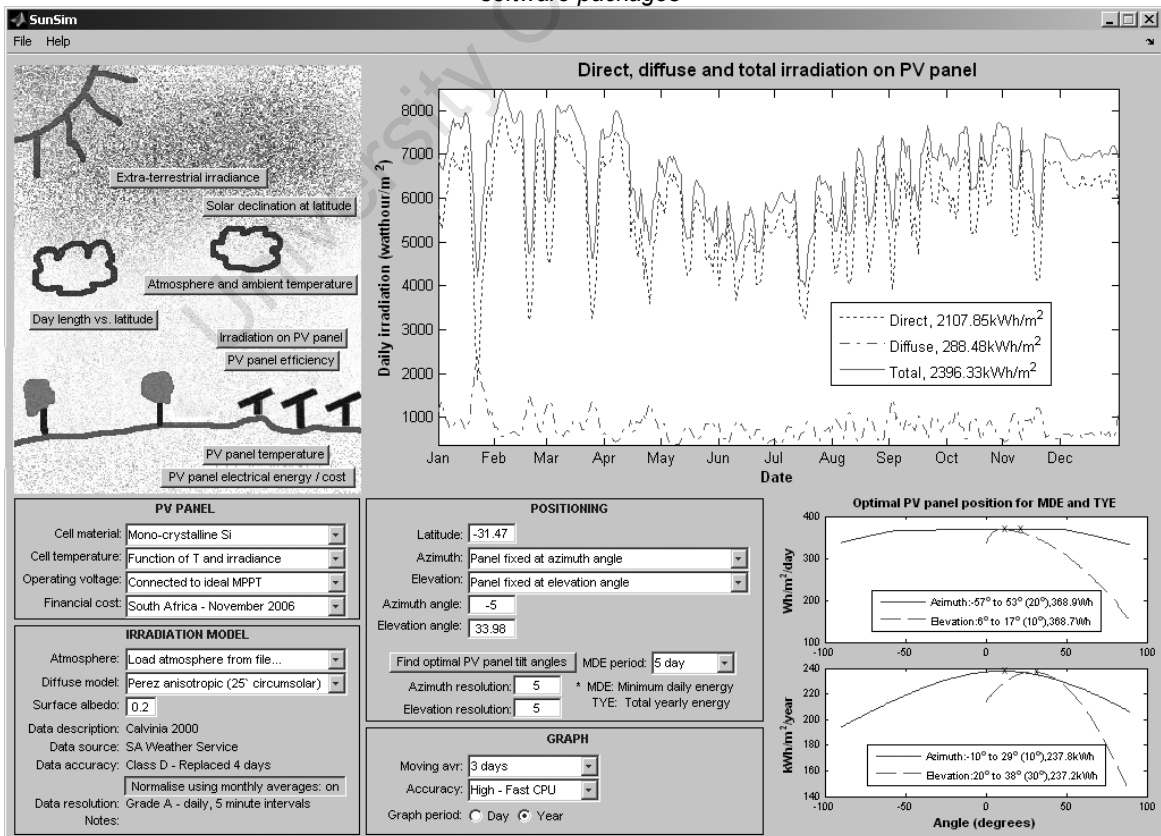


Figure 5-6: The MATLAB-based SunSim PV-array energy estimation software.

The research questions are answered using weather data sets for four different locations representative of South Africa's climate: Cape Town, Durban, De Aar and Polokwane. The weather data sets are used as inputs into the HOMER and RETScreen programs, and the resulting PV energy estimates are compared with estimates from SunSim.

5.3.1.2 Results from the modelling and simulation process

The results from this research is summarised below, with details of how the research questions were answered shown in [Bekker and Gaunt 2008]:

- What influence does the use of averaged monthly and hourly, rather than 5-minute irradiation data sets have on PV array energy output estimation?
 - Software capable of modelling PV systems that are not connected to MPPTs (e.g. for water-pumping applications where the panel is connected directly to the pump) should avoid the use of monthly weather data inputs, as PV energy output might be overestimated by 20-25%
 - The impact on PV energy estimates of using hourly instead of 5-minute data sets is insignificant.
 - Assuming a 'best case' model like SunSim, use of monthly instead of 5-minute data sets result in an overestimation of PV energy by around 5%
- What uncertainty is introduced when only global solar irradiation data sets are used, and diffuse irradiation is estimated?
 - The impact of using synthesized instead of measured diffuse irradiation data sets is insignificant for locations with high beam-to-diffuse irradiation ratios.
 - Using synthesized instead of measured diffuse irradiation at locations with high diffuse irradiation can cause PV energy underestimation of 1-4%.
- How does the type of electrical model used to calculate PV array energy output impact the accuracy of the estimates?
 - The use of PV array performance models that do not take PV cell temperature into account, as in Homer, results in underestimation of PV energy output of as much as 10%.
- How applicable to the South African climatic context is the type of model that is used to calculate the diffuse irradiation on a tilted PV surface?
 - Isotropic tilted surface diffuse irradiation models cause PV energy underestimation of 2-5% compared to anisotropic models.

- What is the combined impact of these uncertainties on the accuracy of using RETScreen and Homer software within the South African climatic context?
 - PV energy output is underestimated by 6-9% by Homer, and 0-6% by RETScreen for the South African locations simulated, compared to a 'best case' model like SunSim. Homer's accuracy should increase if a temperature-informed PV array performance model is used, and RETScreen's if an anisotropic tilted surface diffuse model is used.

5.3.1.3 Integrating the results into the PCM approach

The conclusions above, quantifying the soft uncertainties inherent in the use of decision aiding tools like Homer and RETScreen, has already been published. An additional step is however required where these quantified uncertainties are now integrated into the decision aiding process: being noted in a research paper will not sufficiently acknowledge the impact of these uncertainties within the actual decision making process.

It is proposed that the impact of soft uncertainties related to renewable resource estimation be acknowledged by incorporating this uncertainty into the documentation structure required for the PCM approach. For example, the "Quality factors" section of this structure can make reference to a separate document entitled "Renewable energy estimation guidelines" as shown in Figure 5-7, which can include the following:

- Recommendations on which software tools to use to mitigate this uncertainty, for example RETScreen and Homer, as well as the impact of the uncertainties introduced by using these software tools.
- Details of South African weather data availability, and the impact of the uncertainties introduced by using different types of data. The document should include the main sources of weather data in South Africa (e.g. SAWS, Agromet, NASA satellites) along with details on where to find the data (contact details etc.) and maps showing the location of weather stations.
- Within this document a weather data classification system is recommended, due to the variation between the accuracy of different weather data sources. The classification framework in Table 5-3 was developed in [Bekker 2007] and acknowledges the variations in accuracy and resolution among irradiation data sources. The system identifies the accuracy and resolution of the irradiation data using accuracy grades between A and D: for example, satellite-sourced monthly average only irradiation data are classified as grade C:D using this system.

Table 5-3: Accuracy and resolution classification system for South African irradiation data. The data grade is written as accuracy: resolution, for example sunshine hour derived 5-minute interval data will be classified as B:A [Bekker 2007]

| Accuracy | Grading | Resolution |
|--|---------|---|
| Regularly calibrated ground measurement stations, pyranometer accuracy < 1%, data accuracy < 10% | A | Daily measurements, 5- or 10-minute intervals |
| Estimates from hourly sunshine hour measurements | B | Daily measurements, 1-hour intervals |
| Satellite measurements | C | Monthly average, 1-hour intervals |
| Non-calibrated pyranometers or silicon-based irradiance meters | D | Daily or monthly average only |

Even when outside consultants are responsible for the renewable resource estimation, the above guidelines will still allow the analyst to verify the accuracy and applicability of the estimation process.

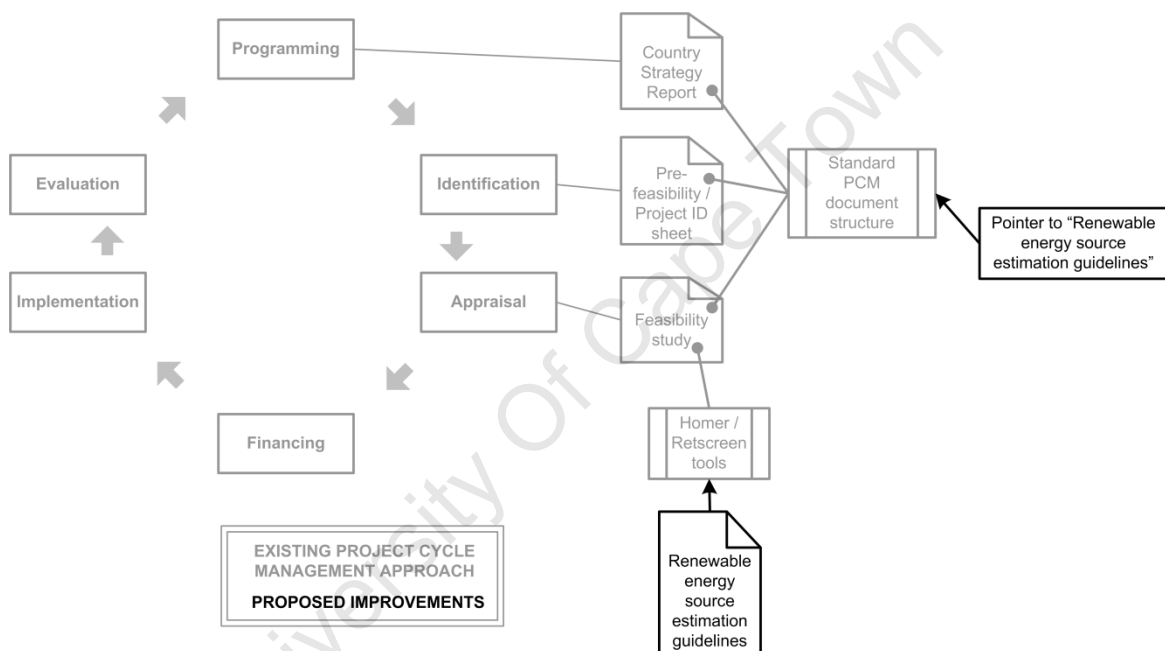


Figure 5-7: Improving the PCM approach through the integration of renewable energy source estimation guidelines.

5.3.2 Renewable energy system adequacy confidence index

In the previous section the soft uncertainties around renewable system energy output estimation were discussed using the example of a PV system. This section zooms out slightly, and looks at soft uncertainty acknowledgment within a larger sub-set of a complete power system, which includes intermittent renewable energy sources, energy storage and the system load, but still excludes the impact of dispatchable and grid energy sources, as shown in Figure 5-8.

Specifically, an *adequacy confidence index* will be presented as developed by Gaunt et al. [2009], capable of acknowledging the soft uncertainty of the adequacy of an

autonomous solar/wind installation to meet the expected load demand. The Lucingweni off-grid project, discussed in detail in Appendix B, will serve as case study.

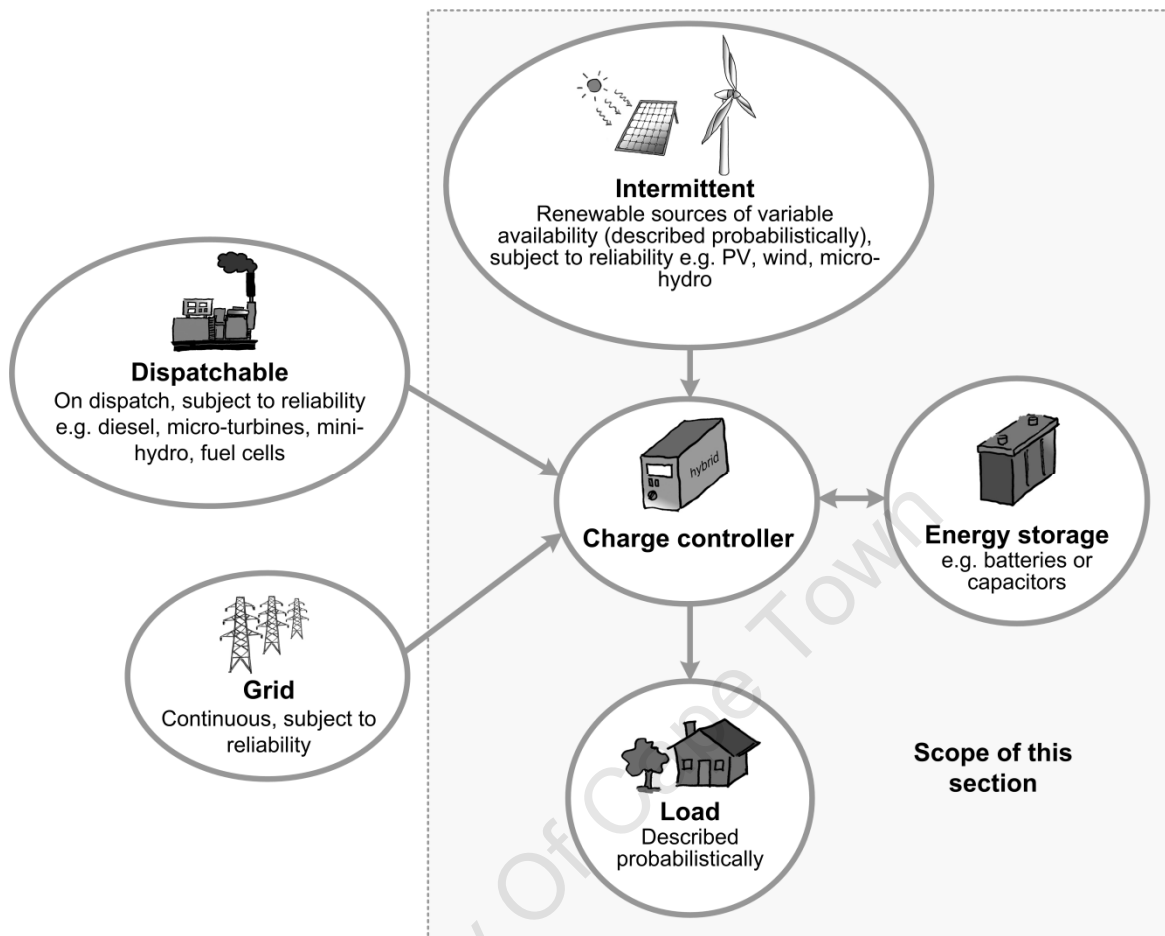


Figure 5-8: Schematic diagram of a power system with renewable energy

5.3.2.1 Development of a renewable energy system adequacy index

The process that derives the adequacy confidence index is described in the flowchart in Figure 5-9. As input it requires expected hourly values for one typical year of a) the system's wind turbine energy output, b) PV array energy output and c) load.

In the case of wind and PV this data can be generated using estimation programs like Homer, RETScreen or SunSim. In the case of load data, it was shown in [Herman and Gaunt 2008] that the Beta probability distribution is useful for modelling small groups of customer loads at any given time interval, with the shape of this Beta pdf dependant on the customer class for the specific project. When the number of customers is larger than around 30 the grouped load distribution will tend towards a Gaussian distribution.

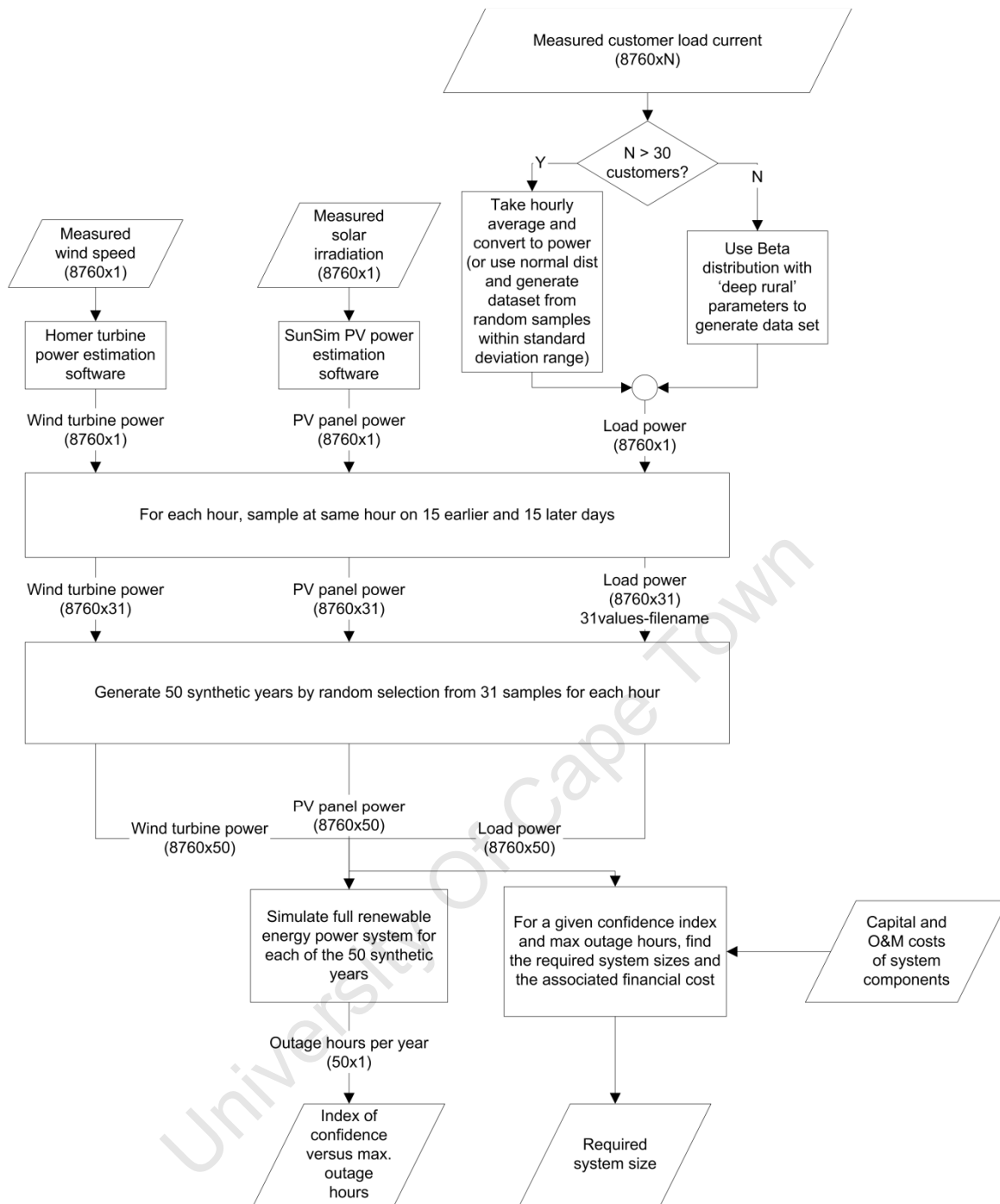


Figure 5-9: Flowchart indicating the process that leads to 1) an adequacy confidence index versus maximum outage hours graph, and 2) a system sizing for a given adequacy confidence index and maximum outage hours.

Variability over different years was then introduced by generating a set of 31 samples for each hour from the above-described one year profile, by taking the average power at the specific hour, as well as the power for the same hour on 15 preceding and 15 following days. Random selection of hourly values from these 31 samples allowed the building of numerous synthetic yearly load power data sets.

A large number of simulations of the full renewable energy power system was then run using different “years” of the synthetic load, PV and wind data sets, but keeping the

battery, PV panel and wind turbine sizes fixed. For each of these simulations the amount of hours per year was recorded during which the load could not be met by the system.

Given the large number of simulations (50 simulations were used in this research) an adequacy confidence index can be defined as to the maximum number of hours per year that the system will not be able to supply the load, as shown in Figure 5-10. For example, if in 45 of the 50 simulations the load outage hours were less than 5 hours, a statement can be made of “90% confidence that load outage will not exceed 5 hours per year”.

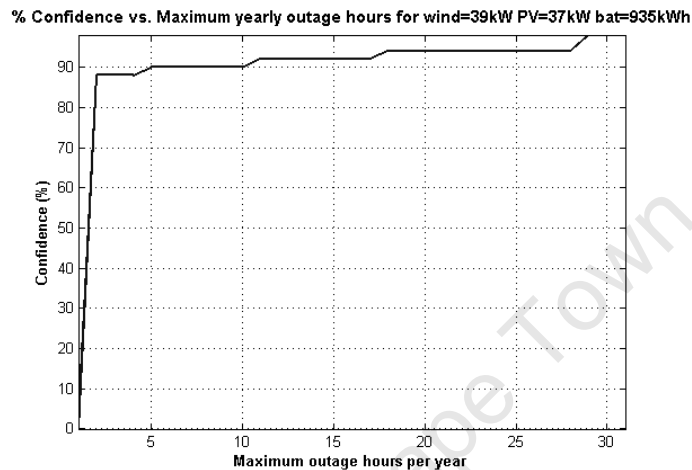


Figure 5-10: The relationship between the maximum yearly outage hours and the confidence adequacy index, for a 39kW wind, 37kW PV and 935 kWh battery power system.

5.3.2.2 The index applied to the Lucingweni project

Applying the adequacy confidence index to the Lucingweni project will illustrate the usefulness of this index, and highlight the impact of using a variable load (demand varies between hours) rather than a constant load (i.e. averaged hourly/daily load is used, calculated by dividing the total yearly load by 8760/365) during system sizing. Two scenarios will be explored:

- a constant load scenario which assumes the same daily energy requirement as the original constant-load Lucingweni design (314kWh/day), and
- a variable load scenario, for which the hourly load varies. As a model of the load, the load current profiles of 84 customers in a grid-connected deep rural village near Lucingweni for one year were used (measured as part of the Eskom load research program at 5-minute intervals [Gaunt et al. 1999]). As the number of customers were significantly larger than 30, the average of these measurements for each hour, was taken to build a single load current data set for a year (with hourly variability). This data set was then normalised to sum to the same total yearly energy requirement as the constant load scenario.

No wind speed or solar irradiation measurement data are available near the Lucingweni site. Resource data was therefore based on hourly measurement data from similar locations (Durban for irradiation and East London for wind), provided by the South African Weather Service. This data was normalised using NASA satellite-based monthly averages for the Lucingweni area.

Estimation software (Homer and SunSim) was then used to obtain the power output profile per kW_{peak} installed for one year at the Lucingweni village site. Note that the motivation of this section is mainly to introduce the concept of the adequacy confidence index; the following assumptions were therefore made in order to constrain the complexity of the simulations and the results:

- system inefficiencies and transmission losses reduced the installed power output of the wind turbines and PV array by 10%,
- energy storage losses were taken as 15%, and
- component reliability was assumed to be perfect.

The process described in Figure 5-9 was then followed to obtain a variety of wind/PV/battery size combinations that would satisfy the adequacy confidence index of “90% confidence in less than 5 hours of outage per year”. The results are shown in Figure 5-11 (a) for the constant load scenario, and Figure 5-11 (b) for the variable load scenario. Figure 5-11 (c) shows the variable load scenario for 80% confidence.

Five battery sizes were selected, from minimum (the smallest battery should at least store PV energy through each night, so one day of average load energy storage was chosen, incorporating 15% storage losses) to maximum (14 days of average load energy storage with losses).

The actual system installed at Lucingweni is indicated on Figure 5-11 (a), (b) and (c) as a black circle (the installed system size was 56kW PV, 36kW wind and 2.2 MWh energy storage, which is reduced to 50.4kW PV, 32.4kW wind and 1.87 MWh energy storage after system losses and inefficiencies were included). The position of the black circle relative to the different lines indicates that in both the constant and variable load scenarios the Lucingweni system was more than adequately sized: in the constant load scenario a battery of just less than 313kWh would have been adequate, and in the variable load scenario a battery of slightly less than 935kWh, for less than 5 hours of outage per year with 90% confidence. This provides evidence that the main problems at Lucingweni was not the size of the power system, but rather the component reliability of the system, design faults (the wind energy was not utilised due to system configuration errors) combined with social and institutional problems.

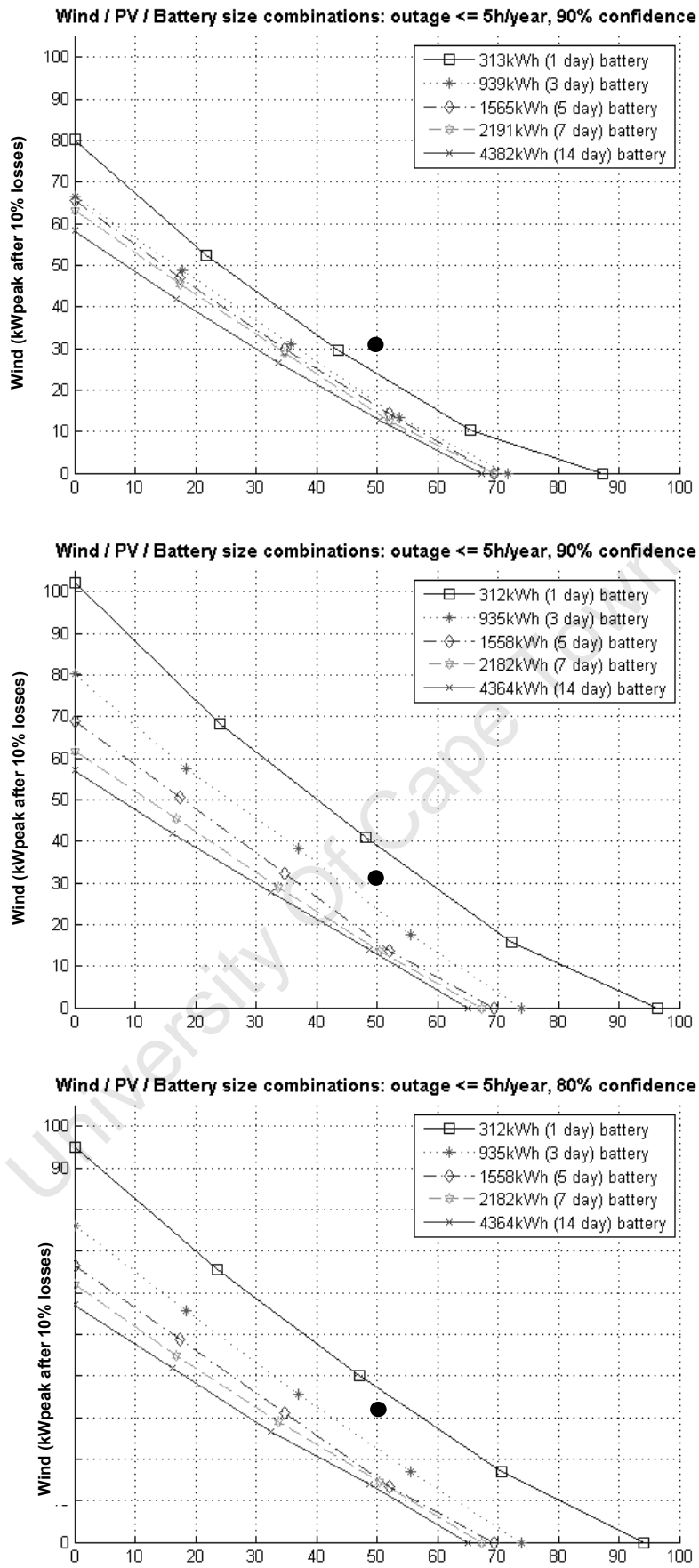


Figure 5-11 (a), (b) and (c): Combinations of PV, wind and battery capacity needed to supply a constant load (a) and two variable load scenarios (b and c) with not more than 5 hours failure to meet demand per year with a confidence index of 90% (a and b) and 80% (c). The black circle represents the Lucingweni system.

The risks of assuming constant load in power system design also becomes apparent from Figure 5-11, when the constant load scenario (a) is compared with the variable load scenario (b):

- With smaller storage a variable load requires substantially more generating capacity to achieve the same adequacy of supply as apparently required for a deterministically-modelled constant load. Or stated differently: for the same generating and limited storage capacity, the system will be inadequate for a variable load more often than expected when modelled as a constant load. The risk of assuming a constant load during system design is clear from these results.
- With very large energy storage (14-days) the variability of the load has negligible effect.

The adequacy confidence index combinations in Figure 5-11 can be used to optimise the system from a capital costs perspective, by finding the lowest cost combination, giving the same levels of adequacy performance, as shown in Figure 5-12. From this graph it is interesting to note that very limited (1 day) storage is has a capital cost premium due to the large amount of renewable generation that is required, in the same way that unlimited (14 day) storage again has a cost premium because of the cost of energy storage. The optimum lies somewhere in between these extremes, in this case at around 3-5 days storage.

Capital cost is an important decision making factor, but so is the lifecycle cost of the system over 15 or 20 years. The graph in Figure 5-12 can easily be adapted to show life cycle costs: in such a graph wind turbines will become significantly less favourable as a technology compared to PV arrays, as PV's high capital cost is offset by low maintenance cost, in contrast with wind turbines' lower capital cost and high maintenance costs.

Cost and Wind / PV / Battery size combinations: outage <= 5h/year, 90% confidence

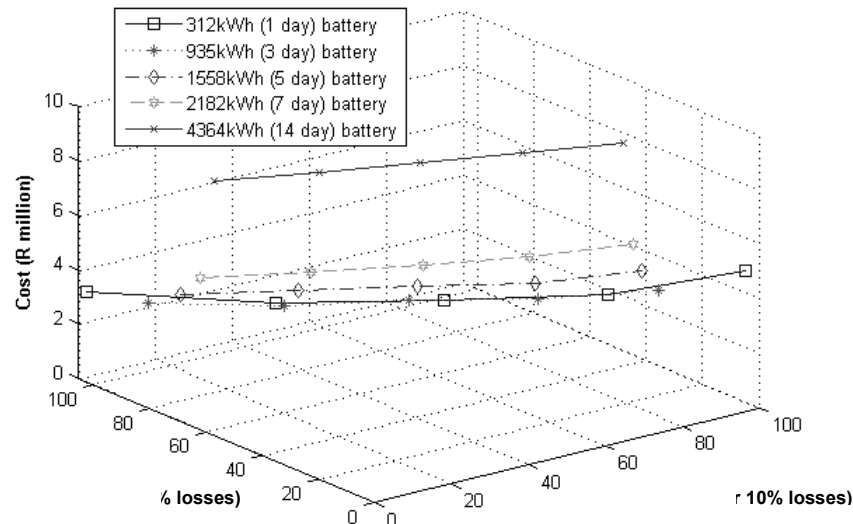


Figure 5-12: The financial optimization results (capital costs only) for the system described in Figure 5-11 (b).

5.3.2.3 Including the adequacy confidence index in the PCM approach

The adequacy confidence index described above is useful during the decision making process both to acknowledge and help quantify uncertainties around renewable energy system adequacy.

The results related to this index will be most useful within the project feasibility study, and it is therefore proposed to incorporate this index and the tool with which to calculate it within the appraisal stage of the PCM approach. This can be done in a similar manner as with the renewable resource estimation uncertainty: by pointing within the “quality factors” section of the PCM documentation structure to a separate document entitled “Renewable energy system sizing guidelines” as shown in Figure 5-13, which details the following:

- Guidelines on the impact of using probabilistic (variable), rather than deterministic (constant) load estimates, along with details on where to find historic load data for different customer classes.
- Guidelines on how to calculate the adequacy confidence index.
- The minimum system adequacy confidence indices required for different customer classes (e.g. purely social electrification might have a lower confidence index minimum requirement than economic electrification¹⁹).

¹⁹ For a more detailed study of social versus economic electrification, refer to Gaunt [2003]

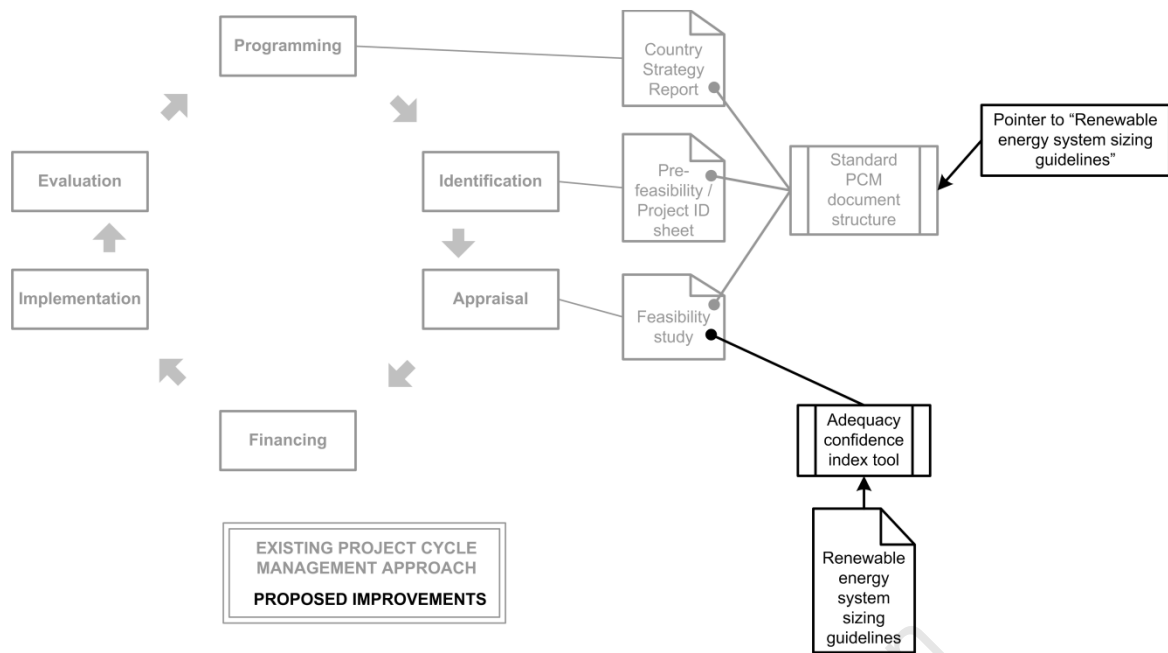


Figure 5-13: Proposed improvement of the PCM approach through renewable energy system sizing guidelines.

5.4 Improving hard uncertainty acknowledgment

This section proposes the use of a degree of surprise tool to acknowledge hard uncertainties within the decision making process.

5.4.1 The degree of surprise tool

Young [2001] concluded from his critique of popular approaches for dealing with uncertainty in decision making that an alternative approach was needed that would deal explicitly with hard uncertainty. For this he proposed an application of the Shackle model, which will inform the development of the “degree of surprise” tool.

