Measuring the rebound effect of energy efficiency initiatives for the future

A South African case study

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Photographs used in this report are by Stephen Davis.

Executive summary

The rebound effect is a phrase which was originally defined to refer to the extent to which energy efficiency improvements are lost due to subsequent behavioural changes. This report documents almost three years of research work that set out to quantify the rebound effect of energy efficiency initiatives in South Africa's residential sector, and to explore ways of mitigating that effect using awareness and education.

RDP housing in Zanemvula after the implementation of the municipal solar water heater roll-out

Society is in an era where energy commodities are characterised by constrained supply, increasing demand, and higher prices, and where the harmful social and environmental externalities resulting from the conversion of primary into useful energy can no longer be ignored. Part of the solution to the sustainable energy provision and consumption challenge has focused on the technology devices used to convert primary and secondary energy to useful energy that can be used for lighting, water heating, space heating and cooling (and a host of other end-uses). Given that all energy demand can ultimately be traced to the energy required for survival, a study of the residential sector is the natural place to begin.

The research led to firstly examining what rebound is, and in what spheres of literature it has been defined, studied and quantified. Having a greater understanding of the effect within a South African context by means of an extensive review of the literature, numerous attempts were made at developing a methodology that would do justice to uncloaking the mystery of rebound. Interestingly, the prevailing lack of understanding of rebound was equalled if not surpassed by the absence of suitable methods for quantifying it. In part, the lack is a consequence of the historical focus on the technical engineering of supply-side solutions to society's energy needs. It is no surprise therefore that the measurement of the extent to which some of these solutions fail has traditionally depended on techno-engineering methods, and therefore failed to adequately measure the effect. The inability of a pure engineering focus to measure a behavioural phenomenon created a niche for economists to make their contribution by conducting macro-economic modelling of energy demand and calculating elasticities to capture the consumption response of users to price changes under efficiency improvements. Scattered among the literature were a few novel approaches that dared to move beyond the techno-engineering and econometric approaches. These methods have made ground in testing behavioural and systems thinking approaches (which can include but are not restricted to technical measurement) and using inter-disciplinary methods for designing a robust approach to studying behavioural response to energy efficiency. The methodology contained in this report makes several inroads into this new realm of understanding rebound, and of developing new approaches to measuring it, beyond but not excluding the techno-economic approaches that have historically dominated.

After reviewing the literature and positioning the research within it, stakeholders were consulted, and suitable case study sites were located. These were locations where large-scale residential energy interventions were to take place, and where the impact of awareness and price could also be assessed. The roll-outs were typical demand-side management and energy efficiency programmes and included a low-income solar water heating implementation in Zanemvula in the Eastern Cape, and an efficient lighting intervention in the Karoo town of Prince Albert in the Western Cape. A further study on high-income solar water heating response is currently underway and the results will be added to this report by December 2010.

A host of qualitative and quantitative information was collected by means of household panel (pre and post) surveys, focus groups, informal interviews and stakeholder interactions. The quantitative data consisted of consumption data which was obtained in the form of records for individual households in the samples. In parallel to the extensive data collection, a feedback simulation model using a systems dynamics approach was successfully developed and tested. The simulation tool and a systems thinking approach proved invaluable for its contribution to understanding complex phenomena associated with household energy consumption. The gap between the systems thinking and the case study data was bridged using statistical validation techniques, and the theoretical model proved to be of value in mimicking that system, and in understanding the dynamics of household energy behaviour.

This kind of approach to energy system modelling will no doubt be of value in work in this area and, although fundamental in nature, its accurate representation of reality, and the fact that it could be validated using actual data, means that it is ready for use as a tool for managing the uncertainties surrounding the responses to technology. With time it is expected that data accessibility will improve while the data needs of the models reduce. It was clear from the experience of the research that the effort required to obtain access, collect and assimilate the data far outweighed the effort invested in building the model, and that the future focus should be on the modelling and smart collection of data (using the technology available for doing that).

The final piece of methodology involved using a conventional energy demand model to build some scenarios that demonstrate the impacts of rebound and the potential to mitigate it, showing that conventional models should not be abandoned as we make inroads into new methodologies. In fact, the many facets of the approaches used in this research are complementary.

Each element of this study exposed, either by intention or co-incidence a number of revealing insights about behavioural response to energy efficiency, and the approach to studying it. The micro-level case studies highlighted – at a practical level – the range of factors that affect attitudes and behaviour. At a localised level, the range of attitudes and awareness levels about energy matters and energy efficiency could be assessed. The regression models on the data collected in the two sites revealed the main factors that can be used to explain electricity consumption behaviour in an integrated manner, and the values and significance of first and second order effects. The main focus was on the presence of the interactions between the first order effects, and how the response differs between households with different characteristics.

The main findings are too numerous to list in this executive summary but have been comprehensively captured in the report.

The simulation model revealed how households make decisions about energy consumption based on the attainment of goals relating to comfort, cost and environmental impact, and how the preferences or weightings attached to these goals are influenced by information feedback. The extent to which simultaneous roll-out of technology, price and information initiatives are complementary can be assessed, with combined interventions being super- or sub-additive. The analysis shows how additional effectiveness can be gained by incorporating the preferences of households in the strategies.

A major contribution of the research has been to highlight the importance of taking into account behavioural response to energy efficiency as well as the need to conduct further research in this area – this point cannot be emphasised enough, as the assimilation of this knowledge into society remains low. Further, the research has recognised that erosion of potential of technical efficiency may (in a developing country context) be indicative of improved energy welfare.

Having achieved a greater understanding of the problem, platforms for engagement with key stakeholders in the policy and implementation arena can be opened, and the knowledge contained in this report will be invaluable in guiding such engagements. The work addressed the extent to which achievable energy efficiency can be met in reality, as well as the factors that need to be considered in future procurement and when influencing behavioural response where appropriate.

1. Introduction

A secure and reliable supply of energy is central to meeting the objectives of social, environmental and economic sustainability. One contributor to meeting the need for such a supply of energy is implementation of energy efficiency measures. These involve less energy to provide the same level of service required by the end user, thus increasing the benefit which can be obtained from often constrained energy supplies. In addition to contributing to energy security, increased R&D and investment in energy efficiency (EE) measures could potentially lead to job creation, and would be a key component of meeting South Africa's emissions reduction targets.

A number of EE interventions have been implemented around the world, across various sectors. While many of these have been successful, there have been reports of a phenomenon known as the rebound effect (RE), in which energy savings benefits achieved through EE are offset by changes in consumption patterns of both energy and other resources. Although typically this is considered undesirable, in the developing country context there may be a certain level of rebound that is desirable where households are gaining access to a broader range of useful energy services as a result of the availability of more efficient technologies.

This report presents the results of a study which was conducted in an attempt to quantify the RE of EE in the residential sector in South Africa, and to assess the effectiveness of measures for reducing the impact of the RE. Together, these understandings will contribute to the promotion, retention and sustained use of electricity efficiency measures. The ultimate aim of this work is thus to provide a context and set of modelling tools which will support utilities and government in more informed policy and planning.

The unique contextual feature of this study is that there are two tiers of targeting for EE and hence need for understanding the rebound effect:

a) Energy efficiency or demand-side management (DSM) penetration in middle- to high-income households is important for reducing demand in the system (both in the peak hours, and in the long-run), and understanding the rebound effect is therefore essential in reducing the need for building additional generation plants for the grid.

b) When considering lower-income households, demand may have a higher elasticity,[1] but DSM could potentially lead to a much larger rebound effect (more disposable income available for purchasing appliances that were not previously owned, using more compact fluorescent light (CFLs), being less conservative about electricity usage, etc). Also, efficiency measures have the potential to increase the monetary savings levels of these households, providing more income for medical expenses, food, schooling and other essentials. If low-income households can successfully sustain DSM measures then there will be potential economic and social upliftment benefits as they begin to spend lower proportions of their income on their energy needs. The study of the RE can therefore be viewed in a holistic sense. If low-income households can reduce the cost of their energy needs through EE, then there will be an overall holistic benefit resulting from the implementation of such measures.

1.1 Research outcomes

The research outcomes listed below were expected to be derived from the project at inception. Not all have been ultimately achieved, but they were all considered in guiding the approach that was adopted for the study and are presented here to help identify gaps and areas for further research.

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[1] Elasticity in this instance refers to the potential percentage by which demand for energy services will increase when the effective price of energy services decreases due to an improvement in conversion efficiency.

- A general understanding of EE in households and how efficiency measures can be implemented across low-, middle- and high-income households. This includes the assessment of the relative importance of the different energy uses for which efficiency programs are implementable (e.g. is household lighting even a significant enough constituent of total demand to warrant efficiency?) What are the important end-uses that should be targeted? Where is efficiency likely to reduce demand and, if so, how can rebound best be avoided?
- Understanding the behavioural/attitudinal aspects of EE. For example, how do different households prioritise their expenditure on energy-consuming devices? What are their attitudes towards the different EE measures? What are the users' perceptions around their electricity consumption? Do the intervention and non-intervention groups differ in whether they think EE initiatives are saving them money/electricity?
- Measuring the rebound effect for a range of different efficiency and fuel-switching measures (CFLs, geyser blankets, power alerts, efficient appliances, solar water heaters (SWHs)) and understanding any substitutions that may lead to increased consumption when one end-use becomes cheaper through technical efficiency.
- Understanding the long-term trajectory of efficiency measures, including reversion to old technologies, and take-up of additional measures.
- Comparing studies of RE between regions/socio-economic groups within South Africa and between South Africa and other countries.
- Understanding likely impacts of nation-wide implementation of DSM.
- Creating in-house models of estimated energy savings, and projected scenarios.
- Developing models for measurement and verification (M&V), and comparison against existing M&V studies.
- Exploring the nature of educational efficacy of DSM initiatives (e.g. the impact of ad hoc awareness campaigns versus rigorous educational campaigns).
- Determining the effectiveness of using schoolchildren as the conveyers of information to households.

In addition to the above direct research aims, the study resulted in a number of social benefits including:

- Developing capacity through employing members of the community to conduct the survey and implement training initiatives. Survey expertise and understanding of EE werer developed across all demographics and socio-economic groups. Thee was further transfer of skills through training in survey administration, data collation and input.
- Employing SMMEs to implement the EE measures.
- Employing M&V teams to conduct the load measurements.
- An environment of collaboration and synergy between the various stakeholders was created (ESCOs, end-users and communities, researchers, municipalities and local government, Eskom's DSM, M&V)
- Creating an understanding and awareness of the uses and benefits of energy-efficient technologies in communities.

1.2 Report outline

The structure of the report is as follows. This current chapter introduces the study, and defines the context within which the research takes place.

The second chapter presents a background discussion on EE to provide a context for studying rebound, and discusses the current state of EE and the policy framework in South Africa. From an extensive body of research, the definitions of rebound are presented, and the various methodologies for measuring and mitigating the effect are discussed, thus providing a basis for the methodological framework chosen for this study. In this chapter a summary is also presented of the empirical studies of rebound as extracted from the literature

Chapter 3 provides detail on the scoping of the study, the research locations of Prince Albert and Zanemvula. The outcomes of preliminary engagements with interested stakeholders are summarised, and the subsequent methodological choices are motivated. A description of the various data collection approaches used during the course of the research is also described in Chapter 3.

In Chapter 4 a description is presented of the data resources that were collected to facilitate the analyses, and the survey methods and data collection efforts for the two main study locations are discussed. The challenges and successes of the various data collection exercises are also described in detail as these are highly relevant for informing future research in this arena.

Chapter 5 presents the analytical tools used in the study. The first of these is a systems dynamics model that enables an exploration of the decision-making of households with regard to energy consumption. A review is presented of the literature applicable to the development of the systems dynamics modelling tools for simulating household energy behaviour alongside the development of the simulation model. An explanation is also given of how the simulation model can be validated in the real world by making use of the data collected described in Chapter 4. Secondly in this chapter, the generic regression model used to analyse the case study data is described. The third and final model described in Chapter 5 is a LEAP model of the South African residential sector, which is used to quantify the relative impacts of rebound on projected energy demand in South Africa. In this section we describe the model and the baseline scenario where no action is taken in regard to rebound. The statistical methods and tools used for analysing the survey and consumption data are described briefly in the third part of this chapter.

Chapter 6 elaborates on the results obtained by analysing the data described in Chapter 4, and using the tools described in Chapter 5. The results of the survey analysis, regression of consumption, systems dynamics simulations and long range forecasting scenarios are presented and discussed in detail.

Chapter 7 concludes with a summary of the results and the methodological recommendations for future energy demand analysis, and discusses the implications of this research, its shortcomings and how the insights generated can be used to facilitate stakeholder engagement for policy recommendations. Opportunities for further work are also suggested.

References follow in Chapter 8, and then a series of appendices containing additional information that is peripheral to the main flow of the report, but contains detailed background to fieldwork, explanations of methodologies, statistical outputs, and reconciliation of expenditure to date. A list of the survey questionnaires, fieldwork reports, data, statistical analysis files, as well as the systems dynamics simulation model and outputs is also given in the appendix, with electronic copies stored in a compact disk that accompanies the final report.

2. Background and literature review

2.1 Introduction

In this chapter, background literature on the rebound effect of EE and DSM initiatives is summarised to provide the foundation for investigating the extent and causes of rebound in the South African residential sector. The literature review summarises outputs of the previous studies and examines international perspectives on a variety of methodologies defining and quantifying the RE. It highlights best practices and drawbacks that would together inform a robust methodology for the current study.

The chapter proceeds as follows: This introduction provides a motivation for the study in light of the existing body of research. Section 2 discusses Energy Efficiency interventions. Section 3 defines and discusses the rebound effect in detail, including its causes, measurement, international experience and previous estimates. Section 4 gives an overview of the South African context for EE in the residential sector, leading into a rationale for the study in section 5. Section 6 concludes the chapter. Further literature on energy consumption behaviour and models of household energy consumption (as a means of expanding the explanation of rebound as a behavioural response phenomenon) is reviewed in the first section of Chapter 5.