5.4.1.1 Shackle’s model

The Shackle model, published in the 1940s, steps entirely outside the expected utility and probability frameworks, and offers a solution to the problem of modelling hard uncertainty, especially where actions are unique. This is possible because Shackle’s model replaces probability as a measure of uncertainty with the measure of the degree of surprise, which is a measure of the decision maker’s surprise at a certain hypothetical future outcome actually occurring.

In the first stage of the model, the analyst generates as full a range as possible of desired and undesired project outcomes of a certain action, ordered from highly

undesired to highly desired, along an arbitrarily chosen -5 to 5 scale. Typically five desired and five undesired outcomes are specified per action. In illustration, a highly undesired and a slightly desired outcome are given below.

Highly undesired outcome A: *A lack of maintenance leads to renewable energy system failure and associated discontent amongst the community – ultimately the system is vandalised to such an extent that major investment is required for repairs.*

Slightly desired outcome F: *The number of injuries caused by fire within the community is somewhat lower than before electrification. The cost of energy per household has fallen slightly.*

In the second stage, every decision maker is interviewed and asked to specify their potential surprises associated with the ten outcomes (A to J) created by the analyst in the previous stage, on an arbitrary scale from 0 (low) to 10 (high). Figure 5-14 shows a typical potential surprise function that might be specified by a decision maker. The highly undesired outcome A described above, for example, is valued at a potential surprise of 8, i.e. the decision maker will be highly surprised if this outcome occurs.

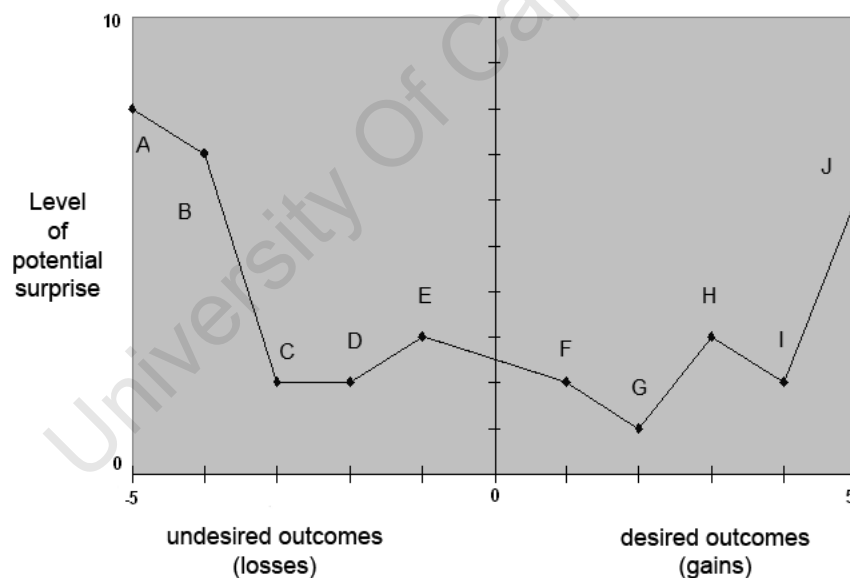


Figure 5-14: A typical potential surprise function, with the alphabetical numbers representing the different outcomes generated by the analyst.

In the third stage, the outcomes / potential surprise pairs (x,y) are weighted using a suitable ascendancy function $\Phi(x,y)$. This ascendancy function is found by selecting from a set of functional forms the form most consistent with the weightings given by the decision makers in response to weighting-orientated questions. The function has the property that its partial derivative is positive with respect to the outcome x and negative with respect to the degree of surprise y. The result of the ascendancy function therefore

focuses the attention of the individual on the outcome with the highest desirability / undesirability where the degree of surprise is not high enough to decrease the weighting of the outcome significantly. The results of applying one of the ascendancy functions defined by Shackle, $\Phi = ax - by^2$, to the potential surprise function found in stage two is shown in Figure 5-15.

The focus gain outcome is represented by outcome I, and the focus loss outcome by outcome C, and represent the best to be hoped for and the worst to be feared outcomes in the project considered, and can be used to focus the attention of the decision-making process on where measures are required to reduce the impacts of hard uncertainties.

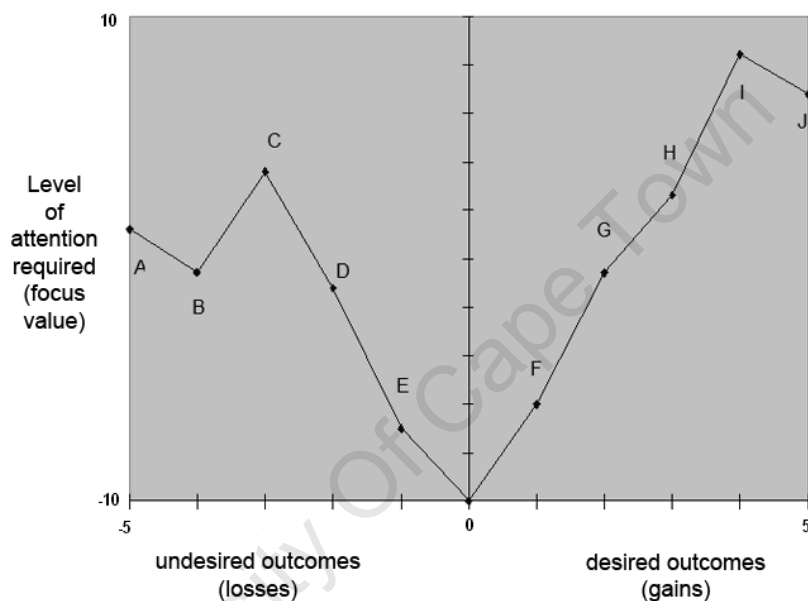


Figure 5-15: A typical ascendancy function, with the alphabetical numbers representing the different outcomes generated by the analyst.

The fourth and final part of Shackle’s model uses the so-called gambler’s preference map to standardize the focus values found within the set of outcomes among different actions, in order to be able to accurately compare the different actions.

5.4.1.2 Advantages of the Shackle model

Shackle’s model as presented above offers a number of advantages when working with hard uncertainty:

- the notion of potential surprise is applicable to unique events, unlike probability,
- potential surprise is defined as non-distributional, allowing an incomplete list of outcomes,
- potential surprise is non-additive and is not constrained to add up to unity, and

- as both the potential surprise and ascendancy functions are separated in desired and undesired outcomes, the decision-maker is allowed to consider uncertainty aversion to gains and losses separately.

5.4.1.3 Young's application of Shackle's model

In the application of the Shackle model as proposed by Young, the fourth part of the model, used to standardize the focus values in order to allow comparison between different actions, each with its own Shackle model and resulting focus values, is dispensed with.

The reason for this is twofold: first the model proposed by Young is focused on the procedural rationality of the decision making process, and as such does not attempt to explain choices between actions. Secondly, by restricting the application of Shackle's model to finding potential surprise and ascendancy functions, and focus gain and loss elements, the problem of stochastic dominance is also sidestepped. This problem occurs in the Shackle model when an action A stochastically dominates an action B, yet the same focus gain value is found for both.

5.4.1.4 Development of the degree of surprise tool

The application of the Shackle model to acknowledge hard uncertainties will never require comparison between different actions, and therefore the fourth stage of Shackle's model will also be dispensed with for the purposes of this research.

An additional requirement is added to Young's application of Shackle's model to ensure better alignment with a multiple criteria context: only qualitative valuations of the desirability / undesirability of each outcome will be presented to the decision maker (e.g. slightly or highly). This ensures that the decision maker is not biased by quantitative valuations of outcomes that are necessarily based on subjective equivalence rates.

Lastly, Young's application of the Shackle model is simplified by dispensing with the requirement that the chosen outcomes be arranged from very undesirable to very desirable by the analyst, ensuring ease of application as explored in section 2.2.6.

The proposed degree of surprise tool was developed in MATLAB, informed by the above theory (also refer to Bekker and Gaunt [2006]). It will now be briefly described:

In stage one the decision maker is presented with an interface as shown in Figure 5-16. This interface shows the decision maker a selection of project outcomes that are directly linked to project hard uncertainties. The analyst has generated these outcomes from a

literature review / project evaluations similar to the process followed in the preceding chapters, and uploaded these outcomes into the tool from a text file. The decision maker is required to rate the impact of these outcomes on the success of the project.

The responses in Figure 5-16 acts as an example of what a decision maker might have answered with reference to a fictional off-grid project: for example this decision maker decided that grid encroachment and maintenance deterioration would have a highly negative impact on the project's success. This stage is equivalent to stage one of the Shackle model.

Q1: What will the impact of each of the following outcomes be on the success of the project?

| | |
|---------------------------------|-----------------------|
| Grid encroachment | <input type="range"/> |
| Low customer uptake | <input type="range"/> |
| Customer unwilling to pay | <input type="range"/> |
| Theft and vandalism | <input type="range"/> |
| Maintenance deterioration | <input type="range"/> |
| Lack of institutional ownership | <input type="range"/> |
| Customer inertia to change | <input type="range"/> |
| Subsidy instability | <input type="range"/> |
| Non-acceptance of technology | <input type="range"/> |
| Customer inability to pay | <input type="range"/> |

*Neutral/
no impact* *Slightly
negative
impact* *Highly
negative
impact*

NEXT

Figure 5-16: The first stage of the degree of surprise tool

In stage two of the degree of surprise tool, the decision maker is asked to rate the same outcomes as to the degree of surprise that the decision maker would feel at these outcomes becoming a reality, on a scale ranging from not at all surprised to very surprised.

In the example in Figure 5-17 the decision maker indicated that he/she would not at all be surprised if grid encroachment occurred in the project, but would be reasonable surprised if the maintenance deteriorated in future. This stage is the equivalent of stage 2 of the Shackle model.

During the final stage of the degree of surprise tool, the answers from the decision maker is displayed as shown in Figure 5-18: the uncertainties associated with the outcomes in the darker bottom right corner of the graph requires additional focus.

How surprised would you be if these outcomes occurred?

| | |
|---------------------------------|----------------------|
| Grid encroachment | <input type="text"/> |
| Low customer uptake | <input type="text"/> |
| Customer unwilling to pay | <input type="text"/> |
| Theft and vandalism | <input type="text"/> |
| Maintenance deterioration | <input type="text"/> |
| Lack of institutional ownership | <input type="text"/> |
| Customer inertia to change | <input type="text"/> |
| Subsidy instability | <input type="text"/> |
| Non-acceptance of technology | <input type="text"/> |
| Customer inability to pay | <input type="text"/> |

Not at all surprised
Very surprised

Figure 5-17: The second stage of the degree of surprise tool

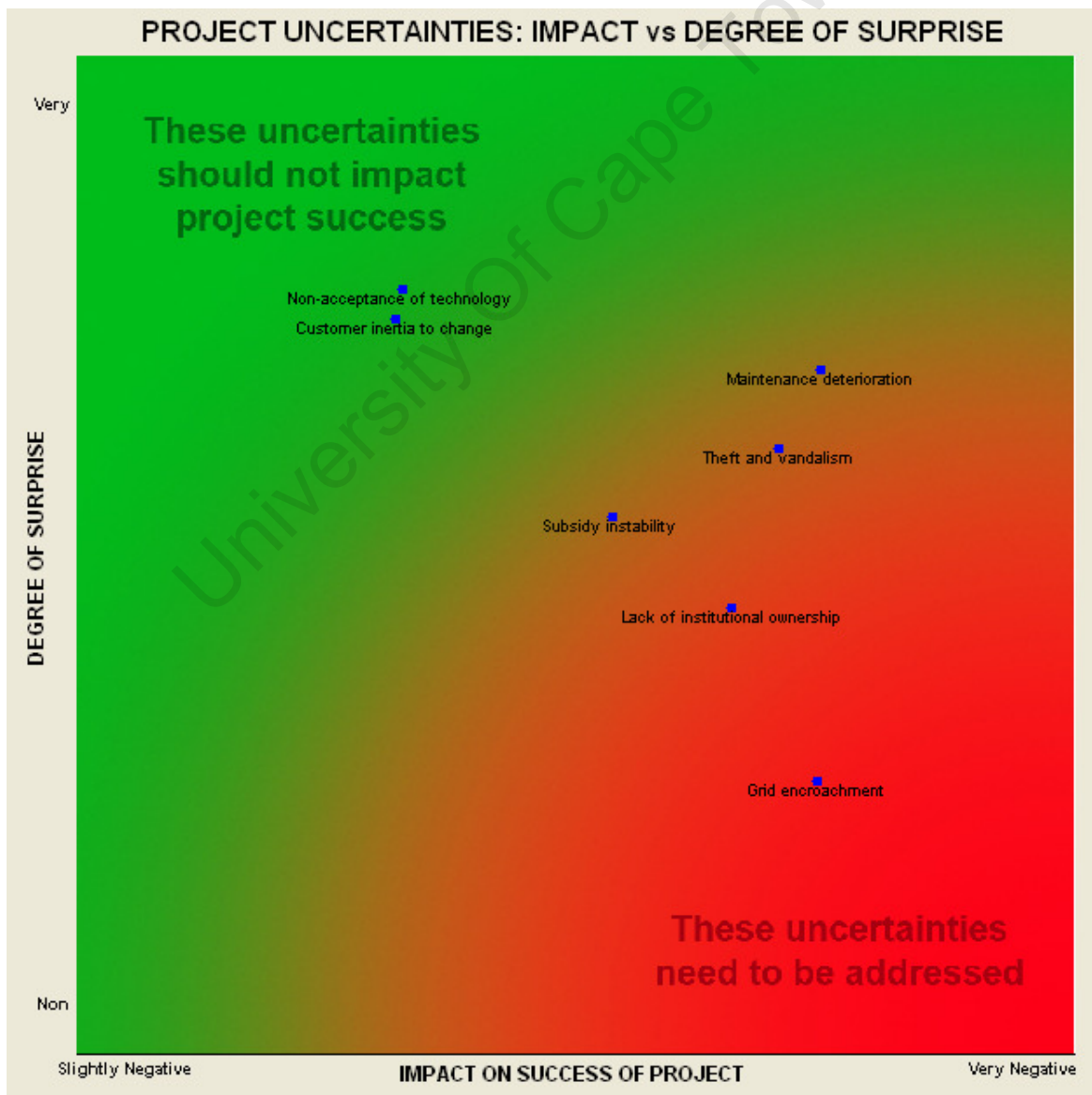


Figure 5-18: The results screen of the degree of surprise tool

The way in which the results are displayed, with the impact of the outcome on the x axis and the degree of surprise on the y axis, makes an ascendancy function redundant. This is in alignment with the constructive philosophy of decision aiding (section 4.3.1.3), with the tool avoiding combining / quantifying decision data wherever possible for increased transparency in the decision process.

From Figure 5-18 it is clear that even though the impacts of grid encroachment and maintenance deterioration were rated similarly by the decision maker, the higher degree of surprise at maintenance deteriorating than grid encroachment meant that more attention would be focussed on the uncertainties around grid encroachment.

5.4.1.5 Integrating the degree of surprise tool into the PCM approach

The degree of surprise tool described above can be useful during programme definition (to make decision makers aware of the hard uncertainties inherent in the programme), the early stages of project decision making and also during the final stages of appraisal (to verify that the uncertainties have been adequately acknowledged, and if not, to re-design the process).

It is therefore proposed that the tool be used in preparing the Country Strategy Report, and twice during the Feasibility Study: at the start to gain an understanding of the decision makers' perceptions around the hard uncertainties present in the project, and towards the end to ensure that, in the decision makers' minds, the identified focus uncertainties have been acknowledged by the decision process, without being replaced by new focus uncertainties.

To ensure that the tool is used, a section with the "Quality factors" section of the PCM document structure can point towards it, requiring its use as shown in Figure 5-19, and documenting the results of its applications.

The degree of surprise tool will be most effective if the programme and project hard uncertainties listed in it are placed within the context of completed off-grid electrification projects, and the lessons learned from them. Take the "grid encroachment" uncertainty / outcome as an example: a decision maker that is not familiar with the off-grid electrification context might have difficulty in understanding why grid encroachment can potentially have a negative impact on the project. If, however, the decision maker is fully informed about historic projects and the impact that grid encroachment had on these, a much better assessment of the impact and degree of surprise will result.

For this reason it is further proposed that "Lessons learned from completed off-grid electrification projects" information be supplied with the degree of surprise tool, for

example summarised from the project evaluations done in Appendix B. This information can either be in the form of a document given to each decision maker as background, or can form part of an information session leading up to the use of the degree of surprise tool. Evaluation of completed projects within the same programme will inform continuous updating of the “lessons learned” information.

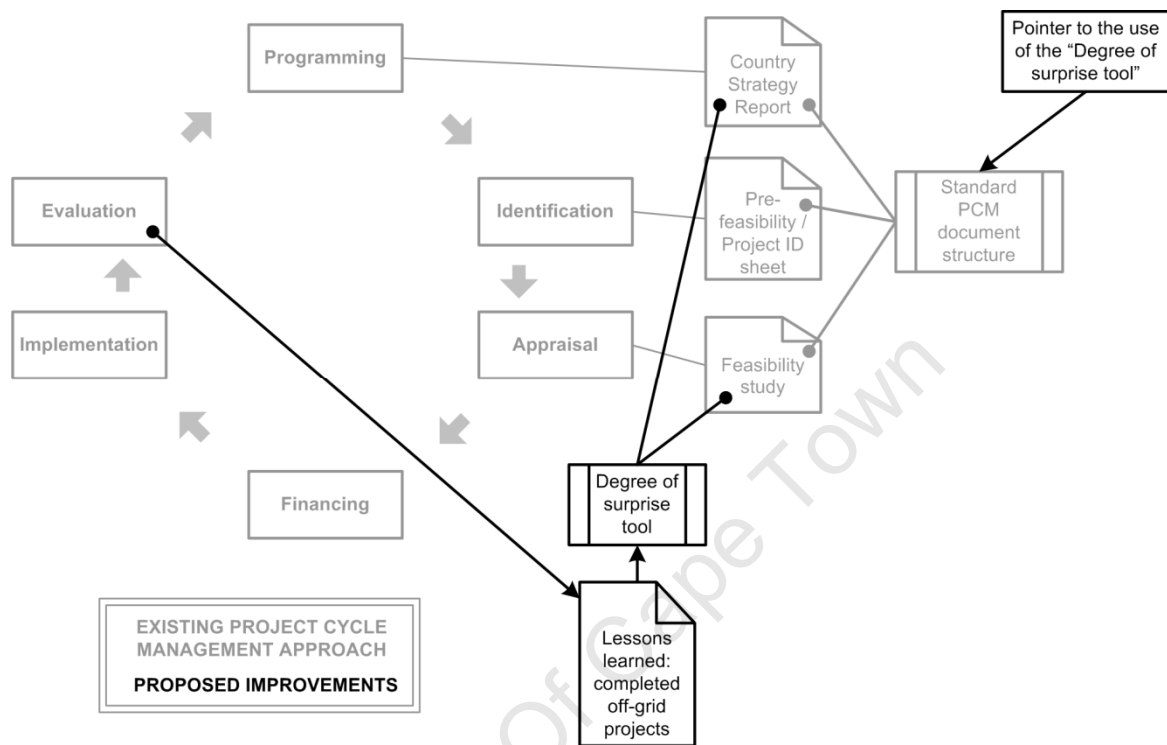


Figure 5-19: Proposed improvements to the PCM approach through the use of the “degree of surprise” tool and “Lessons learned” information

5.5 The impact of improved decision aiding

This section will now briefly revisit two projects, the completed Lucingweni mini-grid project and the DME’s SHS concession programme, with the aim of demonstrating how using the PCM / LFA decision aiding approach and the proposed improvements might have positively impacted on the sustainable development contribution of these projects, were they used.

From the six South African off-grid projects that were evaluated in Appendix B, Lucingweni and the concession programme were chosen to demonstrate the impact of improved decision aiding based on the following:

- The technology implemented at Lucingweni and through the concession programme respectively represents the two main off-grid options currently considered in South Africa: hybrid mini-grids and SHSs.

- Although Lucingweni was ultimately supposed to be one of many similar projects within a bigger programme, in many ways it was implemented as a stand-alone electrification project. In comparison, the concession programme represents a programme within which a number of projects were undertaken.
- In both projects a wide range of causes, across technical, social and institutional dimensions, lead to their ultimate failures.

5.5.1 Improved decision aiding applied to Lucingweni

As background to the following discussion a cause and effect diagram of Lucingweni's problems is reproduced in Figure 5-20, from appendix B.

5.5.1.1 The impact of using a decision aiding approach

No formal decision aiding approach could be identified by this research as having been applied during the pre-implementation stages of the Lucingweni project. The use of such a formal high quality decision aiding approach, for now ignoring any of the proposed improvements regarding uncertainty acknowledgement or objectives alignment, might potentially have avoided at least four problems:

- The fact that electricity was supplied before a revenue collection system could be implemented (block 13 in Figure 5-20) appears to have its roots in a disagreement between the NER and Shell Solar on whether a community centre was agreed to as part of Shell Solar's implementation contract. The NER withheld payment to Shell Solar, and the resulting delays, combined with likely political pressure to complete the project, led to premature system activation without a revenue collection system in place, and the resulting problems described in Figure 5-20 and Appendix B.

If a high quality decision aiding process was followed, a clear audit trail should have existed of all the decisions made during the identification and appraisal stages: such an audit trail might have offered the necessary evidence to resolve any disagreements between stakeholders during implementation.

- One of the primary causes of the theft and vandalism that finally disabled the Lucingweni project was a lack of community ownership of the renewable energy system (1), which was originally caused by limited community interaction (2) and a lack of continued awareness building (3) within the community of the benefits of the system.

The stakeholder participation mechanisms inherent in high quality decision aiding approaches might have avoided these community interaction problems, and instilled an increased sense of ownership of the system in the community.

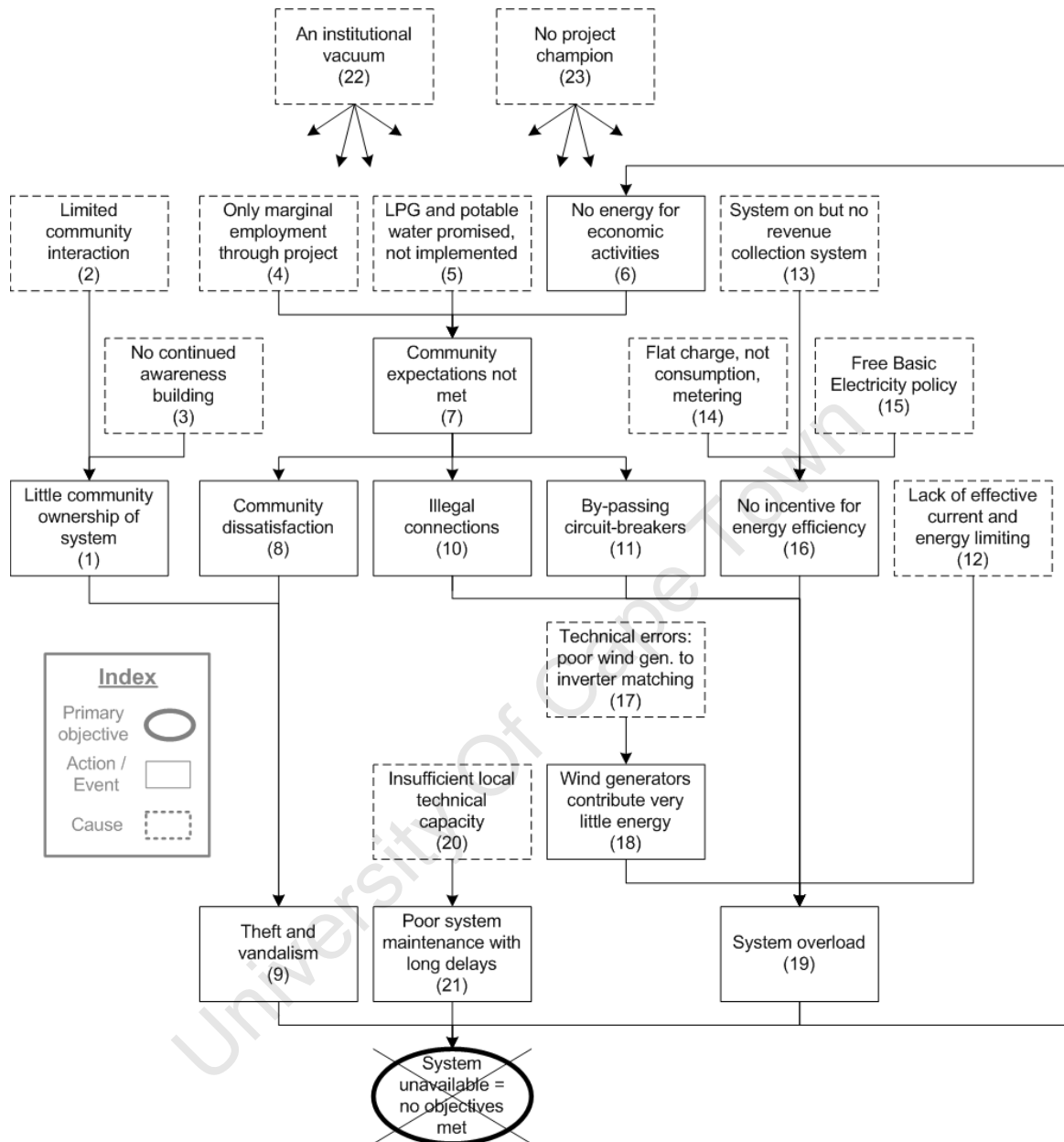


Figure 5-20: Factors identified in literature that prevented the Lucingweni project from meeting certain primary energisation objectives (reproduced from Appendix B).

- Energisation rather than electrification was originally an objective of the project, apparent through the original promises to the community of LPG-based thermal services. The fact that these services were never implemented (5) point to a failure of the decision making process to carry the original project objectives through to implementation. A high quality decision aiding process might have helped structure the project in such a way that these objectives were kept visible throughout the decision making and implementation process.

- If the PCM approach was followed from the start during the Lucingweni project, more importance might have been extended towards structuring the programming stage of the decision process. Although the Lucingweni project was a demonstration project meant to inform a wider roll-out of mini-grid systems in South Africa, it appears from literature that the programme never extended to include a full off-grid energisation action, which included SHSs, mini-grids, grid electrification and other energy sources like LPG etc.

Had such a programme focus been applied, Lucingweni would have been one of the many projects within this programme. Such a programme rather than project focus, might have prevented the institutional vacuum (22) and no project champion (23) problems.

The fact that Lucingweni was implemented as a demonstration project does not change the potential benefit of approaching the project from within a programmatic context: the programme in this case could also have been in “demonstration” phase.

5.5.1.2 The impact of objectives alignment

From literature it is apparent that the primary project objective for Lucingweni was to gain the experience required to inform a wider rollout of mini-grid systems in South Africa. It can be argued that the project actually succeeded in this primary objective: possibly as many lessons can be learned from a failed project as from a successful one. A failed project however does not satisfy any sustainable development objectives.

If a high quality decision aiding approach was used, with the proposed objectives alignment improvements, greater focus might have been placed within the decision making process on sustainable development goals. This focus would have been introduced from the programming stage onwards, possibly resulting in greater attention to objectives in for example the economic dimension mitigating problems like marginal community employment opportunities from the project (4), and the social dimension through actually providing LPG and potable water during implementation, rather than just promising to do so (5).

5.5.1.3 The impact of soft uncertainty acknowledgement

The power system at Lucingweni appeared to be more than adequately sized (for both the constant and variable load scenarios) based on the estimated load of 314kWh/day, as indicated by the adequacy confidence index calculations done in section 5.3.2.2. System inadequacy rather appeared to be caused by a number of hard uncertainties. This disagrees with some statements in literature, for example in the DME’s evaluation of

the Lucingweni project [DME 2007b:p39], where inaccuracies in resource estimation are partly blamed by energy inadequacy.

The use of soft uncertainty acknowledgment tools like the adequacy confidence index, along with the proposed system sizing and renewable resource estimation guidelines, might have increased the accuracy of the alignment between estimated load, system size and minimum cost, potentially resulting in a smaller and less costly system.

Another area where soft uncertainties might have impacted the project was in energy provision for additional economic activities within the community (6): this need was not actually quantified, but was rather assumed to come from whatever excess energy remained after the estimated load has been serviced. The importance of including all potential system loads in the initial load estimate would have been stated in the proposed system sizing guidelines.

5.5.1.4 The impact of hard uncertainty acknowledgement

In applying the degree of surprise tool retrospectively to the two selected projects, almost ten additional years of hindsight and lessons learned are available to the analyst from which to generate a set of outcomes. Insight from these additional ten years were not available when these projects were originally planned, therefore a number of outcomes which in hindsight seems obvious might have been “missed” by the analyst.

By the time Lucingweni was planned some SHS projects like KwaBhaza and Maphephethe have already been implemented, so the lessons learned from these projects would have been available as uncertainty outcomes. If the degree of surprise tool was populated with outcomes based on the experiences in these projects, the following possible effects might have resulted:

- The Lucingweni project never reached a stage where grid encroachment would have impacted the project negatively, due to the early failure of the mini-grid system. However, the fact that it was within 20km of the grid, and that no thermal services (for cooking, space heating etc) were provided, could easily have led to future community dissatisfaction about the “inferior” energy provision compared to nearby grid-electrified villages.

Awareness of this dissatisfaction, through a “grid encroachment leads to community dissatisfaction” outcome might have motivated decision makers to pay more attention to the overall energisation programme of which the Lucingweni project formed a part.

- Acknowledging the “Customers unwilling to pay” hard uncertainty, after being informed of the impacts of this uncertainty through the “Lessons learned” information, might have alerted decision makers to the risks of connecting electricity without having revenue collection mechanisms in place, in effect offering free electricity to customers initially and then expecting payment later on.
- The “insufficient energy or power” outcome in the degree of surprise tool, informed by the supporting “lessons learned” information, might have alerted decision makers to the impact of at least some of the factors which would impact energy sufficiency, possibly including factors that caused problems at Lucingweni: lack of effective current and energy limiting (12), lack of incentives for energy efficiency (16), illegal connections (10) and bypassing of circuit breakers (11). These problems could have been avoided through interventions like prepaid meters, instilling a sense of ownership among the community etc., but first had to be acknowledged.
- Acknowledgement of an outcome which highlighted technical design/configuration errors / component failure might have focussed attention on, for example, including commissioning procedures in the tender documentation, requiring full system testing before connecting customers. This might have highlighted the poor wind generator to inverter matching (17).

5.5.2 Improved decision aiding applied to the concession programme

As background to the following discussion a cause and effect diagram of the SHS concession programme’s problems is reproduced in Figure 5-21, from appendix B.

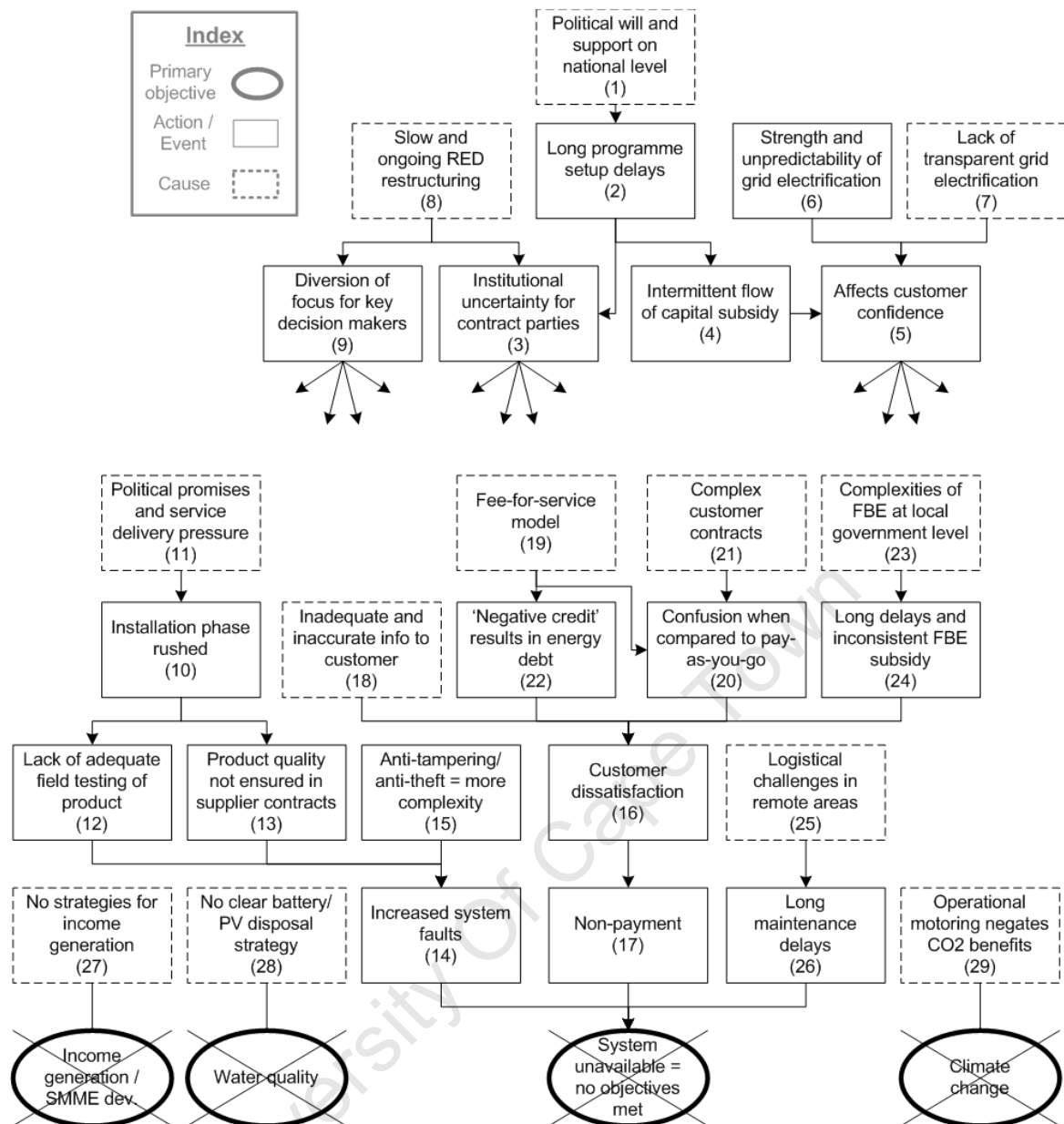


Figure 5-21: Factors identified in literature that prevented the SHS concession programme from meeting certain primary energisation objectives (reproduced from Appendix B).

5.5.2.1 The impact of using a decision aiding approach

The project evaluation in Appendix B could identify no formal decision aiding approach as having been applied within the decision making of the concession programme. Had a high quality approach been applied, without any improved uncertainty acknowledgment or objectives alignment, two characteristics would have been especially of value: an iterative nature within the decision process, and increased stakeholder interaction:

- Lessons learned from early projects within the concession programme (for example the Eskom/Shell joint venture which started installing SHSs in March 1999) might have been incorporated into later projects (the later four consortia only started installing from December 2001) much quicker had formal project monitoring and

feedback systems been pro-actively put in place on a programmatic level. A high quality decision aiding approach would have encouraged the use of such iterative systems, per definition. The ERC [2004] reports that a platform was later established (reactively) among the consortia within which to exchange information, experience and know-how.

Lessons learned early in the programme, and applied to later implementations, might have avoided several operational problems including inaccurate information dissemination (18), problems with the fee-for-service model (19 and 22), complex customer contracts (21), and SHS reliability concerns (12,13 and 15).

- It is likely that increased stakeholder interaction (a characteristic of a high quality decision aiding process) with target communities would have highlighted potential problems before they occurred. So, for example, community expectations around grid electrification might have become apparent through this interaction, highlighting the need to manage the risks to SHS customer confidence (5) from unpredictable and non-transparent grid electrification within the concession areas.

Mitigation could have taken the form of contracts guaranteeing no grid expansion within certain concession areas for the medium term (rather than the agreement that was actually put in place in some areas: specifying the financial compensation to the consortia for each SHS made redundant by grid electrification).

5.5.2.2 The impact of objectives alignment

The stated primary objective of the concession programme was to roll out 50 000 SHSs per consortia within the 5 year period for which the concession was held. The poor performance of the programme, indicated in Table 1-2 with less than 40 000 SHSs installed in total, and no further progress after almost six years, is a clear indicator that the programme has failed to achieve its primary objective.

Even if the programme's targets have been met, a number of the objectives within the energisation framework might still not have been achieved, for example the objectives related to income generation (27), battery and PV disposal (28), and contribution to CO2 reduction (29).

If a high quality decision aiding approach was used, with the proposed objectives alignment improvements, greater focus might have been placed within the decision making process on sustainable development goals within the context of energisation, rather than just connection targets. This focus would have been introduced from the programming stage onwards, possibly resulting in a greater attention to objectives in for example the economic and environmental dimensions, avoiding problems like (27-29).

At this point it is important to acknowledge the influence of political objectives: in South Africa the area of service delivery (which includes electrification) is a central concern during elections. Politicians are often the ultimate decision makers in government-sponsored electrification programmes like the concession programme, which means that these projects are potentially the focus of political objectives. So, for example, connection targets (which are easily measured) might serve a more powerful political purpose than sustainable development targets (which are complex to calculate and can take many years to measure), even though the later would better reflect the success of the programme. Another illustration of the interference of political objectives is cause number 11, where political pressure led to a rushed installation phase (10) and a number of problems (12,13).

The use of a high quality decision aiding tool, which includes objectives alignment, will not be capable of overriding possible non-aligned political programme objectives in a scenario where the decision makers have the ultimate say in the process. It will however ensure that this non-alignment is transparent within the decision process and audit trail.

Only in the case where political interference blocks the use of a high quality decision aiding approach during decision making, specifically to avoid the transparency associated with such an approach, will the approach be powerless to impact the quality of the ultimate decision.

5.5.2.3 The impact of uncertainty acknowledgement

Literature did not report significant impacts from unacknowledged soft uncertainties within the concession programme. A large set of problem causes can however be grouped under impacts of hard uncertainty non-acknowledgement.

As discussed with the retrospective application of the degree of surprise tool at Lucingweni, at the start of the expanded concession programme in 1999 the current large base of South African off-grid project experience would not have been available from which to select outcomes.

Experience gained from for example the earlier Eskom-Shell concession, as well as from international projects, could still have been used to identify hard uncertainties for inclusion as outcomes in the degree of surprise tool. Early acknowledgement of these hard uncertainties might have avoided some of the problems within the concession programme, for example:

- The hard uncertainty of implementation agency non-committal, caused in the case of the concession programme partly by the slow and ongoing RED restructuring (8),

might have been acknowledged early in the process had the degree of surprise tool been used. The outcomes used in the tool might have been informed by international experiences of centralised institutional implementation problems like listed by Mason (1990) as reported in Zomers [2001:p153] with outcomes like “Long setup delays”, or by what Zilberman [1999] calls “Government’s dynamic inconsistency”.

Mitigation of the impacts of this uncertainty would have been more challenging: decisions made within a wider process, over which the decision makers had little control, would significantly impact the commitment of the implementation agency. However, as in the case of political objectives influencing objective alignment, in this case an acknowledgment of the uncertainty would at the least have created awareness about it in the decision process, opening the way to potential mitigation.

- The intermittent flow of capital subsidy to the consortia (4) played a large role in the ultimate failure of the concession programme as, according to Niemand and Banks [2006:p15], this was the main limiting factor to higher installation numbers: “*NuRa can quite easily reach installation targets of 3000 to 4000 installations per month...*”

The long delays and inconsistent FBE subsidies (24) also directly impacted customer satisfaction and ultimately non-payment.

A study of pre-1999 international off-grid projects might have informed a “subsidy inconsistency” outcome within the degree of surprise tool – Pokharel [2003] for example reports that such problems occurred in Nepal. The uncertainty could then be mitigated, for example by requiring/planning for stronger commitment from national government on the availability of adequate capital subsidies for a defined period through medium term budget provisions, and contractual guarantees for the consortia regarding the timely availability of these subsidies.

The uncertainty regarding FBE subsidies would have been challenging to mitigate, given that it is implemented differently among the different responsible local governments. Pre-rollout agreements with all the local governments regarding FBE might have ensured consistent application of the FBE subsidy (Banks [2007:p118] however comments on the complexities of this process), or a restructuring of the FBE policy where national government makes the FBE subsidy available directly to the consortia in charge of revenue collection.

5.5.3 The third part of the hypothesis tested

The preceding application of an improved decision aiding approach to two representative off-grid case studies identified the following:

- In both cases convincing evidence was found that the proposed decision aiding would have increased the impact of the case studies on sustainable development, were it applied originally.
- The proposed approach would be of no value in a scenario where decision aiding was actively excluded from the decision process, due to decision makers wanting to avoid a transparent process and audit trail.
- The analyst plays a crucial role during hard uncertainty acknowledgement, as he/she needs to identify from literature and experience a limited set of hard uncertainties for inclusion in the degree of surprise tool.

Enough evidence exists to confirm the validity of the third and final part of the research hypothesis:

Applying existing high quality decision aiding tools and approaches, with improved uncertainty acknowledgment and objectives alignment capabilities, to off-grid projects will increase such projects' impact on sustainable development.

5.6 In summary

This chapter set out to answer three research questions in order to test the third and final part of the research hypothesis. The following answers were found to these questions:

- *What decision aiding tools and approaches currently exist that will support high quality decision making to a large extent within the context of South African off-grid electrification projects?*

The Homer and RETScreen renewable resource estimation tools, and the approach followed by the EC's PCM and LFA were shown to support high quality decision making to a large extent. These tools were therefore selected as demonstration tools on which to base the remainder of the research.

- *How can the uncertainty acknowledgment and objectives alignment capabilities of these existing tools and approaches be improved?*

The chapter proposed improvements in three areas: objectives alignment, and soft and hard uncertainty acknowledgement.

For objectives alignment it was proposed to include a list of primary energisation sustainable development objectives in the document structure of the PCM approach, with the use of these objectives verified through “Quality Criteria” questions.

For soft uncertainty acknowledgement a renewable energy system adequacy confidence index was proposed and the accuracy of the Homer and RETScreen tools was quantified for South African climatic conditions and different weather data grades. Guidelines were also proposed for inclusion into the PCM process, on system sizing and the applicability and accuracy of renewable energy resource estimation.

For hard uncertainty acknowledgement the degree of surprise tool was proposed, supported by information sharing mechanisms on lessons learned from completed off-grid electrification projects.

- *Would these improved decision aiding tools and approaches, if applied originally, have increased selected South African case study projects' impact on sustainable development?*

Yes, the results of the retrospective application of improved decision aiding to two representative off-grid case studies confirmed that a large percentage of the problems that led to the failure of these projects might have been avoided by applying a high quality decision aiding process with the proposed improvements.

The answers to these three research questions offer sufficient support to conclude that the third part of the research hypothesis is valid. The full hypothesis of this research has now been tested.

6 Conclusions

The fundamental hypothesis that this research sets out to test relates to the crucial roles that objectives and uncertainties, especially those that were not identified early in the planning process, play in the failure of South African off-grid electrification projects to achieve sustainable development goals.

Motivated by this hypothesis, the research showed the usefulness of a structured, formal decision aiding process within which decision makers are guided to consider factors (objectives, uncertainties, outcomes) that could easily have been missed, with serious negative impacts on the project's success.

The testing of this hypothesis contributed to both an improved understanding of the factors that lead to off-grid project failure and to suggestions on how decision-aiding can guide future off-grid projects towards achieving sustainable development objectives.

6.1 An improved understanding of factors that lead to failure

The first part of the research hypothesis investigated the correlation between unacknowledged uncertainties and failed off-grid electrification projects in South Africa. Testing this hypothesis developed an understanding of what actually defines a successful off-grid project (sustainable development objectives are met) and how to measure whether a project succeeded or failed (through evaluation against the proposed energisation framework). The development of the energisation framework, and its application in the evaluation of a selection of off-grid projects, lead to the following main conclusions:

- Off-grid electrification should ideally be approached as part of a wider energisation programme. In this programme grid and off-grid electrification, and other forms of energy supply like LPG, should all be considered within the same programmatic structure informed by sustainable development objectives. Doing this offers many potential benefits, like minimising grid encroachment uncertainties, managing

community expectations, and increasing institutional project ownership. This conclusion is confirmed by a number of sources in literature, for example Banks [2007] and Scholle and Afrane-Okese [2007].

- Unacknowledged uncertainties indeed do correlate strongly to failed electrification projects. This is a new perspective on off-grid project failure: instead of focussing on the direct causes of project failure, like lack of maintenance or inadequate energy supply, this perspective steps back and ask the question why these direct causes occurred at all? Such a perspective allows potential causes of failure to be mitigated early in the project cycle, and also allows a wider net to be cast to catch these causes, especially once different conceptualisations of uncertainty are included.

The second part of the hypothesis investigated whether the conceptualisation of uncertainty as hard or soft within a structured decision aiding process would increase the likelihood of a project contributing to sustainable development. The testing of this hypothesis contributed to the understanding of off-grid projects in the following ways:

- When the hard / soft conceptualisation of uncertainty was applied to the uncertainties identified during the off-grid project evaluation, it became apparent that most of these uncertainties were hard. This conceptualisation has not previously been applied to electrification projects, and this result indicates that the application of this conceptualisation indeed does add value: a decision aiding process where uncertainties could only be represented probabilistically would have been incapable of including hard uncertainties, thereby hiding the main causes of failure in the evaluated projects.
- Very little evidence was found of the use of a structured, formal decision aiding process in any of the evaluated off-grid projects. This highlighted the problem that only focussing on uncertainty acknowledgment would be insufficient: a structured underlying decision aiding process should support uncertainty acknowledgment, with a scope that includes other equally important criteria towards project success. This realisation led to the development of the decision quality framework, against which the ability of a decision aiding process to support high quality decisions can be measured.

Although many authors have commented on the characteristics of decision aiding processes that support high quality decisions, the wide scope of the proposed decision aiding framework and its application as a standard against which decision aiding approaches can be evaluated, appears to be novel.

- The evaluation of the Klipheuvel project, which scored highly when measured against the decision quality framework yet still failed in certain sustainable development objectives, lead to a further realisation: high quality decision making in a project does not necessarily correlate to a contribution to sustainable development. A final factor needs to be present; close alignment between project objectives and sustainable development objectives.

6.2 v

The understanding gained during the testing of the first two parts of the hypothesis led to a number of suggestions on how decision-aiding can guide future off-grid projects towards achieving sustainable development objectives (answered as part of the third part of the research hypothesis). These suggestions are briefly summarised here in the format of a step-by-step guideline, which can be applied to future off-grid programmes and projects:

1. *Identify and use a structured, formal decision aiding process that supports high quality decisions to a large extent, from the inception of the programme/project through to post-implementation monitoring and evaluation.*

The process of identification of the PCM and LFA decision aiding process (as implemented by the EC [2008]) acted in this research as an example of how the first part of this first guideline can be implemented.

- To identify a suitable decision aiding process, a variety of potential processes should be evaluated against the decision quality framework, which will highlighted each process's strengths and weaknesses within the context where it will be applied. It became apparent from the research that identifying a decision aiding process which satisfies all the criteria of the framework will be unlikely: the aim should rather be to select a process which is flexible enough for existing weaknesses to be improved through additional tools or mechanisms.
2. *Include a mechanism within this decision-aiding process that aligns programme and project objectives to sustainable development objectives.*

The PCM and LFA process already included several mechanisms to ensure objective alignment between the programme and individual projects within it. To illustrate the principles contained in this guideline, additional mechanisms were added to the decision aiding process at various programme stages, which ensured that the energisation framework (and therefore sustainable development objectives) was

acknowledged during the definition of programme and project objectives. Implementing this guideline should follow the same process:

- Integrate mechanisms that ensure that programme/project objectives align to the energisation framework into all stages of the decision aiding process where objectives are defined or revisited.
3. *Identify as wide a list as possible of uncertainties that might hinder achievement of sustainable development objectives. From this list, identify the main hard and soft uncertainties.*

The process of testing the first and second parts of the hypothesis demonstrated the methodology through which such a list of hard and soft uncertainties can be obtained. The same methodology can be followed when implementing this guideline.

- Identify a large list of sustainable development-inhibiting factors by evaluating completed off-grid projects against the energisation framework, augmented by a literature study of potential lessons learned from these projects.
- Identify the uncertainties related to these factors from this list, aided by a comprehensive literature review and the definition of what uncertainty is (refer to Loosemore et al. [2006]).
- Select the uncertainties that are likely to have the largest impact on the project. The decision analyst plays an important role at this stage, in selecting what he/she considers to be the main uncertainties impacting the project for inclusion in the rest of the decision aiding process. Ideally the decision makers should be involved in this selection, but when a decision maker is faced with a large list of uncertainties there is the risk of fatigue and unwillingness to again face a subset of these uncertainties later in the process.
- Classify these uncertainties as hard or soft, aided by the classification by Young [2005].

This research, through a detailed evaluation of six off-grid electrification projects and around ten years of experience and hindsight noted in literature, already offers a substantial resource from which future projects can draw.

4. *Ensure that mechanisms are in place within the decision aiding process to acknowledge and quantify the impact of the identified soft uncertainties.*

In order to demonstrate how the impact of soft uncertainties can be acknowledged and quantified, two typical off-grid soft uncertainties were selected: the uncertainties pertaining to the estimation of the renewable energy source potential, and to the sizing of the power system.

The soft uncertainties were acknowledged by incorporating two sets of guidelines into the decision aiding process: guidelines for renewable energy source estimation, and

for renewable energy system sizing. Within each of these guidelines methodologies were proposed to optimally mitigate the uncertainties, while quantifying the remaining uncertainties:

- With regards to source estimation, two popular mitigation tools (Homer and RETScreen) were proposed, and their degree of accuracy for PV-array output estimation quantified for the South African climatic context. The findings of the research indicated that these tools introduced between 0% and 9% underestimation compared to an “ideal” estimation tool, thereby validating their use within PV-based projects in South Africa.

The uncertainty introduced by using various South African weather data sets was also quantified. The results confirmed the value of using soft uncertainty quantification mechanisms: for example, monthly-averaged weather data inputs should be used with care, as PV energy output for certain system configurations (like water pumping) might be overestimated by 20-25%.

- With regards to system sizing, a novel adequacy confidence index was developed to mitigate and quantify this uncertainty. The value of soft uncertainty acknowledgement and quantification was again confirmed through the research results: the assumption of a constant load (rather than the reality of a time-varying load) is not valid during system sizing of deep rural off-grid projects like Lucingweni, as the resulting system based on this assumption might be significantly undersized.

Implementation of this guideline will follow the same methodology as used during the examples in the research:

- Identify tools or mechanisms that will optimally mitigate the main identified soft uncertainties.
- Quantify the accuracy / impact on uncertainty of using these mitigation tools or mechanisms within the context of the specific project where they will be applied.
- Integrate guidelines on how to mitigate soft uncertainties, and how to quantify their accuracy / impact, into the decision aiding process.

5. *Ensure that mechanisms are in place within the decision aiding process to acknowledge and monitor the impact of the identified hard uncertainties.*

The standard PCM and LFA process does not include tools for hard uncertainty acknowledgement. A new “degree of surprise” tool was therefore developed in this research, based on the implementation of the Shackle model by Young [2005], but simplified for ease of application.

- Add mechanisms to the selected decision aiding process that will ensure that the “degree of surprise” tool (populated by the analyst with the selected hard uncertainties identified earlier) is used at project inception, and again pre-

implementation, in order to keep hard uncertainties within the consciousness of decision makers throughout the project design stages.

6.3 Limitations of decision aiding

The example decision aiding approach, tools and improvements identified and developed in this research were finally applied retrospectively to two diverse projects, which between them formed a representative sample of the scope of South African off-grid projects: the Lucingweni hybrid mini-grid project, and the SHS concession programme.

Ideally the impact of improved decision aiding should have been validated through application in a selection of current/future projects, rather than through retrospective application to two completed projects. This was unfortunately impractical, given that off-grid projects are typically implemented over periods of many years.

Retrospective application can also benefit from hindsight. This concern was mitigated by only using lessons learned from earlier projects that would have been completed by the time the validation projects commenced.

The retrospective application led to the following conclusions:

- Sufficient evidence was obtained to conclude that the application of existing high quality decision aiding tools and approaches, with improved uncertainty acknowledgment and objectives alignment capabilities, to off-grid projects will increase such projects' impact on sustainable development. This confirms the third and final part of the research hypothesis.
- Decision aiding can however not be forced upon the decision maker, and it is in this that the limitations of the current research lies: political objectives do not always align with sustainable development energisation objectives, especially in developing countries like South Africa where service delivery represents valuable political capital. A decision maker that is positioned within this political landscape might have little motivation to implement a decision aiding process that will lead to a more transparent decision with an audit trail.

The research results can still be of value even in this context: although a motivation might exist to avoid decision aiding at a programme level, the decision aiding proposed in this research when applied at project level (where the political decision of whom to electrify has already been made) will still increase the likelihood of a sustainable result, benefiting both the decision maker and the community.

6.4 Wider application of this research

The preceding research and resulting guidelines were developed and tested specifically within the context of off-grid electrification programmes/projects in South Africa. The proposed methodology, with its focus on decision aiding for high quality decisions, objectives alignment and uncertainty categorisation and acknowledgement, is however not restricted to this context. The methodology should be as valuable when applied within a wider international context to programmes and projects concerned with sustainable development, for the following reasons:

- The decision quality framework developed in this research can be used to measure the quality of any decision aiding process, and is not limited to just off-grid electrification or the wider context of energisation. The advantages of a formal, structured decision aiding process also applies generally, although the nature of the process (complexity, scope etc.) obviously needs to be adapted to suit the specific programme or project context.
- Alignment of project objectives with an overarching set of sustainable development objectives is also not limited to the South African or energisation context. Objectives frameworks to inform objective alignment within the decision process can be developed for other focus areas of sustainable development, for example potable water supply, in the same way in which an energisation-specific framework was developed in this research.
- Regarding soft uncertainty acknowledgment, mitigation and quantification, the proposed adequacy confidence index is applicable to any power system with renewable energy, and not limited geographically. The proposed methodology to quantify the uncertainties inherent in estimation tools like Homer and RETScreen, for different weather data sets and irradiation and electrical models, was applied to South Africa in this research; the same methodology can easily be applied to other estimation tools and weather data sets of other countries.
- The limitations of using a single conceptualisation of uncertainty (where it is assumed that probability is always applicable as metric) is relevant in any programme or project where social or institutional uncertainties (typically hard uncertainties where probability is not applicable) occur. Young's conceptualisation of uncertainty as hard or soft, and the proposed application of the degree of surprise tool, will therefore also be valuable within this wider context.

Appendix A – Identifying energisation primary sustainable development objectives and indicators

In section 2.3.1 three dimensions were identified as useful for the energisation framework: **social**, **economic** and **environmental**. The IAEA's energy indicators, a literature review and the considerations discussed in section 2.2 will now be used to identify themes, objectives, indicators and measurement scales relevant to energisation.

Social objectives

The equity theme

The SA Energy White Paper lists, as one of its main policy objectives, that government will “*promote access to affordable energy services for disadvantaged households, small businesses, small farms and community services.*” [DME 1998:p8] This confirms the validity, in the context of off-grid energisation projects, of the IAEA's sub-themes of accessibility, affordability and disparities under the theme of equity.

The objective of **accessibility** should focus on the adequacy of the customer's (whether it be a household, school or clinic) access to modern energy sources²⁰, rather than just whether the customer has access to modern energy sources or not.

The DME's evaluation of the first phase of South Africa's National Electrification Programme (NEP), which was strongly connection-target driven, highlights this fact:

²⁰ Kloot [1999] defines **modern energy sources** as clean, labour effective, affordable, safe and accessible.

“Target-setting in future electrification needs to be more comprehensive than merely connection targets, in order to maximise impact and cost-effectiveness.”

[DME 2001b:pviii]

Adequate access entails enough energy to supply the basic lighting, media, communication, cooking, space heating, water heating (especially in clinics) and refrigeration needs of the customer. As very few off-grid energisation projects provide adequate energy for all these household energy needs, it is suggested that the energy indicators (a more accurate description is perhaps *performance indicators*, which will be used from this point forward) measure the adequacy of energy from modern energy sources for each of the listed energy needs separately.

Affordability deals with the ability of the different income groups to meet the cost of energy from modern energy sources. Two indicators are suggested: a) whether the average customers are able to pay, and b) whether the poorest customers are able to pay. Differentiating between the ability to pay of the average versus the poorest customers allows the impact of pro-poor policies (as described in Prasad and Visagie 2006) to be measured.

Disparities address disparities in access to or affordability of energy between different locations or social groups within the project’s target region. Two indicators are suggested: a) whether disparities in access exist between different locations, and b) whether disparities in affordability exist between different social groups.

The South African government’s Free Basic Electricity (FBE) policy is specifically aimed at reducing energy affordability disparities. It is interesting to note that differences in the implementation of FBE between municipalities actually lead to an increase in geographical disparities in affordability, as reported in Banks [2007:p118]. This problem will be explored in detail later in this chapter.

The health theme

Regarding the health impacts of energisation, the SA Energy White Paper’s policy objectives aim to reduce a) fuel-related negative health impacts and b) harmful energy-related emissions:

“Government will promote access to basic energy services for poor households, in order to ameliorate the negative health impacts arising from the use of certain fuels. Government will work towards the establishment and acceptance of broad

national targets for the reduction of energy-related emissions that are harmful to the environment and to human health.” [DME 1998:p8]

Within the context of off-grid energisation the fuel-related “*negative health impacts*” are taken to include paraffin poisoning and fire-related injuries (e.g. Banks [2007:p113]), which can be classified under the IAEA’s theme of *health*, as a sub-theme ***fuel-use safety***. Suggested indicators for this objective are the occurrence of a) paraffin poisoning and b) fire-related injuries within the region targeted by the energisation project.

The IAEA’s framework in Table 2-1 classifies all air-quality related objectives under the environmental dimension, differentiating between climate change and air quality. From an off-grid energisation perspective, however, the ***air quality*** sub-theme relates better to the *social* dimension under the *health* theme, as indicated in the SA white paper:

“Studies have shown that fuelwood users are exposed to extremely high levels of particulate emissions from wood smoke, which result in adverse health effects, such as Acute Respiratory Illness in children.” [DME 1998:p31]

A suggested indicator for the air quality objective is the prevalence of particulate emission-related illnesses within the region targeted by the energisation project.

A number of studies, including Magilindane [2003:p91] and DME [2001b:p30], have reported on the security benefits derived from energisation, especially exterior lighting (both from SHSs and community street lighting) in making customers feel more secure and reducing theft. ***Security*** can be identified as a sub-theme to the theme of *health*. The suggested indicator simply measures whether adequate exterior lighting has been provided by the energisation project.

SHSs often replace car lead-acid batteries as energy sources for media appliances. These car batteries require frequent charging at often-distant charging stations. Magilindane [2003:p57] identified in his survey of the Eskom-Shell concession area of Mbizana that lighting “*as well as relief from the heavy burden of transporting the battery to charging facilities located far away, seem to be the most important reasons why the householders like the solar.*” The physical labour involved in activities like gathering fuel wood can be also be detrimental to health, as a survey conducted in the Maphephethe community illustrates:

“Women involved in this programme confirm that ... [the availability of biogas has] had a beneficial impact in reducing neck-, back- and head-aches, resulting from carrying heavy wood or water loads on their heads.” [Sparknet 2003]

These examples allow the objective of **energy-supply related physical labour** to be identified as a sub-theme to *health*. A suggested indicator is the extent to which energy-supply related physical labour has been reduced through energisation.

Regarding migration, Zomers [2001:p37 and p44] argues that although the reduction of migration from rural to urban areas has often been an objective of rural electrification, it is not an outcome of electrification per se. Migration is rather influenced by population control, economic development and education of individuals and families. For this reason the reduction of rural to urban migration is not included as a primary objective within the framework, but can be seen as an ultimate objective.

Table A-1: Social sustainable development objectives and indicators within the context of off-grid energisation projects.

| Social dimension | | | |
|------------------|---------------------------------------|---|---|
| Theme | Objective | Indicator | Measurement scale |
| Equity | Accessibility of energy | Adequacy of energy from modern sources for basic needs of a) indoor lighting, b) media, c) communication, d) cooking, e) space heating, f) water heating and g) refrigeration | Not available Available but inadequate Available and adequate |
| | Affordability of energy | a) Average customers' ability to pay b) Poorest customers' ability to pay | Not able to pay Able to pay |
| | Addressing disparities | Disparities in access to and affordability of modern energy sources between a) different locations and b) different social groups. | Significant disparities Some disparities No disparities |
| Health | Fuel-use safety | The occurrence of a) paraffin poisoning, and b) fire-related injuries | More than before No change Less than before |
| | Indoor air quality | The occurrence of indoor particulate emission-related illnesses | More than before No change Less than before |
| | Security | Adequacy of exterior lighting | Not available Available but inadequate Available and adequate |
| | Energy-supply related physical labour | The amount of energy-related physical labour | More than before No change Less than before |

Economic objectives

The IAEA's economic themes and sub-themes are aimed at a national level, and not directly relevant within the off-grid energisation context. The two themes of *supply* and *productive use* can however potentially be useful.

The supply theme

The reliability and, in cases where sensitive electrical equipment are used, the quality of energy supply are supporting factors towards realising economic development. These factors should however be balanced by the cost of connection, as highlighted by Gaunt [2003]:

“In particular, where the distribution is to reach poor customers with subsidised tariffs, there is a significant incentive to reduce costs to a minimum. The issue is whether a customer not meeting the full costs of supply is entitled to receive a supply of the same quality as customers paying the full costs or even premium costs.” [Gaunt 2003:p87]

Even where energisation is targeted mainly on the poor, as is currently the typical case in the off-grid context in South Africa, a minimum level of supply reliability and quality need to be maintained. If supply reliability is too low, customers potentially will be discouraged from switching to modern energy sources, thereby impacting all the primary objectives of off-grid energisation. Too low supply quality again adversely affects the life span of electrical appliances like CFL lights.

Supply quality and supply reliability will not be included in the framework, as it is argued that these are not primary objectives of sustainable development, but rather important supportive objectives that make realisation of the primary objectives possible.

Another potential sub-theme of the supply theme might be energy security through supply diversity, one of the South African Energy White Paper's five main supply-side energy objectives: *“... government will pursue energy security by encouraging a diversity of both supply sources and primary energy carriers.” [DME 1998:p9]* The objective of supply diversity, however, contributes little to sustainable development within the off-grid energisation context, except by potentially increasing the reliability of supply, and will therefore not be included in the proposed energisation framework.

In the light of the above, the supply theme under the economic dimension remains empty of sub-themes, and will therefore be removed from the energisation framework.

The productive use theme

It can be argued that the ***access to information*** made possible by television and radio can increase economic productivity in rural areas, although no references could be found to support or oppose this view. The suggested performance indicators for this objective are the level of use of a) radio b) TV and c) Internet within the project's target area.

Activities like wood fuel gathering and transporting car batteries to and from distant charging stations are time-intensive activities. The use of modern energy sources can free the customer from such activities [Green 2003:p165], and through better quality lighting increase the amount of time available for potentially productive activities:

“By far the most appreciated advantage of inside solar lighting is the brightness and the possibility of undertaking evening activities previously not possible. Such activities included opening the shop for longer hours, reading or doing housework.” [ERC 2004b:piv]

This ***increased time availability*** can be identified as a sub-theme of productive use. The suggested indicator for this sub-theme is the amount of free time that the average customer has per day compared to before energisation.

In the South African rural context, where off-grid energisation is most likely to occur, women are largely responsible for energy-supply related activities like gathering wood fuel, as explored in [Green 2003]. Because of this, the benefits brought by the use of modern energy source, especially the decrease in energy-supply related time expenditure and physical labour, will impact women most, resulting in increased *gender equality*. As this important objective of energisation is however mainly the result of two other primary objectives, it will not be included as a separate primary objective, but will rather be seen as an ultimate objective.

Another sub-theme under the *productive use* theme can be identified as small, medium and micro enterprises (***SMME***) ***development***. A number of studies, for example [Borchers & Hofmeyr 1997] and [Prasad and Dieden 2007], have concluded that electrification does stimulate the establishment and growth of local businesses, although inputs like market access and financing play an even more important role. An indicator for this sub-theme is whether the number of SMMEs in the target area of the energisation project has increased.

A final sub-theme can be identified as **long-term income generation**. The concept of job creation, highlighted as a central objective in the South African government's *Growth, Employment and Redistribution* macro-economic strategy [DME 1998:p7], falls within this classification – income generation describes this objective more clearly, as the concept 'job' requires further definition. An indicator for this sub-theme is whether the average household income in the target area of the energisation project has increased.

Table A-2: Economic sustainable development objectives and indicators within the context of off-grid energisation projects.

| Economic dimension | | | |
|---------------------------|-----------------------------|---|---|
| <i>Theme</i> | <i>Objective</i> | <i>Indicator</i> | <i>Measurement scale</i> |
| Productive use | Access to information | The use of a) radio, b) TV and c) Internet within the target area of the energisation project | More than before No change Less than before |
| | Increased time availability | The amount of free time daily compared to before energisation | More than before No change Less than before |
| | SMME development | The number of SMMEs within the target area of the energisation project | Less than before No change More than before |
| | Long-term income generation | The average household income within the target area of the energisation project | Less than before No change More than before |

Environmental objectives

The IAEA's environmental themes and sub-themes are well suited to off-grid electrification projects, as will be shown below.

The atmosphere theme

The South African renewable energy white paper [2003:pix] states that the government's medium term target is "10 000 GWh renewable energy contribution to final energy consumption by 2013, to be produced mainly from biomass, wind, solar and small-scale hydro." Although part of the objective of this target is economic, its main objective lies within the environmental dimension under the theme of atmosphere: impacting **climate change**:

"...it is the intention of the Government to make South Africa's due contribution to the global effort to mitigate greenhouse gas emissions. For this purpose, the Government will develop the framework within which the renewable energy

industry can operate, grow, and contribute positively to the South African economy and to the global environment.” [DME 2003:pvii]

The suggested indicator for the sub-theme of climate change is the contribution of renewable energy sources towards the total energy produced by modern energy sources in the project.

The water theme

Water quality can be negatively impacted by off-grid energisation. A good example of this occurred at the Hluleka Nature Reserve (discussed in more detail later), where diesel seeped in the local river from the original diesel generator system [NER 2003b:p4]. A suitable indicator will basically measure the impact of energisation on water quality.

The irresponsible disposal of especially batteries at their life end (Hluleka once again can act as an example – see [NER 2003b:p4]) can also have a negative impact on the environment, with heavy metals like lead and cadmium polluting ground water, and battery acid seeping into rivers. Proper procedures to deal with the *disposal of waste* are therefore identified as an important objective within the environmental dimension. It is however supportive in nature, and will therefore not be included in the energisation framework.

The land theme

Regarding land, the sub-themes of **deforestation** are highlighted in the SA Energy White Paper, which expresses concern that “*many areas experience an over-harvesting of natural woodland resources, resulting in environmental degradation, soil erosion, and desertification.*” [DME 1998:p31] Energisation that meets the thermal needs of a community can dramatically impact this problem, as the results of a survey at Maphephethe indicates:

“... when the data for women with access to biogas were compared to the traditional energy users, there was a significant difference – namely no wood collection at all [by women with access to biogas].” [Green 2003:p165]

The objectives of soil erosion and desertification are to a large extent the results of deforestation (i.e. ultimate objectives), and will not be considered separately. The indicator for this sub-theme will measure the impact of energisation on deforestation.

Table A-3: Environmental sustainable development objectives and indicators within the context of off-grid energisation projects.

| Environmental dimension | | | |
|--------------------------------|---------------------------|--|--|
| <i>Theme</i> | <i>Objective</i> | <i>Indicator</i> | <i>Measurement scale</i> |
| Atmosphere | Addressing climate change | Green house gas contribution from energy sources | Worse than before No change Better than before |
| Water | Water quality | The impact of the use of modern energy sources on drinking and general water quality | Worse than before No change Better than before |
| Land | Deforestation | The impact of the use of modern energy sources on deforestation | Worse than before No change Better than before |

University Of Cape Town

Appendix B – Evaluation of implemented SA off-grid electrification projects

In this appendix a selection of implemented South African off-grid electrification projects will be evaluated against the sustainable development objectives defined in the energisation framework.

Information sources and structure of project evaluations

The main sources of information on the projects are existing literature, but where these sources are not sufficient people who were involved in these projects have been interviewed. In addition the author has visited the Hluleka and Lucingweni projects a number of times since 2003.

Each project evaluation will be structured as follows:

- A background to the project will be presented, which includes the main actors, the technology used and the delivery model.
- Factors that led to the project not reaching the context-specific electrification primary objectives, as commented on above, will be explored. In most cases a cause and effect diagram will be constructed to add clarity to the discussion.
- Lessons learned that might be relevant to this research will be listed.