2.2 Energy efficiency

The intention of EE is to reduce the consumption of energy – thereby reducing economy-wide energy intensity and elasticity[2] of energy demand growth with respect to GDP growth – and lower the costs of energy services consumed by households, making more income available for other basic needs. Ultimately, reduced consumption would also have the benefit of avoided investment in new generation capacity and also reduce the externalities associated with the procurement of that energy (for example CO_2 emissions from coal-fired power stations).

The following section describes a selection of the technical, institutional and educational/behavioural measures that have been used to achieve EE.

2.2.1 Technology

Technologies commonly used for improving EE in the residential sector include energy efficient lighting, improved thermal performance of households, energy efficient appliances, and fuel switching for cooking and water heating. Solar water heaters and CFLs are receiving particular focus in South Africa, as having the potential for significant reductions in consumption and cost of provision of their respective energy services. The following sections describe the various EE technology interventions in more detail.

Energy efficient lighting

Compact fluorescent light bulbs (CFLs) use significantly less power than conventional incandescent bulbs. In South Africa the majority of low-income households use less than 100 kWh of electricity per month since high energy consumption appliances (geysers and others) are often too expensive to purchase and use (Clarke 1997). Seemingly, much of the energy used in low-income households is for lighting and thus CFLs may reduce electricity bills and result in significant savings for them. Although lighting contributes less than 10% of Eskom's load profile, replacing incandescents with CFLs can potentially reduce peak demand because it coincides with the time that energy is used for cooking, space heating and water heating (DME 2007), and lighting is a component of peak demand that can easily be reduced using CFLs. There is currently some research on the potential for light emitting diode (LED) roll-outs (SAJE

2 Elasticity of demand is defined as the percentage of 1% by which demand increases (or decreases) for every increase in the main driver – in this case GDP i.e. an elasticity of 0.5 implies that demand will increase by 0.5% when GDP increases by 1%.

2007) which are even more efficient than CFLs and thus may reduce the amount of power required for lighting even further.

Some of the justifications for the focus on energy efficient lighting thus include (Clarke 1997 citing Dutt & Nadel 1991) the follwing observations:

- Lighting consumes 8-17% of total electricity produced in industrialised countries and the share in developing countries can be larger.
- Energy use can be reduced by as much as 75% without reducing lighting levels – such a reduction is difficult to achieve in most other end-uses.
- Lamps have a relatively short life compared to other capital equipment and, therefore, savings can be quickly realised through an implementation programme which capitalises on this high turnover rate

Reducing space heating requirements
Low-income households in South Africa spend a large portion of their energy (which may or may not be be electricity) budget on space heating in winter. A ceiling is one of the most cost-effective means of improving a dwelling's thermal performance. It is predicted that a 50% or higher energy saving can be derived from the installation of a ceiling and passive insulation. Studies like that of Spalding-Fetcher et al (2002) report that poor households use mainly coal, wood or paraffin, instead of electricity for space heating, so that, while encouraging households to install ceiling may result in significant savings on heating costs for them, the reduction in electricity demand for the utility may be negligible. However, space heating contributes significantly to peak demand in winter (particularly in medium and high income households), and with the growing rates of urbanisation and continuing efforts to meet the housing backlog, this aspect requires consideration.

Energy efficient appliances
In the majority of South African households, energy appliances like fridges, stoves, TVs and hi-fis represent a major purchase. Due to the large capital cost most households are more sensitive to the price of the appliance than to the operating cost which in turn depends on its EE. Households may switch to more efficient appliances, or use existing appliances more efficiently (for example by using geyser blankets or only boiling as much water as needed at a time).

Fuel switching
Although not strictly an efficiency intervention per se, there is a need to consider behavioural response to fuel switching interventions. While fuel switching may not benefit DSM directly, its overall benefit for household EE, subsequent savings and eco-efficiency implications requires attention. Externalities are particularly important in this case. Externalities are the costs borne by society, for example through illness or even death resulting from indoor air pollution from wood fires, fatalities and destruction of property related to paraffin use, that are not reflected in energy prices. Added to this are the global external costs associated with greenhouse gas emissions. Included in such measures are alternative cooking fuels e.g. gas, and moves towards solar heated water technologies.

2.2.2 Supporting roll-out of energy efficiency: Policy, regulation, institutional arrangements and pricing

Through subsidies, taxes, standards, and other measures, government policies have a direct impact on energy supply, demand, and the levels of EE prevalent in the residential, commercial and industrial sector. For instance, government energy policies that are effectively implemented using these measures, may be used to sway or enforce users and producers of energy towards certain fuels or towards lest wasteful usage of these fuels.

Climate change experts argue that government policies affecting the price of energy are among the most important measures for combating wasteful usage of energy, as energy prices are among the fundamental factors determining a nation's energy use (Spalding-Fecher et al, 2002). Countries with higher energy prices, like Japan and Germany, also have lower energy intensities, while those with lower prices are generally quite energy-intensive, like the United States and South Africa.

The ultimate challenge from a developing country perspective is how to encourage and support the transition to the use of modern energy sources that encourage improved livelihoods underpinning sustainable development objectives, whilst constraining energy demand. Winkler et al (2007) suggest that an integrated sustainable development framework that creates synergies between climate policies and EE policies and meets developing countries' social priorities is a key driver for change.

The possible measures for implementing EE in South Africa include market-based instruments, regulatory measures, a supportive and effective institutional and legal environment, and voluntary agreements on EE. The first three of these (with specific reference to residential measures) are (EDRC, 2003):

a) Market based instruments:

- financing energy efficient housing and appliances (bonds and loans);
- incremental housing subsidy for EE upgrades in low-cost housing;
- concessionary loans for incremental efficiency costs;
- pollution taxes;
- wires charges;
- other sources of financing.

b) Policy and regulatory instruments – targets, codes and standards:

- residential building codes;
- household appliance labelling and mandatory energy performance standards;
- regulatory interventions to promote EE.

c) Institutional and legal environment:

- strengthen the institutional framework for EE;
- research, development and demonstration.

Some of the possible approaches that do not fall directly into the above lists or span the categories but can be used for implementing EE include subsidies, wholesale buy-downs, bulk procurement, give-aways, education and consumer financing mechanisms (Martinot & Borg 1998).

Political will and effective institutions, appropriate policies and regulations are essential for driving change in energy consumption patterns. But it depends on people as individuals, both as households, consumers and as members of diverse communities, to recognise the links between consumption patterns and choices made and the impacts that this has on energy demand. Seemingly more and more people are choosing larger appliances, bigger homes and vehicles, whilst in low-income households the choice is influenced by cost. In discussing the latter aspects, Greening et al (2000) say that the 'consumer's double role' as producers and consumers of energy services should not be ignored.

However, there are those people who are purchasing more efficient appliances and using energy from renewable sources. Through education and awareness programmes it is possible to help people make informed choices that lead to the reduction of energy demand and change consumption patterns (Throne-Holst et al 2007). Through measures like these, it may be possible to change the way that society behaves and subsequently save energy and the environment.

2.2.3 The role of awareness, education and behaviour in promoting energy efficiency

The previous two sections discussed the role of technology and policy, regulation and pricing in supporting EE. Ensuring that these considerations are adopted, however, requires the raising of awareness through education to support behavioural changes around energy usage. Feedback and information have been recognised as valuable tools for encouraging energy efficient behaviour and take up of efficient technologies, however it is important to take cognisance of the motivational factors and barriers to behaviour change This subsection reviews the experiences of a number of researchers who have examined this area of research.

Potential impacts of feedback and information on consumption

Owens and Driffill (2008) argue that although the instinct to target attitudes and behaviours through education and awareness-raising remains strong, information is unlikely to be effective if it runs counter to other powerful influences such as social norms or prices. Information is not a dispensible motivator, but it should form part of a wider strategy. Further influences on behaviour are price, awareness, trust and commitment, including a sense of moral obligation.

Psychological models have been sought to answer the question as to what kinds of awareness or consumption behaviour feedback are most successful, (see for example Fischer (2008)). Consumption feedback can come in various forms: advice, comparisons – historical and normative, energy audit, increased tariffs, billing, saving tips, and various combinations of these. Features of feedback that may determine effectiveness include frequency, duration, content, breakdown, medium and mode of presentation, combinations and comparisons. Studies have suggested that feedback stimulates energy savings in the range of 1.1% to 20%, but usually between 5% and 12% (no information on statistical significance is given, but numbers are an indicator of the general effectiveness of the feedback).

Feedback is more successful if it is given frequently and/or over a long period of time, especially if it captures the consumer's attention, is presented in a clear and appealing way using computerized and interactive tools, draws links between specific actions and their effects by providing appliance-specific breakdown, and activates various motives that appeal to different consumer groups. Electronic smart-metering appears to be a useful tool; however reactions vary between target groups and smart-metering currently requires sophisticated technology that is unlikely to be widely installed. Motivation for feedback mechanisms and conservation will also tend to be low when electricity prices are low. Examples and practices are abundant in developed countries of the likes of Sweden, Denmark, Germany and the UK; however the environment for such practices is likely to be significantly different in the developing country context.

Harris et al (2007) argue that progressive efficiency should be embedded in voluntary information and incentive programs. Policy makers and programme sponsors can then consider how to extend the mandatory codes and standards. The authors say energy indicators should include *extensive* (consumption) figures as well as *intensive* (efficiency or productivity) ones in conjunction with each other to produce effective sustainable energy balance.

Gyberg and Palm (2009) also suggest that changing behaviour is motivated by economic and environmental factors. These authors indicate that efficient technology or changing to efficient appliances is not necessarily a means for changing lifestyle; rather it is a means of *not* changing lifestyle. In their study of Swedish household, four categories of feedback are identified with regard to how (Swedish) households relate to and act towards EE: individual choices, creating incentives, creating a measurable world, and technological improvements. The four categories are not mutually exclusive and some issues fit well into several of them.

A further point noted by Owens and Driffill (2008) highlighted the importance of the opinions of family, friends and social networks, and to a lesser extent media. Advice centres were less favourable sources of information in their sample

Motivation and barriers to behaviour change

Caird, Roy and Herring (2008) present a summary of previous studies on motivations for adopting or not adopting renewable energy or EE technologies in the UK. Incentives include saving money or increasing comfort. Barriers include up-front costs, lack of information, hassle and disruption. Rebound effects occur when EE leads to reduced price, and consumers take back some of those savings in the form of additional comfort. The study identified four key groups of variables: socio-economic context (fuel prices and regulation), communication sources (professional, interpersonal), consumer variables (income, attitudes, lifestyle), properties of the product or system itself (functional utility, symbolic value, price and interconnectedness with other systems). The conclusions of their study suggest the sale of EE and renewables as potential interventions.

In Griskevicius, Cialdini, and Goldstein (2008), it is suggested that social norms are a powerful motivator for behaviour change. In their view the belief that others were conserving correlated twice as highly with reported energy saving efforts than any of the reasons that had been rated as more important personal motivators. In raising awareness, effectiveness can be enhanced by relating an individual’s behaviour to others in similar social groups.

Steg (2008) mentions three barriers for fossil fuel conservation: insufficient knowledge of means for reducing consumption, low priority and high costs of energy savings, and an absence of feasible alternatives. Steg argues that policies are more acceptable when they increase rather than restrict freedom of choice. Topics for future consideration in the psychology of household energy conservation are indirect energy use, individual and contextual factors, provision of tailored information, psychological and structural strategies for behaviour change, acceptability and adoption of sustainable energy sources, feedback on energy use, systematic evaluation of intervention programmes, and interdisciplinary research.

In Wall and Crosbie (2008), it is interesting to note that motivations (e.g. energy and environment) are not necessarily mutually exclusive (and individual motivations such as environment may be multifaceted: for example the environmental motivation for using CFLs could be to reduce waste production as the devices have a longer lifetime, or to reduce carbon emissions). These arguments provide a motivation for the use of weightings for motivational factors in models of household energy use. Comments by interviewees suggest that peer-to-peer social influence can be an effective prompt for behaviour change when personal motivation is weak. Poor quality interventions may lead to backfire and reversion, the example being consumers choosing halogens over CFLs when incandescents are outlawed.

2.3 The rebound effect

In the context of the understanding of EE, this section discusses the rebound effect, and includes a definition thereof, approaches to calculation, measurement and analysis, and a discussion of previous studies on the effect.

2.3.1 Definition, causes and manifestations of the rebound effect

A number of definitions of rebound are found in the literature, with some differences depending on the context. The *Oxford Dictionary* definition of ‘rebound’ reads as follows:

> The action of rebounding; the springing or bouncing back of an object after impact or release of pressure; an instance of this. Also: the ability to do this; resilience.

By inference, the term ‘rebound effect’ (RE) suggests that improved EE, can result in a release of pressure on energy consumption, an easing of the constraint and consequently enhanced usage of energy services. Additionally, ‘rebound’ can also be interpreted as a *resilience* of a system to technological interference, and hence describes the response whereby improved technology does not lead to reduced energy consumption by consumers.. Colloquially, rebound can be thought of as a ‘spend, save and splurge’ mentality, such which is found at 'end-of - season' sales when a consumer's overall spend on a class of goods may be higher than normal even though the cost of individual items is lower. The RE is also referred to as the Khazzoom-Brookes Postulate and, sometimes, as the ‘take-back’ or ‘snap-back’ effect – although it will be shown that ‘take-back’ is only one element of the rebound. Issues other than price or savings may also contribute to rebound, such as dissatisfaction with the service provided by a new technology, cost barriers to re-purchase, and unwillingness to accept the new technology, changing trends and social factors leading to a shift in the demand for a particular service.

The concept of economic rebound was first suggested by Jevons in 1865. He realised that the gain in energy productivity as a result of introducing EE is not entirely met by the gains in productivity of other inputs, thus offsetting the gains resulting from EE.

With the world-wide increase in energy consumption, the RE has become an important aspect to consider with regard to energy policy, particularly with both energy analysts and (more recently) environmentalists claiming that increasing EE would reduce national energy consumption, improve energy security and lead to the environmental benefit of lowering GHG emissions (DME 2005). The increase (or shortfall in expected decrease) in consumption offsets the predicted energy savings and has the potential to undermine the policy or regulatory instruments for EE or eco-efficiency. When rebound is present, efforts to reduce energy demand, manage load or assist in climate change mitigation may be thwarted.

Variables such as demographic sector, and type of energy service and method of roll-out must be considered when trying to explore the RE. The RE is reported to differ by energy end-use, (e.g. lighting, space-heating, cooking, water-heating, etc), and also by sectors of usage (Dimitropoulos & Sorrel 2006; Sorrel 2007).

Depending on the cost of energy services and levels of unmet demand for certain energy services, variations also occur between developed and developing countries. There are a number of examples indicating that the RE may be higher in developing countries due to the high elasticity of demand (Roy 2002; Jin 2007). A study in a country such as South Africa, which operates according to a dual economy, will have to consider both tiers of the (dual) economy when analysing the RE on both macro- and micro-levels. The RE can also be explored in relation to time frames (e.g. short, medium and long term) as well as system boundaries (household, firm, sector, national economy).

The types of EE interventions, the context in which they take place, and the intended outcomes of the interventions, will also all impact the manner in which rebound is defined, understood and quantified in this sector. Furthermore, various disciplines consider rebound from different perspectives and points of interest:

- From the engineering or energy system perspective, rebound can be considered as the proportion of pure technically achievable efficiency improvement that is not achieved due to increased consumption of the energy service the technology provides. The EE engineer, energy systems planner or DSM manager will thus be interested in the extent to which their technologies are ineffective at reducing energy consumption.
- Economists may understand rebound as a parameter closely linked to elasticity of energy demand with respect to price, as EE can be viewed as a reduction in the effective price. The economist will be interested in the economy-wide implications of EE, and the extent to which it results in an overall increase in the demand for energy in the economy.
- Behavioural scientists will be interested in the extent to which technological interventions such as EE enhancements improve or impact the welfare of the individuals, their energy consumption behaviour and adoption of new technologies. For the behavioural scientist, consumer attitudes, awareness, psychology and decision-making patterns will be of interest.

- The CDM project manager or auditor will be concerned with emissions that are assumed to have been saved by implementing an EE or renewable energy intervention, but which are then lost due to direct and indirect rebound effects.

Further complexities in defining the RE are attributed to the ways in which EE can be measured by using physical indicators (tonnes of coal per tonne of steel) or economic assessments (energy per unit output measured in Rands) and at different levels (like households, manufacturing sector, factories, economy-wide) which are all time-bound (Sorrel 2007). In addition to this, the response at the micro-level (i.e. in relation to individual households) is different to that at the macro-level (in terms of the national economy). These factors are discussed in further detail below.

In an article discussing the definitions of the RE, Greening et al (2000) suggest a four-part typology that includes microeconomic and macroeconomic views of rebound. It is suggested that the RE is small for energy services with low marginal costs close to saturation levels, such as hi-fi or TV but larger for services with substantial marginal costs such as space heating, air conditioning.

As a final note, Herring (2006) places an emphasis on studying rebound as an avenue for exploring change the behaviour and perception in relation to consumption patterns. In his paper he discusses the idea that instead of sending the message of EE which implies more efficient consumption of goods and services, what society needs to consider is consuming less.

Many authors note that in spite of occurrences of rebound, in many instances there is also the presence of the so-called 'ratchet effect'. This is the locking in of efficiency improvements for the future even if there is an element of rebound. The reasoning for the ratchet relates to the presence of learning (Birol and Keppler 2000); Education, information and awareness; EE standards; appliance labelling; R&D of new technology; energy audits, green accounting; monitoring and targeting (Howells *et al 2005*). Martinot and Borg (1998) also present a comparison of programme approaches, technology diffusion & market transformation impact. Therefore the strategies and interventions should also aim to raise consumer awareness, create and strengthen effective distribution channels for new technology and to improve product quality and the management and control thereof.

Rebound can be viewed from different perspectives. Whilst the roots of explaining the RE lies in neo-classical economic theory, the real controversy lies in the mechanisms used to frame the RE. The mechanisms differ depending on whether the theorist is an economists or an environmentalist. The former focuses on energy consumption (EE) and the latter focuses on zero emission strategies (eco-efficiency). There does however, appear to be general agreement that the RE is closely linked to price elasticity, and also to the elasticity of substitution (Jaccard & Bataille 2000). If a high price elasticity of an energy service is observed, a high RE can be expected. This is an important consideration in relation to policy instruments that aim to reduce energy use through measures like carbon taxes where the existence of a high price elasticity and therefore high RE will have the effect of limiting the potential energy savings of a particular policy measure.

2.3.2 Types of rebound

The rebound can classified in one of three ways, being take-back or direct rebound, indirect rebound, reversion or substitution. Rebound can also have economy-wide implications.

Take-back/direct rebound

Take-back or direct effects refer to the observation that when the relative cost of an energy (or other) service is cheaper, there is a tendency to consume more of it. This effect is less pronounced if users are satisfied with their prior consumption levels and have no reason to consume more, and if the cost was a prohibitive factor to begin with. The difference in response therefore ties in directly with the developing (elastic) or developed (inelastic) demographic of the consumer. When demand for a particular service is inelastic, the rebound will be low or absent; when it is elastic, rebound will be higher.

Where the energy service usage is close to the level of saturation the conservation potential is small and larger for those energy services which are not close to saturation. This suggests that households may be more willing to adopt EE measures having a large energy cost. Therefore Wirl (1997) suggests that the RE appears more significant for energy services with a significant conservation potential but negligible for services with a minor power savings potential like lighting.

Indirect rebound

Indirect rebound is when the savings in energy from an EE intervention result in increased energy consumption in areas other than that related directly to the intervention. Examples of indirect effects are (Sorrel, 2007):

- Energy efficient equipment requires energy for its manufacture and distribution, offsetting some of the savings. Another way of referring to this effect is through life cycle impacts, which come into play in two situations:
  - when equipment is replaced before the end of its life
  - when the emissions associated with providing the energy efficient equipment are higher than non-energy efficient equipment
- Monetary savings from EE are spent on other goods that require energy.
- Producers use energy savings to increase output resulting in an increase in the use of other factors of production (capital, labour and materials) which also require energy.
- Cost-effective EE may lead to economic growth, which if not decoupled from energy demand growth will lead to increased energy use.
- Lower energy prices increase real income, stimulating energy demand.
- Energy services become cheaper reducing the effective cost of energy intensive goods and therefore increasing their usage.

Rebound through reversion

A potentially significant component of the RE is termed reversion. If, for instance, the EE measure involves distributing CFLs to households and subsequently it is found that they give poor quality lighting or fail, then the users may revert back to incandescents since the replacement cost is lower. Factors influencing reversion are replacement costs, availability of the technology, traditions, norms and dissatisfaction with the quality of the service. Lack of awareness, convenience and other social factors may also play a role. Reversion is said to be affected by socio-economic and cultural factors and requires careful consideration when conducting a bottom-up study (Throne-Host et al 2007; Roy 2000).

Rebound through substitution

If the cost of one energy service becomes cheaper, consumers who are not concerned about savings in their energy budget may purchase additional energy-consuming devices, so that the savings are reduced through take-back in other services. The response to the EE technology will be tied to the elasticity of substitution of the service[3]. Substitution may also be more subtle. For example a user who saves on their energy budget, may use the additional funds to save for an overseas holiday, leading to an increase in energy consumed (and emissions produced). Such indirect effects are more difficult to measure.

According to Dimitropoulos and Sorrell (2006) the size of the rebound from EE improvements affects electricity demand through increasing the service demand. Yet they concede that in reality some of this feedback may not lead to a direct increase of the energy service but instead

[3] Elasticity of substitution indicates easy or difficult it is for the consumer to choose alternative energy carriers for an energy service when the price of obtaining the energy service through a particular carrier changes (a theoretical definition of substitutability is given in a paper by Saunders (2000)).

to an ‘upgrading’ thereof to meet unsatisfied demand of another energy service. In other words, users will increase their consumption of a particular energy service (where EE has improved) to make up for their inability to increase their consumption of the energy services to the level they desire for those services (due to cost or other constraints).

Economy-wide rebound implications
A price reduction of the energy service may reduce the price of other goods and services throughout the economy, leading to a series of price adjustments in the service chain. Energy efficiency improvements may have the effect of reducing energy prices and increasing economic growth which eventually leads to an increase in energy demand. Sorrel (2006) claims that evidence suggests an economy-wide RE of at least 10%, which is not insignificant and should therefore not be ignored by policymakers.

2.3.3 Calculating rebound

Simply stated, the rebound is a behavioural tendency to consume more energy due to the lower cost of energy services derived from an EE improvement (Berkhout et al 2000). In its simplest form, therefore, the RE can be expressed as:

$$\text{Rebound effect} = \frac{\text{expected savings} - \text{actual savings}}{\text{expected savings}}$$

A RE of 0% assumes that the expected (engineering-technical) savings were achieved through reduced consumption, whilst 100% means that no energy savings were realized and that the EE programme failed. When consumption increases to the extent that the rebound exceeds 100% it is referred to as the ‘backfire effect’. Empirical macro and micro-economic studies have shown that rebound is generally somewhere between 0% and 100% (Greening *et al* 2000; Jaccard & Bataille 2000; Laitner 2000; Saunders 2000; Berkhout *et al* 2000). It is also possible to have a negative RE, such that the energy savings are greater than originally anticipated, for behavioural or technical reasons, or both. An example of the latter would be when EE is implemented alongside an EE educational campaign and the resultant savings are greater than anticipated. The different scenarios for rebound are illustrated in Figure 1.

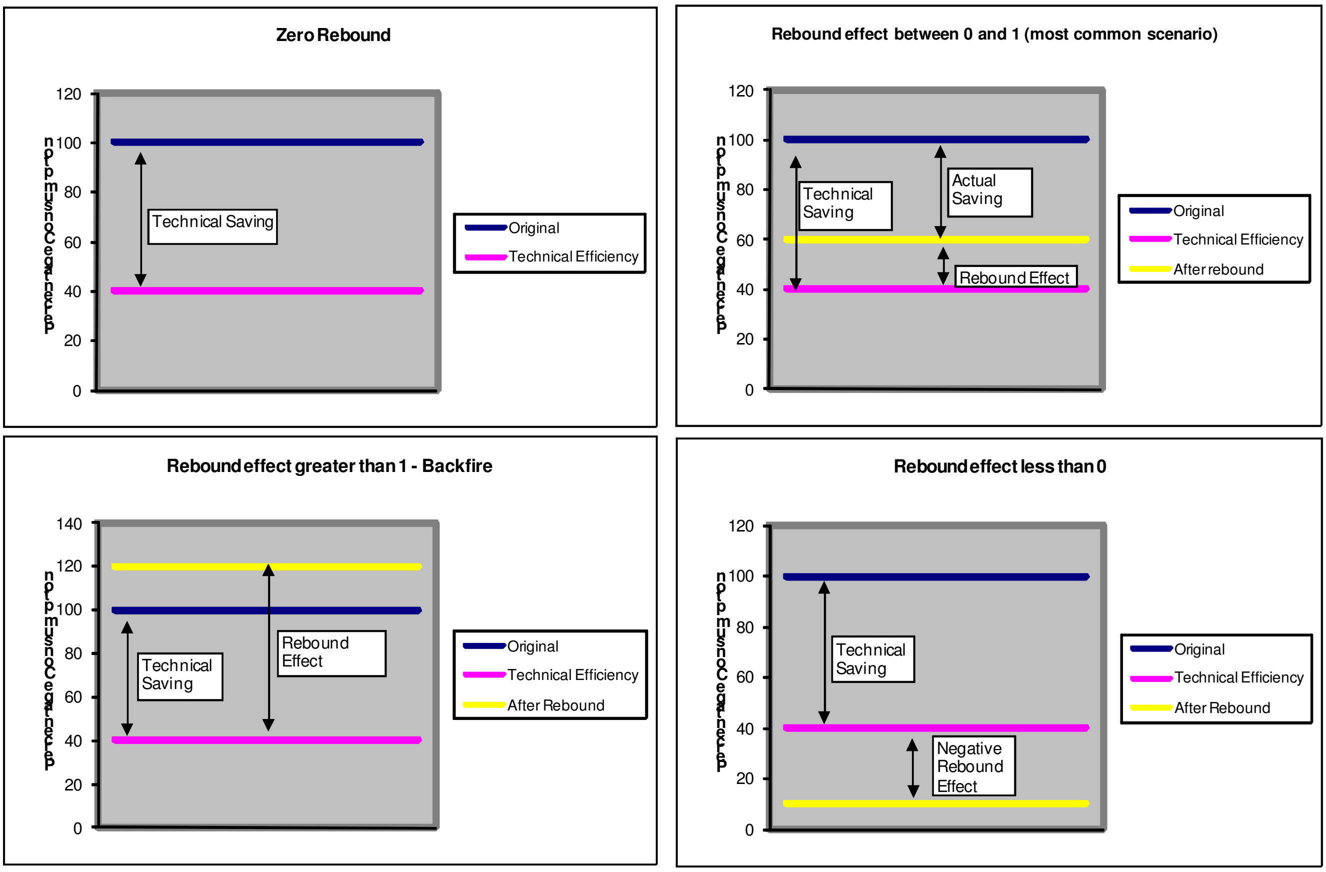

Figure 1: Graphical illustration of the impacts of the rebound effect on the potential for energy efficiency

2.3.4 Measurement and study approaches

This section presents a discussion on the techniques and approaches that have been used historically to understand and quantify the RE.