Maphephethe pilot SHS project

Background

General information on the project was obtained from [Magilindane 2003], [Bonnet and Andrew 2003] and [Sparknet 2003] unless otherwise stated.

Maphephethe is a rural village some 80km west of Durban, characterised by dispersed settlement patterns. The total number of homesteads in the village is estimated at around 2200, with each homestead housing on average 8 persons in 4 dwellings.

Grid electrification was available only at the edges of the village, but was extended into the village to power the clinic, local authority administration centre and the Kamangwa and Myeka high schools by 2003. Prior to grid electrification Myeka high school received power from PV arrays supplied by Eskom in 1995 as part of its rural schools electrification programme.

A pilot project commenced in January 1996 with the aim of developing and testing a replicable mode of practice for installing SHSs in South Africa. The Solar Electric Light Fund (SELF), a US-based NGO, initiated the project and Solar Engineering Services (SES), a Durban based service company, was responsible for site identification, project management and training.

SES identified Maphephethe as a suitable site for the pilot SHS project through a limited consultation process with various grid electricity distributors and rural communities. The village was deemed suitable for SHSs as grid electricity was not scheduled for at least 5 years, the community leaders showed a co-operative spirit, the density of households were low, and it was located in a mountainous area which would have increased the cost of electricity distribution.

The pilot project was completed within two years, having installed 50 SHSs, consisting of a 50 to 55Wp solar module, 3 compact fluorescent lights of 9W, a 105Ah battery, battery cover and a charge controller fitted with 12 volt DC Monochrome TV or 12 V DC radio connection point.

A number of additional energisation projects were undertaken in this village, including projects focussed on solar cooking, the use of biogas digesters, and the establishment of a PV/biogas hybrid supply at the Myeka High School, which supported among other the development of a computer centre with internet access.

Delivery model

A credit-based SHS dissemination model was used, where customers were expected to pay the full capital and maintenance costs, repayable at between R57 and R82 per month (depending on the interest rate and loan period) through 3- or 4-year loans. The KwaZulu Finance and Investment Corporation (KFC) provided loan funding at commercial interest rates, with the US Department of Energy (DOE) providing the guarantees for loan funding.

The SHS was guaranteed for the period of the loan, with replacement subject to the customer's account being up-to-date. Interest on the loan guarantee was adequate to cover the cost of warranty replacements. In the eventuality of grid becoming available, SELF has instituted a guaranteed buy-back scheme for the equipment supplied.

A small community-based organisation took responsibility for marketing the SHSs and provided assistance with the processing of loans. SES procured the SHSs, managed the project, prepared marketing materials and monitored quality and trained local community members as installers. These installers were responsible for SHS installations and ongoing maintenance.

Green and Zwebe [2006:p12] however reports that maintenance deteriorated after the SHS installers moved to Durban or passed away. SES initiated a new project in 2004 where customers were to pay a monthly fee of R18 in return for maintenance and repair. The community was grid-electrified from around 2001, but a number of households interviewed by Green and Zwebe continue to use the SHS, and expressed satisfaction with it.

Factors that prevented objectives being met

Factors in the Maphephethe SHS project that prevented it from meeting certain primary electrification objectives are shown in the diagram below, Figure B-1.

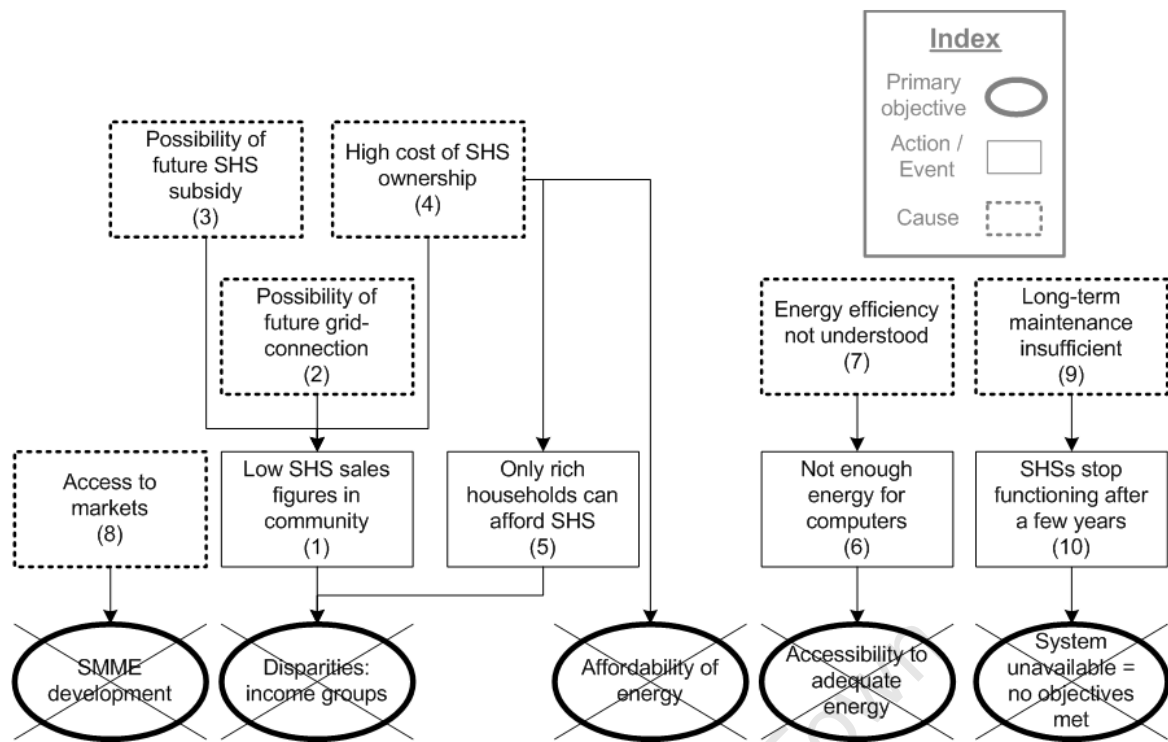


Figure B-1: Factors identified in literature that prevented the Maphethe SHS project from meeting certain primary energisation objectives.

An important problem identified in the literature was that SHS sales figures remained low (1), with only 50 SHS systems installed in households throughout the entire Maphethe village by 2003 [Sparknet 2003], even though a survey conducted in 1995 indicated very high demand for the systems [Magilindane 2005:p15].

Reasons cited in literature for the low SHS sales figures included that a “large proportion of the community [were] awaiting the electric grid extension as their source of energy.” [Bonnet and Andrew 2003:p148] (2), that uncertainty around the possibility of future SHS subsidies caused residents to rather wait [Banks 1998] (3), and that the “cost of ownership of the SHS and expanding the capacity of existing systems is very high” [Bonnet and Andrew 2003:p148] (4).

High cost of ownership meant that only the better off households had access to SHSs, as was concluded in a community survey conducted by Green [2003:p162] (5).

Low sales figures and high cost of ownership impacted on the primary objectives of removing disparities in energy use between different income groups, and affordability of energy.

An additional problem reported by Myeka high school teachers interviewed on the utilisation of the PV array-powered computer centre, was “the shortage of power through

the excess use of electrical appliances other than the computers” [Green 2003:p163] **(6)**. This related to the more general problem reported by Green [2003:p166], that *“the concept of efficiency in using the technologies was not understood”* in the community **(7)**. Energy efficiency impacts the adequacy of energy, and therefore the primary objective of accessibility.

Green [2003:p166] further concluded through her survey of the Maphephethe project that *“very little income generation has resulted from the access to energy technology”*, caused according to her mainly by a lack of local markets **(8)**.

After the SHS installers who were supposed to look after maintenance left the village or died, maintenance became a problem, as reported by Green and Zwebe [2006], necessitating a new project to try and solve the maintenance issues. This indicates that the long-term maintenance arrangements were insufficient **(9)** and **(10)**.

Lessons learned

The literature identified a number of lessons learned:

- A definite **correlation between adequate and ongoing maintenance and loan repayment** was identified in Sparknet [2003]. System maintenance and loan repayment were successful, as Bonnet and Andrew [2003:p149] reports that 35 out of the 50 installed SHSs were still operational at the end of 2002, while Sparknet [2003] reports that although 19 systems have been repossessed due to poor payment records, by 2003 30 other systems were fully paid, and 1 in the process of being paid.
- The fact that only one incident of SHS **theft** has been reported since the project's inception, compared to significant theft at the local schools' PV arrays and Telkom installations, is attributed by Sparknet [2003] to **personal ownership of the SHS systems**. In addition, Bonnet and Andrew [2003:p148] attribute the low incidence of theft to the fact that the SHS installations are mostly not visible from the public access road, and often located in mountainous terrain with very few vehicle tracks.
- Sparknet [2003] reported **positive results from the participative style of project management** that was used in the SHS pilot project, **where key role players were engaged** in order to solicit their support, and the community participated in decisions (e.g. regarding the financing mechanisms) and were involved in the maintenance and administrative structures. Lack of **community engagement** was

identified as one of the main problems in some of the other Maphephethe development projects:

“Participation and motivation are two closely related concepts. We believe that if local people participate in a project at all levels, they will be motivated to make it succeed. The opposite is also true.” [Woudstra and Zoller 2004:p6]

- **Raising awareness within the community of the benefits of development projects**, for example by using promotional materials, surveys and demonstrations, **leads to increased community project ownership**. This was observed at, among other places, Maphephethe, by Woudstra and Zoller:

“It is important that the locals feel the need for water supply, electricity, education, income and job creation. Many of the people are not aware of the importance of development. ... When everyone in the community perceives the importance of the development projects, the projects will become more sustainable and efficient.” [Woudstra and Zoller 2004:p4]

- One of the reasons listed by Bikam and Mulaudzi [2006] why the Maphephethe project was successful was that **the responsibilities of the project beneficiaries were made clear to them**:

“[The beneficiaries] were made to understand that the cost of maintenance of the project was their responsibility. It was also made clear to them that they would be responsible for making sure that the project remains sustainable.” [Bikam and Mulaudzi 2006:1562]

Bonnet and Andrew [2003:p148] agrees with this perspective:

“developing a shared understanding among all stakeholders as to their legitimate vested interests will go a long way in ensuring sustainable infrastructure development and usage.”

- It was recommended that **SHS installations be undertaken as part of a basket of development projects** in order to share the overhead costs of training, supervision, travel, marketing, financing, quality control etc. between the projects [Sparknet 2003].
- The literature highlights the importance of **speedy technology and skills transfer to the community** in order to **decrease the dependence of the community on**

the providers / sponsors of the technology [Bonnet and Andrew 2003:p150]. Green [2003:p163] found that a number of SHS owners reported fixing their systems themselves.

- The fact that ***important project issues*** like “*the problems of capacity building, maintenance and cost implications* “ ***were addressed during the planning stages*** of the project contributed to its success, according to Bikam and Mulaudzi [2006:1562]

KwaBhaza energisation project

Background

The information in this section is based on Sparknet [2003] and Kloot [1999] unless otherwise stated.

Eskom first tested the idea of off-grid energisation through PV and LPG in 1997 in the settlement of Papendorp, a remote extension of the town of Ebenezer on the Cape West Coast. This trail project was however abandoned due to pressure from residents for grid electrification.

Hereafter Eskom embarked on official pilot projects within a framework set out in the Energisation Pilot Project Proposal [Eskom 1997]. Six remote rural sites were identified for energisation, each matched with the supply division of one of a number of South African LPG companies. The identification criteria used included that the site must be further than 5km from the existing grid, must not be earmarked for grid electrification in the next 5 years, must be accessible by road for a 1-ton LPG delivery truck, and must have a PV-electrified school in the area so that residents will have some familiarity with PV.

Due to institutional and financial problems (the REFSA subsidy problem will be discussed in more detail below), the energisation pilot project was finally only implemented fully at KwaBhaza in KwaZulu-Natal. KwaBhaza is located around 20 km from Tugela Ferry and 87 km from Dundee, and 10 km from the nearest existing Eskom grid at the time of implementation.

The project was implemented as a joint venture between Eskom, Total and the Liquefied Petroleum Gas Association of Southern Africa (LPGSA). Eskom identified the site,

procured SHS products and provided project management and interim finance (and subsidy, after REFSA's failure). Total installed the LPG cage in the village and provided training on LPG filling procedures, while LPGSA arranged gas supply, subsidy and interim finance.

A 50Wp SHS for light and media, and a two-plate LPG stove and two 4.5kg LPG cylinders were to be supplied to households as a subsidised energisation package. The residents had a choice between a pole-mounted and roof-mounted package, with or without TV. The Eskom supplied black and white TVs however did not work at KwaBhaza, apparently due to the weak signal strength. The TV option was therefore removed.

Installations started in July 1998, and a total of 120 systems have been installed in at KwaBhaza through this energisation project. It was anticipated that the project would eventually form part of the EDF/Total concession area.

Delivery model

The KwaBhaza energisation project tested a credit-based model, where the household paid a R140 deposit, and then a monthly fee of R55 or R65 over a 35 or 37-month period, depending on the equipment ordered. The monthly fee includes the refill of one gas cylinder per month. Additional 4.5 kg gas cylinder refills cost R22.50. The household owns the equipment upon completion of payment. Flexible repayment systems were used, where if the monthly repayment were not made the household could continue to use the SHS but did not receive the free monthly refill of gas.

Three additional concepts were also tested during this project: that of an energy agent, a demonstration house and an energy day.

The concept of an **energy agent** involves training a community-appointed member (and possibly some part-time assistants) to maintain the energisation packages and provide LPG fuel. At Kwabhaza the selected energy agent received training in basic business and accounting skills and LPG refilling and safety procedures, and along with four other villagers training in the installation and maintenance of the SHSs. The energy agent is also responsible for sales, repayment collection and collection of deposits for new systems.

Two **demonstration houses** were selected, in consultation with the community, at which two demonstration energisation systems were installed in order to familiarise the

community to the energisation technology. A few weeks after the demonstration systems were installed, in mid-April 1998, an **energy day** was held where the product offering was formally introduced to the community in the form of a festive meeting. Information exchange and marketing activities, for example the handing out promotional gifts and pamphlets, took place on this day, along with the initial signing on of customers. Kloot [1999] was sceptical about this marketing exercise:

“... the enthusiasm of the suppliers in convincing rural people that energisation is the answer to their energy needs may stray into modes of advertising inappropriate to the traditional rural context. This may result in people buying into the idea of energisation and the glossy presentation of a modern lifestyle that it seems to offer rather than a sober assessment of its advantages and disadvantages.” [Kloot 1999:p32]

At the energy day 83 households indicated that they would be interested in the package, although this number dropped to around 40 households when the TV was removed from the system due to lack of TV signal in the area.

The energisation process at KwaBhaza, guided by Eskom's Project Proposal, was divided into three phases. During the first phase the project was introduced to the community, market research was done within the community, and the energisation package was developed and finalised. During phase two the majority of the interaction with the community took place, informing them of the benefits of the project and convincing them to buy the package. During this phase the energy agent and demonstration houses were also identified, and the energy day held. The third phase involved the installation of the packages once deposits have been collected. Community involvement during the project was seen as a primary focus of Eskom:

“The process ... aims to involve the community every step of the way and to get their understanding and buy in. In addition, the process checks everything very systematically, especially such things as disposable income, affordability, customer choice, and gets a commitment at each stage. In this way it minimises risk and thoroughly markets the whole energisation package.” [Eskom 1997]

Factors that prevented objectives being met

Figure B-2 diagrammatically presents a number of causes identified in literature that led, or can potentially lead, to the KwaBhaza project not meeting some of its primary objectives.

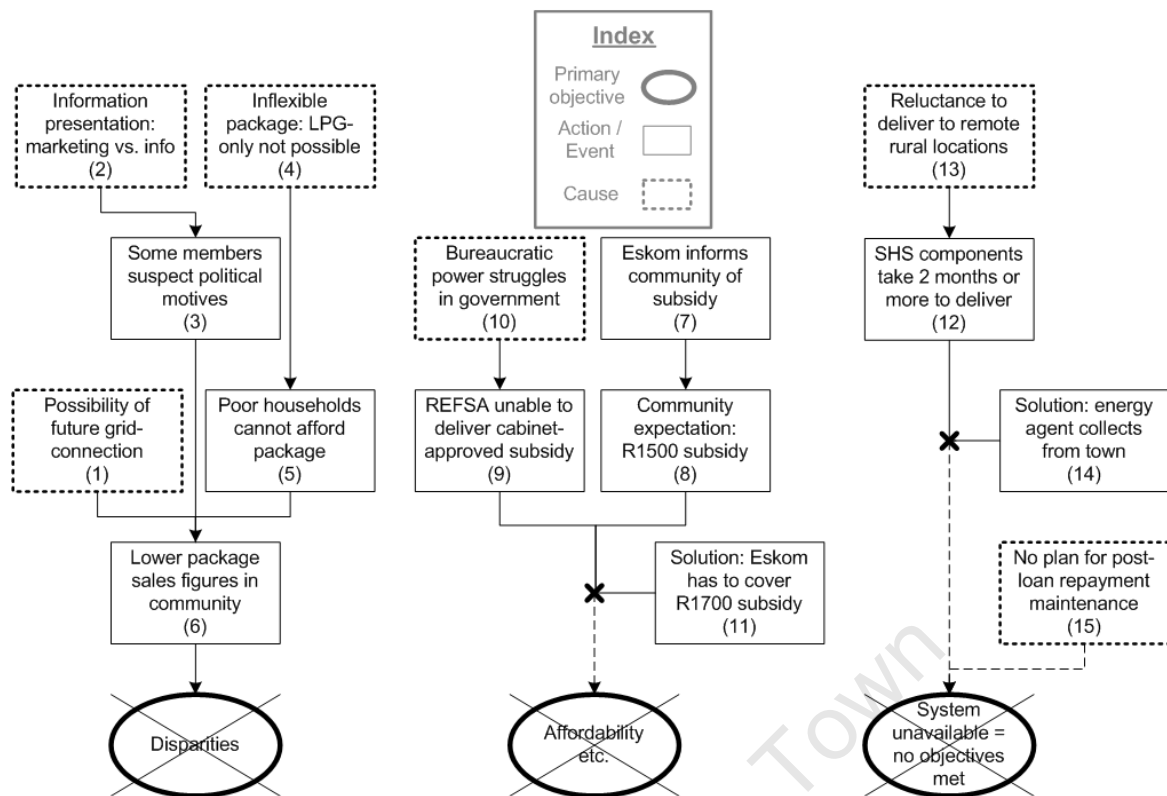


Figure B-2: Factors identified in literature that prevented the KwaBhaza energisation project from meeting certain primary energisation objectives.

Kloot [1999:p31] suggested that “expectations of grid are the main factor causing the rejection of energisation” in the KwaBhaza community (1).

In addition, the marketing process used at the energy day (2), with promotional gifts etc., led to suspicion among some members of the community that the motives behind the energisation project were political in nature (3):

“The energy agent’s wife said that the Anti-energisation Group [a term used by the author to group those in the community against energisation] were of the opinion that energisation was not really aimed at helping the community but was driven by political motives (perhaps ... Eskom’s marketing strategies at the Energy Day precipitated these beliefs). She added that their aim was to expose energisation as a ‘canvassing drive’ and questions its legitimacy as a development initiative.” [Kloot 1999:p91]

The fact that the subsidy and loan arrangements applied only to the full energisation package, consisting of both LPG and the costly SHS (4), excluded the poor from the benefits of energisation (5). Kloot [1999:p83] suggests a more flexible package where poor households can opt for an LPG-only option, while allowing more affluent households the option of upgrading, for example stronger / more lights and a colour TV.

The rejection of energisation by some members of the community, and the inability of some households to afford the full package, resulted in lower energisation package sales figures **(6)**, which impacted the primary objective of decreased disparities within the community.

At the first community meeting with Eskom, the project leader made it clear that a government subsidy of R1500 was available for each package **(7)**, thereby creating community expectations **(8)**. This subsidy was to be funded by REFSA (Renewable Energy for South Africa). REFSA was established by the DME in 1995 as an implementing arm to finance and implement renewable energy projects in South Africa. In addition to channelling the R1500 per off-grid household subsidy approved by cabinet, REFSA's role at KwaBhaza would have been to underwrite the community's loans for the energisation packages.

However, by the end of 1997 REFSA had not yet implemented any projects, as the subsidy still had to be ratified by the minister of minerals and energy in order for it to be released. As no commitment had yet been received from REFSA, "*energisation was going ahead on the understanding that Eskom would 'crisis manage' when the time came.*" [Kloot 1999:p56]

REFSA was put under review in November 1997 **(9)**, and later drafted back into the DME, its functionality "*marred by bureaucratic power struggles*" **(10)** according to Kloot [1999:p69]. Eskom tried to identify other sources for the subsidy, but finally had to provide the subsidy themselves and underwrite the loans in order to ensure the continuation of the project **(11)**. They further offered the systems at the original price quoted at the community meeting even though the cost has increased, leading to a subsidy of R1700 per package. If Eskom had not been willing to take over the subsidies the energisation package would have been too expensive for most of the community, impacting a whole range of primary objectives including affordability.

A number of SHS component delivery problems occurred at KwaBhaza: lights returned for replacement or repairs did not come back, and newly ordered SHSs took around two months to arrive **(12)**. The cause of these problems was identified as a reluctance of courier companies or other transport service providers to deliver components to remote rural areas **(13)**. Asking companies to deliver to nearby Tugela Ferry, from where the energy agent collected the components, solved the problem **(14)**.

System maintenance was paid from the monthly loan repayment. However, no provision has been made for maintenance after loans have been repaid **(15)** – this was left to the community:

“The fee required and the structure for continued maintenance beyond the SHSs loan repayment has not been finalised. Despite the lack of a well-planned future maintenance programme and the agreement on the associated service-fees, the project has the potential to be sustainable over the longer term if the parties involved make the necessary arrangements during the next year or two.”
[Sparknet 2003]

Maintenance is crucial to maintain the availability of especially the SHSs. A lack of availability impacts all primary objectives.

Lessons learned

- Klood [1999] strongly argues for **product information sharing rather than marketing** when introducing a energisation package to a community:

“If it is recognised that the community need is education regarding alternative energy sources then transparent and informative discussion and learning would certainly be more beneficial than marketing.” [Klood 1999:p100]

“Building trust between the community and implementers: “Trust is built up silently, not with the distribution of free gifts. ... Awareness of where the power lies in the community [the induna and the elders] would probably create a better impression.” [Klood 1999:p89]

A number of lessons are identified in Sparknet [2003]:

- **Consultation** with the relevant role players is important, as is involving them in the project process.
- The **energisation packages should be flexible**, i.e. include a number of different options to cater for a wider range of households in the community, as discussed earlier.
- More than half of the customers who originally expressed interest in the energisation package withdrew after the TV was dropped from the package due to reception problems. This illustrates the **importance of TV** within the community.

- A **flexible loan repayment method is essential** given the erratic nature of income in rural areas. Such a flexible system was used at KwaBhaza with positive results: Sparknet [2003] reports that in 2003 at least 80% of household repayments were up to date, with no SHS having been removed due to non-payment. This is in agreement with Kloot [1999]:

“In terms of the capital cost repayment, it is recognised that the conditions at which credit is provided will influence the sustainability. In particular, ‘flexible payment options’ are a factor that will allow debtors to meet their financial obligations.” [Kloot 1999:p38]

- Sparknet [2003] reports only one incident of panel theft, with the panel returned within 24 hours due to community pressure. This **low incidence of theft and lack of vandalism is ascribed to** considerable **community ‘buy-in’** in the project, and **a sense of ownership**.

Folovhodwe project

Background

Details about the Folovhodwe project were obtained from [Sparknet 2003] and [Magilindane 2003] except where stated.

Folovhodwe is a village approximately 80 km from both Thohoyandou and Messina in the Northern province, which in 1996 contained around 670 households, located around 10 km from the nearest grid.

The community was originally approached in August 1995 for interest in participating in a SHS pilot project. A project committee was established after 31 households expressed interest. However, the community subsequently had discussions with Eskom, which gave the community confidence that the village would be electrified within the next few years. This grid expectation led to the abandonment of the proposed SHS pilot project [Cowan et al 1996].

In 1997 the Bavarian government approached the DME with a proposal to establish a demonstration Solar Village utilising SHS technology. The Bavarian government was willing to fund most of the hardware, if the DME would fund the balance of the system equipment and installation cost (ultimately around 36% of the total budget). The

Folovhodwe village was identified as a suitable site, as information about this village was available from the 1995 failed project, and as it was (after all) unlikely to receive grid electricity in the short- or medium-term.

A number of stakeholder interaction meetings were held between 1997 and 1998 between village representatives, local and foreign government representatives, manufacturer representatives and other actors. According to Sparknet [2003] these meetings created unrealistic expectations within the community:

“Unfortunately this [stakeholder interaction] process was not well planned. The focus of these meetings was on the donation, the benefits thereof and the generosity thereof. The over eagerness of some of the government officials and manufacturers’ representatives in getting the project established, lead to unrealistic presentations and promises. The presentations did not cover or stress the necessity of paying a service fee, the maintenance of the donation’s value, product guarantees and what a guarantee really means. The roles, functions and responsibilities of the different stakeholders were also not clarified and defined.”
[Sparknet 2003]

These unrealistic expectations resulted in great dissatisfaction when the community was later informed that they would have to pay for the SHSs. The project went ahead despite this community dissatisfaction. The three community schools were the first sites in the village to receive solar electricity in October 1998. By February 1999 the previously electrified local clinic’s PV system was repaired and upgraded, and all 582 formally inhabited houses in the village supplied with 50Wp Solar Home Systems (SHS). The official opening of the project took place in March 1999.

No connection or service fees were received from individual households until November 1999, when RAPS, on the request of the DME, implemented a second project to try and solve the problems related to payment for the SHS service.

Bikam and Mulaudzi [2006:p1563] reports that by the middle of 2004 only 13 SHSs out of the original 582 were still in good working condition

Delivery model

The Folovhodwe Solar Village project received infrastructure as a donation from the Bavarian government and the DME. The DME originally intended to collect a R100

connection fee from all customers, but decided to cancel this fee given that the SHSs were already installed without any connection fees having been received.

A meeting with the community, held in early December 1999, resulted in an agreement where customers would start paying a R20 monthly service fee from the beginning of December, even though RAPS calculated that at least R35 per month was required to cover administration costs, the maintenance of systems and the purchase of replacement parts. Customers were expected to sign a service agreement in which they agreed to pay the service fee and take proper care of their SHS. The ownership of the SHSs was transferred from the DME to the region's Transitional Local Council (TLC).

Sparknet [2003] reports that 9 SHSs had their PV modules removed due to non-payment in April 2000.

The community, through a Project Steering Committee, was responsible for the maintenance of the SHSs and Solar School Systems, as well as the management of the project funds. A payment office was established, staffed by one administrator and one technician, selected at random from six villagers who received training in SHS installation and maintenance procedures.

It was agreed that when in the future Folovhodwe village received grid electrification, the SHSs would be moved to another location requiring SHSs.

Factors that prevented objectives being met

The diagram in Figure B-3 illustrates the factors that prevented energisation primary objectives from being met at Folovhodwe.

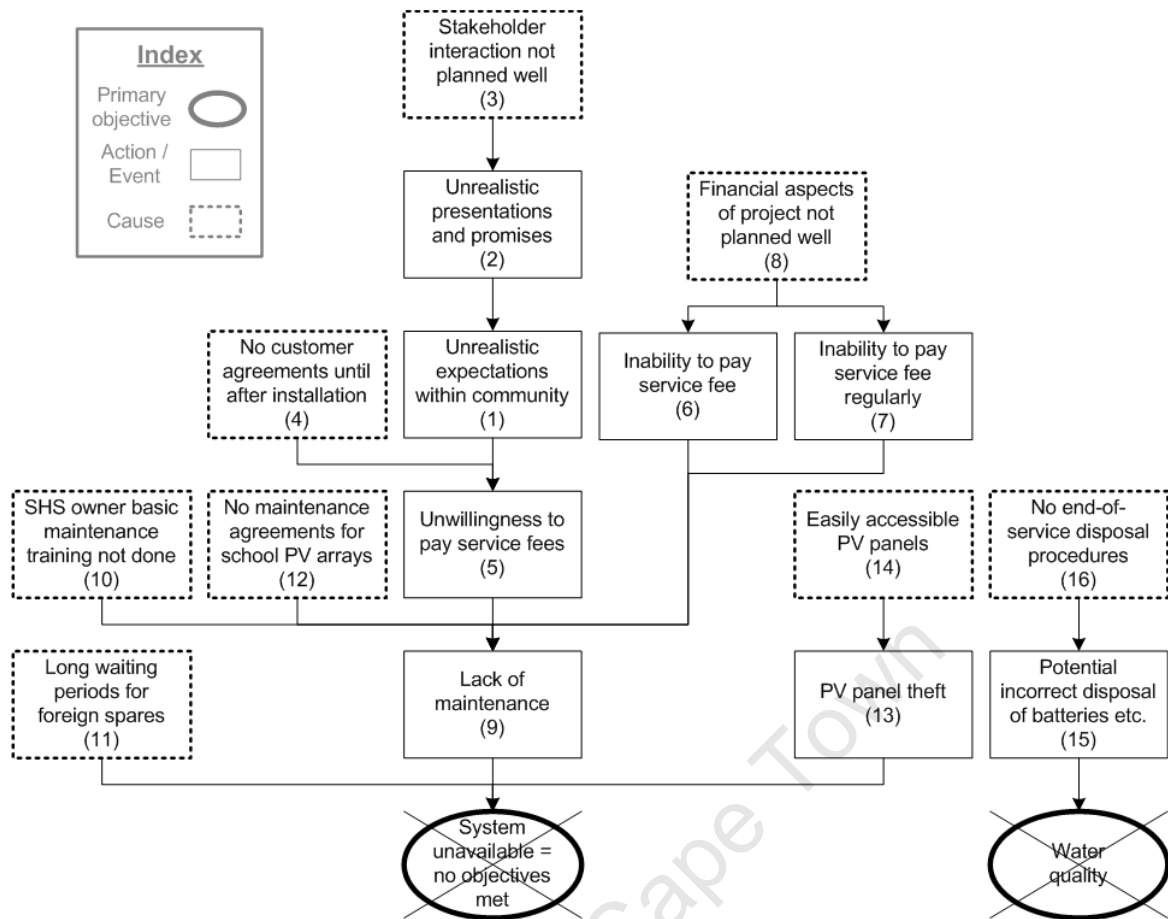


Figure B-3: Factors identified in literature that prevented the Folvhodwe project from meeting certain primary energisation objectives.

As discussed above, the community originally assumed that they would get the SHSs for free, with no monthly service charges (1). This expectation was partly created by unrealistic presentations and promises during the initial stages of the project (2), which can be blamed on a stakeholder interaction process that was not planned well (3). Adequate sharing of information at an early stage by the project team with the community could have addressed these unrealistic expectations:

“The residents in Folvhodwe village wondered why they should pay for the maintenance of the facilities when it is the reverse in conventional sources of energy supply [i.e. Eskom’s grid, which is maintained by Eskom]. It was not explained to them that solar energy supply systems operate differently from conventional systems.” [Bikam and Mulaudzi:p1566]

Customer service agreements were further lacking, even though the installation of the SHSs has already been completed (4). The result of all of these factors was unwillingness within the community to pay the monthly service charge (5).

In addition to the unwillingness to pay, according to Bikam and Mulaudzi [2006:p1565] many members within the community could not afford the monthly service payments (6). This was partly due to the fact that around 40% of the households were on the government pension scheme. Those who could afford to pay did so irregularly (7), for reasons such as that “*most of the residents depend on the seasonal sale of agricultural produce.*” The inability of residents to pay should have been made apparent, for example through community surveys, early in the planning process (8)

The provision of SHS maintenance was dependant on the income from the service payment, and ground to a halt due to this irregular or total lack of payment (9). For example during 2000 40% of the total households paid the maintenance fee, in 2001 25%, and in 2002 and 2003 only 15% paid [Bikam and Mulaudzi 2006:p1568]. By 2001 all the members of the maintenance team have left their jobs because of the non-payment of their salaries.

This fact, in addition to the fact that little attention was given to end-user training in the use and basic maintenance of the SHS (10), led to a steady decline in SHS functionality, as shown in Table B-1, with only 13 SHSs out of the original 582 still functioning by 2004.

Table B-1: The decline in the functionality of the SHSs at Folovhodwe, reproduced from [Bikam and Mulaudzi 2006]

| Solar energy facility statistics in Folovhodwe, 1999–2004 | | | | | | | | | | | | | | | | | | |
|---|-------|----|----|------|-----|----|------|-----|-----|------|-----|------|------|-----|------|------|----|------|
| Equipment | Years | | | | | | | | | | | | | | | | | |
| | 1999 | | | 2000 | | | 2001 | | | 2002 | | | 2003 | | | 2004 | | |
| | FC | FP | OU | FC | FP | OU | FC | FP | OU | FC | FP | OU | FC | FP | OU | FC | FP | OU |
| Solar module | 562 | 0 | 0 | 447 | 100 | 15 | 199 | 163 | 200 | 30 | 52 | 480 | 14 | 60 | 448 | 13 | 0 | 549 |
| Battery | 562 | 0 | 0 | 430 | 102 | 30 | 317 | 110 | 135 | 30 | 54 | 478 | 25 | 37 | 500 | 13 | 0 | 549 |
| Lights | 1686 | 0 | 0 | 1500 | 182 | 0 | 855 | 297 | 534 | 135 | 192 | 1359 | 135 | 192 | 1359 | 39 | 0 | 1647 |
| Charge controller | 562 | 0 | 0 | 450 | 100 | 12 | 462 | 85 | 15 | 87 | 75 | 400 | 40 | 42 | 480 | 13 | 0 | 549 |
| Radio adapter | 562 | 0 | 0 | 447 | 100 | 15 | 199 | 163 | 200 | 30 | 52 | 480 | 14 | 100 | 448 | 13 | 0 | 549 |

Source: Authors field data, 2004.

Key: FC: Functioning perfectly, FP: Functioning partially, OU: Out of use completely.

Bikam and Mulaudzi [2006:p1567] highlight a sharp rise in the total number of SHS breakdowns by 2002 to 3189, from 72 in 2000. Apart from normal wear-and-tear, they blame this increase on “*the slow pace of spare parts procurement from abroad. The problem of spare parts procurement was due to the long period of waiting for replacement parts to arrive from abroad.*” (11)

As no attention has been given to maintenance agreements during the planning process, maintenance of the school PV systems stopped in September 1999 when the one-year installation guarantee expired (12).

Theft was also a problem **(13)**, with Bikam and Mulaudzi [2006:p1568] reporting that 20 panels were stolen in 2003. They blamed the way that the PV panels were installed for the problems **(14)**:

“The initial installation of the solar panels outside the dwellings on a 3m poles, made the facility easy targets for theft and vandalism. As a result of this, many solar modules were stolen. Although the heights of the poles were raised above the rooftops to avoid the problem of theft, it continued unabated.” Bikam and Mulaudzi [2006:p1568]

The incidence of panel theft decreased only after actions including the following were taken: the panels were moved onto the less accessible roofs of the houses, the panels were chained to the mounting pole, all bolts and nuts were welded, or the module was stored indoors when not in use.

Sparknet [2003] highlights the absence in the project of any disposal or recycling strategy to deal with end-of-life environmentally hazardous equipment like lead-acid batteries **(15)**. The possibility exist that dysfunctional SHS equipment have been disposed of irresponsibly **(16)**, as uncertainty exist among project stakeholders on what happened to this equipment.

Lessons learned

The reviewed literature reported the following lessons learned:

- The project initiators (in this case the DME and Bavarian Government) should **clarify**, during the initial planning stages of the project, the future role of customers in terms of **ownership and maintenance**, thereby making the customers aware “*in advance [of] the amount of financial and participation commitment*” that they will need to invest [Bikam and Mulaudzi 2006:p1569]
- Sparknet [2003] reports that a number of systems were damaged through incorrect repair actions by owners in the absence of trained maintenance technicians. This highlights the importance of **training SHS customers in basic maintenance procedures**.

“The ability to repair the equipment has the potential of empowering the beneficiaries of the project facility and also guarantees the sustainability of the project.” [Bikam and Mulaudzi 2006:p1570]

- Sparknet [2003] concludes that ***community-managed maintenance and development funds have “a limited potential for success in South Africa due to the political nature of stakeholders, which causes polarisation and mistrust.”***
- ***A properly documented and implemented disposal or recycling strategy is important*** to minimise the impact of environmental hazards like lead-acid
- Regarding the ultimate breakdown in relations between the project implementers and the project’s beneficiaries due to the problems of unrealistic expectations and poor financial planning, Sparknet [2003] notes that “***sustainable development is not simply about resources but includes the management of relations between people and resources.***”

The DME’s SHS concession program

The literature on which this section is based focuses mainly on three concessionaires and their customers: the Eskom- Shell joint venture in the Eastern Cape, NuRa in KwaZulu-Natal, and Solar Vision in the Limpopo Province.

Background

Towards the end of the 1990s the DME decided to allocate a number of remote rural concession areas to private off-grid service provider companies for subsidised SHS installations.

The first implementation of this concession policy involved a joint venture between Eskom and Shell International Renewables, announced in October 1998 and launched in March 1999, to install SHSs in the Flagstaff region of the Eastern Cape province. The joint venture undertook to electrify some 50 000 rural households using SHSs over the following 5 years [DME 2001:p94].

The DME invited submissions in January 1999 for additional off-grid service providers, based on which six additional consortia were identified in May 1999. Interim contracts between the consortia and NERSA and Eskom (operating under a mandate from the DME) were however only signed in May 2002, after extended institutional delays in finalising the programme structure, the roles of different stakeholders, contract terms and subsidy structures [Afrane-Okese 2003].

This allowed the first phase installation of SHSs to commence in concession areas²¹. Two of the six selected consortia never started operations due to a variety of reasons. The remaining four companies were expected to connect 50 000 customers per concession area over an initial period of 5 years [Banks 2007]

However, in February 2004 capital subsidy funds were stopped at short notice by the DME, halting new SHS installations. Negotiations between stakeholders led to a new contract been signed in October 2004 for phase two of the concession program. This new contract ended in April 2006 without a new one being in place, again halting new SHS installations. In November 2007, after several meetings, the consortia were informed by the DME that the contract will not be renewed “*at this time*” [Banks 2008]. From May 2006 to the time of writing (February 2010) no further subsidy funding has been received from national government by the consortia [Boussard 2010].

The total number of SHSs installed by the consortia between March 1999 and October 2007 are reported in Table B-2. From this table it is evident that not even 40 000 SHSs have been installed in total by October 2007, against a target of 50 000 per consortium.

Table B-2: Consortia, concession areas and total number of installations by June 2004 and October 2007

| Consortia | Concession Area | <i>Total installations by June 2004 [Create Acceptance 2007]</i> | <i>Total installations by October 2007 [Banks 2008]</i> |
|--|--|--|---|
| Nuon-Raps (NuRa) | Northern KwaZulu-Natal | 6541 | 10393 |
| Solar Vision | Northern Limpopo | 4758 | 9200 |
| EDF-Total (KES) | Interior KwaZulu-Natal | 3300 | 9000 |
| Renewable Energy Africa | Central Eastern Cape | 0 | - |
| Shell-Eskom (Replaced by the 3 companies below in 05/06) | Northern Eastern Cape and Southern KwaZulu-Natal | 5800 | 5800 |
| Summer Sun | | - | 1600 |
| Shine the way | | - | 1600 |
| Elita Co-op | | - | 1700 |
| Total | | 20399 | 39293 |

In July 2007 KES obtained the concession to electrify the Northern region of the Eastern Cape, as shown on the map in Figure 1-3. KES started installing SHSs in January 2009,

²¹ The NuRa consortia already started installing SHSs in December 2001, with 400 SHSs funded by a Programme for Co-operation with Emerging Markets grant (Dutch government) [Banks 2003].

and at the time of writing (February 2010) has installed around 3000 SHSs in the concession area. KfW, the German development bank, funds the installation of SHSs via the DME.

A number of institutional delays impacted the KfW (KES) concession: negotiations leading to the signing of contracts in July 2007 already started in 2005. The contract for the interim monitoring consultancy (responsible for auditing the installation numbers) expired in December 2009 without a new consultancy and contract being in place (due to delays in the tender process), impacting installation progress [Boussard 2010].

Delivery model

The DME, in consultation with a variety of stakeholders, decided to base the concession programme on a fee-for-service delivery model, where the SHS remains the property of the consortia, which are responsible for ongoing maintenance funded by a monthly service fee from the customer. The customer would also have to pay a low application fee.

Part of the vision of the DME was that the consortia should adopt an energisation delivery model, including LPG gas delivery in the model. In addition it was envisioned that the consortia would assume responsibility for maintaining institutional PV systems in their area of operation, charging a fee-for-service. According to Banks [2007:p118], one concessionaire recently “*maintained several hundred school PV systems, but the others have not yet been actively engaged in institutional system maintenance.*”

SHS capital cost subsidies were provided through the National Electrification Fund, administered by the DME. Each concessionaire received exclusive rights to receive off-grid electrification subsidies in the identified geographical areas for a pilot period of 5 years (ending March 2004), although the off-grid service contracts are to remain in place for a period of 20 years. [ERC 2004:p111]

The detailed implementation of the delivery model varied between the consortia, influenced by the specific organisational and operational difficulties that each concessionaire had to contend with during the initial years of operation. An association through which the exchange of information, experience and know-how can take place was formed later [ERC 2004].

Delivery models differ slightly between consortia, but in essence follow the approach of a time-based prepaid SHS system with a card reader, which allow the customer to load

credit onto their SHS prepaid meter through a card, which can be recharged at their nearest energy store. Maintenance technicians are also based at the energy stores, and LPG gas can be bought here. In order to shorten the distance customers have to travel to get to the energy store, NuRa has also started licensing local agents to sell solar credit on a commission basis, envisioning one local agent for every 500 customers in the future [Niemand and Banks 2006:p14].

According to the DME [2003b], SHS customers are entitled to a monthly FBE grant of R48 (later changed to R40). Niemand and Banks [2006:p12] report a number of problems with the implementation of the FBE subsidy. Originally the DME undertook to pay the subsidies, which it started to do on 1 March 2003, lowering the SHS service rate from R58 to R18 per month. However, the funding stopped after 8 months when it was decided that local government was responsible to pay for these subsidies. Service rates were increased back to R58 per month until such time that the local municipality implemented the subsidy. This resulted in dissatisfied customers and a “*huge increase in non-payment*” [Niemand and Banks 2006:p12].

Bantsijang [2007] states that municipalities currently have the responsibility to give energy to the minimum monthly value of R55 to non-electrified households in their area, with the amount increasing on an annual basis by the inflation rate plus 1.5%. They however have a choice over the fuel and delivery method used. A problem identified by Banks [2007:p115] is that “*at present there is significant variation in implementation methodology, and as far as this author is aware, there are many situations in which the FBE grant is not available to indigent rural households.*”

The NER initially provided a subsidy of around R3500 per installation, and has not made any revisions to this rate since, despite significant exchange rate variations and high inflation indexes. Tariffs for users currently stand at R61 per month [Banks 2007:p117]

Problems experienced

Banks [2007:p118] identifies “*the question of political will and support for the process at national level*” (1) as a cause of the long delays (2) in getting the first and second phases of the programme up and running, and the current uncertainty whether the third stage of the installations will be implemented. The ultimate liquidation of the Eskom-Shell joint venture was mainly caused by financial problems, which Afrane-Okese [2003:p43] partly blames on these long delays:

“After the first two years of implementation, the company was not coping with the costs since they had been waiting a while for the subsidies promised by government.”

The stop-start nature of the process has led to institutional uncertainties for the contracting parties **(3)**, for example in planning production and ongoing product improvement. In addition, it led to an intermittent flow of the SHS capital subsidy **(4)** (stopped in February 2004, resumed in October 2004, stopped again in April 2006, as described earlier), the impact of which can clearly be seen in the number of monthly SHS installations reported by NuRa, as shown in Figure B-4. Niemand and Banks [2006:p12] reports that this uncertainty around new SHS installations affects customer confidence **(5)**, with 1000 outstanding NuRa customer installations that can not take place until the contracts for the third phase is in place.

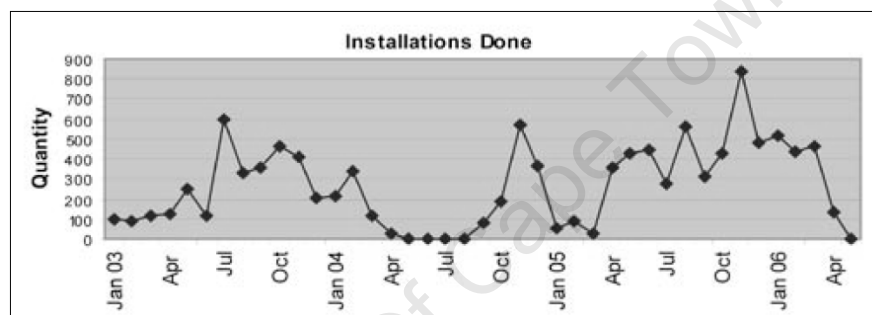


Figure B-4: Number of SHSs installed by NuRa. Reproduced from Niemand and Banks [2007:p12]

The “*strength and unpredictability*” of the grid electrification programme **(6)** is identified by Banks [2007:p118,p122] as a challenge to off-grid electrification, and a significant barrier to renewable energy investment. He notes that even the Eskom-Shell joint venture, where the grid utility was a 50% shareholder, had to remove more than 1000 SHS where the arrival of grid rendered them obsolete. Create Acceptance [2007:p9] blames a “*lack of transparent electricity planning and communication*” **(7)** for the fact that some customers were connected to the grid shortly after receiving SHSs. She also notes that “*when clients are expecting grid electricity they are generally not willing to accept SHSs.*”

Banks [2007:p118] identifies the “*slow and ongoing*” RED restructuring process **(8)** as a cause of institutional uncertainty for all contracting parties, and as a diversion of focus for key decision makers **(9)**.

[Afrane-Okese 2003:p35] notes that the installation phase of the initial Eskom-Shell joint venture project was rushed **(10)**, as “*political promises needed to be fulfilled and many*

pressures towards service delivery to the deprived people existed” (11). This rushed implementation resulted that adequate field-testing of the product was not done before roll-out (12), and contractual agreements with suppliers did not protect the joint venture from the risk of low product quality (13). This led to an increased likelihood of SHS technical faults (14).

The fact that anti-tampering and anti-theft devices in the SHS introduced a high level of technical complexity to the system (15) also increased the risk of failure and limited the possibility of onsite maintenance and fault-finding [Afrane-Okese 2003:p40].

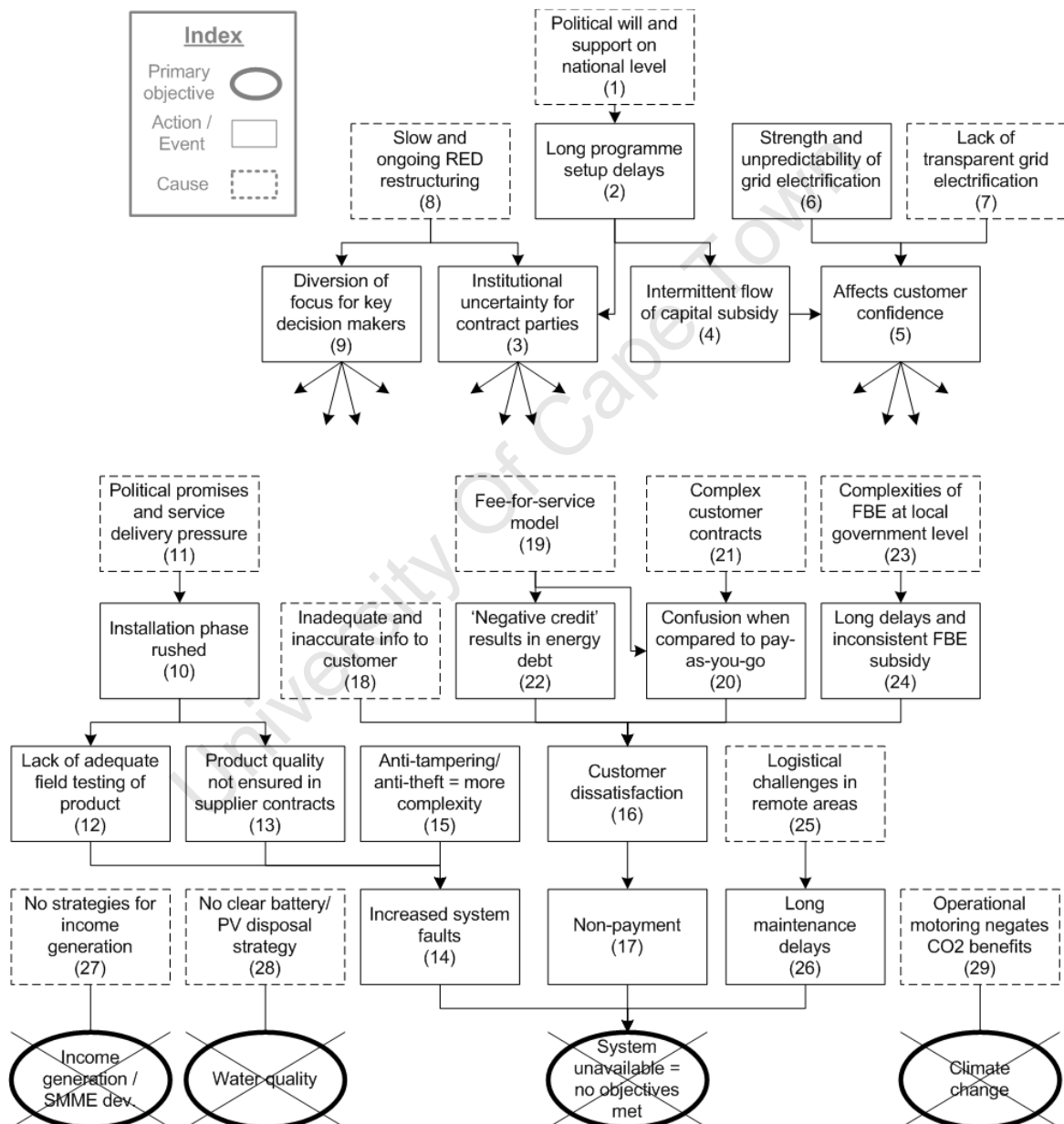


Figure B-5: Factors that prevented the DME’s SHS concession programme from meeting certain primary energisation objectives.

A number of factors in the concession programme led to customer dissatisfaction **(16)** and ultimately non-payment **(17)**:

- Inaccurate information disseminated **(18)** by “*over-enthusiastic*” sales agents and installers, along with situations where the customer service contract was not properly explained to customers, led to customer dissatisfaction, according to Afrane-Okese [2003:p43].
- The fee-for-service prepaid system **(19)** used in the SHS not only denies the customer access to SHS energy until credit has been loaded onto the system, but also records all non-paid days as ‘negative credit’ against the customer. This compulsory payment, even if the SHS is not used, differs significantly from the prepaid / pay-as-you-go systems used for grid electricity and cellphone credit, and both the ERC [2004:piv], and Afrane-Okese [2003:p38] reports that this model causes significant confusion **(20)** and dissatisfaction among customers. This agrees with Prasad and Visagie’s [2005:p34] concern that the customer often does not understand the technology and the often-complex agreements **(21)** that go with it. The ERC [2004:piv] cautions that the fee-for-service model can lead to household ‘energy debt’ **(22)**, a problem especially in impoverished communities.
- Banks [2007:p118] identifies “*the complexities of dealing with several local municipalities to set up service agreements, and access the operational subsidy (FBE)*” **(23)** as causes that led to delays and geographical and time-based variations in the application of FBE subsidies **(24)**. Prasad and Visagie [2005:p36] agrees that the reason for the difficulty in implementing the FBE subsidy lies in the fact that although national government makes the subsidy available, it has to be administered at local government level (in the case of off-grid electrification often impoverished rural district municipalities).

Niemand and Banks [2006:p12] mention as example that only two of the five municipalities where NuRa has installations pays FBE subsidies (since the end of 2005), one paying R40 and the other R30 per month. At the time the literature was written, only 57% of NuRa’s customers benefited from an FBE subsidy. These geographical variations obviously lead to customer dissatisfaction, and contribute to “*significant non-payment problems.*”

It is noted by Banks [2007:p122] that rural logistics are a key challenge **(25)**, especially in remote areas, with challenges including poor road infrastructure and households that are difficult to locate. This results in long maintenance delays **(26)**. Long maintenance

delays, along with the previously discussed problems of non-payment and increased system faults leads to long periods of SHS unavailability, during which none of the primary objectives of off-grid electrification are reached.

A number of individual primary objectives were also impacted by problems experienced during the concession programme:

- The SHS concession programme did not succeed in the objective of income generation, as is clearly stated in the following quotation:

“Hardly any income generation was created by acquiring SHSs. Although productive end uses for PV systems are known in other parts of South Africa, the concessions programme has failed to initiate income generation among its customers.” Prasad and Visagie [2005:p36]

A possible reason for this, suggested by Prasad and Visagie [2006:p24], is that the programme did not include “*strategies for productive and income generation activities*” (27), as it falls outside the responsibility of utilities and energy ministries.

- Prasad and Visagie [2005:p34] raises the concern that no clear strategy has been developed to dispose of old batteries and solar panels (28), which ultimately might impact the primary objective of water quality.
- Afrane-Okese [2003:p46] notes that the emissions caused by the intensive use of motor vehicles for operations within the widely-dispersed SHS area, could far exceed the reduction in CO₂ obtained from using PV as a energy source (29). This impacts the primary objective of climate change mitigation.

Lessons learned

- Prasad and Visagie [2006:p24] suggest that ***productive and income generation activities should be integrated into off-grid electrification programmes***, through cooperation between ministries and organizations that have knowledge of these activities, and the implementing utilities and ministries. These actions will form part of what Banks [2007:p122] calls a “*truly integrated service delivery process*”.

- **Customers should be adequately represented by an independent body** or organization [ERC 2004b:pvii]. NERSA currently fulfils this function, but is unknown to most rural customers.
- Prasad and Visagie [2005:p34], Afrane-Okese [2003:p50], ERC [2004b:pvii], ERC [2005:piv] and Banks [2003:p5] identify **the importance of accurate and adequate dissemination of information** to potential and current SHS customers, so that the characteristics of the technology, the intentions of government, and future grid plans are well understood. The level of literacy of the customer should be taken into account when drawing up customer manuals.
- Banks [2003:p5-6] highlights **the usefulness of innovative customer service enhancements** like using GPS coordinates to accurately locate customers, the use of motorcycles by maintenance technicians, improved testing and quality assurance of components before installation, and a “*more formalised fault reporting procedure, to facilitate more reliable and precise logging of faults.*”
- Banks [2007:p124] suggest three main strategies **to overcome grid planning uncertainty: 1) have robust, long-term plans in place** so that all parties know where the grid will go, 2) “**utilise off-grid systems that are compatible with subsequent grid electrification**”, and 3) “**integrate the implementation and management of grid and off-grid energy service delivery so that one party manages the planning and risks associated.**”

Regarding the first strategy, Banks states that even where clear long-term plans are available, “*the politics of rural electrification mean that plans will change, and with the best will in the world – this author is of the opinion that off-grid installations, their consumers, funders and the companies that support them will remain vulnerable to bitter sweet risk of grid connection.*”

Regarding the second strategy, Banks identified the current lack of feed-in tariffs and standards as a challenge, along with the lack of capital to install renewable systems that will comply with grid standards.

Banks identifies the following challenges regarding the third strategy: regulatory and institutional hurdles to integrating grid and off-grid, the risk of establishing monopolies for energy services, and the difficulties of accommodating less commercially viable activities “*within a framework that retains business viability*” and focuses on integrated energy service delivery. Banks states that if these hurdles can

be overcome, “a ‘home’ for the implementation and sustainable management of a diversity of energy service interventions” can be created.

- Niemand and Banks [2006:p15] notes that although “a major criticism of solar electrical projects is that they fail to address the thermal needs of the customer ...it is also rather questionable as to whether grid achieves this” in many rural communities:

“A grid customer using less than the 50 kWh FBE allocation per month ...is, at most, using a kettle, iron or hot plate infrequently during the month. It should be noted that 56% of Eskom prepaid customers use less than 50 kWh per month. If one considers this as the major benefit of grid electricity compared to solar (the ability to infrequently use a thermal appliance) it becomes increasingly difficult to justify the huge additional capital expenditure for grid.” [Niemand and Banks 2006:p15]

- Niemand and Banks [2006:p15] identifies the **main limiting factor of solar roll out** as “one of **cash flow** which is essentially controlled by Government. NuRa can quite easily reach installation targets of 3 000 to 4 000 installations per month provided it had the right climate under which to operate.”
- According to Niemand and Banks [2006:p16] **the fee-for-service model is working**, with adequate maintenance and support infrastructure and payment levels, in the case of NuRa, of 77% and climbing.
- The ERC [2005:piv] states that **the issue of SHS ownership need to be addressed**, and suggest an arrangement “whereby the ownership of the solar home system passes to the household, coupled with training of local freelance technicians with a system of certification may be useful.”
- The security provided by **medium term budget provisions** shall “considerably assist planning for implementation and appropriate capacity development” according to Niemand and Banks [2006:p16].
- **Social inclusion is an important condition for project sustainability**, according to Afrane-Okese [2003 P46], as it can easily lead to “community ownership for the service, improve customer satisfaction and consequently raise payment levels” and would “allay the fears of the community, dispel false and ‘great’ expectations and restore community confidence and satisfaction in the service.”

Hluleka and Lucingweni hybrid mini-grid demonstration projects

The general project information contained in this section is based on [NER 2003b] and [Scholle and Afrane-Okese 2007] except where otherwise mentioned.

Background

The NER, within the policy context defined by the White Paper on Energy, was mandated to investigate and propose a suitable regulatory framework for off-grid electrification. Within this context Cabinet requested that the NER and the Independent Development Trust (IDT) facilitate the piloting of hybrid mini-grid systems in South Africa, with the aim of gaining the experience required to inform a wider rollout of mini-grid systems in the country.

The rural areas of the Eastern Cape province were identified as a suitable area for the hybrid mini-grid demonstration projects, as *“it was obvious that intervention measures need to be applied to increase the economic activity”* [NER 2003b:p3].

The Hluleka Nature Reserve and adjacent communities were identified as the optimal location for the demonstration project after consultation with the Department of Economic Affairs, Environment & Tourism and the Wild Coast Strategic Development Initiative.

Shell Solar South Africa was mandated to identify the most suitable communities within this area, and identified 2 villages, namely Lucingweni and Lucingweni 2. Settlement density at Lucingweni was highest, and this site was chosen for the demonstration project. Shell evaluated the risk associated with the Lucingweni village as follows:

“... Lucingweni village appears to be a component of a stable, organized, and well-structured region. ... Risk has further been reduced by the wide consultation undertaken, and the levels of acceptance received, in the region. The location of the equipment, coupled with the proximity of the proposed community centre, further reduces risk. The site is on a cul de sac i.e. the road terminates at Hluleka Reserve.”
[NER 2003b:p7]

Implementation at the selected Hluleka Nature Reserve and nearby Lucingweni community was to be project managed by the NER.

Hluleka

When identified as a demonstration project location, the Hluleka reserve's 12 guest cottages, offices and guest quarters were already fully reticulated, and connected to two 75 kW, 220V AC diesel generators. However, a number of problems were being experienced with this original system, as reported in [NER 2003b:p4]:

- The operating cost of the diesel generators was high, as they were running for 10 hours a day using around 90000 litres of diesel per year.
- The generators suffered from unreliable maintenance.
- The original energy system design did not take energy efficiency into account.
- The location of the diesel generators near the Hluleka River caused a pollution problem, due to diesel fuel seepage and irresponsible battery disposal.
- The water supply was pumped directly from the river without any purification process.
- Telecommunications was problematic.

As a solution to these problems, a 220V AC hybrid mini-grid energy system was installed capable of providing energy for the 12 guest chalets, offices and staff quarters, and water pumping and purification. The system consisted of two 2.5kW Proven wind generators, a PV array consisting of 56 100W crystalline PV modules and a 141 kWh battery bank capable of storing up to 5 days of reserve energy. SMA's Sunny / Windy Boy inverters were used, along with an environmental monitoring system and a GSM-based data capturing system.

Energy efficiency at the reserve was enhanced in a number of ways. Electric geysers were replaced with solar water heaters and LPG gas-based instantaneous water heaters, and baths replaced with showers utilising water conservation showerheads. Inefficient refrigerators and lighting were replaced, and electric stoves were replaced with LPG gas models. All 220V sockets were removed in the chalets except for one at the kitchen counter to charge cell phones and other small consumer appliances. Finally existing circuit breakers were replaced in consideration of the limitations of the energy supply.

Furthermore, the existing three-phase water pumps were replaced with two (one on standby) high efficiency single-phase submersed pumps. A micro filter water purification system was also installed.

The Hluleka hybrid mini-grid system was completed by December 2002 [NER 2003c:p18] and operated, with a number of often lengthy interruptions due to technical problems, until the reserve closed for renovation in mid 2006, by which time the first PV panels have already been stolen. By the end of 2006 the Eastern Cape Parks Board requested that the remaining PV panels be removed and stored [Nkwentsha 2007] but by June 2007 the panels, of which a significant number were stolen by this time (see Figure B-6), were still mounted outside.

In an interview in June 2007, a representative of the Eastern Cape Parks Board [Nkwentsha 2007] stated that the Board was considering again using diesel generation due to the problems experienced with the hybrid system. A new diesel generator has already been installed in May 2007, at the same site next to the river where the original generators were located.

At the time of writing (2008) the DME has not yet made any decision regarding rehabilitation of the hybrid system.



Figure B-6: The PV array at Hluleka, photographed in June 2003 (top left), July 2006 (top right) and May 2007 (bottom). July 2006 photograph by C. T. Gaunt.

Lucingweni

The Lucingweni village consisted of 220 dwellings, grouped on the slopes of a headland in a manner that facilitates relatively easy electricity reticulation. Before the demonstration project was initiated, the community used mostly wood and paraffin as energy sources.

The demonstration hybrid mini-grid system consisted of 560 100W crystalline PV panels and six 6kW Proven wind generators, located next to a cabin that holds the 2.2 MWh battery bank and control equipment on a North-facing hill in close proximity to the village. The system was designed so that the PV array generated onto the DC bus of the system, and the wind generators directly onto the AC bus.

According to the consumption estimates used during the hybrid system design, the hybrid generation system had to provide 314kWh of energy per day. This energy were to supply 70 street lights, a community centre, water pumping, 4 shop refrigerators and a radio, TV, decoder, cell phone charger and 4 lights in each of the 220 dwellings [NER 2003b:p9].

The $56\text{kW}_{\text{peak}}$ PV array would have generated roughly $224 \text{ kWh / day}^{22}$, while the $36\text{kW}_{\text{peak}}$ wind generators would have generated the required additional 90kWh / day operating at a capacity factor of $10.4\%^{23}$. Any excess energy from the system was to be used *“for the establishment of off-shoot industries, commercial enterprises, and additional connections.”* [NER 2003b:p9]

Each dwelling was supplied with a ready-board and a 2A current limiting device, which would trip if high-power devices like irons or hotplates were used. The consumption estimates, on which the system sizing was based, allowed 900Wh / day for each household, although no devices other than the current limiters (e.g. prepaid meters) were installed to enforce this energy limit.

The Lucingweni mini-grid system was switched on towards the end of 2005, even though the project was not fully completed by that stage. According to Scholle and Afrane-Okese

²²⁾ The 224kWh / day assumes solar irradiation of $1900 \text{ kWh / m}^2 / \text{year}$ [NASA 2008], PV system (excluding batteries) efficiency of 10%, and $130\text{W}_{\text{peak}} / \text{m}^2$ (Banks [2007] calculated 252 kWh / day).

²³⁾ $90 \text{ kWh} / (36 \text{ kW} \times 24 \text{ hours}) = 10.4\%$

[2007:p101] the decision to switch on was taken to instil a sense of system ownership within the community, thereby increasing “*the security of the system*” (presumable against theft and vandalism).

The system operated for a few months, but was quickly overloaded due to reasons explored later. Theft started at a slow pace in early 2007, and soon afterwards a large percentage of panels were stolen and vandalised in a single evening. The photos in Figure B-7 were taken shortly after this event. At the time of writing (2008) the system was not in use, with its future being decided by the system owners, the DME.



Figure B-7: The Lucingweni hybrid mini-grid system in May 2007, shortly after it was vandalised. Around 40% of the total PV panels were either stolen or inoperable due to vandalism.

Delivery model

Hluleka

Hluleka reserve was electrified in full by the hybrid mini-grid system, with the required capital and diesel fuel being an external cost, not carried by the reserve management.

An East-London based company, Telecom Techniques, were contracted to install the system.

Lucingweni

At Lucingweni, emphasis was placed on stakeholder participation during the planning process:

“A consultative process was undertaken with the community, whereby all processes were communicated and agreed upon before implementation.” [NER 2003b:p7]

The implementation process was managed through the establishment of work committees appointed by the community. These committees allocated labour, and acted as communication channels to the community.

The following recommendations were made by the NER [2003b] report, which was published before the completion of the Lucingweni project:

- That responsibility of the system maintenance is situated fully with the OR Tambo District Municipality (ORT). As ORT lacks maintenance capacity, that ORT and Shell Solar (Pty) Ltd. (SSSA) should enter into a 5-year duration service contract for SSSA to provide the required maintenance, with clauses relating to the quality of service.
- An ownership agreement between ORT and NER/DME.
- A tariff agreement between NER and ORT
- A customer agreement.
- Insurance against lightning or surges, hail, fire, acts of god and theft and civil disobedience.

According to the NER, Shell Solar has not delivered a community centre as was agreed contractually (and at the time of writing still has not), and has therefore not been paid in full. Before the contract was not completed, handover of ownership to the Oliver Tambo municipality was not possible, which means the above agreements could not be implemented.

“The Lucingweni system was never completely commissioned into operation as some of the deliverables still remained outstanding.” [Scholle and Afrane-Okese 2007:p105]

The planned revenue collection approach at Lucingweni was based on a monthly flat rate charge per household. This however was not implemented prior to commencement of the electricity service.

The importance of project evaluation, once all the systems and their associated activities have been installed and are effectively operational, is also highlighted by the NER [2003b] report. Such an evaluation is being completed at the time of writing: a draft document [DME 2007b] has been made available to the author, and the conclusions are incorporated in later parts of this section.

Problems experienced

Hluleka

According to Scholle and Afrane-Okese [2007], the Hluleka system was technically well designed and professionally installed. A number of problems however impacted the sustainable operation of the system, which will now be discussed.