In general, data collection and end-use metering approaches for measuring rebound are lacking. Moreover, it is necessary to emphasise that direct measurement of rebound often requires measurement of fuel consumption and/or demand. Therefore it is common for analysis of consumption to become the dominant feature of any research relating to rebound, and that is indeed the case in this report.

In turn, for a meaningful characterisation of residential fuel demand, the key variables to consider are income, other expenditure, household demographics, capital cost of appliances, opportunity costs of capital and length of holding and efficiencies of the fuel-using devices. Variability in demand may arise due to the type and availability of devices used for a particular energy service and levels of consumer awareness. Empirical validation of the baseline is crucial for producing a meaningful measure of the RE. (Greening *et al* 2000).

In the following, it is important to note the subtle distinction between direct and indirect *methods of measurement* of REs and *estimates* of direct/indirect REs.

The literature discussing the RE focuses on measurement of the direct, indirect and economy-wide effects (Greening et al 2000; Jaccard & Bataille 2000; Laitner 2000; Saunders 2000; Berkhout et al 2000). Direct RE can be determined explicitly through experimental studies. Approaches to calculation of the indirect RE and the economy-wide effect is less documented, difficult to measure empirically and not well understood. Indirect and economy-wide effects are usually measured indirectly e.g. through econometric methods.

Direct measurement of rebound

Improved EE for an energy service leads to a decrease in the price of that energy service and may lead to an increase in consumption of that particular energy service. This will offset the expected reduction in energy consumption provided by the efficiency improvement. Direct measurement involves measuring consumption patterns at the pre and post-intervention stages of a study on EE and calculating the actual reductions versus the expected reductions. Such studies ought to consider temporal effects, the type of intervention, mode of roll-out and a host of other influencing factors.

Historically, the methodologies utilised for estimating/calculating hours of use vary amongst the literature and include the following types of data:

- surveys conducted via telephone, face-to face and mail;
- diaries given to users to record daily hours of use of certain appliances/technologies and;
- monitoring of appliances using data loggers.

Indirect estimation of rebound

For indirect estimation, Jin (2007) citing Khazzoum equates the RE with energy price elasticity which is defined as the change in demand according to the decrease in price. To estimate the rebound price elasticity residential energy use and price and income are required. A limitation of his calculation is that it does not consider the capital outlay of the technology, which would lower the RE (Dimitripoulos & Sorrel 2006).

Jaccard and Bataille (2000) and Berkhout *et al* (2000) explore the relationship of RE to price elasticity and discuss the factors affecting the elasticity itself. Laitner (2000) says that the extent of rebound is determined by income and price elasticities as well as supply/demand interaction in a macroeconomic model. Similarly, Birol and Keppler (2000) discuss three impacts on the RE, namely price decrease, relative prices of the product being produced, and the knock-on effect of increased productivity leading to increased consumption. Others explore links to GDP.

Data collection

In a CFL methodological review on hours-of-use, Vine and Fielding (2005) recommend that a combination of research methods is required in order to accurately determine the hours of use of a particular appliance/energy service. In their view, hours of use are often overstated through the use of the manufacturers' estimates or self-reported surveys and may be the main source of variation in the calculation of both direct and market impacts of the RE.

Whilst the method used to collect data on hours of use may cause variation, other sources of variation may be attributed to a lack of a base-line survey and follow-up impact study that considers socio-economic characteristics, attitudes and behaviour, variation in the type of dwellings, the current level of market penetration, and the timing of the adoption of the technology. Whilst these factors are acknowledged to cause variation, there is still some uncertainty about the causal links, for instance between the direct RE and household income or the relationship between hours of use and the number of household occupants (Vine & Fielding 2006; Sorrel 2007).

For data and study data collection, considerations and methodology refer to 'A load research project for South Africa' by Heunis & Dekenah (2006). See also Grobler & van der Merwe (Undated) for a case study looking at measurement and verification as well as residential load management.

Sampling, survey and monitoring strategies

It is suggested that households should not be treated as a homogenous group and that EE should target groups of households according to their energy consumption patterns, demographics and other relevant characteristics. In a study on CFLs in Sweden, participation rates reflect the importance of demographics where it was found that single family households and pensioners represented a greater proportion of programme participants (Clarke 1997).

Since the SANERI study was run over a two-year period, mitigation strategies to overcome research fatigue within the households participating in the study for the entire duration of the project were important. Co-ordinated participation of all stakeholders, particularly the households being monitored, was essential for the success of the project. In the Vine and Fielding (2005) study the authors suggest that EE interventions require effective monitoring and evaluation strategies, and that a flexible approach is adopted, which is able to adapt according the households' needs as the study progresses. Ongoing technical and educational support is also advised to mitigate for any problems associated with the roll-out of the technology.

There exists a need to discuss the types of monitoring instruments, and whether they ought to be appliance-specific or household-specific (or even community/location-specific). We also need to choose a level at which to aggregate the measurements. For solar water heaters remote-sensing measuring devices are available and can be used to collect almost continuous data. Some other studies (such as Grobler and van der Merwe) have looked at CFL usage and at the load shaving DSM initiatives using appliance-specific usage-measurement devices.

In summary participation of all stakeholders, particularly the households, is the key to the success of the study. Household participation is important in the residential sector where human behaviour is the overriding factor determining the response to EE.

Sources of variation and uncertainty

There are many sources of variation and uncertainty that arise in the measurement (direct or indirect) and monitoring of energy or electricity consumption for analytical purposes. Some examples of such source include:

- Hours of use: Some appliances are switched on, and left on without the family's or respondent's knowledge, even when family is not home e.g. lights and geyser boilers.
- The respondent may not have accurate detailed knowledge on how and when everyone in the household utilises the various energy services.
- Self-reflection on hours of use using surveys generally over-reports hours-of-use compared to monitored studies (approximately 77-81% of self-reported use involving lighting surveys (Vine & Fielding 2005).
- The household's energy use may be influenced by the survey and perhaps become more energy-efficient as awareness about energy use is raised during the study. Survey bias is therefore a potential source of variation.
- Changing patterns of energy use over time (through awareness of EE, technology changes, lifestyle changes, economic conditions)

Practical issues affecting the take-up of new technology technology

It is widely argued that the introduction of energy efficient technologies is only considered to be beneficial to households if the technology is properly used, serviced and maintained. This argument points to two central areas related to the role of the user as the consumer of the energy service and specifically to the user's understanding of the technology use. In spite of this, the current focus in most EE programmes appears to be on the wide-scale dissemination of energy-efficient energy services without the necessary education and awareness programmes.

Without the necessary maintenance and/or service delivery support, users may become dissatisfied. Dissatisfaction in turn affects perceptions and levels of satisfaction of the product. This aspect often does not receive the attention it deserves, yet affects the sustainable use of the energy service by the target users of the energy efficient programme. Individual households, as well as the community, should be informed of the opportunities and the limitations of the technology to allow them to make informed decisions. Once a decision has been reached, users need to be educated on the proper use of the energy service. Ultimately, the energy service being delivered should contribute towards an improvement in households energy use.

Therefore it is important to establish a programme that is regular, ongoing and responsive to the households needs. Education should include understanding EE broadly and the technology specifically where households are able to make an informed decision when a choice of products are offered. Since the RE is affected by the user's behavioural response, another aspect of the education programme should be on changing behaviour in relation to energy and appliance use to encourage sustainable use, for example fuel switching or reversion, and awareness of costs and externalities such as health impacts from pollutants and the output of greenhouse gases.

Case studies of the impacts of DSM and energy efficiency

Studies have been undertaken which have attempted to measure and verify the savings in demand and consumption resulting from the national CFL roll-out.

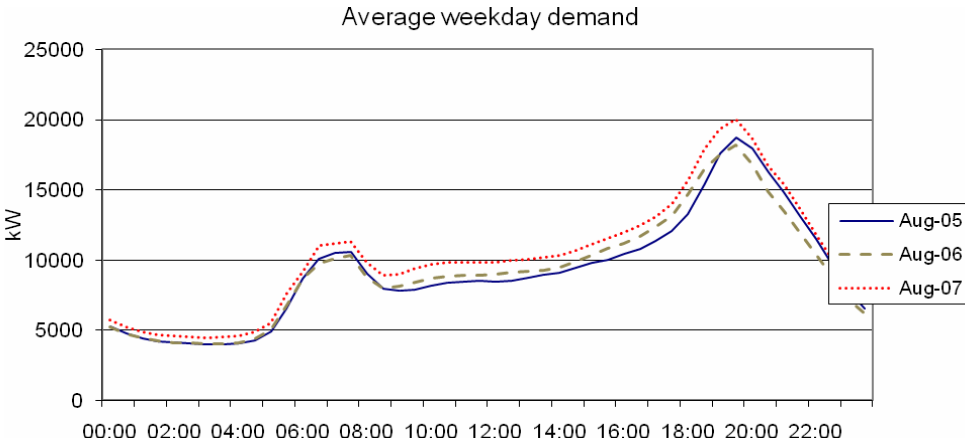

Figure 2: Delft CFL rollout showing the year-on-year shift in the load profile and possible rebound effects

A previous study on the impact of the Eskom's DSM rollout of CFLs was carried out by the ERC's Measurement and Verification team at Delft in the Western Cape. The graph in Figure 2 is useful for showing the impact on the load profile over time. The CFL exchange for this location took place in April to June 2006. Incandescent lamps were replaced with CFLs in a door-to-door project as for the Prince Albert study. In total 52392 incandescent were exchanged for CFLs, resulting in a maximum evening peak demand reduction of 3071 kW. The average impact between 18:00 and 20:00 on weekdays only – based on analysis of the metered data – is 465 kW

It is not possible to calculate exact figures for rebound using this graph as there are a number of confounding factors:

- increasing population size in the area;
- inter-annual weather differences;
- reversion to incandescent lights: the original CFLs had a cold blue light that was not well-received by consumers, and lifetimes were an average of 3 years;
- other behavioural variation; and

indirect REsThis work illustrates the difficulty of extracting an exact number for direct rebound, indirect rebound, and other effects from load curve analysis. Individual load monitoring of households for a large sample over an extended period, alongside hard records of appliance purchases would be a plausible means of detecting pure rebound in one energy service, however the study would be non-trivial as described in the section of this report on methodological choice.

2.3.5 International experience and estimates

Numerical estimates of rebound

This section provides a summary of some of the previous empirical studies and direct and indirect estimation of REs in a variety of countries and contexts. The summaries contained here highlight the differences between countries, developing and developed and include indirect and economy-wide effects. The estimates are useful when considered in conjunction with qualitative information on household decision-making around energy consumption.

Surveys conducted in mainly developed countries indicate that the RE for space-heating is relatively small, of the order of 10–30%, while for lighting it may be as low as 5–20% (Spalding-Fetcher et al 2002). The relatively low REs may be attributed to the saturation level of the technology because most of these households had enough space-heating, lighting and cooking services before EE measures were introduced. In the study contained in this report, the relative size of rebound would depend on the sample's demographic characteristics.

In a comprehensive UKERC report by Sorrel (2007), direct REs in developed countries are reported to be less than 30% and closer to 10% for transport, and are smaller when energy forms a small proportion of total costs. Inclusion of indirect effects means that less than 70% of the technical reduction in energy consumption will be achieved. The link between direct rebound and household income has not been explored.

The opposite would be true for developing countries. In many developing countries like South Africa, and particularly in low-income communities, there is an almost complete lack of adequate, affordable, modern energy services. Even where households have access to electricity, they may not be able to afford to use it regularly. Progress on urban electrification in South Africa since the early 1990s has meant that most urban poor homes do have access to electricity and many have access to other energy carriers such as LPG and kerosene. The level of energy services in poor households is often very low, however, with inadequate lighting, space-heating, and other services. As research in India on the RE effect has shown, unmet demand may be very high in poor communities, so the rebound could also be very high (Roy 2002). The UKERC report states that estimates of economy-wide REs in developing countries frequently exceed 50%, particularly since economic growth may not have been decoupled from growth in energy consumption. Therefore the relationship of energy to economic growth must also be investigated.

Reporting on a previous publication, Greening *et al* (2000) state some results of econometric studies and direct measurements indicate that the potential rebound for water heating is somewhere between 10 and40% and for lighting 5-12% (that is, for a 100% improvement in efficiency). Potentials are also given for space heating (10-30%), space cooling (0-50%), automotive transport (10-30%), and other appliances (0%). However the authors report that the studies on which the estimates were based are not conclusive and may include some indirect effects that could not be measured.

A ten-case, eight-country study is summarised in a 1998 paper by Martinot and Borg on energy-efficient lighting programs. Some important experience and lessons are documented. Their report highlights the importance of good design of roll-out strategies to enable maximum savings of energy and cost, however the RE is not mentioned explicitly in any of the studies. Again the absence of pre-project baselines was emphasised as a definite draw-back to be considered in future work. The value of the paper lies in its very good overview of the lessons learned in various CFL campaigns, and should be a referral document for any DSM programme focussed on lighting.

The following table summarises the various estimates of rebound that have been obtained from a wide range of literature sources. In particular, the following studies have been invaluable resources, most of which were summarised by Greening (2000), Geller et al (2005), Herring et al (2007), Grotton (2001), Figueres, C & Bosi, M. (2006), Oikonomou, V. (2008), and Polimeni et al (2008)

Duplicate results have been removed where identified. The numerical values will be of use in benchmarking the estimates from the empirical studies conducted for this report, and where the latter are insufficient for building long term forecasting, estimates from the tables below will be used as a starting point, with suitable modifications made where necessary.