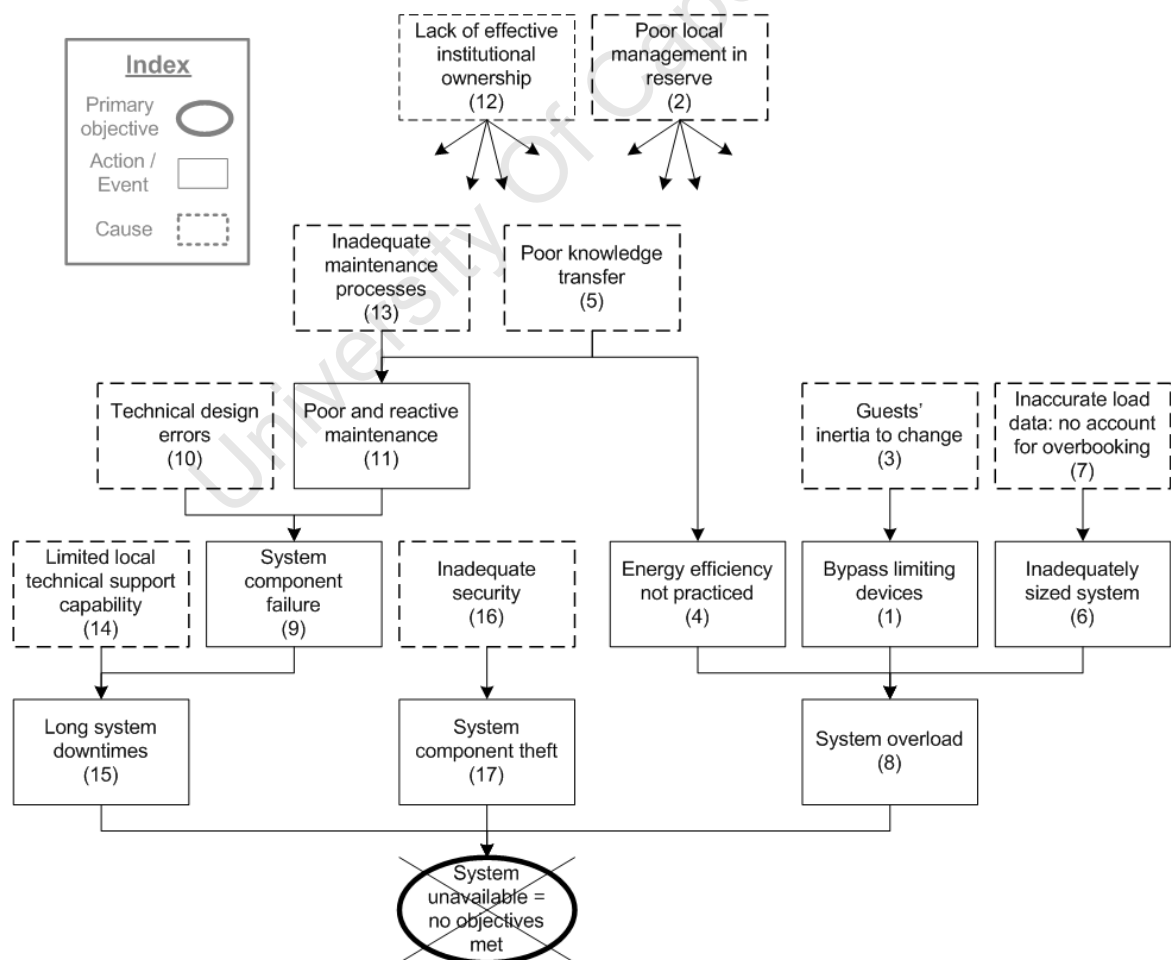


Figure B-8: Factors that prevented the Hluleka project from meeting certain primary energisation objectives.

The December 2003 progress report on the demonstration projects [NER 2003b] found that the mini-grid system was abused by guests **(1)**, for example through bypassing distribution boards in order to power large freezers and portable swimming pool pumps. This is blamed on a lack of control by reserve management, and inadequate communication between staff and guests regarding information on the operation of appliances and energy efficiency, i.e. poor reserve management **(2)**, a cause that affects a number of other problems still to be discussed. Human inertia to change **(3)** also played a role: freezers and portable swimming pools were allowed at Hluleka prior to the installation of the hybrid system (the original diesel generators supplied sufficient power).

Energy efficiency was not practiced at the reserve **(4)**, according to both NER [2003b] and Scholle and Afrane-Okese [2007:p102]: CFL lights were for example replaced with standard incandescent lamps. Reasons for this lack of energy efficiency include high staff turnover associated with poor hand-over during this process **(5)**, and the fact that the reserve management were not incentivised to practice energy efficiency:

“The Hluleka Nature Reserve hybrid system failed as the operation was not appropriately incentivised to control fuel consumption through effective and efficient use of the hybrid system. The management opted for switching on the diesel generator [which was meant to be used only if PV and wind energy ran out due to prolonged periods of no wind or sun] because it was an external cost by government to their operations. The reserve was not managed as a proper commercial entity that optimises the use of its resources.” Scholle and Afrane-Okese [2007:p106]

The problem of an undersized hybrid system was also mentioned **(6)**. Although the system sizing was accurate for the load data supplied by the reserve management, the reserve was often overbooked **(7)** (sometimes the system had to cater for 150 people instead of the designed-for 90)

All these problems lead to regular system overload **(8)**, which impacted on the primary objective of accessibility: supplying adequate energy to the customers.

Due to the overload of the system, a 6kVA diesel generator was installed at the solar generation site to provide additional power, along with automatic delay timers at each chalet to reduce instantaneous start up currents.

According to Scholle and Afrane-Okese [2007:p102] this generator was however incorrectly integrated into the hybrid system (*“connected to the DC bus which is incorrect*

in an AC bus system of the type installed at Hluleka). In addition differences existed in the frequency-based protocol with which the SMA Sunny Island inverters controlled the power delivery of the Sunny Boy PV-array-linked inverters. While the Sunny Island used the German grid-based narrow range of frequencies, the Sunny Boy was configured for off-grid connection and uses a wider range of frequencies. The effect of this was that PV energy was delivered to the system even during no-load, batteries fully charged conditions [Jochem 2008].

These technical design errors **(9)** led to inverter failure **(10)**. The manufacturers (SMA) replaced the failed inverters in December 2003.

The NER [2003b] reports that maintenance at the reserve was poor and tended to be reactive in nature **(11)**, which impacted system component reliability and energy availability. Examples of poor maintenance include not cleaning PV panels regularly, erratic water plant dosing and unreliable recording of logs. These problems are again blamed on poor management at the reserve:

“Despite repeated training, it is apparent that poor management exists on site.”

[NER 2003b:p4]

In addition, Scholle and Afanre-Okese [2007:p108] blames *“a lack of institutional ownership (as well as community ownership)”* **(12)** for the fact that sustainable maintenance processes were not properly implemented **(13)**. Lack of institutional ownership impacts a variety of problems, as illustrated in Figure B-8.

The above, combined with limited local technical support capability **(14)**, led to long periods of system unavailability **(15)**, which impacted all primary objectives of the project. The distance of about one kilometre between the location of the hybrid site and the reserve buildings **(16)** increased the risk of panel theft **(17)** [Scholle and Afrane-Okese 2007:p102], which indeed started occurring incrementally, increasing system unavailability.

Lucingweni

A number of problems plagued Lucingweni, as diagrammatically represented in Figure B-9. These problems were often interlinked, making an accurate diagrammatic representation problematic: for this reason only the main causes of problems are shown.

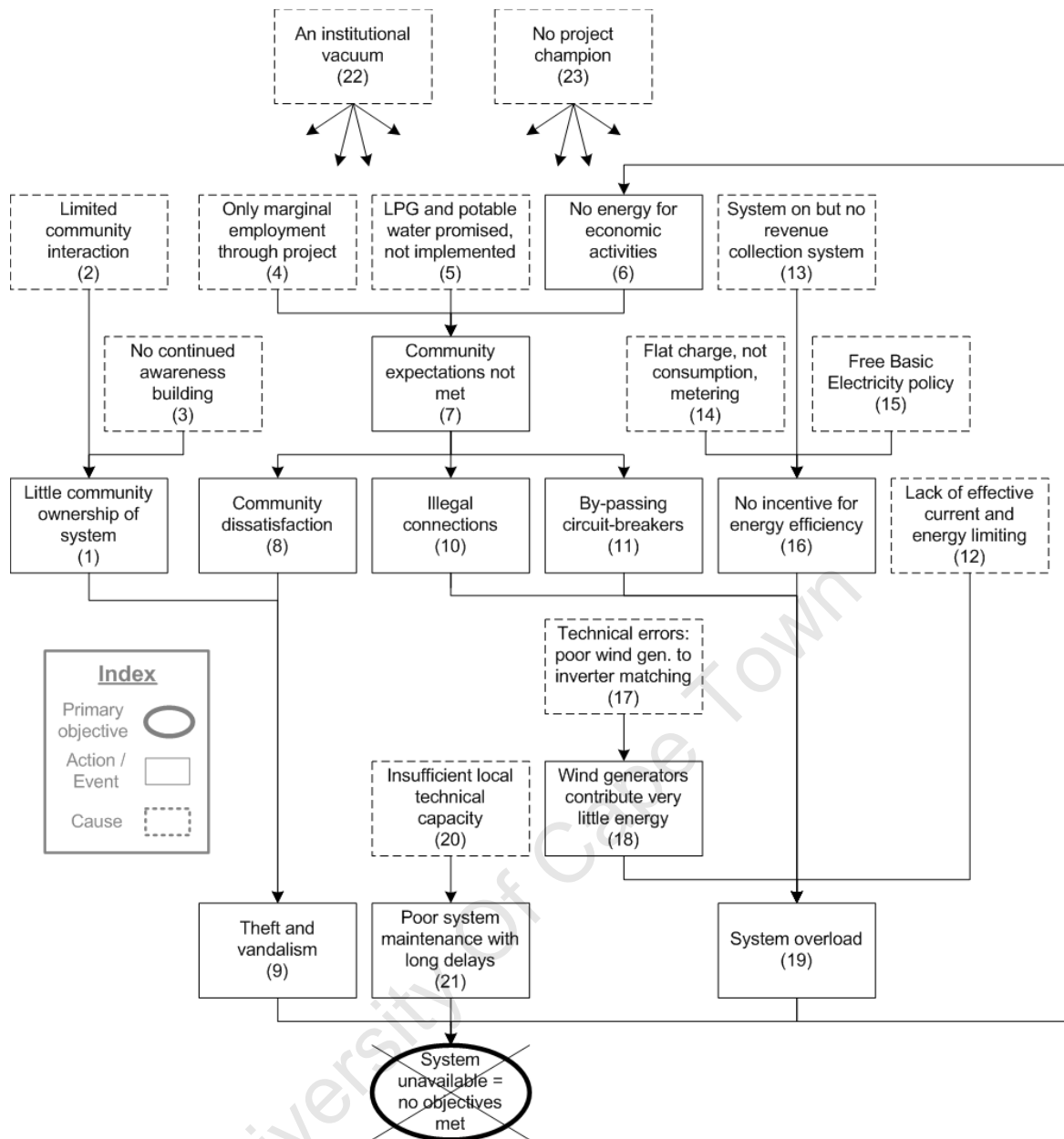


Figure B-9: Factors that prevented the Lucingweni project from meeting certain primary energisation objectives.

According to Scholle and Afrane-Okese [2007] the Lucingweni community had little sense of “buy-in” or ownership in the hybrid system (1), which were possibly the result of limited community interaction (2) and a lack of continued community awareness building (3) (especially necessary during the first 5 years of operation, according to the reference).

“It is therefore questioned whether sufficient community consultation, participative processes and information sharing on envisaged system operation, capabilities and limitations was shared with the community.” Scholle and Afrane-Okese [2007:p106]

The Lucingweni community were only marginally involved in the actual project construction work (4), and were not provided with LPG-based thermal services and potable water from boreholes even though this was originally promised (5).

In addition system sizing and later system overload made very little energy available for economic activities (6), even though expectations within the community with regards to the economic outcomes of the project were already raised during the initial site identification stages:

“The committee has emphasized on the community understanding of the potential benefit of such a project. Aside from the short-term project implementation employment creation possibilities and transfer of skills, they are fully aware and encouraged by the future commercial possibilities.” [NER 2003b:p7]

The above problems resulted in the community’s expectations not being met (7), which ultimately led to dissatisfaction within the community (8).

Dissatisfaction within the community, and little sense of system ownership, appears to be among the main reasons why the community condoned the eventual theft and vandalism of the system (9).

“Since the system is fairly central to the community, this [theft and vandalism] must have been heard and possibly observed by community members and essentially indicated a conscious rejection of the hybrid system by the community.” Scholle and Afrane-Okese [2007:p105]

Scholle and Afrane-Okese [2007] reports that many illegal connections occurred in Lucingweni (10), and that circuit breakers were bypassed to connect for example hotplates to the system (11):

“...if no solution is offered for cooking and space heating then this leads to attempts to use the electrical equivalents on the hybrid system.” Scholle and Afrane-Okese [2007:p107]

The lack of effective current and energy monitoring devices made these illegal connections and circuit breaker bypassing possible (12). Devices that would have prevented these problems includes energy metering that limited the daily energy budget per user, monitoring at distributions point to protect against illegal connections, and a circuit breaker system that prevented a cascading overload [Scholle and Afrane-Okese 2007:p103].

The electricity supply to customers was connected before revenue collection systems have been implemented **(13)**, to try and minimise community dissatisfaction, as previously mentioned. A flat monthly service fee was later considered **(14)**, along with applying the Free Basic Electricity policy **(15)**, which allows households 50kWh free electricity per month, or around 1500 Wh per day. These factors all took away any incentive for the community to practice energy efficiency **(16)**.

“The notion of free service erodes the value of responsible consumption and ownership.” [Scholle and Afrane-Okese 2007:p104]

Technical design errors **(17)**, specifically the use of the wrong type of inverters to connect the wind generators to the hybrid system, resulted in the wind generators contributing very little energy to the hybrid system **(18)**.

This and the rest of the above-mentioned factors, including illegal connections, bypassed circuit breakers, lack of proper consumption-controlling devices and no energy efficiency incentives, led to regular system overload **(19)**.

Scholle and Afrane-Okese [2007:p108] reports that the *“technical capacity at the local authority level was not sufficient to support the operations of the systems sufficiently”* **(20)**. System maintenance therefore depended on outside experts, resulting in high costs and long system down-times **(21)** when faults occurred.

These long system down-times, regular system overload, and finally theft and vandalism resulted in a hybrid system that was regularly unavailable, and therefore could not impact any energisation primary objectives.

Although the above causes and problems all contributed to the ultimate failure of the Lucingweni project, Scholle and Afrane-Okese [2007] identified two overriding causes of failure that influenced most of the other smaller problems:

1. A weak institutional framework **(22)**, caused mainly by lukewarm support from the DME and a lack of an *“institutional home”* for off-grid electrification:

“... it is clear that the projects were implemented in an institutional vacuum which carries a high risk in complex energy service delivery programmes.” [Scholle and Afrane-Okese 2007:p109]

2. A lack of a project champion **(23)**. The DME originally tasked the NER to implement the hybrid pilot projects. The fact that this task essentially fell outside the regulator's

scope of responsibilities, along with a lack of interest in the project in other government departments due to the challenges it presented, meant that there was no real project champion.

“NER/NERSA is a regulator and not a project implementer or an electrification agent and therefore never assumed the role as the project champion.” [Scholle and Afrane-Okese 2007:p105]

Lessons learned

Scholle and Afrane-Okese [2007] provides a comprehensive list of lessons learned from the Hluleka and Lucingweni projects. This section will group these lessons according to three of the four criteria that Scholle and Afrane-Okese identifies as impacting *“significantly on the sustainable long-term operation of hybrid system”*: local socio-economic realities, energy efficiency and tariffs, and institutional framework.

Local socio-economic realities

- **Interaction with the community is essential** for a number of reasons:
 - to gain an understanding of their needs and priorities, and to ensure affordability,
 - to monitor and increase acceptance of the solution,
 - to create awareness of efficient energy use, and
 - to ensure that some organisational capacity exists or is established in the community.
- The required **community interaction** processes should occur **prior to project implementation**.
- The project will have a greater chance of long-term sustainability if the community sees the hybrid system as a **long-term rather than a pre-grid solution**.
- A **focus on energisation rather than just electrification** is important, as a lack of provision for thermal needs result in attempts to use the electrical equivalents.
- **Ongoing awareness building and information sharing**, at least for the first five years, ensures community buy-in and results in improve community ownership.

Energy efficiency and tariffs

- A key aspect for a sustainable project is to **charge revenue for metered consumption**:

“The introduction of Free Basic Electricity in conjunction with a flat rate charge does not send out the message to the consumer that electricity is a valuable service. Therefore, either technical or social means have to be found to encourage efficient use of electricity. This approach often leads to dissatisfaction by users (inflexibility to use more electricity and voluntary self-restrictions) and therefore leads to further challenges ...” [Scholle and Afrane-Okese 2007:p108]

“The notion of free service erodes the value of responsible consumption and ownership.” [Scholle and Afrane-Okese 2007:p103]

“[At Lucingweni] the most essential energy management tool - charging for electricity - was therefore rendered ineffectual.” [Scholle and Afrane-Okese 2007:p108]

“In the absence of a sensible tariff which reflects electricity as a valuable service, a renewable energy system can never be sustainable.” [Scholle and Afrane-Okese 2007:p106]

- When using renewable energy-based systems, **apply the subsidy on the energy efficiency side** and rather maintain a cost-reflective tariff.
- Use a **robust technical solution for current and energy limiting**, which does not allow for simple by-passing, for example limiting the daily energy budget per household and monitoring at distribution points to prevent illegal connections.

Institutional framework

The institutional framework in which an energy service is delivered is defined by Scholle and Afrane-Okese [2007:p109] as including definitions of ownership, subsidy levels, tariffs and the roles and responsibilities of the various parties involved in the service delivery, primarily in the governance sector.

- **A weak institutional framework undermines** the sustainability of hybrid projects *“virtually from the start of the project”*:

“A critical aspect in off-grid energy service provision is a clear support from DME with regards to either hybrid mini-grid implementation or decentralised solar PV supply solutions. As long as off-grid energy services are considered second-best by policy makers, this sentiment will be echoed by the local institutional authority as well as the community.” [Scholle and Afrane-Okese 2007:p109]

- A **project champion**, who takes ownership of the project, ensures effective coordination between stakeholders, and project manages the implementation process, is an important way of reducing the risk of project failure.
- **Off-grid service delivery needs an institutional “home”**, given that it is significantly different from rural grid electrification delivery models.
- **PV-based systems should not be seen as compromise solutions**; as long as governments and beneficiaries hold this perspective, there will be only weak resolve for off-grid projects.

“Only once off-grid supplies are seen as final solutions with no promises of grid power will off-grid be able to play a key role in delivering a high value service to a remote area.” [Scholle and Afrane-Okese 2007:p105]

The **institutional framework needs to be defined upfront**, not during or after project implementation.

Appendix C – The structure of the decision process

Two descriptions in literature of the structure, or different stages, of the decision process are presented here to provide background to the decision aiding tools and approaches evaluated and developed during this research.

Roy's [1996] four levels of the decision process

Bernard Roy [1996] divides the decision process into four levels, emphasising that these levels do not necessarily occur in sequence. Rather, the levels influence each other continuously throughout the decision process until such a time that the analyst is satisfied that the objectives of the decision process have been reached.

1. *Object of the decision and spirit of recommendation or participation*

The object or essence of the decision is defined at this level, by trying to answer questions like “How should the decision be modelled?” and “How can the various potential actions be differentiated?”

During this stage the analyst also defines the spirit of recommendation. Roy emphasise that *“both the analyst and the decision maker understand that the decision maker remains free to act however she wishes, even after the recommendation is made.”*

2. *Analysing consequences and developing criteria*

The second level tries to answer the following questions:

- *“What consequences of the possible decision could be relevant to the objectives and to the value systems of the stakeholders?”*
- *“Which of these consequences need to be explicitly modelled, and how?”*

- *“How helpful will each be in clarifying the decision, given the factors of imprecision, uncertainty, and inaccurate determination in the process?”*
- *“How can criteria be constructed that recognise these consequences and factors?”*

The focus at this level is to construct criteria that will give insight and clarify comparison between the different actions.

3. *Modelling comprehensive preferences and operationally aggregating performances*

The third level attempts to answer two sets of questions. The first set deals with choosing, within the wide range of possible criteria, those that best capture the consequences of the potential actions, and can best lead to a well-considered decision.

The differences in paradigm between the descriptive and constructive approaches of decision aiding become clear at this level. For example, *“should each of the criteria in the family be considered as an instrument that will describe the actors’ intangible preferences or, on the contrary, that will help unestablished preferences emerge, evolve, and perhaps converge?”* [Roy 1996].

The second set of questions tries to map the way in which an action’s performance can be compared as better as or worse than another action’s, based on aggregation of the various chosen criteria. For example, how should the relative importance of the criteria be decided?

4. *Investigating and developing the recommendation*

A variety of procedures is available at this level to process the information obtained in the other three levels, leading to a “solution” of the specified decision problem.

Belton and Steward [2002]: a simplified structure

Belton and Steward [2002:p6,p14] simplifies the decision process into three stages, once again highlighting the iterative relationship between the stages:

1. *Identifying and structuring the problem*

In this stage the various stakeholders need *“to develop a common understanding of the problem, of the decisions that need to be made, and of the criteria by which such decisions are to be judged and evaluated”*.

Typically key concerns, uncertainties, goals, stakeholders and actions will be defined in this stage, following any of a number of problem structuring techniques, for example Kipling's six thinking men: who, how, where, when, what, why.

2. *Building a model of the decision problem, and using this model*

In this stage formal models need to be developed “*of decision maker preferences, value tradeoffs, goals, etc., so that the alternative policies or actions under consideration can be compared relative to each other in a systematic and transparent manner.*”

A wide variety of model-building approaches are available, but they should all include the following elements [Belton and Steward 2002:p7,p52]:

- The alternatives (options, strategies, action plans) to be evaluated.
- The model of values (criteria, objectives, goals) against which these alternatives will be evaluated, along with some reference to the significance or importance of the criteria.
- The most important stakeholders, their opinions, and how this will be taken into account.
- Key uncertainties and how these will be modelled.

3. *Developing an action plan*

Belton and Steward emphasize that “*analysis does not ‘solve’ the decision problem*”; therefore support and insight into translating the analysis into specific plans of action is as important.

The whole decision process is described by Belton and Steward [2002:p6] as moving “*through complexity to simplicity*”. In this view the initial problem structuring phase required divergent thinking, “*opening up the issue, surfacing and capturing the complexity which undoubtedly exists, and beginning to manage this and to understand how the decision makers might move forward*”.

The next phase of model building and use required more convergent thinking to extract “*the essence of the issue from the complex representation in a way which supports more detailed and precise evaluation of potential ways of moving forward*”, resulting finally in the development of an action plan.

Appendix D - Case studies in decision aiding

The author has been involved in a number of projects where decision aiding was given to support high quality decision making. Three case studies based on these experiences will now be presented, to clarify and confirm decision aiding concepts introduced in this research.

Case study 1: Strategic Infrastructure Plan for the Western Cape

In 2006 the Western Cape provincial government prepared a Strategic Infrastructure Plan (SIP) to guide infrastructure investment by both the government and the private sector over the following five to ten years, and to improve the management and use of the state's existing infrastructure assets.

The author participated in compiling the section of the SIP that dealt with energy-related infrastructure, with energy experts based mainly in UCT's electrical engineering department and UCT's Energy Research Centre.

Actors

The SIP process was similar to a typical rural electrification decision making process in that analysts (including the author) interacted with experts and other stakeholders to define and model the decision problem and arrive at preliminary decisions. These preliminary decisions were then presented to the political decision makers, along with an audit trail (the bulk of the SIP report) on how the preliminary decisions were arrived at.

Stages of the process

The stages of decision aiding used in the SIP report closely followed those defined by Belton and Steward in Appendix C, namely structuring the decision problem, then

modelling it, and finally developing action plans. The introduction to the energy section of the report defines the stages as follows, with an emphasis on the first two stages [SIP 2006:p1]:

- *“improve the availability of information to decision-makers within the Western Cape provincial government on energy infrastructure options [which includes both physical and institutional infrastructure];*
- *present a framework within which these energy infrastructure options can be compared with clarity, based on criteria representing the provincial government’s future vision; and*
- *highlight the energy infrastructure options closest aligned to the provincial government’s future vision.”*

The spirit of recommendation of the decision aiding was also defined early in the report, by introducing the concepts of multi- and single-criteria analysis and the advantages of using a *“coherent family of criteria that can be used throughout the decision-making process to provide structure and a common language for discussion.”* [SIP 2006:p3]

A family of criteria was then identified, representing the most important characteristics identified in policy documents representing the provincial government’s future vision. The choice of criteria was informed by Belton and Steward’s guidelines on developing a coherent family of criteria, especially balancing the need for a comprehensive / exhaustive family with the requirement for simplicity. For this reason only six criteria were selected, many containing several sub-criteria that would have over-complicated the process were they included as separate criteria.

A study then identified a list of alternatives to be considered (both on the demand and supply sides). The criteria used, and a sub-set of the alternatives considered in the SIP is shown in Table D-1.

Table D-1: Supply side alternatives considered in the SIP, with weightings given for each criterion.

| CRITERIA ALTERNATIVES | LABOUR INTENSITY | FINANCIAL IMPACT Capital costs O&M costs Energy cost saving potential Subsidy required Revenue potential | ENVIRONMENTAL IMPACT Local air pollution Global air pollution Other impacts | ENERGY SECURITY AND RELIABILITY IMPACT | EASE OF IMPLEMENTATION Skills availability Influencing power of WC Provincial Government End-user acceptability Implementation time Scalability | CONTRIBUTION TO EQUITY Geographic Socio-economic |
|----------------------------------|---------------------------------|---|--|--|--|--|
| | Renewable energy options | | | | | |
| Wind generation | 1 | -2 | 2 | 1 | -1 | 0 |
| PV solar generation | 2 | -3 | 2 | 1 | 1 | 0 |
| Solar thermal generation | 1 | -2 | 2 | 1 | 0 | 0 |
| Landfill gas generation | 1 | 0 | 2 | 1 | 1 | 0 |
| Biomass generation | 1 | -1 | 1 | 2 | 0 | 0 |
| Pumped storage | 0 | 0 | 0 | 1 | 0 | 0 |
| Conventional options | | | | | | |
| PBMR nuclear generation | 0 | -1 | 1 | 2 | -1 | 1 |
| Other options | | | | | | |
| Rail and port upgrades for COGSI | 1 | -1 | 0 | 0 | 0 | 1 |
| Solar thermal water heating | 3 | 1 | 2 | 2 | 2 | 2 |
| Bio-diesel | 2 | -1 | 1 | 1 | 1 | 0 |
| Bio-ethanol | 1 | -1 | 1 | 2 | 1 | 0 |

The impact of each criterion on an alternative was measured on a colour-coded qualitative scale from -3 to 3, as defined in Table D-2. The importance of the different criteria relative to each other was specifically not defined in the report, as it was felt that the SIP report “forms part of the decision-making process regarding infrastructure investments, and does not act as a decision maker.” [SIP 2006:p4]

Table D-2: Rating system used in SIP to represent the value of a criterion for each alternative. Positive means desirable, neutral means zero impact on the criterion, and negative means undesirable.

| Rating | Number |
|-------------------|--------|
| Very positive | 3 |
| Positive | 2 |
| Slightly positive | 1 |
| Neutral | 0 |
| Slightly negative | -1 |
| Negative | -2 |
| Very negative | -3 |

Lessons learnt

- *Multi-criteria analysis greatly improves information transfer between different shareholders, and provides a useful framework for discussions.* Originally only the energy section of the SIP made use of a multi-criteria approach for comparing different alternatives. The compilers of the SIP document, after recognising the benefits of this approach in conveying information to the decision makers and providing an audit trail of the preliminary decisions, recommended that all the remaining sections of the SIP, for example health and transport, also incorporate this methodology. The recommendation was not adopted in all sectors, but it clearly illustrated the value of using a multi-criteria analysis.

- *Using qualitative rather than quantitative measurement scales during early project stages makes the process more efficient, and avoids the distraction of shareholder disagreements about quantitative details that are irrelevant at this stage of the decision process.* The most accurate manner in which to decide on the rating for each alternative's individual criteria would have been by using a quantitative value (i.e. Rand and cents values for the financial impact). Some criteria, for example ease of implementation, are however very difficult to measure quantitatively. In addition, the effort to arrive at accurate quantitative ratings is often significant (compared to asking different experts for their subjective ratings, as was done in the SIP), and often does not add much value to informing initial discussions aimed at broadly identifying further paths for exploration.

Literature agrees on the value of qualitative measurement scales: "...in many situations decision makers may be much more comfortable in expressing values on semantic scales (e.g. moderately important, highly important) rather than in terms of numerical scores." [Belton and Steward 2002:p336]. Vincke [1992] notes that too much precision during iterative processes is useless if it is accepted that the decision-makers might change their minds during the iteration process. He also notes that the cognitive strain for each question should also not be too high, as this might lead to the decision-maker maintaining answers from previous iterations.

- *Valuable information is maintained within the decision making process by not aggregating criteria ratings too early in a decision process.* A decision was made not to assign a weighting to each criteria and then aggregate the ratings, thereby arriving at a "score" value for each alternative. This avoids a situation where the focus is on the "score" rather than on the ratings of the different criteria used to calculate this value, and aligns with the constructive spirit of recommendation. This approach worked well in the SIP: obvious alternatives stood out clearly from the rest even without aggregation (e.g. solar water heating in Table D-1), while arguments supporting less obvious alternatives could refer to the different criteria, instead of referring to an aggregation value of which the detailed arithmetic remained hidden. Aggregation of weighted criteria ratings might however be of value during the final stages of decision processes, especially where quantitative criteria measures are possible.
- *Information sources / methodologies should be transparent.* A political decision maker on the SIP queried the validity of the criteria ratings for the different renewable energy technology alternatives, as she was under the impression that the ratings

were the authors' own opinions. This situation could have been avoided by making transparent in the decision aiding process the methodology used to arrive at the criteria ratings.

Case Study 2: Energy storage technologies overview

Decision aiding to a client building a luxury residential house illustrated the usefulness of effective visual design in information transfer, as well as that choosing a set of criteria is highly context specific.

Background

The client requested an overview of the complete spectrum of available energy storage technologies for his own background, and requested assistance in then deciding which technology was best suited to his own residential house's backup power needs and potential business opportunities.

As the client defined the decision problem very clearly along with the scope of the investigation, the decision aiding could start with the modelling of the decision. A multi-criteria decision modelling approach was followed, with no aggregation of the different criteria ratings for the same motivations as with the SIP.

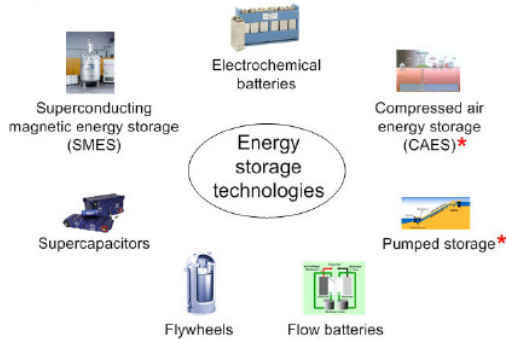
The decision aiding process consisted of a report (the summary page is shown in Figure D-1) and a clarification meeting with the client. The report provided illustrated descriptions of each storage technology (aimed at a non-technical reader that is interested in technology, as shown in Figure D-2), with enough technical detail to clearly show the rationale leading to the conclusions.

Whereas the SIP report rated alternatives against criteria using both desirable and undesirable ratings, the energy storage overview used a rating scale that included only *neutral*, *less desirable* and *not recommended*, with no additional ratings for desirable characteristics. This was done as the client asked for the full range of energy storage alternatives to be investigated and presented, including technologies like compressed air energy storage (CAES) that are impractical for residential use. Given this wide range, a rating scale that would eliminate totally impractical alternatives yet also highlight small nuances in desirability between remaining alternatives, would have added too much complexity to the analysis. Instead, a limited scale was chosen to clearly highlight the

remaining alternatives once all non-recommended technologies have been eliminated. These remaining alternatives were then the subjects of further analysis.

Summary

A variety of electrical energy storage technologies are explored in this document, as shown below:



* Not practical for residential use - for interest only

The table below summarises the characteristics of these technologies. Technologies with characteristics **outlined in orange** are not recommended for residential use, while characteristics **outlined in blue** make a technology less desirable for residential use.

The following technologies can be considered for use, although a more detailed feasibility study is recommended in the case of flow batteries:

- **Lead-acid batteries:** well suited from the perspectives of cost, reliability, energy and local availability.
- **Flow batteries:** the technology is in the process of commercialisation, so local implementation time might be long, and reliability is not proven. In addition flow batteries will require significantly more space than lead-acid batteries, and might generate some noise. Within this family of technologies, the VRB product appears to be the most suitable for residential applications.

| Values in bold are suitable for residential applications | Efficiency | Cycle Life (cycles) | Energy Density (kWh/m ³) | Output Power (Watt) | Output duration (time) | Capital Cost (\$/kWh) | Lifetime Cost (\$/kWh/cycle) | Maturity of technology |
|--|------------|---------------------|--------------------------------------|---------------------|------------------------|-----------------------|------------------------------|--|
| Electrochemical: Lead-Acid | 78% | 4 500 | 60 - 90 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| Electrochemical: Nickel-based | 80% | 1000-8000 | 30 - 65 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| Electrochemical: Lithium-Ion | 85% | 3 500 | 160 - 300 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| Flow Batteries | 75% | > 10 000 | 10 - 35 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| Flywheels | 0 - 85% | 100 000 | 2 - 10 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| Super Capacitor | 86% | 70 000 | 2 - 7 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| SMES | 0 - 90% | 30 years | 20 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| CAES | 80% | 20 years | - | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |
| Pumped Hydro | 75% | 40 years | 0.003 | W kW MW GW | ms second hour day | 10 100 1k 10k 100k | 0.1 1 10 100 | Research Commercial Mass production |

Figure D-1: Comparison of electrical energy storage technologies for residential use.

Flywheels

Energy can be stored as kinetic energy in the form of a wheel that spins on an axis. This configuration is called a flywheel and has been in use since ancient times, for example in the form of the potter's wheel.

Modern electrical energy storage flywheels consist of a flywheel that can spin at a very high speed (up to 22 000 rpm), and an electrical motor/generator that transfers energy to and from the flywheel.

The energy E stored in a flywheel can be approximated by $E = \frac{1}{2}mv^2$ where m is the wheel mass and v the linear rim velocity of the wheel. From this equation it becomes clear that the speed of the flywheel contributes more to the energy stored than its mass. At high speeds, however, the impact of friction becomes critical, and this led to the development of high-speed flywheels that spin inside a vacuum on magnetic levitation bearings.

Commercially available flywheels typically come in two types: fast-spinning low power, long discharge time flywheels and slower-spinning high power, short discharge time flywheels. Long discharge type flywheels are typically sized for around 15 minutes UPS backup periods, and high power flywheels for 15 seconds power quality correction periods.

In the same manner as supercapacitors, flywheels are often used in conjunction with electrochemical batteries or diesel generators because of the fast access to stored energy that they offer. In automotive and space applications flywheels also act as gyroscopes.

An element of risk is involved with the use of flywheels: if for some reason the flywheel shatters or the axis breaks, all the energy is released at once, causing the device to explode. For this reason flywheels are typically embedded in the ground or within strong containment vessels as a safety precaution. This increases the mass of the device and the total area required.

Advantages:

- High cycle life
- Fast charging and discharging
- Temperature independent operation and low maintenance

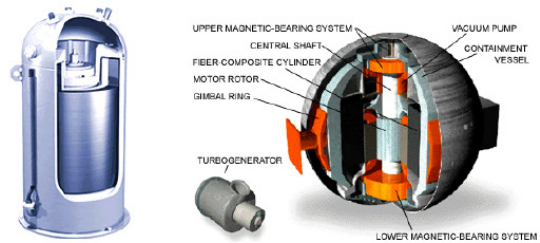
- High efficiency (however, the longer the period between discharges, the lower the efficiency, because of the self-consumption of the flywheel to keep the wheel spinning)

Disadvantages:

- The requirement for a containment vessel
- Generates some noise (<55dB(A) at 6 ft underground)

Supplier details:

- www.beaconpower.com



Left: Beacon Power's 2kW, 6kWh flywheel (www.beaconpower.com)
Right: A diagrammatic representation of a flywheel (www.upei.ca)

| | |
|---|---|
| Round trip efficiency | 0 - 85% |
| Cycle Life (cycles or years) | 100 000 cycles |
| Energy Density (kWh/m ³) | 2 - 10 |
| Output Power (Watt) | W kW MW GW |
| Output duration (time) | ms second hour day |
| Capital Cost (\$/kWh) | 10 100 1k 10k 100k (\$1000 - 1500/kWh) |
| Lifetime Cost (\$/kWh/cycle) | 0.1 1 10 100 (1¢ - 2\$/kWh/cycle) |
| Maturity of technology | Research Commercial Mass production |
| <i>Values in bold are suitable for residential applications</i> | |

Figure D-2: An example of a typical technology description in the energy storage report

Lessons learned

- *The choice of criteria family is highly context specific.* It is clear from the choice of criteria that the client / decision maker in this case study had very different needs to those in the SIP case study: *labour intensity* and *contribution to equity*, for example, was essential in the SIP for political and economic reasons, and totally irrelevant to the residential client.
- *Even in the case where one alternative is clearly superior to all the rest, the runner-up alternative and the process that led to their identification should still be clearly communicated.* This gives the decision maker confidence in the process, and informs the construction of his/her preferences. The main motivation for this decision aiding project was that the client was not convinced that lead-acid batteries, recommended by all the contractors on his building project, was indeed the best choice for his needs. In this decision aiding it was therefore crucial that the client fully understood the rationality of the process that led to the final recommendation, and that alternatives (flow batteries) were provided against which the recommended solution (lead acid batteries) could be weighed.

Case Study 3: Electricity supply for a rural school in Limpopo

In 2008/2009 the feasibility was investigated of using renewable energy to supply the energy requirements of a newly donated computer centre, which formed part of a newly-build school in a rural part of the Limpopo province.

Background

The client requested advice on how to implement a renewable energy system within the following context:

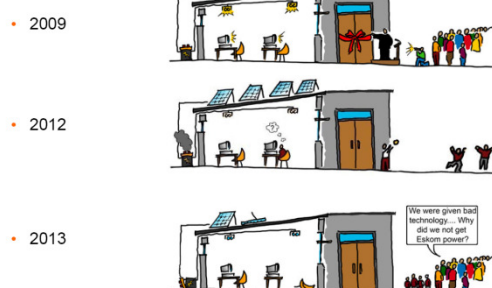
- the school would be connected to the Eskom grid, with the capacity of the supply exceeding the load / demand,
- no reliability problems have been experienced with the Eskom supply to the original school which was been replaced by the new school,
- the donors did not want to burden the school with additional monthly energy expenditures from the extra consumption of the computer centre, and therefore decided to supply the computer centre's energy from renewables,
- initial capital expenditure did not appear to be a limiting factor to the donors – they however wished to walk away from the project financially after implementation, and to a certain extent saw renewable energy as a “pay now, free energy for the next decade” solution.

It was apparent from the client's request that the problem (the additional financial burden due to the donated computers' energy consumption), and to a large extent the solution (renewable energy) was already defined from their perspective: all that was expected from the analysts was to design the actual renewable energy system.

As, from the client's perspective the decision problem was already defined, the problem-structuring phase of the project had to be approached sensitively. A presentation was made to the fiduciary stakeholders (the donors and the architects designing the new school) informing them about past experiences with rural renewable energy projects in South Africa, highlighting the social and technical uncertainties involved and recommending taking a step backwards towards reconsidering the problem in more detail (see Figure D-3).

What typically goes wrong?

- A typical project (up to now in South Africa):



Conclusions

- RES can be very useful in rural projects, BUT
 - RES is much more expensive than grid
 - RES is NOT maintenance-free
 - Theft of PV panels is a significant problem
 - Social dimension of project is vital for success

Figure D-3: Extracts from a presentation given to donors during problem structuring on the uncertainties around the use of renewable energy in rural areas.

This presentation, and the facilitated discussions around it, resulted in a shared understanding among stakeholders that a more thorough analysis of the problem, and potential solutions to it, was required. Problem structuring could now commence, informed by the original primary objective, *minimising the financial impact to the school of additional energy consumption from donated computers*, along with the following additional primary objectives, defined mostly during the facilitated discussions:

- *Minimise energy consumption of donated computers, and the school in general.* This objective was informed by lessons that were learned from a similar project in KwaZulu-Natal, where energy consumption increased dramatically after the school was upgraded. No energy management strategy was implemented at this school. A crucial element of successful renewable energy projects were highlighted through this objective: due to the restrictive nature of a renewable energy supply, focus firstly on managing energy consumption before worrying about the renewable energy supply.
- *Minimise outside support / maintenance for the implemented systems.* Apart from the financial impacts, the school is also located in a deep rural area making support and maintenance logistically challenging.
- *The implemented system should be easy to understand and use by the teachers.*
- *The implemented system should provide educational opportunities where possible.*
- *Environmental pollution should be minimised, for example battery disposal and light pollution.*

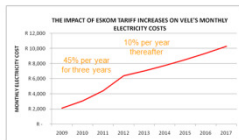
Informed by these objectives, the problem structuring process now presented more detailed information to the stakeholders (see Figure D-4):

- the estimated electricity consumption of the computer centre compared to the total (based on experience with a similar school in rural KwaZulu-Natal),

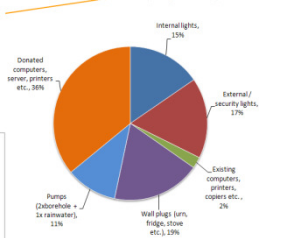
- the estimated wind and solar resource availability at the school (the wind resource was shown to be poor),
- the capital and maintenance costs over a 20 year period of wind turbines and PV panels and the associated batteries and inverters, compared to energy from the grid given future scenarios which included substantial Eskom tariff increased, and
- energy consumption management options available to the school.

The impact of Eskom tariff hikes

If Eskom's requested tariff increases becomes a reality, the monthly electricity costs will increase by 200% in the next three years. Eskom requested 45% tariff increases for each of the next three years. The red graph below indicates the impact of this scenario, with a 10% annual increase in tariffs after three years.

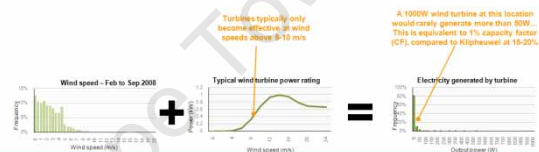


Future estimate
Monthly energy: ~ 2,700 kWh
Monthly cost: ~ R2,100 (in 2009)
~ R6,400 (in 2012?)



Renewable resources at school - wind

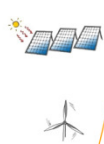
- Wind was measured onsite at the current school
 - Only available from Feb to Sept 2008
- For these months, the prevailing wind direction was from the South-East
- The weather station might experience some shading from surrounding trees
- Although wind shading might impact the speed measurements, the data still give a fair indication of the available resource. The wind appears to blow often, but at low wind speeds: **not suitable for wind turbine generation.**



Future electricity estimate

Using renewable energy for the donated computers

Renewable energy can be considered to offset the energy consumed by the donated computers. This will significantly lower the monthly energy costs. The renewable energy technology (PV panels or wind) is sized to generate the same amount of energy through the year as the estimated consumption of the donated computers. Rough estimate sizes and costs of using either PV panels or wind turbines are shown below.

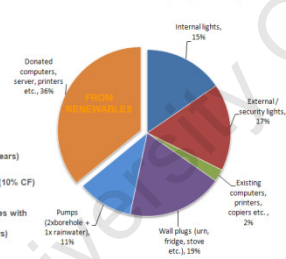


PV panels
Assume same radiation as Polokwane
Rating: 6.3 kW/peak
Capital cost: R330,000
Size of panels: 50 m²
O&M cost: very low (R50,000 over 10 years)

Wind turbines
Assume 3x more wind than measured (10% CF)
Rating: 13.6 kW/peak
Capital cost: R400,000
Number of turbines: 6-8 2.5kW turbines with rotor diameters of 3.5m
O&M cost: high (R200,000 over 10 years)

NOTE THAT WIND SPEEDS OF THREE TIMES THE MEASURED DATA IS ASSUMED...

Future estimate
Monthly energy: ~ 2,700 kWh
Monthly cost: ~ R2,100 (in 2009) ~ R1,300 (in 2009)
~ R6,400 (in 2012?) ~ R4,000 (in 2012?)



Using renewable energy

Summary of Energy Management Strategy 1/2

This presentation introduces the proposed strategy in eyelid-dropping detail – in summary the strategy is simple:

- Technical strategies:
- Meter energy consumption in different zones: reporting easily available to staff
 - Allow staff to limit energy consumption in different zones: limits easily configurable by staff
 - Place often-needed light switches within easy reach, less used switches requires more effort to switch (as per 7 fountains classroom switching)
 - Choose luminaires that are incompatible with low-efficiency lamps
 - Use daylight and movement sensors for security lights
 - Use timers for feature lights, watertank pumps and hot water cylinders
 - Implement surge arrestors
 - Make provision for future additions of UPS and renewable energy technologies
- User strategies:
- Ensure staff ownership through consultation and training in the use of the management tools
 - Identify a project champion/s among the staff, i.e. an energy manager
 - Raise awareness through posters and competitions
 - Implement theft / vandalism protection

Using renewable energy

17



Energy management strategy

4



Figure D-4: Extracts from presentations sharing information with stakeholders.

Further stakeholder deliberation finally led to the following plan of action:

- A portion of the capital originally allocated for the renewable energy system would instead be allocated to a basic but reliable energy management system that measured and displayed the energy consumption of different zones of the school in real time (as explained in Figure D-5). The system would display the energy consumption in the staff room, constantly building awareness among the teachers of energy efficiency. Ideally the consumption statistics can also be accessed by pupils working in the donated computer centre, presenting educational opportunities.

- The design of the new school would make provision for easily future implementation of a renewable energy system, through renewable energy ready wiring and distribution board layouts, difficult to reach structures for PV panel mounting, and room for an inverter and batteries. The real consumption of the donated computers would be monitored for a few months after completion of the school, after which the renewable energy system would be sized and installed.
- The theft uncertainty will be addressed by investigating theft-proofing solutions, for example PV panels that are destroyed when removed, as implemented by Telkom.
- The use of batteries will be avoided as far as possible (the inverter needs a minimum amount of batteries to operate) in order to minimise maintenance.
- The Department of Education will be approached regarding increasing budgets for schools with computer centres.
- The parents of pupils at the school have agreed to a special levy that will be allocated specifically for energy-related expenditure.

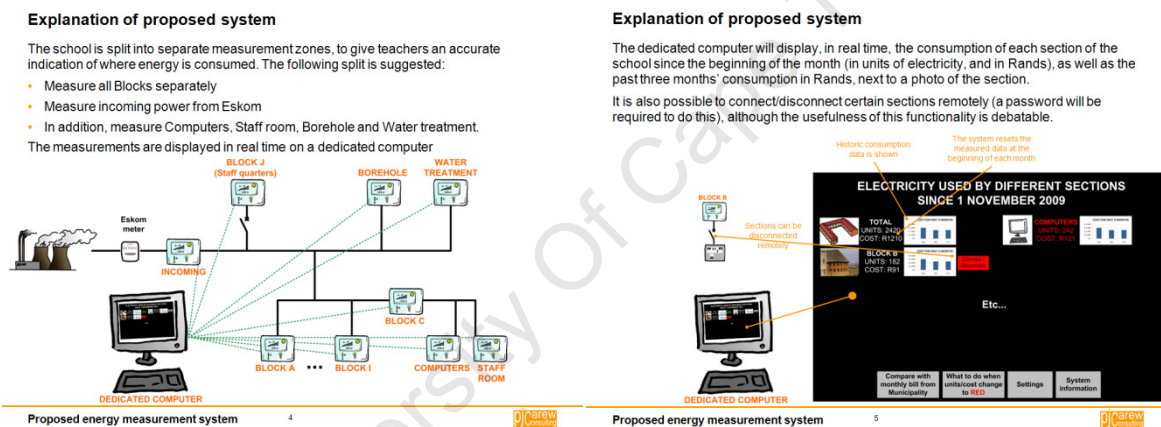


Figure D-5: Extracts from a presentation explaining the proposed energy consumption monitoring system.

Lessons learned

- *The sustainability of the project depended on non-technological factors which appear to over-ride the technical preferences of the project initiators.* Through the problem structuring phase it became clear that, with regard to project sustainability, uncertainties like uncontrolled consumption, theft and financial management capability overshadowed any technical preferences that the clients had.
- *Sharing accurate information and highlighting uncertainties during the problem structuring phase of decision aiding can significantly alter the preferences of decision makers.* By providing adequate and unbiased information during the problem structuring phase of the decision process, the “obvious” alternative of installing PV

was replaced with a set of informed alternatives with a greater probability of resulting in a sustainable implementation.

- *Including previous experience / lessons learned in the decision aiding process offer significant benefits.* Part of the presentation to the donors and architects included photos and statistics relating experiences at previous renewable energy projects. It was clear from the reaction of the audience that sharing experiences and lessons learned are more effective than theoretical information.

University Of Cape Town

Appendix E – Evaluation of decision making within the Klipheuwel project

This appendix will evaluate the extent to which decision aiding supported high quality decision making in the site-selection decision making process within the Klipheuwel Wind Energy Demonstration Facility (KWEDF) project. As measurement standard the decision quality framework developed in section 4.3 will be used.

Background to the KWEDF project

The South African Bulk Renewable Energy Generation (SABRE-Gen) program was initiated in 1998 by Eskom to investigate the viability of utility scale, renewable electricity generation as a supply-side option. The SABRE-Gen wind program, launched in 1999, focused on the following aims [CSIR 2001]:

- Understanding the implications of using wind energy on a large scale in an African environment
- Determining the most suitable application for wind energy
- Determining the most appropriate scale of implementation
- Obtaining all necessary information for the effective implementation of wind energy projects
- Preparing the market and industry for implementation
- Investigating the sustainability of wind energy in an African environment.

These aims led to a high-level request from Eskom for a wind turbine facility satisfying the following criteria [Smit et. al. 2004]:

- Near Cape Town for research purposes
- Accessible by the public for demonstrations and visits
- Different size wind turbines

- Variety of wind turbine technologies, including different generator, blade and control technologies
- Variety of wind turbine manufacturers

The objective informing these criteria were summarised by Eskom in a response to an issue raised during the scoping process in 2001 [CSIR 2001:34]: “*It is well known in commercial, engineering and R&D circles that the premature commitment to a particular technology or supplier invariably leads to a non-optimal solution. Eskom has over the years learnt that local evaluation of a technology on a pilot or demonstration basis is highly desirable prior to the making of firm and costly decisions*”

This high-level request initiated a project in 1999 that ultimately resulted in the construction of the Klipheuwel WEDF, around 50 km north of Cape Town. This wind farm, the first in South Africa, was completed (except for the ongoing business development phase) in February 2003, when the last of three wind generators (660 kW, 1.75 MW and 750 kW) was commissioned.

The facility is connected via 2.58 km of 11kV overhead cables to the Klipheuwel substation, and maintained mainly by personnel of the nearby gas turbines at Acacia. The area around the wind turbines is leased to a farmer for wheat production and grazing.

The decision problems

Two decision problems can be identified within the KWEDF project:

- **Site selection problem**, i.e. where to locate the wind farm. For the purposes of this analysis this decision problem is divided into three phases: a *preliminary phase* in which three potentially suitable sites was identified (two for inclusion in an environmental impact assessment (EIA) as required by South African legislation, and one as backup should the preferred two fail), a *scoping phase* (part of the EIA) identifying the significant issues, alternatives and decision points that should be addressed by the EIA process, and a *specialist studies phase* (part of the EIA) addressing the issues and points identified in the scoping phase.
- **Technology choice problem**, i.e. which wind turbine technology and manufacturers to use.

While the decision aiding process behind the site selection problem has been well documented (partly due to South African EIA requirements), little data is available on the process behind the technology choice problem, as the tender processes and decision structures used by Eskom during this second problem are not publicly documented. For this reason only the site selection problem will be analysed further.

Preliminary phase decision aiding

Preliminary site selection was carried out towards the end of 2000 by a team from Eskom (TSI), wind technologists from CSIR division of Manufacturing and Materials, environmental consultants from the CSIR Division of Water Environment and Forestry Technology, and the Cape Town electricity directorate. The process is described in the CSIR Site Selection Study [CSIR 2000], released in December 2000.

The aim of the preliminary phase was to identify a number of suitable sites on which to erect six to ten wind turbines rated at around 10 MW in total, and recommend two or three sites for further assessment in an EIA.

The criteria used to identify the potential sites were:

- Technical:
 - Wind energy and climate using existing data sources (speed, direction, turbulence and obstructions, data availability). This was defined as the primary criterion
 - Geology and soil type
 - Access by road for large construction vehicles and equipment
 - Accessible to researchers and the public
 - Profile
 - Land ownership
 - Compatibility with current planning and zoning
 - Ease of grid integration
- Environmental:
 - Proximity to socially sensitive sites (e.g. residential areas)
 - Proximity to ecologically sensitive sites (e.g. wetlands, protected areas).
 - Archeologically sensitive sites
- Other:
 - Electromagnetic compatibility
 - Potential for supporting local alliances

During October 2000, an initial list of 21 Western Cape sites was compiled during brainstorming sessions, based on the existing knowledge of the site selection team. The 21 identified sites were scattered around the Western Cape, but were concentrated within the greater Cape Metropolitan Area, due to the alliance between Eskom and the City of Cape Town [CSIR 2001]

The number of these sites was then reduced to 10 by eliminating sites with obvious flaws in relation to the above criteria. Table E-1 below indicates the eleven sites that were eliminated, along with the reasons for elimination.

Table E-1: Listing of the 11 sites eliminated from the 21 original sites. Reproduced from [CSIR 2002:30]

| Sites eliminated | Reasons for elimination |
|------------------------------|--|
| Agulhas area | Relatively low profile; too far from Cape Town metropolitan area |
| Athlone power station | Relatively poor wind conditions; too close to metropolitan area. |
| Cape Point | Part of a protected area (Cape Peninsula National Park) |
| Culemborg | Too close to metropolitan area; non-alignment with existing planning and zoning |
| Danger Point / Quoin Point | Relatively low profile; too far from metropolitan area |
| Darling area | A private wind power generation initiative is already in progress in this area |
| Koeberg power station area | Part of a protected area and Natural Heritage Site (Koeberg Nature Reserve) |
| Lambert's Bay | Relatively low profile; too far from metropolitan area |
| Saldanha | Too far from metropolitan area; also, suitable site could not be located for inclusion in the site selection; site excluded from further analysis; |
| Somerset West / Gordon's Bay | Relatively low profile; non-alignment with existing planning and zoning |
| Koeberg Hill | Non-alignment with existing planning and zoning; possible problems with electromagnetic compatibility with beacons on site. |

The site selection team conducted site visits to the remaining sites between 15 and 17 November 2000. After conducting some further research, each member of the selection team was asked to rank the 10 remaining sites according to the site identification criteria. This process reduced the number of suitable sites to five. Table E-2 indicates the eliminated sites and reasons.

Table E-2: Sites eliminated during team-members ranking process. Reproduced from [CSIR 2002:30]

| Site eliminated | Reasons for elimination |
|------------------------|--------------------------------|
|------------------------|--------------------------------|

| | |
|---------------------------------------|--|
| Beacon 426, north of Durbanville | Available area too small to accommodate planned number of turbines |
| Lebanon State Forest, Grabouw | Part of a conservation area (Kogelberg Biosphere Reserve, core area) |
| Red Hill, Simonstown | Part of a conservation area (Cape Peninsula National Park) |
| Rondebossieberg, north of Durbanville | Available area too small to accommodate planned number of turbines; difficult access over steep farm roads |
| Steenbras Dam, Grabouw | Part of a conservation area (Kogelberg Biosphere Reserve, core area). |

Detailed analysis was now done on the five remaining sites, from which a ranking preference was obtained in order to identify the top three sites for the EIA study. Table E-3 presents the decision matrix and the resulting ranking, while Table E-4 gives more details of each site.

The Oliphantskop and Klipheuwel sites were found to be most suitable for the EIA process, with the Philadelphia site kept in reserve.

Table E-3: Synthesis of detailed site assessment. Reproduced from [CSIR 2001, Appendix 10]

| Criteria | Klipheuwel | Oliphantskop | Philadelphia | Strandfontein | Wingfield |
|--------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| Wind Speed | 5 m.s ⁻¹ (modelled) | 5 m.s ⁻¹ (modelled) | 5 m.s ⁻¹ (modelled) | 6 m.s ⁻¹ (modelled) | 5 m.s ⁻¹ (measured) |
| Turbulence & Obstruction | Medium | Medium | Medium | Low | Medium |
| Grid Integration | Favourable | Medium | Unfavourable | Unfavourable | Favourable |
| Land ownership | Negotiation required | No negotiation required | Negotiation required | No negotiation required | Negotiation required |
| Accessibility | High | Medium | Medium | Medium | High |
| Profile | High | High | High | Medium | High |
| Social Sensitivity | Residential: near site | None identified | Residential: near site | Residential: near site | Residential: near site |
| Ecological Sensitivity | None identified | Possibility of bird strikes | None identified | Possibility of bird strike | Possibility of bird strike |
| E'magnetic Interference | To be assessed | To be assessed | To be assessed | To be assessed | To be assessed |
| Ranking | 1 | 2 | 3 | 4 | 5 |

Table E-4: The alternatives considered for selection to the final EIA process. Reproduced from [CSIR 2002:31]

| Site | Comments |
|--|--|
| Oliphantskop (Oliphantskop 81, Blouberg) | Preferred site; ranked among the top three sites - |

| | |
|--|--|
| | considered to be a very suitable site |
| Klipheuwel Telkom farm (Radio 918, Klipheuwel) | Preferred site; ranked among the top three sites - considered to be a very suitable site |
| Philadelphia (Dassenvaley 45/2) | Ranked among the top three sites - considered a very suitable site except for possible non-alignment with planning and zoning and expected difficulties with land acquisition; kept in reserve in case either of the preferred two sites were eliminated during the EIA process. |
| Strandfontein coast (Macassar to Muizenburg) | Despite extensive research, no suitable locality could be identified within the broad 'Strandfontein' coastal stretch; deep, shifting sands in this area could present problems for construction; therefore this site was eliminated in the final stage. |
| Wingfield Aerodrome | Considered a relatively suitable site but due to its very close proximity to the central business district, and the possibility of problems with bird strikes, this site was eliminated in the final stage |

The actors in the decision making process can be identified as follows:

- Decision maker: Eskom
- Client: Eskom
- Analyst: Eskom, CSIR, Cape Town electricity directorate
- Standard and fiduciary stakeholders: possibly government and municipal authorities
- Silent stakeholders: local residents, community groups and general public

Scoping phase decision aiding

Since the construction of a wind energy facility is listed in South African legislation as an activity that may significantly affect the environment, it is subject to an environmental impact assessment (EIA). Eskom commissioned CSIR Environmentek and Phila Development & Communications to undertake an EIA for the proposed WEDF.

In December 2000 a meeting was held between CSIR and the provincial Department of Environmental and Cultural Affairs and Sport (DECAS), the body responsible for approving the EIA, to discuss the proposed project, the relevant processes and legislative requirements. An application form and screening checklist to undertake an EIA of the proposed activity was then submitted to DECAS.

The first part of this EIA process was the scoping process, defined by the CSIR [2001] as *“the process of identifying the significant issues, alternatives and decision points that should be addressed by the EIA process. The aim of the scoping process is to support*

informed decision-making by providing information on the potential environment effects of developments before decisions are taken.”

Scoping took place between January and August 2001, and was based around the following project alternatives:

- Do not construct a WEDF, i.e. maintain the status quo.
- Establish a WEDF on Groot Oliphantskop Farm, Blaauwberg
- Establish a WEDF at the Telkom site, Klipheuwel

In January 2001, a plan outlining the proposed process for scoping was submitted to DECAS by the CSIR for review. A social probe in the form of telephone and personal discussions with key individuals also took place in this month, in order to refine the public participation process.

A number of workshops were held with key stakeholders: on 1 and 5 February 2001 with the Durbanville and Blaauwberg municipalities, and environmental groups, and on 22 and 23 Feb 2001 with residents of Klipheuwel and Oliphantskop.

Press advertisements were placed in two metropolitan and four community newspapers between 12 and 17 February 2001, giving notice of the EIA and dates and venues of the scoping workshops and contact details of the public participation facilitator. Signboards were also placed at the entrances of both sites for 21 days in March 2001.

On 21 February 2001 Information Sheet No 1: Background Information Document (BID) was sent out to all interested and affected parties (I&APs), describing what the WEDF was about, and inviting comments and participation in the EIA process.

The BID and press notices marked the formal start of public involvement in the EIA process, with public scoping workshops held between 7 and 14 March 2001 at Melkbosstrand, Klipheuwel, Durbanville and Milnerton.

On 12 June 2001 a Draft Scoping Report and Information Sheet No 2: Summary of Draft Scoping Report were released. The report was sent out for public comment to the relevant authorities and key interest groups, and the summary to all I&APs. The purpose of the report was to present potential environmental impact issues associated with the facility, as identified by EIA consultants, I&APs, and from responses to the BID and press notices.

A public review and comments period of four weeks was allowed after the release of the Draft Scoping Report. A wide range of questions and comments were received during this period, although only the following comments were found to be potentially relevant to this research:

- The acting CEO of the Cape Metropolitan Council administration expressed concern that the preliminary phase had no public or local authority input.

Comments during this period were synthesized by the CSIR into a Comments Report. The Final Scoping Report [CSIR 2001], incorporating all comments received on earlier documentation, was submitted to DECAS in August 2001.

DECAS had to decide, after review of this document, on one of the following courses of action:

- issue authorization for the project to proceed, possibly with conditions attached,
- require the process to expand into an EIA where certain issues and alternatives will be investigated further,
- or decline the application.

DECAS advised that an EIA was needed for further investigation of the following outstanding issues and alternatives related to the Oliphantskop and Klipheuwel sites:

- Visual impacts
- Noise impacts
- Impacts on bird populations
- Impact on heritage resources
- Wind climate at the proposed sites
- Electromagnetic interference

The actors in the process can be identified as follows:

- Decision maker: DECAS
- Client: Eskom
- Analyst: CSIR Environmentek and Phila Development and Communication
- Standard and fiduciary stakeholders: initially government and municipal authorities, local residents, and community groups, and later general public
- No silent stakeholders

Specialist studies phase decision aiding

Eskom now commissioned technical studies of two issues identified in the scoping process, namely:

- wind climate at the proposed sites and
- electromagnetic interference,

while the CSIR appointed specialists to investigate the remaining four issues:

- visual impacts
- noise impacts
- birding impacts, and
- heritage and archaeological impact.

The CSIR stipulated that the specialist studies should conform to the following requirements [CSIR 2001:40]:

- Quantify wherever possible, the potential direct and cumulative environmental effects
- Assess impacts during all phases of the project: site preparation and construction, operation, closure and rehabilitation
- Assess the impacts with and without mitigation

Specialists were instructed to use the following criteria to assess the significance of the impacts:

- Extent of impact: immediate areas only, within 5km of development, regional, national or international
- Duration of impact: short-term (shorter than 5 years), medium term (5 to 15 years), long term (15 years or longer) or permanent
- Intensity of impact: high, medium, low, and negligible. *“The specialist studies must attempt to quantify the magnitude of impacts and outline the rationale used. Where appropriate, national standards are to be used as a measure of the level of impact.”*
- Probability of occurrence: improbable, probable, highly probable or definite
- Legal requirements: list specific legislation and permit requirements.
- Status of impact: positive (a benefit), negative (a cost), or neutral

- Degree of confidence in predictions: based on the availability of information and specialist knowledge.

The CSIR finally required that the significance of the impacts should be aggregated from the results of the above criteria, and then described as follows:

- Low: the impact will not have an influence on the decision or require significant accommodation in the project design
- Medium: the influence on the environment will require modification of the project design or another form of mitigation
- High: where it would have a “no-go” implication for the project regardless of any possible mitigation

By September 2001 these specialist studies were in the process of being peer reviewed.

The findings of the studies by Eskom and the CSIR-appointed specialists are presented in Table E-5. The significance rating given in this table assume that all mitigation measures recommended by the specialist studies have been implemented.

Table E-5: Summary of impact assessments. Reproduced from [CSIR 2002:118]

| | Impact category | Oliphantskop | Klipheuwel |
|-------|---|---------------------|-------------------|
| | Visual | Low | Low |
| Noise | Effects on humans | Low | Low |
| | Effects on livestock | Negligible | Negligible |
| Birds | Wild birds | Medium | Medium |
| | Racing pigeons | Low | Low |
| | Heritage / archaeology | Medium | Low |
| | Electromagnetic interference | Negligible | Negligible |
| | Other issues that may inform decision-making: | | |
| | Wind climate | Adequate | Adequate |
| | Compatibility with land use planning | Moderate | Well-aligned |

The residual impacts (impacts remaining once appropriate mitigation has been implemented) at each of the sites are listed below [CSIR 2002:117]:

- Oliphantskop:
 - Possible, infrequent, bird strikes by large-bodied birds such as cranes and storks, coastal birds and raptors.

- Loss of cultural landscape values related to the integrity of the rural agricultural setting in the area, and possible damage to existing historical buildings and archaeological sites.
- Klipheuwel:
 - The main impact of concern is the seasonal pan located on the area earmarked for construction of the wind turbines.

No fatal flaws, or impacts of high significance that would necessitate substantial redesign or termination of the project, were identified during the specialist studies within the EIA process.

On 23 November the Draft Environmental Impact Report and associated Information Sheet No 3: Summary of Draft EIR was released to key stakeholders and I&APs for comment.

The Final Environmental Impact Report [CSIR 2002], incorporating any comments received on earlier documentation, was submitted to DECAS in February 2002. DECAS approved the EIA, selecting Klipheuwel as the preferred site, and issued a Record of Decision. Eskom communicated this decision to all key stakeholders and I&APs, who was given a 30-day appeal period against the decision.

The actors in the decision making process can be identified as follows:

- Decision maker: DECAS
- Client: Eskom and CSIR
- Analyst: Specialists undertaking studies
- Standard and fiduciary stakeholders: government and municipal authorities, local residents, community groups and general public
- No silent stakeholders

Eskom's involvement in community development

Eskom was involved in the development of the Klipheuwel community in the following ways [Smit et. al. 2004]:

- Two large containers, donated by Maersk, were converted into an additional classroom for the Klipheuwel Primary School, situated 3km from a poor community. Eskom and Partners International funded the material and labour.

- Eskom also committed R1 million into a trust towards building a new school closer to the community.

Analysis of the quality of the decision aiding process

The decision aiding process underlying the KWEDF site selection problem, as described above, were generally of high quality, as shown in the analysis contained in Table E-6. In this analysis the identified characteristics of high quality decision making serves as benchmark against which to compare the decision aiding process. It can be argued that the South African policy and legislative context, as explored previously, significantly informed the quality of this process.

Table E-6: Analysis of the quality of decision aiding used in the KWEDF site selection project.

| High quality decision making characteristics | Criteria of tools and approaches that aid high quality decision making | Contribution of the tool/approach (Negative, None, Limited, Strong, Not Applicable) |
|--|---|---|
| Well considered | Decision problem structured (i.e. objectives, criteria and alternatives clearly defined)? | Strong: From inception the project objectives were clearly defined, informed by the objectives of the SABRE-Gen program, and during the specialist studies phase by objectives/requirements stipulated by the CSIR. These objectives guided the development of formal families of criteria and ultimately decision alternatives. |
| | Multi-dimensionality acknowledged? | Strong: Multi-dimensionality is a underlying principle of the EIA legislation of South Africa, and this principle has been acknowledged throughout the site selection process, from the preliminary phase decision criteria which ranged from technical and environmental to social, to the specialist studies phase's criteria on the significance of the impact of each topic under study. |
| | Soft uncertainties acknowledged? | Strong: An important reason for the requirement to undertake an EIA was to address any possible uncertainties associated with the project. A number of soft uncertainties were acknowledged during the scoping phase of the decision process (e.g. wind climate and electro-magnetic interference); these soft uncertainties were minimised through specialist studies. Uncertainty within the results of these specialist studies was managed by including the 'probability of occurrence' and 'degree of confidence in predictions' criteria. |
| | Hard uncertainties acknowledged? | Limited: Potential hard uncertainties, although not specifically identified as such, were addressed in the site selection decision process, for example: <ul style="list-style-type: none"> • whether one of the two sites selected for the EIA process would be acceptable (acknowledged by identifying a third site as backup) • whether noise and visual impacts would be perceived as unacceptable by people living nearby (acknowledged during the preliminary phase by including a 'social' criteria which specified the distance of the site from residential areas, and later during the process by including a site far from residential areas as one of the two sites put forward for the EIA) |

| | | |
|-----------------------|--|--|
| Informed | Incorporate past lessons learned / experiences? | Strong: During the preliminary phase brainstorming sessions was used to draw from past experiences of the task group members and encourage divergent thinking. During the next two phases wide public participation and specialist studies was used to inform the decision process. The strong emphasis in EIA requirements on stakeholder inclusiveness and transparency improved the likelihood of accurate, adequate and unbiased data. |
| | Accurate, adequate and unbiased data? | |
| Inclusive | Stakeholder inclusive? | Strong: Only small task and special interest groups were involved in the preliminary phase decision process. This cannot be deemed non-inclusive, as the preliminary stage involved problem definition, a process that would not have benefited from wider stakeholder participation. The scoping and specialist studies phases of the process attempted to involve a wide range of stakeholders through a social probe, workshops with key stakeholders, press advertisements, signboards, public scoping workshops etc, resulting in an excellent example of a successful public participation process. |
| Transparent | Transparent data sources / methodologies? | Strong: Transparency results from strong stakeholder participation and a well-documented audit trail, both characteristics of the site selection process. The client supplied and described preference scales wherever possible, and referenced data sources. Although no information is given on the weighing between criteria used in the preliminary phase (except that the 'wind energy and climate' criterion was considered 'primary'), a simple outranking exercise could have indicated the preferred alternative, making weighing largely unnecessary. The client did not specify the method of aggregation of criteria, nor was the rational used for aggregation described in any of the specialist studies. |
| | Audit trail? | Strong: The site selection process was comprehensively documented, with all documents available to the general public. |
| Flexible and adaptive | Process can adapt to context through iterative feedback loops? | Strong: Feedback loops were built into the decision process through regular opportunities for stakeholders to comment on and question the decision process. These comments and answers were documented and disseminated to stakeholders throughout the process, thereby encouraging a constructive decision aiding process where stakeholder preferences and the decision process can adapt to the context. |
| Implementation plans | Detailed implementation plans as outcome? | Strong: CSIR [2002:114] lists 17 "recommendations for design and monitoring" related to visual and noise, bird population, and heritage and archaeological impacts. These detailed recommendations range from the colour of the wind turbine blades for minimum visual impact, to monthly bird surveys on site (and bird strike recording). These recommendations were incorporated into an Environmental Management Plan as required by the EIA process [CSIR 2002:viii] |
| | Post-process monitoring plans as outcome? | |

Appendix F – Project Cycle Management and the Logical Framework Approach

Project Cycle Management (PCM) and the Logical Framework Approach (LFA) are introduced and explained in this appendix.