Table 1: Detailed overview of rebound effect estimates from previous studies

EE intervention	*Notes*	*% rebound*	*ref*
Most sources refer to L.A. Greening summary of literature regarding rebound. The original table is given bellow which shows how many reports per category were reviewed.			
Residential lighting	Industrialised country	5-12	Greening
Commercial lighting	Industrialised country	2	Greening

EE intervention	*Notes*	*% rebound*	*ref*
Space Heating	Industrialised country	10-30	Greening
Space cooling	Industrialised country	0-50	Greening
Water Heating	Industrialised country	10-40	Greening
Home Appliances	Industrialised country	0	Greening
Home Appliances	Based on lit review of other studies i.e. IEA 1998; Greening, Greene and Difiglio 2000.	Less than 10	Geller et al 2005
Space Heating	An analysis of residential building retrofits in Austria.	20-30	Haas and Biermayr 2000
Economy Wide		0.48	Oikonomou, V. 2008
Various residential		8-12	Dubin et al 1986
Residential	Leaving CFLs for longer (survey)	10%	Caird et al 2007
Residential lighting		0 to 30	Berkhout et al 2000
Lighting	India solar lanterns were introduced to replace kerosene lamps. Rebound was calculated based on the expected reduction in the use of kerosene and the actual reduction.	50 to 80	Roy, J. 2000
Cooking	Estimated potential India	200	Roy, J. 2000
Various residential	Empirically estimated direct REs for UK policies	75% in early years due to energy poverty. 28% in 2005 and 23% in 2010	Barker, T. 2006
Commercial and residential in 2020	Direct and micro-economic estimated	44.3	Barker, T. 2009
Residential various	Australia	20- 30 increase in consumption	Polimeni et al 2008
Residential	Sweden (based on carbon emissions)		20% efficiency leads to 5% more carbon emissions
UK residential	total RE, i.e. (assumed) direct rebound plus (projected) indirect rebound	33 in 2005 30 in 2010	Barker, T. 2006
Electrical appliances	Based on actual measurements on various electrical appliances. Original ref hard to locate	0 - 40	Grotton 2001
lighting	US Residential	10	Nadel, S. 1993.
Water heating	US Residential	0	Nadel, S. 1993.
Macro-economic rebound	UK averaged across all sectors	11	Herring H 2006
Direct rebound	UK averaged across all sectors	15	Herring H 2006

Macro-economic REs are insignificant in developed countries but significant in developing countries

The table below comes from Greene and Greening's (1998) review of over 75 estimates of rebound in the literature. They restricted their study to examining the effects of fuel efficiency on a specific energy service rather than on fuel consumption.

Table 2: Summary of empirical estimates of rebound from previous studies
Source: Adapted from Greening (2000)

Device	*Size of rebound (%)*	*Number of studies*
Space heating	10-30	26
Space cooling	0-50	9
Water heating	10-40	5
Residential lighting	5-12	4
Home appliances	0	2
Automobiles	10-30	

A more detailed table showing the impacts of direct and economy-wide effects is shown below.

Table 3: More detailed summary of rebound effect estimates including economy-wide effects

Summary of empirical evidence for rebound effects

Economic actor	End use	Potential size of the rebound[a]	Comments	Number of studies*
Consumers				
	Space heating	10–30%	The unmeasured part of this effect includes an increase in space conditioned and an increase in comfort.	26[++]
	Space cooling	0–50%	The unmeasured part of this effect includes an increase in space conditioned and an increase in comfort.	9[+]
	Water heating	< 10–40%	Reports of increased shower length or the purchase of increased water heating unit size indicate some indirect effects, which cannot be measured.	5[−]
	Residential lighting	5–12%	An indirect effect in terms of an increase in operating hours was reported.	4[−]
	Appliances ("White Goods")	0%	Indirect effects in terms of the purchase of larger units with more features were reported.	2[−]
	Automotive transport	10–30%	The unmeasured part of this effect includes changes in automotive attributes, particularly the shifts toward attributes such as increases in weight, horsepower and acceleration.	22[−]
Firms				
	Process uses (Short-run)	0%–20%	Alhough increases in output occurred for less than 20% of the study participants, no values were reported.	1[−]
	Lighting (Short-run)	0–2%	Changes in output were not reported. However, labor productivity probably improved.	4[−]
	Long-run aggregate impacts	< 100–0%	Changes in output show a great deal of variability in the literature.	Any number of studies with a variety of conclusions.
Economy-wide effects				
	Change in total output growth	0.48%	Postulated effects include an increase in standard of living and consumption of more energy-consuming "luxury" goods.	1[−]

[a] These estimates are expressed as a percentage increase in consumption estimated to result from a 100% increase in energy efficiency (i.e., the estimated elasticity of demand times — 100%).
*Grading system used for the quality of estimate:
[++] These studies are done with a number of methods that provide good correspondence of estimates.
[+] These studies are done with only a moderate number of different methods that show some variability in estimates.
[−] These studies are done with only one or two methods and are inconclusive in results.
Note: All estimates assume a 10% increase in efficiency of fuel consumption.

Anecdotal evidence of rebound

The subject of RE generated much interest among many of the authors' peers, and it was interesting to note the range of opinions expressed by people with different backgrounds and understandings. What follows is a list of insights from various conversations during the term of this project:

1. Some users felt that the take-up and presence of new technologies raises the profile of energy matters and that rebound is in fact negative. This view was generally held by those

who are conscious of environmental and energy issues, and would be more likely to take up the new technologies of their own accord and at extra cost, with the potential of reducing their consumption below the levels that are achievable purely with technology, for example through switching to less energy intensive behaviour.

2. Users do not notice the reductions from interventions that are small from an energy point of view. In essence they do not see a noticeable saving in their consumption (for example by installing CFLs), so tend to be resigned and put up with the new technology. The random variation, and relatively small contribution of lighting tends to smother any savings in kilowatt hours. It is worth mentioning that the benefits of peak reduction to the utility will be more valuable than the benefit to the consumer. It also raises the question of whether rebound should be measured with reference to peak demand or energy consumed. Installation of CFLs will reduce peak demand, even if rebound is 100% and the lights are left on for longer, eroding energy savings (but not peak savings). For indirect rebound, there may be rebound in load/power terms as well as energy terms.
3. Many people mentioned that they'd never heard of rebound, although the concept made sense, and it would appear that the propensity to consume more (e.g. leave CFLs burning longer) was quite high. This was generally true among well-educated people (who also happen to be more affluent and less concerned about the cost of electricity (relatively small in their overall budget). Reasons include security (justification for outside lights burning all night, or when nobody is home in order to dissuade intruders), laziness, and a 'use-as-much-as-I-need mentality'.
4. One of the authors of this report has had the personal experience of having installed a solar water heater, and noted that despite seeing a drastic reduction in electricity consumption, the 'free' energy sourced from the sun is a justifiable motivation for utilising additional hot water (no rebound with regard to electricity demanded or consumed, yet an increment in water demand) for comfort, particularly in winter months when the utility derived from hot water is greater (and the solar resources in Cape Town smaller).

2.4 South African context

EE is widely regarded as a positive initiative in households. In a 2008 report on SABC news in a response to news of expected load shedding, Eskom was quoted as saying 'Energy efficiency needed to become a way of life.' In this section the key issues relevant to a South African study that arise out of the international literature review are discussed, keeping in mind the dual nature of South Africa's economy, integrating developed and developing country contexts.

Reducing energy demand as a component of environmental, EE or general energy policies will have different outcomes, so any approach initiated at a national level needs to take into account the overlaps and conflicts of interest between them. Also the behavioural response to technological improvements within the context of developing countries must be ascertained as far as possible. In South Africa, there remains an unsatisfied demand for a variety of energy services, often leading to fuel- or appliance-shifting to satisfy that demand and resulting in subsequent enhanced or increased activity with high rebound potential.

The developing country perspective presumes an increase in energy demand determined by the relationship between energy demand and growth. The pending growth in such countries highlights the need to lock EE into the trajectory of increased consumption, since retro-fitting EE to a mature economy is likely to be more costly than starting it earlier in the development phase, and cumulative savings will be lost in the interim. Measures, other than EE technology (e.g. price interventions) aimed to meet greenhouse gas reduction targets may lead to adverse effects on economic growth and particularly efforts to improve living standards. The raising of awareness of EE (and climate change) in conjunction with consideration of the end needs of the users is important in this regard (Roy 2000).

Winkler (2009) discusses the challenge of realising the full potential of efficiency gains, and states that the removal of key barriers is critical. The barriers are informational, institutional, social, financial and technical in nature. However it should be noted that it is not always in the best social interest to realise full technical efficiency, for example when an element of the rebound comprises improved access to essential energy services. Some barriers to EE are only viewed as barriers to achieving technical efficiency, where policy may purposefully wish to compromise on achieving full potential for the social benefits that may result. Important success factors in mitigating rebound include government policy (standards, incentives, recovery of programme costs), electricity pricing mechanisms that do not penalise efficiency, and effectiveness of DSM delivery agencies. An important conclusion is that achievement of the full socially acceptable level of EE is essential from a climate change mitigation point of view, with energy cost savings and short-term payback periods, and rapid take-up (as distinct from supply diversity that can be a longer-term endeavour). Although the gains in the residential sector are smaller in absolute terms relative to industry and transport sectors, the improvement of quality of life at reduced cost has a value that cannot easily be quantified in economic terms (EDRC 2003).

Energy efficiency and demand-side management

The Integrated National Electricity Programme (INEP) aims to provide access to basic electricity services to all households in South Africa by 2012. The intention is to address the historical inequalities related to the provision of electricity to all. The INEP's ambitious target will inevitably increase energy demand and impact the current generation capacity which is already under pressure with low reserve margins and increasing levels of load-shedding. Electricity demand was predicted to outstrip the current generation capacity and infrastructural development by this year, 2007. (Clark (1997), Energy White Paper (2008)). The annual economic growth rate in the country averaged at about 3.9% for the period 1993 to 2004 over the same period, total primary energy supply increased from 3.924 PJ to 4.295PJ amounting to an increase of 9.5% (DME 2007). It is estimated that approximately 1 500MW of additional generation capacity will be required to meet the growing demand each year (DME 2006).

One of the questions for the SANERI study is (for an EE intervention) how great the unmet demand for the service is likely to be, particularly if the quality of energy service is currently very poor or constrained by income or access problems. In this instance the unmet demand, and hence RE, is likely to be large. For example in the case of a CFL intervention, if our target households have incandescent electric lighting, we may expect the RE to be less than revealed in studies like the one in India, where the sample homes are rural households moving from paraffin lamps to solar lanterns. Given that lighting is often the only electricity service that is affordable for the poor, and that even poor households have several lamps per household, we may assume a 20% upper boundary to represent more hours of lighting use and in some cases more lamps in the home (Spalding-Fetcher et al 2002). In the case of space-heating a different scenario can be predicted. A relatively large RE may be expected due to the high cost of appliances and fuels and poor quality housing. In the Spalding-Fetcher et al study it is assumed to be as high as 50%. For an EE intervention involving energy appliances, if the EE intervention involves an efficient refrigerator, stove or heater it is unlikely that the households will purchase another unit so the direct RE effect should be low.

Further benefits and intentions of EE and DSM are the effects on the transmission networks and quality of power provided. The roll-out of certain technologies has technical repercussions. We also need to consider, for example that peak power investment costs are high relative to the residential variable peak load that it serves (due to a large capital outlay of generation capacity). We can be sure that the benefits extend beyond the users to the suppliers of electricity and the economy as a whole. The opportunity costs of alternative energy uses (e.g. beneficiation of raw materials in industry) are also important when motivating a DSM or EE intervention

Broadly the contribution which EE can make to South Africa is seen as the following: enhanced energy security; improved security of supply and energy independence; reduction of the cost of meeting the required level of energy service; reduction of the impact on households, and in particular low income households, resulting from the use of fuels such as wood, coal and paraffin; reduction of the cost of energy to the poor (energy forms a large portion of low income household budget and reducing the amount of energy needed can help alleviate this burden); more recently EE is seen as an important mitigation option to reduce GHG emissions in South Africa. Due to the important role that EE can play in meeting government targets and national priorities, EE and more recently DSM receives attention in several government policy documents.

Policy documents often motivate for EE in the residential sector by highlighting the benefits that accrue to poor households as a result of improved EE. It is also recognised that there are many low cost opportunities to improve EE in households. Some examples are improved appliance efficiencies, reduction of standby power, improved building efficiency eg orientation and insulation, education and behavioral change. DSM, which includes EE and load shifting, has brought with it the realisation that, because household demand is high at peak times, households can play a key role in DSM and ensuring grid stability at times of high demand. The residential sector can also be an easier target for EE measures through standards, appliance labelling and awareness campaigns, or retrofits and savings can be significant. The DSM awareness campaign Power Alert, which draws customers attention to the stress on the supply system though a dial indicating green (limited stress) to red (high stress) has achieved an average saving during the red flag periods of 320 MW (Eskom DSM Power Alert Study).

The following provides a short overview of policies and programmes where residential EE is mentioned explicitly. Although the 1986 White paper has content related to EE, it is safe to say the little was done between 1986 and the introduction of the 1998 White Paper on Energy Policy by the Department of Minerals and Energy. This overview begins with the 1998 White Paper on Energy Policy.

The 1998 White Paper on Energy Policy, initiated in 1994, reflects a change in the energy agenda post democracy. The White Paper introduces a shift in policy from a predominantly supply side focus to including the demand side. Included in the demand side is the recognition of the importance of EE to policy and the benefit of EE to energy security and the economy. The White Paper mandates the efficient production and use of energy and highlights the importance of promoting EE in the residential sector:

> Energy efficiency needs to be promoted, especially in households where such measures will increase disposable income. These issues are important not only from a financially viable energy supply aspect but also from an environmental aspect.' Building thermally efficient low cost housing presents an opportunity to promote energy efficiency and conservation. There is also great potential to stimulate energy demand management and other strategies in middle and high-income households. Energy savings would free resources and delay the need for further investment. Government commits itself to the promotion of energy efficiency awareness in households. An initiative is needed to inform householders on how to use appliances and fuels.

The White Paper also states that:

> Significant potential exists for energy efficiency improvements in South Africa. In developing policies to achieve greater efficiency of energy use, government is mindful of the need to overcome shortcomings in energy markets. Government would create energy efficiency consciousness and would encourage energy efficiency in commerce and industry, will establish energy efficiency norms and standards for commercial buildings and industrial equipment and voluntary guidelines for the thermal performance of housing. A domestic appliance-labeling programme will be introduced and publicity campaigns will be undertaken to ensure that appliance purchasers are aware of the purpose of the labels. Targets for industrial and commercial energy efficiency improvements will be set and monitored.

Whilst the White paper does not address how EE is to be improved and provides no implementation strategies, it does promote the importance of EE and the attention paid to EE within policy. The white paper identifies integrated energy planning as an approach which can be used to simultaneously promote both energy and social concerns. An integrated energy planning process recognises that energy is needed to produce a service, but that the same level of service can be provided with different types and quantities of fuels through a variety of appliances with different economic and social impacts.

In 2001 the first Integrated Energy Plan (IEP) for South Africa was initiated, in 2003 an 'Integrated Energy Plan for the Republic of South Africa' was published by the Department of Energy. On the demand side in the residential sector, the IEP considered the end use efficiency of cooking, heating and lighting in urban and rural, low and high income households. Opportunities for improving EE through improved appliance efficiency are included in the baseline optimised and Siyaphambile optimised scenarios in the IEP. The IEP does not address the practicalities of improving EE, but does highlight the advantages and importance of improving EE to the economy and the well-being of households. In summary, after testing the costs and benefits of EE against the alternative of increasing supply, the IEP concludes that South Africa should 'promote the use of EE management and technologies' and 'introduce policy, legislation and regulation for the promotion of renewable energy and EE measures and mandatory provision of energy data'

The 2002 World Summit on Sustainable Development, held in Johannesburg, recognised EE as a key tool to enhance clean energy development and to mitigate the negative effects of energy use upon the environment.

A process for introducing EE in earnest was initiated through a joint project undertaken by the Danish and South African governments to build capacity in EE and renewable energy (CABEERE). Under the CABEERE programme the first EE strategy for South Africa was developed in 2004. The National Energy Efficiency Strategy was approved by cabinet in March 2005 and marks the first serious attempt by government to put programmes in place which would influence the long term EE of all sectors. The strategy sets out to promote improved EE through economic and legislative activities, the introduction of efficiency labels and performance standards and by promoting energy management activities, energy audits and efficient practices. Whilst there has been much attention paid to appliance labelling since the strategy was developed, appliance labelling in South Africa is still in its infancy.

The strategy reviews opportunities for EE and potential improvements in EE in all sectors individually and sets targets for each sector based on a percentage reduction in energy use from an assumed 'business as usual' energy consumption. The strategy also introduces a three phased approach to improving EE in each sector. Improvements in the residential sector of 10% by 2015 indicate the savings South Africa could achieve through setting standards for housing (SANS 283), appliance labelling, awareness, efficient lighting, standards for non-electric appliances and fuel standards. The Energy Efficiency Strategy includes a fairly comprehensive list of appliances and policies, but it is my no means exhaustive.

The EE strategy was reviewed in 2008. The review mentions limited capacity to implement EE programmes required by the Energy Efficiency Strategy. It mentions that the DME 'has embarked upon a programme to develop detailed methodologies for the monitoring and tracking of sectoral targets' but does not include a review of savings that have been achieved since the EE strategy came into effect. Reviewing residential sector savings it concludes that 'an ongoing public awareness drive will be necessary to achieve a saving of 10% by 2015, based on a projection from present consumption. An easy to follow guide for households will be developed, such as energy savings tips, taking into consideration that changing people's lifestyle is by no means straightforward'.

DSM was introduced to South Africa in the mid 80's after a Working Group on electricity conservation was established in response to a need to mitigate against investment requirements [Marquard, 2006]. ESKOM (then Escom) was to play a large role in overseeing DSM. At the time Escom was facing supply shortages at peak time and opted for load shifting (time of use tariffs and interruptible supply agreements) rather then pursuing EE programmes. By the late 1980's there was overcapacity and DSM lost momentum.

In recent years DSM has regained momentum as South Africa is once again faced with insufficient generation capacity to meet demand. Demand Side Management is currently implemented by ESKOM. NERSA set targets and supply funding to ESKOM for the programme and ESKOM report all savings achieved to NERSA. DSM is applied across all sectors. During the electricity crisis of 2006 several DSM measures were pursued in the residential sector such as, installing geyser blankets, replacing incandescent lights with CFLs, replacing electric stoves with gas stoves, residential load management programmes and power alert. These programmes are monitored in order to assess savings against a baseline. The monitoring is intended to be rigorous. The DSM lighting replacement programme in Prince Albert forms a case study for this report. In recent years, DSM initiatives in the residential sector have been extended to include a subsidy for solar water heaters and an awareness campaign through television. DSM targets are included in future build programmes under the integrated resource plans.

Around 2003 Cities began to develop State of Energy Reports and Energy Strategies. These reports highlight the opportunities and benefits of improving the EE of households within the city boundary. The reports have raised the profile of EE within local governments. For instance the City of Cape Town has established an Energy Efficiency Forum for owners and managers of commercial and public buildings.

Under the National Energy Act (NEA) no 34 of 2008, the South African National Energy Development Institute (SANEDI) is established. According to the act, the role of SANEDI in EE is to:

- (i) undertake EE measures as directed by the Minister;
- (ii) increase EE throughout the economy;
- (iii) increase the gross domestic product per unit of energy consumed; and
- (iv) optimise the utilisation of finite energy resources.

The act does not suggest how SANEDI is to do this, however it does provide a platform through which the Department of Energy can regulate energy management, and monitor and verify progress against objectives. Under the act the National Energy Efficiency Agency (NEEA), which was established in April 2006 and was housed within the Central Energy Fund (CEF), will be transferred to SANEDI. Listed under NEEA's objectives on the CEF website are overseeing and prioritizing DSM projects within South Africa, as well as the measurement and verification of savings. NEEA is also tasked with developing and implementing awareness campaigns around EE, and training in EE. In other words, many of the initiatives under the Energy Efficiency Strategy could be achieved through the NEEA. NEEA has however been running with a skeleton staff with limited support from government.

In 2006 the Department of Environmental Affairs and Tourism began a Long Term Mitigation Scenario (LTMS) study. LTMS was a cabinet mandated process to identify scenarios for climate change mitigation. The outputs provide South Africa with a negotiating position for post 2012 negotiations and recommendations for long term climate policy. In 2008 cabinet endorsed the peak plateau and decline emissions trajectory of the LTMS. LTMS projected baseline energy consumption in South Africa until 2050, and then compared savings in energy or emissions possible through a series of measures, often referred to as 'Wedges'. Energy efficiency in all sectors features prominently in the scenarios as a least cost, large scale opportunity to meet energy consumption and simultaneously green house gas emissions.

Residential EE came out as a ‘medium’-sized wedge.[4] The LTMS considered energy reductions in the residential sector are from improved combustion efficiency in coal braziers, improved thermal efficiency of houses through ceiling insulation, solar water heaters and energy efficient lighting.

The Clean Development Mechanism (CDM) has become an opportunity for improving EE in households. CDM is a mechanism developed under the Kyoto protocol. CDM provides a means for developed countries which are signatories of the Kyoto protocol to meet their emissions reduction targets through investing in abatement opportunities in developing countries. South Africa became a signatory of the Kyoto protocol in 2002 as a non-Annex 1, developing country. The residential sectors of developing countries present many opportunities under the CDM due to the generally low efficiency at which many traditional fuels and appliances are operated. An example of CDM at work in the residential sector is the Kuyasa project. Through CDM financing, 2300 homes in Khayelitsha were retrofitted with insulated ceilings, solar water heaters and EE lighting. A glaring gap in many of the policies is the fact that the RE is not mentioned.

2.5 Rationale for the study

The literature review indicates that there are a number of behavioural response factors that need to be considered when implementing EE and climate change mitigation measures so that socio-economic and environmental sustainability objectives can be achieved. Among these is the RE which is particularly acute in developing countries that have a prevalence of unmet demand for modern energy services. However, existing research mainly focuses on the developed country scenario. In particular, there is limited evidence on the nature and extent of rebound in South Africa, nor is there much on bottom-up measurement at the household level.

This study aims to further the understanding of the behavioural response to climate change mitigation and EE initiatives such as demand-side management within the developing country context and lay a foundation for local study that will foster an understanding the behavioural response to EE and climate change in South African households. Furthermore, the outcomes of the study will give rise to suggestions for mitigating rebound and improving EE which is necessary for meeting the government’s objectives of social, environmental and economic sustainability.

Ideally, an integrated approach to energy conservation and reducing greenhouse gas emissions should be taken, and both have been amply considered in the literature as sound reasons for exploring the RE. However, the two are related, and not in a linear fashion as might have been expected. This study is, however, restricted to considering rebound in the context of EE, which in no way implies that this is more or less important motivation than climate change mitigation. For the ease of discussion it is assumed that achieving maximum EE also satisfies the goal of greenhouse gas reduction.

The rationale for studying the RE is to understand the underlying causal factors. Consequently, this understanding contributes to improving EE, which, in turn, is necessary for meeting the government’s objectives of social, environmental and economic sustainability (from Howells *et al*, 2005 discussing the DME’s 2004 objectives and looking at the Energy Efficiency Scenario for South Africa).

When examining the topic of the RE of energy use, the challenge exists in bringing together ideas from a host of disciplines ranging from engineering to economics to human behavioural sciences. Simply put, the question is: ‘What proportion of the technically achievable reduction is achieved in reality, and why do the actual reductions differ from the expected?’ A comprehensive report by Sorrel (2007) poses a slightly different question, ‘What is the evidence that improvements in EE will lead to economy-wide reductions in energy consumption?’ A great deal of complexity emerges when an attempt is made to bridge the divide between

[4] The wedges were intended to measure emissions rather than energy, so the results are not directly interpretable in an energy terms.

practical considerations for understanding and implementing EE, and the academic theory that has emerged around those considerations

Sustainability

From a sustainable development perspective, EE is usually considered to be beneficial. According to Munasinghe 2007, EE 'lowers investment and fuel costs, increases business profits and consumer welfare, while reducing environmental harm and enhancing social benefits. However the demand stimulated by subsequent reductions of energy costs, new uses of energy, and population growth, often expands energy use'. EE is important for reducing an economy's carbon intensity. Consideration needs to be given to both supply and end-use when implementing EE and subsequent reductions in intensity.

Changing attitudes and behaviour

Previous studies on EE emphasise the need for analysis of energy use, response behaviour and technological trends, and for integration into the more general question of how best to achieve joint goals of socio-economic development and climate mitigation. Studying the RE furthers the understanding of the behaviour of consumers in the face of technology choice (attitudinal effects). Increasing the awareness of the link between energy consumption and environmental impacts, coupled with improvements of energy-consuming devices should minimise the shift in consumer preferences that would otherwise lead to increased consumption (Laitner 2000).

Energy conservation

The energy crises in 1973 and in 1979, and more recently capacity constraints in South Africa in 2008, turned the attention of developing countries to DSM activities that promote the use of efficient technologies for lighting, refrigeration, space heating and cooling, water heating, cooking and other energy services. DSM and EE strategies in developed countries have spurred on efforts in developing countries to examine the potential for saving electricity, whilst at the same time continuing efforts to increase access to electricity.

Although residential consumption accounts for only 10-15% of the country's national energy demand, it is estimated to constitute about 75% of the national variable load during peak demand (DME 2007). It is evident that household electricity demand fluctuates more than industrial and commercial use at peak times. The residential sector in developing countries is thought to have the highest growth potential for electricity usage, mainly due to the (currently) large numbers of unelectrified households. The potential is particularly large in areas with increased levels of urbanisation, where there is a demand for the provision of electricity along with formal housing development. The purchase of additional household appliances facilitates such energy demand growth. In the literature, Clarke (1997) and Roy (2000) have suggested that the potential for the largest savings in electricity is possible from households in developing countries, primarily because these households are using appliances with the cheapest capital outlay rather than the most efficient appliances available. Improved understandings of the RE can help to put measures into place to minimise rebound and maximise energy conservation.

Greenhouse gas mitigation

Around 70% of greenhouse gas emissions are energy related (Birol & Keppler 2000), and EE is a necessary tool in contributing to meeting emissions reduction targets. This opportunity is even more pronounced in developing countries if they are able to leapfrog their developed counterparts and lock-in efficiency early in their development trajectory.

2.6 Conclusions

This chapter has summarised an extensive survey of the literature on rebound and behavioural response to EE in the residential sector, including a discussion of previously applied methodologies for quantifying and measuring rebound. Rebound was broadly defined as the percentage of technical EE potential that is not achieved in reality, and it is noted that the way rebound is defined will depend on the perspective and intention of the analyst measuring it. The review has also explored potential sources of and evidence for rebound in household EE interventions, and distinguished direct, indirect, and economy-wide effects, summarising the numerical estimates available from a broad set of studies. The chapter has also contextualised the study in the South African context, through a review of the country's EE strategies, policies and socio-economic needs.

It has been identified that for successful EE interventions, it is essential to integrate policy measures for energy, climate change and EE within a sustainable development framework in order to reduce consumption through the use of taxes, subsidies, laws/regulations and trading schemes. Unless an integrated policy approach is adopted, specific EE or climate change policies may not have the desired outcomes.