A brief overview of PCM and LFA

A variety of PCM and LFA variants exist. For this research the PCM and LFA described in “Project Cycle Management Handbook version 2”, published by the European Commission in 2002 [EC 2002], is used. The decision to use this specific interpretation of LFA was largely based on the facts that the EC’s PCM approach is well documented in the public domain, and focuses strongly on objective alignment.

Project Cycle Management is used to define the management activities and decision making procedures during different stages of the project life. The project cycle also provides a structure which is meant to ensure that crucial activities, for example stakeholder participation, are engaged in at the required times to ensure “*informed decisions*” [EC 2002:p3].

Within the PCM, LFA is the methodology that is followed for planning, managing and evaluating. The LFA was developed in 1969 by Rosenberg for USAID, and is used by a number of large donor organisations, for example AUSAID, SIDA, UNDP and the EC. The product of the LFA is a matrix called the Logframe which summarises what the project intends to do and how, what the key assumptions are, and how outputs and outcomes will be monitored and evaluated.

The following two sections introduce PCM and the LFA in more detail, specifically related to ways in which they support high quality decision making. For a full explanation of these approaches, please refer to [EC 2002]. The diagrams used in these sections have all been reproduced from [EC 2002].

The EC's Project Cycle Management

The aim of PCM as defined by the EC [2002:p4] is to try to ensure that:

- “projects respect and contribute to overarching policy objectives of the EC”,
- projects are relevant to the real problems of target groups / beneficiaries,
- project objectives are realistically achievable within the project constraints, and
- projects deliver sustainable benefits.

In order to try and ensure the above, the EC's PCM approach has the following characteristics:

- the LFA is used to provide a structure to analyse problems, work out solutions, and successfully implement them,
- high quality key documents must be produced in each phase, as shown in Figure F-1,
- stakeholder participation is required,
- clear formulation and focus on one project objective, defined in terms of the sustainable benefit to the target group(s), and
- the incorporation of key quality issues into the design from the beginning.



Figure F-1: The project cycle: major documents and decisions [EC 2002:p4]

An important part of ensuring high quality documentation is to require that the documents used in the various phases of the PCM share a common format based on the core logic of the LFA, as shown in Figure F-2.

| |
|---|
| <p>1. Summary</p> <p>2. Background: Overall EC and Government policy objectives, and links with the Commission's country programme or strategy, commitment of Government to overarching policy objectives of the EC such as respect of human rights</p> <p>3. Sectoral and problem analysis, including stakeholder analysis and their potentials</p> <p>4. Project / programme description, objectives, and the strategy to attain them ⇒ Including lessons from past experience, and linkage with other donors' activities ⇒ Description of the intervention (objectives, and strategy to reach them, including Project Purpose, Results and Activities and main Indicators)</p> <p>5. Assumptions, Risks</p> <p>6. Implementation arrangements ⇒ Physical and non-physical means ⇒ Organisation and implementation procedures ⇒ Timetable (work plan) ⇒ Estimated cost and financing plan ⇒ Special conditions and accompanying measures by Government / partners ⇒ Monitoring and Evaluation</p> <p>7. Quality factors ⇒ Participation and ownership by beneficiaries ⇒ Policy support ⇒ Appropriate technology ⇒ Socio-cultural aspects ⇒ Gender equality ⇒ Environmental protection ⇒ Institutional and management capacities ⇒ Financial and economic viability</p> <p>Annex: Logframe (completed or outline, depending on the phase)</p> |
|---|

Figure F-2: Standard document structure required by the PCM [EC 2002:p5]

The manner in which high quality decision aiding is ensured within PCM will now be explored in more detail, focussing on each individual phase:

Programming

In the programming phase problems, constraints and co-operation opportunities on a national and sectoral level are identified. The purpose of this phase is to develop a relevant and feasible programming framework within which projects can be identified and planned.

This framework is documented in a Country Strategy Paper (CSP), which should be drafted on the basis of close discussion and consensus with the partner country (improving ownership and therefore the chances of successful implementation).

The EC specify that the CSP must have the following structure, which fundamentally reflects the major elements of the LFA:

1. *“A description of the EC co-operation objectives.*
2. *The policy objectives of the partner country.*
3. *An analysis of the political, economic and social situation, including the sustainability of current policies and medium-term challenges.*
4. *An overview of past and ongoing EC co-operation (lessons and experience), information on programmes of EU Member States and other donors.*
5. *The EC response strategy, identifying a strictly limited number of intervention sectors that is complementary to interventions by other donors.”* [EC 2002:p6]
6. A National Indicative Programme (NIP), which is in essence a detailed translation of the response strategy.

The NIP may be an integral part of the CSP document, covers a future period of typically 3-5 years, and identifies and defines appropriate measures and actions to reach the objectives defined earlier in the CSP. The NIP should contain the following:

- Global objectives which sets out the strategic choices for EC co-operation, based on the EU's and the country's priorities;
- Financial requirements for each identified co-operation area, which might include indicative timing and size of EC contributions;
- Co-operation area-specific objectives and expected results, with main performance and key outcome indicators which must relate to developments that are measurable in the short/medium term;
- How crosscutting issues are taken into consideration (gender, environment, etc.);
- Details of programmes to be implemented in pursuit of these objectives, the intended beneficiaries and the type of assistance to be provided (e.g. macroeconomic support, technical assistance, training, investment, supply of equipment, etc). The NIP should also include project ideas, along with general criteria for their realisation (such as geographical area, most suitable partners, suitable duration of projects). [EC 2002:p7]

A number of indicators are used in the programming stage, based on the LFA except for the input indicators:

- Input indicators: a measure of the financial, administrative and regulatory resources provided by the Government and donors. Useful to establish a link

between the resources used and the results achieved, which gives an indication of the efficiency of the actions carried out.

- Output indicators: a measure of the immediate and concrete consequences of the measures taken and resources used. Within the LFA these indicators will measure direct consequences of activities implemented.
- Outcome indicators: a measure of short-term results at the level of beneficiaries. Within the LFA these indicators correspond to results level indicators.
- Impact indicators: a measure of the long-term consequences of the outcomes, which measure the general objectives in terms of national development and poverty reduction. Within the LFA impact indicators are measures at the level of the Purpose and the Overall Objectives. [EC 2002:p8]

The EC suggest that the following questions should be asked to provide guidance when checking the quality of an Indicative Programme:

- *“Are the objectives of the indicative programme clear and unambiguous? Do they cover aspects of good governance, poverty alleviation, environmental protection and gender equality?”*
- *Are the sectoral objectives clearly linked to the objectives of the indicative programme?*
- *Are the objectives clearly defined? Are the indicators appropriate?*
- *What are the assumptions and risks underlying the objectives? How critical to the programme’s success are they and how likely is it that they will be achieved?*
- *Have the goals and objectives been clearly understood and accepted by all relevant partner country institutions?”* [EC 2002:p10]

Identification

During the identification phase the relevance of project ideas generated during the programme phase are analysed within the framework established by the CSP. This phase includes analysis of stakeholders, likely target groups and beneficiaries (who they are, the problems they face, and identification of options to address these problems).

The expected outcomes of the identification stage are [EC 2002:p10]:

- Pre-feasibility studies, to be done when required to identify or clarify specific ideas, and to identify what further studies might be required to formulate a project or action. The pre-feasibility study should include a draft implementation

schedule, which outline the timing for the major elements of further preparation and implementation.

- A project identification sheet based on the pre-feasibility study, which also examines the alignment between the proposed project and the CSP/NIP objectives.
- A decision whether or not to take a specific project idea further, along with a priority list which indicates which projects to implement first.

Figure F-3 indicates which parts of the Logical Framework should be completed by the end of the identification stage: the pre-feasibility study should develop a rough project description informing the Intervention Logic and the Assumptions. The study should therefore go through the Analysis Stage and parts of the Planning Stage of the LFA, including Stakeholder Analysis, Problem Analysis, Analysis of Objectives, and Strategy Analysis. Typically a rough elaboration of the Intervention Logic and the Assumptions for the preferred option is sufficient, along with some indication of possible Indicators, especially at the level of the Project Purpose and the Results.

| Intervention Logic | Objectively Verifiable Indicators | Sources of Verification | Assumptions |
|--------------------|-----------------------------------|-------------------------|----------------|
| Overall Objectives | | | |
| Project Purpose | | | |
| Results | | | |
| Activities | Means | Cost | |
| | | | Pre-conditions |

Figure F-3: The parts of the Logframe that should be completed by the end of the identification stage [EC 2002:p11]

The EC provides questions and assessment criteria to check the quality of the pre-feasibility study generated in this phase. In essence this verifies that the project ideas are likely to be relevant and feasible:

Relating to relevance, questions include:

- “Are the project objectives in line with the overarching policy objectives of strengthening good governance, human rights and the rule of law, and poverty alleviation?” [EC 2002:p13]

Relating to feasibility, questions include:

- *“Will the Project Purpose contribute to the Overall Objectives (if the Assumptions hold true)?*
- *Are Results products of the implementation of Activities?*
- *Will the Project Purpose be achieved if the Results are attained?*
- *Have important external factors been identified?*
- *Is the probability of realisation of the Assumptions acceptable?”* [EC 2002:p14]

Appraisal

During the appraisal phase project ideas that have proven feasible and relevant are developed into detailed project plans. The EC stresses a focus on feasibility and sustainability / quality in these plans, while checks need to ensure stakeholder participation and consideration for cross-cutting issues and overarching objectives.

A feasibility study is used in this stage to inform a decision on whether or not to continue with the project, drawing up a formal financing proposal and seeking funding.

The expected outcomes of the Appraisal phase are:

- A feasibility study to establish whether the project identified in the pre-feasibility study is relevant, feasible and likely to be sustainable, and to detail the technical, economic and financial, institutional and management, environmental and socio-cultural and operational aspects of the project. A detailed Logical Framework should form part of this study, covering all aspects of the framework as shown in Figure F-4. In addition an outline of an Activity and Resource Schedule should be prepared, along with a first draft financing proposal. [EC 2002:p15] Holding a planning workshop focussing on eliciting final agreement between various stakeholders on the various parts of the Logical Framework is strongly recommended by the EC, as this improves ownership by the target groups / beneficiaries.
- A decision taken by the EC and the partner country to either prepare a financing proposal based on the study, reject the proposal, or to further study certain aspects that required clarification.

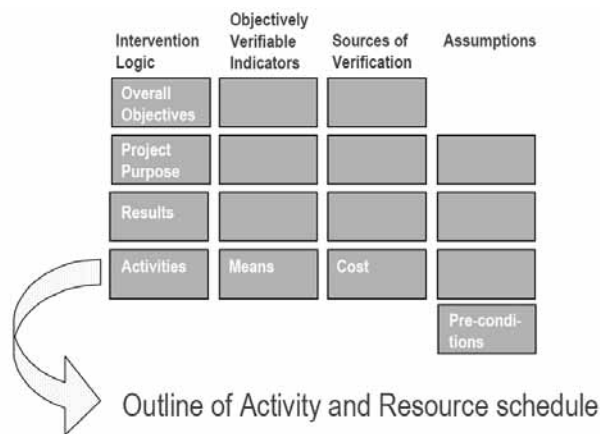


Figure F-4: The parts of the Logframe that should be completed by the end of the appraisal stage [EC 2002:p15]

A number of quality criteria, in the form of questions, are proposed for use while preparing the feasibility study, to ensure that the project is relevant, feasible and likely to be sustainable.

Questions relating to feasibility include:

- *“Have important external factors been identified?”*
- *“Is the probability of realisation of the Assumptions acceptable?”*

Questions relating to sustainability include:

- *“Will there be adequate ownership of the project by the target groups / beneficiaries*
- *Will the relevant authorities have a supportive policy during implementation and after project completion?”*
- *Is the technology approach appropriate for the local conditions?”*
- *Will all beneficiaries have adequate access to benefits and products during and after the project?”*
- *Will the implementing agencies be able to provide follow-up after the project?”*

[EC 2002:p17-18]

Financing

In the financing phase a financing proposal is completed, based on which a decision is made on whether or not to fund the project. A formal agreement is then entered into with the partner Government or another entity, including essential financing implementation arrangements.

The expected outcomes of Financing are:

- A final version of the financing proposal in the defined format, which must include the following [EC 2002:p20]:
 - A complete Logical Framework
 - Stakeholder analysis, problem and objectives analysis
 - Implementation Schedule and Overall Activity Schedule
 - Environmental Integration Form
 - Gender Integration Form
 - Economic and Financial Analysis
- A decision taken by the EC and the partner country to either fund, redesign or reject the project.
- If accepted, a signed financing agreement or memorandum signed by the EC and the partner country.

Implementation

The implementation phase aims to achieve the project purpose and contribute to the overall objectives, typically through contracts for studies, technical assistance, works or supplies. The progress of the implementation is monitored and reported on, in order to enable adjustment to changing circumstances.

The expected outcomes of Implementation are:

- A project that meets its purpose and contribute to its overall objectives.
- Evidence that shows that project resources have been used in an “*efficient, effective and transparent*” way. [EC 2002:p21]

Three principles apply throughout the implementation process:

1. Planning and replanning: ensuring that the initial Implementation Schedule, Logframe and Activity and Resource schedules are regularly reviewed, refined and updated.
2. Monitoring: ensuring that the project stays on track. Monitoring is defined by the EC [2002:p22] as “*the systematic and continuous collection, analysis and use of information for management control and decision-making. Implementation is a continuous learning process where experience gathered is analysed and fed back into planning and updated implementation approaches.*”

3. Reporting: progress reports, typically submitted on a quarterly basis, aims to check the state of advance of the project in light of its objectives, including details of budget implementation and future budgetary provisions.

Evaluation

Evaluation is a systematic and objective assessment of a project, and aims to determine “the *relevance and fulfilment of objectives, developmental efficiency, effectiveness, impact and sustainability*” of such a project. The outcomes of an evaluation should provide information that enables the incorporation of lessons learned into the decision making processes of future projects.

Evaluations can take at any stage of a project:

- Ex ante evaluations: typically studies done during the preparatory phases of the project cycle, for example pre-feasibility or feasibility studies.
- Mid-term and final evaluations: done during and at the end of implementation. These evaluations are distinct from monitoring during the implementation phase, in that it analyses the efficiency, effectiveness, impact, relevance and sustainability of aid policies and actions, compared to monitoring which mainly measures actual vs. planned project deliverables.
- Ex post evaluation: done a number of years after completion, often focusing on the impact of the project.

Evaluations under EC funds follow evaluation criteria [EC 2002:p28] that are closely linked to the Logframe, as shown in Figure F-5:

- Relevance: how closely project objectives aligned with the problems it set out to address, and with the physical and policy environment within which it operated.
- Efficiency: how well project means have been converted into results, in terms of quality, quantity and time.
- Effectiveness: how much the project results contributed to achievement of the project purpose, and the influence of assumptions.
- Impact: what the effect of the project was on its wider context, including its contribution to Overall Objectives and the overarching policy objectives of the EC.
- Sustainability: the likelihood that project benefits will continue to flow after external funding has ended, focussing specifically on factors of ownership by beneficiaries, policy support, economic and financial factors, socio-cultural

aspects, gender equality, appropriate technology, environmental aspects, and institutional and management capacity.

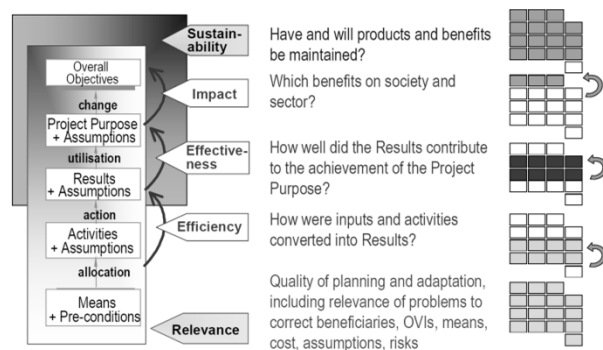


Figure F-5: Linking evaluation criteria to the Logframe [EC 2002:p29]

The EC's implementation of the LFA and Logframe

As with PCM an overview of the LFA will be given here. The overview will be brief, as the Logframe has already been discussed in some detail in the previous section; detailed methodology can be found in a number of sources, for example [EC 2002].

The Logical Framework Approach (LFA) is an important tool within the PCM for project planning and management. During project planning the LFA is used to identify and analyse a given situation, and to then define objectives and activities that can be undertaken to improve on this situation. During implementation the LFA is a key management tool that informs activity scheduling and monitoring, and after implementation provides a project evaluation framework.

It should be noted that the LFA is supported by a range of other tools during PCM, including Environmental Impact Assessment, Gender Impact Analysis, and Financial and Economic Analysis. The advantages of using the LFA includes that it structures the objectives of programmes/projects and indicates whether they have been achieved, and monitors factors outside the scope of the programme/project which influences its success.

The logical framework matrix (Logframe) is used to summarise the most important aspects of a project, resulting from the LFA process. The structure of the Logframe is shown in Figure F-6, summarising:

- “why a project is carried out (*Intervention Logic*)
- what the project is expected to achieve (*Intervention Logic and Indicators*)

- *how the project is going to achieve it (Activities, Means)*
- *which external factors are crucial for its success (Assumptions)*
- *where to find the information required to assess the success of the project (Sources of Verification)*
- *which means are required (Means)*
- *what the project will cost (Cost)*
- *which pre-conditions have to be fulfilled before the project can start (Pre-conditions)” [EC 2002:p33]*

| | Intervention Logic | Objectively Verifiable Indicators | Sources of Verification | Assumptions |
|--------------------|--------------------|-----------------------------------|-------------------------|----------------|
| Overall Objectives | | | | |
| Project Purpose | | | | |
| Results | | | | |
| Activities | | Means | Cost | |
| | | | | Pre-conditions |

Figure F-6: The logical framework matrix [EC 2002:p33]

The LFA is evolutionary and iterative in nature, and starts with a comprehensive analysis of the existing situation, which is then used to inform planning. The process of drawing the Logframe is split into these two phases: analysis and planning.

The analysis phase consists of four steps, designed to analyse the existing situation:

1. Stakeholder analysis, where major stakeholders, target groups and beneficiaries are identified and characterised.
2. Problem Analysis, where key problems, constraints and opportunities are identified, and cause-and-effect relationships are developed.
3. Analysis of Objectives, where an image of an improved future situation is generated by generating objectives from the identified problems with the help of means to ends relationships.
4. Analysis of Strategies, where the most appropriate strategy to achieve the objective is identified

During the planning phase the results from the analysis phase is translated into an operational plan for implementation, which include activity and resource scheduling.

References

Alexander T 2000, *Global accountability: how to improve international decision making*, a discussion paper in two parts, Charter 99, London, UK as quoted from Hemmati [2002:p63]

Afrane-Okese Y 2003, *Operational Challenges of Large Scale Off-grid Programme in SA*, NER Quarterly Journal, Issue 4, 2003, National Electricity Regulator

Aitken R 2008, telephone conversation.

Afrane-Okese Y 2005, email correspondence.

Anonymous 2007, personal interview with decision maker involved in electrification projects, who requested anonymity

Banks DI 1998, *Off-grid electrification for the poor: constraints and possibilities*, EDRC, University of Cape Town

Banks DI 2003, *Rural energy service delivery: a public private approach*, Domestic use of energy conference, 2003

Banks DI 2007, *Perspectives on Providing Rural Energy Services in Rural Areas*, Hybrid Electricity Systems Powering Mini-Grids: A Southern African Perspective, Desert Research Foundation of Namibia

Banks DI 2008, conversations and email correspondence.

Banks DI and Aitken R 2004, *KwaZulu-Natal Mini-grid Feasibility Study*, National Electricity Regulator, June 2004

Banks DI and Karottki R 2000, *Energy service to rural communities: power, service and profit?*, Renewable Energy World magazine, January 2000 – updated version available on www.restio.co.za

- Banks DI, Mocke F, Jonck EC, Labuschagne E and Eberhard R 2000, *Electrification Planning Decision Support Tool*, Domestic use of energy conference, Cape Town, April
- Banville C, Landry M, Martel JM and Boulaire C, 1998, *A Stakeholder Approach to MCDA*, Systems Research and Behavioural Science Journal, Vol.15, No.1, pp.15-32.
- Bekker B and Gaunt CT 2005, *Site selection for the Klipheuwel wind energy demonstration facility: a multiple criteria analysis of the decision process*, CIGRE SC-C6 colloquium, Somerset West, South Africa
- Bekker B and Gaunt CT 2006, *Modeling hard uncertainty in rural electrification projects in South Africa using the Shackle model*, Probabilistic Methods Applied for Power Systems Conference, Stockholm, 2006
- Bekker B and Gaunt CT 2007, *Sustainable rural electrification projects through a multi-criteria informed logical framework approach*, CIGRE SC-C6 colloquium, Malaysia, 2007
- Bekker B 2007, *Irradiation and PV array energy output, cost, and optimal positioning estimation for South Africa*, South African Journal of Energy, 2007
- Bekker B and Gaunt CT 2008, *Simulating the impact of design-stage uncertainties on PV array energy output estimation*, Power Systems Computations Conference, Glasgow, July 2008
- Bekker B, Eberhard A, Gaunt CT and Marquard A 2008, *Uncertainties within South Africa's goal of universal access by 2012*, South African Journal of Energy, 2008.
- Bekker B, Eberhard A, Gaunt CT and Marquard A 2008b, *South Africa's rapid electrification programme: Policy, institutional, planning, financing and technical innovations*, Energy Policy journal, 2008
- Belton V and Steward TJ 2002, *Multiple Criteria Decision Analysis – An integrated approach*, Kluwer Academic Publishers, 2002
- Bikam P and Mulaudzi DJ 2006, *Solar energy trial in Folvhodwe South Africa: Lessons for policy and decision-makers*, Renewable Energy Journal 31 (2006) 1561–1571
- Bonnet P and Andrew T 2003, *Challenges of providing sustainable renewable energy to rural communities in KwaZulu-Natal: a case study of the Maphephethe community*, Proceedings of the domestic use of electrical energy conference, Cape Technikon, Cape Town

- Borchers M and Hofmeyer I 1997, *Rural Electrification supply options to support health, education and SMME development*, EDRC, University of Cape Town
- Boussard T 2010, *Telephonic conversation on 18 February 2010*, Eastern Cape Project Manager, KES Pty. Ltd.
- Brundtland 1987, *The Brundtland report on sustainable development*, United Nations, 1987
- Create Acceptance 2007, *Electricity from Solar Home Systems in South Africa*, Work Package 2, Create Acceptance
- CSIR 2000, *Site Selection Study: SABRE-Gen Wind Demonstration Facility, Western Cape, South Africa*, Report prepared for Eskom. CSIR report no. ENV-S-C 2000-128, Stellenbosch
- CSIR 2001, *Final Scoping Report: Environmental Impact Assessment for the Eskom Wind Energy Demonstration Facility in the Western Cape*, CSIR Report ENV-S-C 2001-024, Stellenbosch
- CSIR 2002, *Environmental Impact Assessment for the Eskom Wind Energy Demonstration Facility in the Western Cape*, Final Environmental Impact report, CSIR Report ENV-S-C 2001-103, February 2002
- Davidson P 1996, *Reality and economic theory*, Journal of Post Keynesian Economics / Summer 1996, 18(4)
- DEAT 2004, *Overview of Integrated Environmental Management*, Integrated environmental management information series, Department of Environmental Affairs and Tourism, Pretoria, 2004
- DME 1998, *White Paper on Energy Policy*, Department of Minerals and Energy, Pretoria
- DME 2001, *Annual Report 00/01*, Department of Minerals and Energy, Pretoria
- DME 2001b, Borchers M, Qase N, Gaunt T, Mavhungu J, Winkler H, Afrane-Okese Y & Thom C, *National Electrification Programme evaluation: Summary report*, Evaluation commissioned by the Department of Minerals & Energy and the Development Bank of Southern Africa, Cape Town, EDRC, University of Cape Town

DME 2002, *Integrated National Electrification Programme (INEP) planning and implementation manual*, version 0 - 2002/07/01 available from www.dme.gov.za, Department of Minerals and Energy, Pretoria

DME 2003, *White Paper on Renewable Energy*, Department of Minerals and Energy, Pretoria, November 2003

DME 2005, *Annual Report 04/05*, Department of Minerals and Energy, Pretoria

DME 2006, *Strategic Report 06/07 – 10/11*, Department of Minerals and Energy, Pretoria

DME 2007, *Annual Report 06/07*, Department of Minerals and Energy, Pretoria

DME 2007b, *Mini-grid hybrid viability and replication potential*, Draft Final Report, Department of Minerals and Energy, Pretoria, July 2007

E7 2003, *Community electricity in rural South Africa: Renewable mini-grid assessment*, Report by ScottishPower plc for the E7 electricity companies

EC 2002, *Project Cycle Management Handbook version 2*, EuropeAid, European Commission, March 2002

ERC 2004, *Solar Electrification by the concession approach in the rural Eastern Cape – Phase 1. Baseline survey*, Energy Research Centre, University of Cape Town, March 2004

ERC 2004b, *Solar electrification by the concession approach in the rural Eastern Cape – phase 2. Monitoring survey*, Energy Research Centre, University of Cape Town, November 2004

ERC 2005, *Solar electrification by the concession approach in rural Limpopo province – phase 1. Baseline survey*, Energy Research Centre, University of Cape Town, April 2005

Eskom 1997, *Energisation Pilot Project Proposal – KwaBhaza*, Megawatt Park, Johannesburg

Eskom 2007, *Annual report 2007*, Megawatt Park, Johannesburg

Gaunt CT 2003, *Electrification Technology and Processes to Meet Economic and Social Objectives in Southern Africa*, PhD Thesis, Department of Electrical Engineering, University of Cape Town

Gaunt CT 2008, *Electricity distribution industry restructuring in South Africa: A case study*, Energy Policy 36, pp 3448– 3459

Gaunt CT, Herman R and Bekker B 2009, *Probabilistic Methods for Renewable Energy Sources and Associated Electrical Loads for Southern African Distribution Systems*, Cigre conference, Calgary, 2009

Gaunt CT, Herman R, Dekenah M, Sellick RL and Heunis SW 1999, *Data collection, load modelling and probabilistic analysis for LV domestic electrification*, CIRED conference 1999, Nice

Green JM 2003, *Gender sensitive impacts of various renewable energy technologies in Maphephethe, KwaZulu-Natal*, Proceedings of the domestic use of electrical energy conference, Cape Technikon, Cape Town

Green JM and Zwebe DI 2006, *From SHS to grid electricity in low-income rural households*, Journal of Energy in Southern Africa, Vol 17 No 2, May 2006

Heinrich GS 2008, *A comprehensive approach to electricity investment planning for multiple objectives and uncertainty*, PhD Thesis, University of Cape Town, 2008

Hemmati M 2002, *Multi-stakeholder processes for governance and sustainability – beyond deadlock and conflict*, Earthscan Publications Ltd., 2002

Herek GM, Janis IL and Huth P, *Decision Making during International Crises: Is Quality of Process Related to Outcome?*, The Journal of Conflict Resolution, Vol. 31, No. 2 (Jun., 1987), pp. 203-226

Herman R and Gaunt CT 2008, “*A Practical Probabilistic Design Procedure for LV Residential Distribution Systems*”, IEEE Transactions on Power Delivery, Vol 23 (4), 2008, pp 2247 – 2254.

Homer 2009, Version 2.67beta, available from NREL website, www.nrel.gov/Homer, last accessed 13 May 2009

IAEA 2005, *Energy Indicators for Sustainable Development: Guidelines and Methodologies*, International Atomic Energy Agency, Vienna, April

Ilskog E 2008, *Indicators for assessment of rural electrification - An approach for the comparison of apples and pears*, Energy Policy 36, pp 2665– 2673

Janis IL and Mann L 1977, *Decision making: A Psychological Analysis of Conflict, Choice, and Commitment*. New York: Free Press.

Jochem 2008, Personal communication with Fabian Jochem, SMA inverters, April 2008

Keeney RL and Raiffa H 1976, *Decision Analysis with Multiple Conflicting Objectives: preferences and value tradeoffs*, Wiley, New York

Khatib H 2003, Economic evaluation of projects in the electricity supply industry, The Institution for Engineering and Technology, London

Kloot 1999, *The energisation of KwaBhaza: a case study in rural energy and development*, EDRC, UCT, January 1999

Kovach H, Neligan C and Burall S 2003, *Power without accountability?*, The global accountability report part 1, One World Trust

Loosemore M, Raftery J and Reilly C 2006, *Risk management in projects*, Taylor and Francis, New York, 2006

Magilindane F 2003, *Constraints to the wide dissemination of PV solar home systems in the rural areas of South Africa*, Master's thesis, University of Cape Town, July 2003

Mbeki T 2004, *Address of the President of South Africa, Thabo Mbeki, to the first joint sitting of the third democratic Parliament, Cape Town, 21 May 2004*

Mbeki T 2008, *State of the Nation address, 2008*

NEMA 2008, *National Environmental Management Act 107 of 1998*, South African Government, Pretoria.

NER 2003, *Lighting Up South Africa 2003*, National Electricity Regulator, Pretoria

NER 2003b, *Progress report on Hybrid Mini-grid Pilot Project at Hluleka and Lucingweni*, National Electricity Regulator, Pretoria, December 2003

NER 2003c, *Annual Report 02/03*, National Electricity Regulator, Pretoria

Niemand FR and Banks DI 2006, *NuRa - a success story for rural energy service delivery*, Energise magazine, July 2006

Nieuwenhout FDJ, Van Dijk A, Van Dijk VAP, Hirsch D, Lasschuit PE, Van Roekel G, Arriaza H, Hankins M, Sharma BD and Wade H, 2000 *Monitoring and evaluation of Solar*

Home System, Experiences with applications of solar PV for households in developing countries, Netherlands Energy Research Foundation ECN 2000

Nkwentsha 2007, Personal conversation.

Pokharel S 2003, *Promotional issues on alternative energy technologies in Nepal*, Energy Policy Volume 31, Issue 4, March 2003, Pages 307-318

Prasad G and Dieden S 2007, *Does access to electricity enable the uptake of small and medium enterprises in Southern Africa?*, Domestic use of energy conference, 2007

Prasad G and Visagie E 2005, *Renewable energy technologies for poverty alleviation, Initial assessment report: South Africa*, Global Network on Energy for Sustainable Development, Energy Research Centre, University of Cape Town

Prasad G and Visagie E 2006, *Impact of energy reforms on the poor in Southern Africa*, Global Network on Energy for Sustainable Development, Energy Research Centre, University of Cape Town

Reneke JA and Wiecek MM 2002, *Performance-based multicriteria decision making for service sector systems*, Department of Mathematical Sciences, Clemson University, Clemson, SC, March 8, 2002, <http://www.sc.edu/sustainableu/dsi1.pdf>

RETScreen 2009, Version 4, available from Canada's Natural Resources website, www.RETScreen.net, last accessed 13 May 2009

Roy B 1996, *Multicriteria Methodology for Decision Aiding*, Kluwer Academic Publishers, 1996

SA Government 1996, *Constitution of the Republic of South Africa, Act 108 of 1996*, South African Government

SA Government 2002, *Government Gazette 25088*, South African Government

Scharlig A 1985, *Decider sur plusieurs criteres*, Collection Diriger l'Entreprise, Presses Polytechniques Romandes, as quoted from [Vincke 1992].

Scholle A and Afrane-Okese Y 2007, *Experience with hybrid systems in South Africa*, Proceedings: Hybrid Electricity Systems Powering Mini-Grids: A Southern African Perspective, Desert Research Foundation of Namibia

Sebitosi AB and Pillay P 2005, *Energy services in sub-saharan Africa: how conducive is the Environment?*, Energy Policy Journal 33, p2044-2051

Smit R, Smit I, Van der Westhuyzen D, and Van Heerden L 2004, *Wind Energy Research and Operations Experiences at Klipheuwel*, EWEC 2004

Sparknet 2003, project descriptions on the 'Sustainable energy Policy And Research Knowledge Network' website www.sparknet.info, last accessed 1 February 2008

Stats SA 2003, *Investigation into appropriate definitions of urban and rural areas for South Africa*, Census 2001, Statistics South Africa, Pretoria

Vincke P 1992, *Multicriteria decision-aid*, John Wiley & Sons Ltd, Baffins Lane

Willis HL and Scott WG 2000, *Distributed power generation: planning and evaluation*, Marcel Dekker Inc, New York 2000

World Energy Council 1999, *The Challenge of Rural Energy Poverty in Developing Countries*, The World Energy Council and Food and Agriculture Organization of the United Nations, London, October 1999

Woudstra J and Zoller F 2004, *Social aspects of doing sustainable projects with students in developing countries*, Domestic use of energy conference 2004, Cape Technikon, Cape Town

Young RA 2001, *Uncertainty and the environment: implications for decision making and environmental policy*, Edward Elgar, 2001.

Zilberman D 1999, *Energy and the Environment: the Case of India*, Lecture notes from the EEP 101 course, Department of Agricultural and Resource Economics, University of California at Berkeley, Chapter 20, are.berkeley.edu/courses/eep101

Zomers AN 2001, *Rural electrification*, Ph.D. thesis, University of Twente