In the developing country context, where there is a large unmet need for a variety of energy services, the behavioural response to technological improvements often leads to a shift in fuel/appliance use in order satisfy that demand, resulting in increased activity and high rebound. Adopting an approach to EE that focuses on one specific technology may not be viable in the South African context. Further it is worth noting that REs may contain as constituents certain welfare benefits of EE enhancements through implicit relaxation of the household energy budget. In such instances the constituent may represent a desirable component of rebound.

Specific additions to the body of commonly referenced literature on rebound have been made, with the inclusion of literature relevant to the modelling household consumption behaviour. Qualitative studies of energy usage in households, and descriptive modelling approaches for exploring household response to EE have been reviewed, increasing the range of factors that ought to be considered when implementing DSM and EE. It has been identified that users respond according to their desired comfort and awareness levels alongside their environmental impact goals, and that the interventions can be expanded beyond technology to include price and awareness interventions. It is important for planners to understand the interplay between the needs of the consumers and the various interactions between the intervention options. This is an area which will be explored further in this report, as it is intricately related to – and possibly more important than – estimating the potential for rebound. Having said that, it is clear from the historical policies that the RE has not been acknowledged, and it is clear that its omission offers an opportunity through this report to raise its profile. This chapter has also laid the foundation for the development of our research methodology.

3. Methodology

3.1 Introduction

This chapter describes the methodology used to investigate the RE of EE in the residential sector. Although the focus is on South Africa's residential sector, many of the principles applied are universal.

This chapter is not only important for describing the final methodology that was used for the research, but has intrinsic value in that during the process of scoping the study it was found that traditional methodologies for measuring the RE were inadequate for dealing with the complexities and practicalities associated with EE intervention studies. In particular, many of the previous studies – and indeed the original methodology suggested for this study – attempted to perform a purely quantitative study on the RE of an EE intervention without recognising the intricacies of the rebound phenomenon, nor questioning whether the term 'intervention' need be confined to technology changes. The nature of the phenomenon being studied was not found to be amenable to the 'traditional' approach consisting of:

- measuring a baseline;
- applying an intervention; and
- measuring the impact in a follow-up; with all aspects of the study taking place in an idealised and somewhat artificial experiment.

Furthermore, many previous studies have used estimated baselines or had no baseline at all.

Also, we restrict our study to EE that directly impacts the user of a specific energy service (resulting in a change in price or the quality of the energy service required) rather than EE measures that are embedded in the carrier (e.g. users will not necessarily interact with an improved efficiency of a coal-fired power station generating electricity, unless the improvement results in a price reduction to the end-user).

The methodology used in this study was developed in recognition of the complexity of the various causes of the RE and endeavoured to explore the interactions and influences themselves, for example through the use of systems dynamics. Ultimately the choice of methodology evolved with the study itself. The main purpose of the chapter is to describe the approaches that were finally adopted, and lays the foundation for the data described and analysed in the next two chapters.

The conceptual framework for the study is captured in Figure 3, and the current chapter demonstrates how each of boxes are linked, with a specific focus on the second box on data collection considerations and data requirements. The following section presents a description of the study scoping processes and outcomes. The third section describes and motivates the choice of study locations, and the fourth section gives a foundation for the development of a simulation model of household energy behaviour. Section 5 describes the methodology used for quantifying national impacts of rebound and associated scenario development. The final section concludes the chapter.

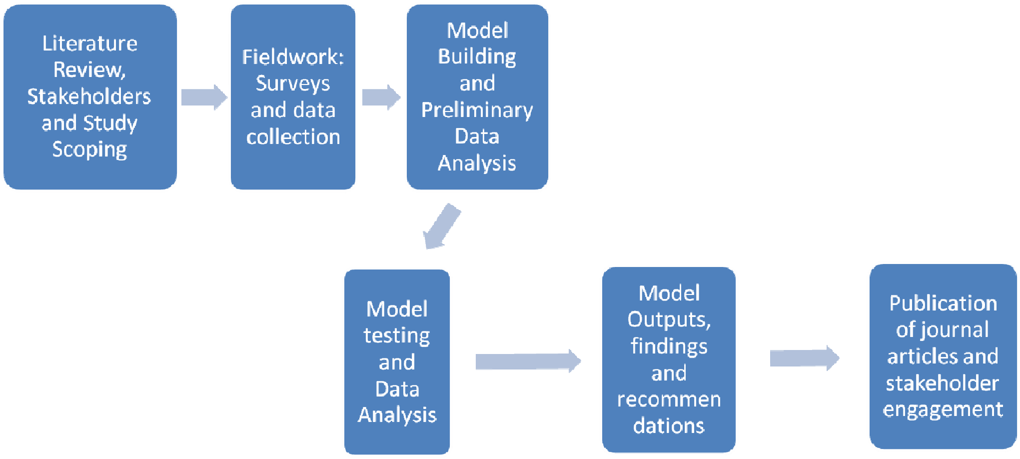

Figure 3: Research pathway

3.2 Stakeholders, target areas, criteria for assessment and data collection considerations

3.2.1 Stakeholders

Early in the study an assessment was made of the various stakeholders in the research. The identification of stakeholders was useful for increasing the relevance of the study as well as identifying study sites and potential collaborators. The stakeholders selected were parties that would have had an interest in the results of the research, and the implementation of the findings. The various stakeholder groupings are shown in Figure 4.

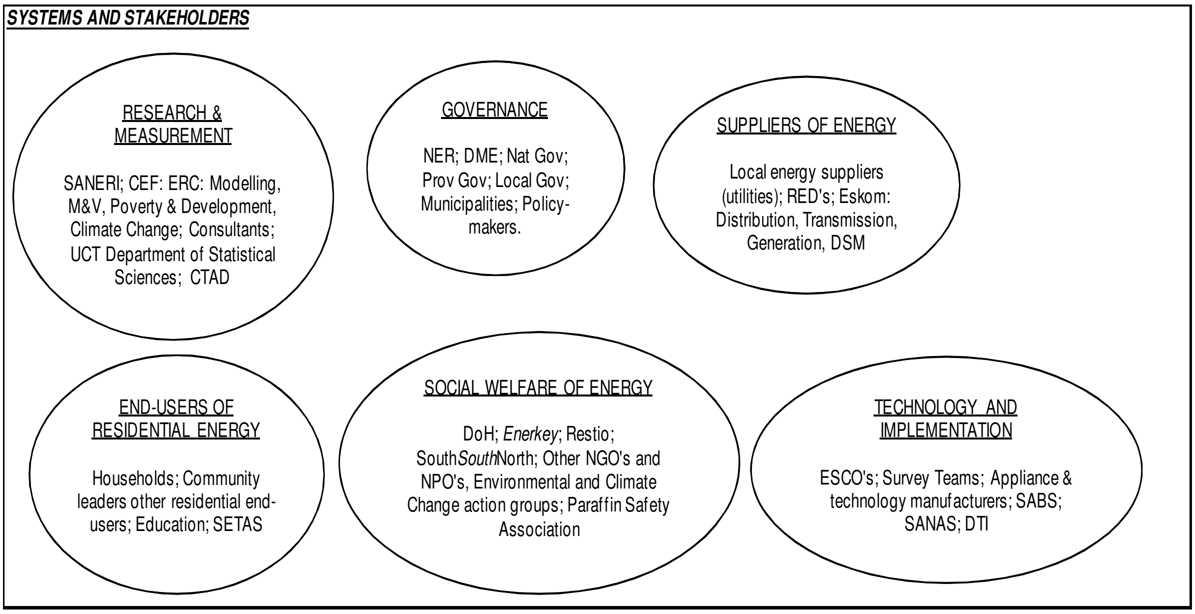

Figure 4: Potential stakeholders in the study

A list of individuals and organisations who were involved in the original study scoping is given in the Appendix 1.

3.2.2 Target areas and criteria for assessment

The following table summarises the key target areas, outcomes (with associated indicators) and end goals for the research identified by the stakeholders.

Table 4: Initial scoping of target areas, outcomes and goals from the study

Target areas	*End goal*	*Measurable Outcomes*	*Indicators*
Sustainability of Energy Systems. Energy security, climate change mitigation, energy poverty alleviation, capacity building (energy analysis and disadvantaged communities)	Understanding the RE	Capacity built - students, interviewers trained, communities impacted	Certificates awarded, school projects, money invested in community, numbers of related degrees awarded
	Quantifying RE of EE initiatives including direct and indirect effects (economy-wise), feedback	Research - project report, conference papers, published research articles, model (behavioural or optimal pathway with regard to technology, laws, awareness and education). Policy recommendations. Awareness / Education tools	Numbers of each
	Dissemination and uptake of knowledge of mitigating options, changing attitudes to EE and awareness-raising strategies	Practical Impact - Megawatts/ Energy saved, GHG's avoided, awareness raised, money saved by end-users, avoided costs of unserved energy	Levels of awareness

The stakeholder engagement process which resulted in the above table was carried out in the early stages of the study, and formed the basis for the methodology development and subsequent data analysis and modelling.

Towards the end of the study a further workshop was held with representatives from the four research groups at the Energy Research Centre (ERC), being Monitoring and Verification (M&V), Energy Poverty, and Policy and Modelling, as well as with an MCDA expert from UCT’s Department of Statistical Sciences. The intention of the workshop was to develop a set of criteria by which the effectiveness of an intervention campaign for EE in the residential sector could be measured. These criteria were structured into a value tree. This exercise was useful in reaffirming the approach used in the study, and is also useful for informing future implementation of the results of the study.

The workshop suggested that the overall objectives against which the interventions should be assessed included those relating to:

- reliable energy services;
- saving money;
- comparison to best practices;
- indirect effects;
- saving electricity;
- timeline of realising benefits;
- savings in CO_2 emissions;
- awareness of EE; and
- other items.

These headings were further explored to develop a list of criteria for assessing the success of the intervention. The discussions suggested that these criteria fall into the broad categories of:

- provision of social upliftment,
- effect on economic wellbeing,
- effect on environmental degradation.

The criteria used to assess the contribution within these broad categories are as follows:

- quality of life following intervention;
- awareness of energy issues following intervention;
- extent of community involvement/participation;
- direct cost of intervention;
- direct savings on energy by households;
- direct savings on energy by suppliers;
- number of jobs created;
- any other indirect monetary effects;
- revenue lost due to load shedding;
- other costs associated with overburdened grid;
- other monetary effects of intervention;
- CO_2 emissions;
- other environmental impacts.

An example of a value true representing the above criteria is given in Appendix 2 at the end of the report.

3.2.3 Data collection considerations

A mixture of quantitative and qualitative data was required to inform the research questions and the development of the model. A decision had to be made as to how to collect consumption data, through load research – aggregate cohort of households or individual household, or individual appliance/end use. For measurement of rebound it was deemed important to be able to separate between impacts of using the installed efficiency technology from those of random fluctuation and overall appliance use.

Data collection methods, survey questionnaire instruments and focus group interviews had to be developed. The survey instruments were designed to be applicable to all household types, and sufficiently versatile to capture sufficient detail to enable disaggregation of energy end uses and the presence of the intervention. Part of understanding the RE is noticing whether efficiency gains are substituted for additional appliances, and the follow-up questionnaires were designed to capture such shifts. School learners were chosen for monitoring of their own household energy consumption. Further we had to consider whether to collect aggregate data (e.g. electricity bills at the end of each month and estimate savings from total use), or do a more detailed analysis of hourly load data.

The measurement of the RE on a single mode of intervention or even a single energy service is problematic. Take the example of lighting. Light meters were considered for direct measuring the number of hours of illumination; however the devices can pick up external light. Lighting circuits were also considered but would also not reliably measure light usage, as plug points may be used to power lamps off the main lighting circuit. Measuring the entire household electricity consumption would aggregate all the energy services such that light usage is smothered. Methodologically it would be difficult to separate energy services while simultaneously measuring pure rebound on one service, as well as indirect effects on other energy services.

For this study it was decided that prepaid meter or credit meter billing information would be the best means of monitoring electricity consumption in the baseline and follow-up studies. The availability of town load data would be used as a cross reference if it was readily available.

Section 3.2 has summarised the selection of stakeholders, target areas and data collection considerations. The following section discusses the detail of the methodological development.

3.3 Considerations in methodological development

As mentioned previously, there were a number of iterations in development of the approach used in this study, and the original planning procedure is included in Appendix 3. The final approach taken in this study is summarised in Figure 5. Considerations in data collection and analysis, including a description of the factors affecting the methodology and the study outcomes, are discussed below.

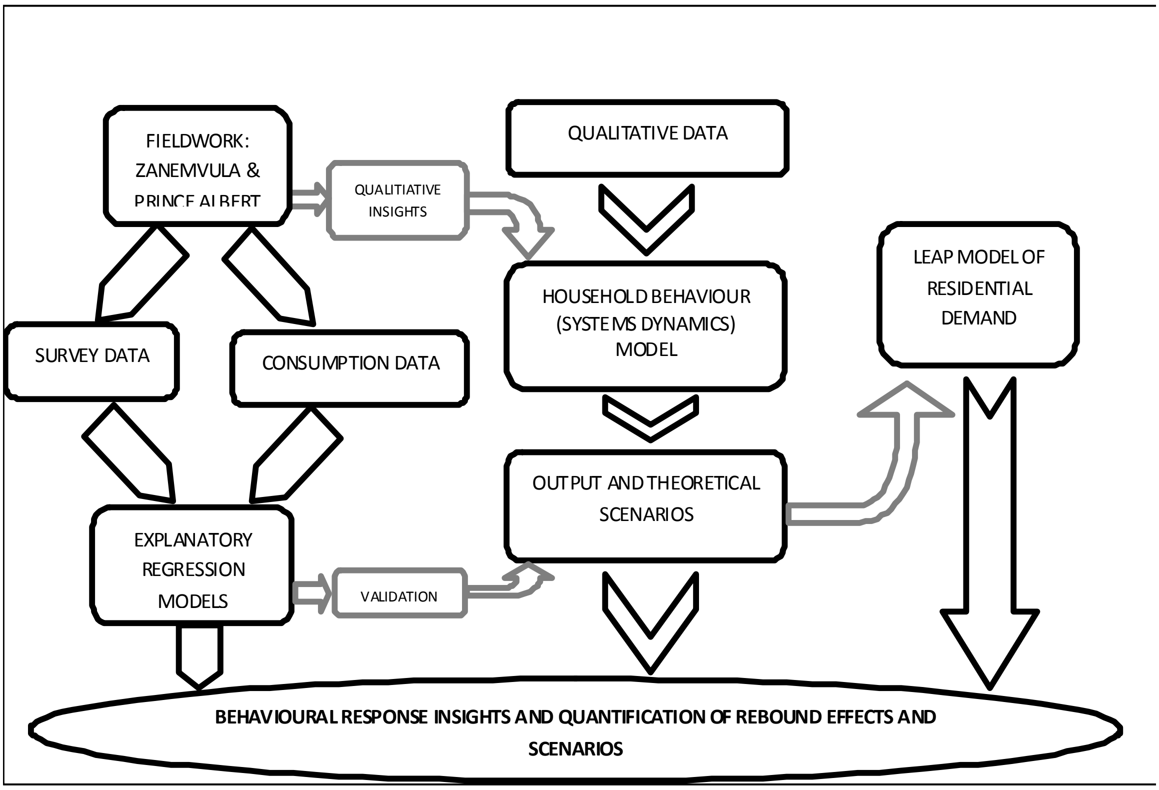

Figure 5: Methodological framework for the study

3.3.1 Factors affecting responses to the interventions

Some of the factors considered to have a potential impact on behavioural response (and hence on rebound) include the type of intervention, sample selection, price of energy, awareness, and electricity consumption measurement.

Type of technology intervention

It was necessary to select the technology intervention measures to focus on. Specific technology interventions that were in progress at the time of the study scoping ranged from large-scale roll-outs of compact fluorescent light bulbs (CFLs), geyser blankets, timer switches on geysers, two-plate stoves, solar water heaters (SWHs), and efficient space heaters.

The presence of a new technology does not imply that the desired outcome of introduction has been achieved, as many users may refuse the take-up of the new technology, or take on the technology and revert over time – for any range of reasons from dissatisfaction with the quality of the energy service to additional capital outlay required for replacement costs – even if the net present value of the new technology is lower than the old one. For example, lack of take-up is in poor households would be a consequence of such households attaching a much higher implicit discount rate to energy investment decisions; the utility of future savings is lower when cash resources are scarce or absent.

The approach to roll-out of new technology also plays a role. In the study sites chosen for this project, the technology interventions were implemented on a hand-out basis with the funding provided by Eskom DSM (in the case of the Prince Albert efficient lighting exchange), and by the municipality (in the case of the Nelson Mandela Bay solar water heater roll-out). The reaction to the roll-out and consumption response will also be impacted by the fact that the new technology is free. Previous studies examined the effectiveness of other roll-out methods (for example voluntary purchase, exchange points, and marketing campaigns), but there are no conclusive or comprehensive findings, and many of the reports are not available as they were commercially motivated. In this study both of the interventions examined take place at zero cost to the consumer, and this should be borne in mind when analysing the results.

An example of the context sensitivity of the methodology chosen is illustrated by the example of an outright legislated ban of incandescent lights (as has been observed in certain countries). In such a ban the normal dynamics of reversion and behavioural response would not be applicable so the research outcome would not be relevant. In developing countries, the high cost of the intervention (or low net present value of the saving due to high discount rates) may be a barrier to implementing outright bans on inefficient technology. Alongside cost, the absence of prioritisation of EE and DSM would mean that such an intervention would be unlikely.

Most previous studies discussed in the literature focussed on introducing micro-measurement of one technology or a single energy service, however in the research presented in this report, the impact of the EE intervention was looked at holistically rather than attempting to directly measure the effect. Said another way, the response to technology is the item of interest in the research, yet it is arguable at the outset whether technology is more appropriate than other kinds of interventions or not. Furthermore, to understand the response to technology alone, an exploration of the various influences (endogenous and exogenous) that result in the response is necessary, as well as an understanding of the interplay between the causal factors. However, to ensure that the study was not purely philosophical and theoretical, it was necessary to delve into an actual intervention and use the insights generated in reality to inform the holistic and theoretical framing just described.

Ultimately the focus or the research was on the behavioural and consumption response to large scale roll-outs of a singular intervention (CFLs or SWHs), with the aim of measuring indirect effects and substitution effect through observation and survey responses.

Sample selection

A study by Applied Media Logic (TGI) categorises energy users into three groups, namely the ‘Responsibles’, the ‘Opinion Leaders’ and the ‘Comfortables’. It was critical for the study to incorporate the attitudinal implication of this categorisation into the sample targeting strategy for the survey i.e. the random sample should not be biased towards one or more of the potential attitudinal characteristics.

Users may react in a number of ways, and the sample should not be biased towards a group of households that may react in a particular manner. For example, the manner in which users may react may include any of the following, and the reactions will not necessarily be fixed over time:

- They may take up the comfort effect (additional usage for added utility, over and above the usage prior to the intervention) as a result of cheaper cost of an equivalent energy service (pure rebound)
- Some users may become more aware of EE as a national priority (‘Responsibles’) as a result of receiving CFLs, so it would be expected that overall consumption of such users would drop below the baseline when an intervention takes place.
- Monitored groups may be biased if incentives are given for participation in the study.

- Latent/suppressed demand in poorer households will be released as the cost constraint of running essential energy services is relaxed. A component of latent demand may include welfare benefits for those households experiencing energy poverty. Welfare benefits may be an unintended and unexpected (but desirable) outcome of EE intervention.
- Users may spend money on additional energy services such as entertainment, or increase their stock of energy consuming devices.
- Users may be disillusioned with the technology's ability to save energy because lighting may be such a small proportion of their consumption that the savings are not visible

In a sample of households, it is likely that the observed behaviour may be attributed to any combination of the above factors, and since the various forces operate in different directions with respect to final consumption, it is difficult to discern and separate the various effects from each other, as well as quantify their interactions. Also, households may be made of a number of individuals with varying attitudes, awareness levels and behavioural characteristics. Our unit of measure is at the level of household, so any attributes that are measured will be those claimed by the head of the household being interviewed, not necessarily the attributes of the household itself.

In addition to intrinsic behavioural characteristics there may be the presence of national shortages (e.g. due to load shedding) leading to the awareness-based responses described earlier. Moreover energy consumption by definition is a dynamic phenomenon depending on peoples' needs, attitudes, vulnerability to weather phenomena, and income constraints. Households may also change their characteristics, for example users may move house (a factor that proved to be more common than originally anticipated) or the numbers of occupants of the households may vary over time. These factors will be related to household demographic characteristics, however homogenous grouping of users is a challenge in its own right.

The combination of the dynamic nature of energy consumption and the other factors makes it challenging to isolate different household types. Previous studies have reported relatively low rates of pure rebound for energy services such as lighting, and if there findings are true, pure rebound may be difficult to estimate given the low values, the high intra-user variability, and the presence of dependencies between various energy services. There are also few study sites that are 'virgin', completely untouched by EE interventions of any kind, or which have zero awareness of EE matters.

Price of energy

In addition to the intervention and sample selection influences just described, there will also be changes in the cost of energy that influence users' consumptions. The phenomenon of price elasticity will influence consumption in a way that is not necessarily independent of the presence of new technology. Pure price elasticity is usually quantified using econometric methods, but the definition of elasticity consists of a mathematical relationship in which price is the only factor influencing consumption. With energy in particular, consumption choice is (as demonstrated in the development of the systems dynamics framework) a complex interplay of cost/price, comfort/usefulness and impact/socio-environmental responsibility. In summary, price cannot easily be controlled for in a study on demand response as from the point of view of the user, and for the researcher, it is determined exogenously.

Awareness

Awareness interventions that may be used as methods of reducing potential rebound include:

- Education and training alongside the technology roll-out
- Offer households a choice of products for each technology

Another dimension of demand response is consumer awareness, which can for example, be exacerbated by the presence of load-shedding, power cuts and television/media broadcasts of

'Power Alert'. In the SWH study, an awareness workshop was to take place alongside the intervention. The implementation of 'Awareness' as a research control variable may not be plausible, and relies to some extent on a pre-existing and third party ownership of the awareness intervention. For research purposes, the presence of an awareness intervention can be included in the research if carried out by third parties, or alternatively a method of self-selection can be used whereby respondents' awareness levels are determined from survey responses, and are self-selected in the sample. Examples of external awareness interventions include 'Power Alert', energy surveys and information flyers would have had an impact on awareness levels. Self-selection assumes that these interventions may have already made an impact prior to the research being carried out.

3.3.2 Factors affecting study outcomes

Some of the more specific items that had to be addressed with regard to survey design and monitoring of consumption, and dealing with sources of uncertainty are described below. These items need to be taken into account in the analysis.

Monitoring method

- Aggregation level: Depending on the site, there was a choice between measurement at the level of individual households versus the whole town or a subsection of town.
- Measurement device: Individual data loggers add significant cost to the study, are more expensive and have reliability issues.
- Frequency of measurement: Monthly intervals and town load profiles would be a useful combination.
- Expected savings resulting from the intervention could be estimated from the ESCO's records of the number of CFLs exchanged and installed, with assumptions being made about the number of hours lights are on.
- Single energy service or aggregate consumption of energy: the potential to measuring the energy service specific to the intervention, overall electricity usage or comprehensive measurement of individual energy services within a household exist.

Survey instrument

- Length of questionnaire and relevance of questions.
- Comprehensiveness of demographic data.
- Inclusion of behavioural, attitudinal and awareness questions.
- Questions on the usage of the energy service for the intervention concerned.

Sources of uncertainty

- Survey and sampling bias: interpretation of questions can vary among the different interviewers and between respondents.
- Changing daylight hours would affect the usage of energy services such as lighting.
- Weather patterns may be inconsistent between years.
- Natural variation in electricity usage at the household level (e.g. members away from the household for periods of time, changing household size, or new trends in energy consumption behaviour). The hours of usage may be affected by the season or occupancy levels at certain times of the year, such as Christmas holidays.
- Additional installations or failures of the intervention appliance.
- Increased appliance installation and usage e.g. air conditioners.

- Measurement period: rebound and/or reversion (say through immediate accidental breakage of the new device) can happen over time or immediately, and indirect rebound may arise over periods of time that vary greatly between households.

The following sections describe the study locations and the nature of the data collected in each of the sites.

3.4 Study locations

Figure 6: Example of living area and appliance usage in a low income household

A decision was taken early on to focus on specific locations rather than do a national study. In this section a motivation is provided for the choice of the two study sites . The first focuses on the efficient lighting roll-out in Prince Albert and the second on the roll-out of solar water heating in Nelson Mandela Bay (with separate studies being conducted on high and low income locations). In addition to background information for each of the two locations, the various approaches to data collection for each of the sites is described, including the surveys, electricity consumption data, focus groups, school learner worksheets and awareness workshops.

One of the main conditions for site selection was that the specific site was untouched by a previous intervention of the type that was about to be implemented. This condition was necessary to ensure that the impact of the intervention could be clearly seen and isolated. Other criteria included the presence of demographic diversity in the areas and willing collaborators. There were a number of practical advantages of selecting a small area that covers a range of socio-economic groups provided it is possible to measure end-use demand in such an area, and at a reasonable cost.

The following steps were adopted in establishing the study sites:

- Selecting the community and making contact.
- Preliminary site visit to establish positive relations with relevant community leaders and get a sense of the layout of the town and the energy needs of the households, existing EE measures, and general awareness of the electricity and energy sector.
- Site stakeholder interaction and assessment.
- Speaking to local institutional authorities about energy use, and other active organisations that are performing energy-related activities.

- Organising a broad community meeting. Visiting a few households from the various income groups and areas, to get a sense of the energy needs and usage. Meet with the people accountable for the electricity infrastructure and billing.
- Conducting informal interviews at different households to get a feel for the energy use in the town, and the local perceptions around energy consumption.
- Setting up the meetings with the active stakeholders with appropriate agendas delivered to participants.

The locations and the data sources that were collected are described in the next subsections.

3.4.1 Prince Albert

Background

The person accountable for Eskom's DSM programme in Eskom's western region assisted in identifying the remaining towns that had not yet experienced an intervention under the national CFL roll-out. Niewoudtville and Prince Albert were recommended, and both were visited and found to be suitable locations. Prince Albert was found to be more suitable due to its closer proximity to Cape Town, and the fact that the roll-out was scheduled later in the year. The imminence of the roll-out in Niewoudtville meant that there was insufficient time to prepare the survey and fieldwork process.

The town

Prince Albert lies in the Prince Albert Municipality that includes Prince Albert, Leeu Gamka and Klaarstroom. The municipality is home to approximately 10000 residents. The town is known for its historic architecture and agriculture, and draws significant numbers of local and foreign tourists. At the time of the study team's first visit it was a virgin site as far as the national CFL roll-out was concerned, with a only a few households that had voluntarily adopted the technology (CFLs were available in the local supermarket and hardware stores for purchase, but at a substantially higher price than the incandescent lamps (normal in the South African market for light bulbs). Prince Albert was ideal in the sense that the municipality was co-operative and the town had a good spectrum of demographic characteristics from low to middle and high income households. It was also a 'typical' South African town in the sense that the income groupings were separated historically under Apartheid with the high income dominantly white families living close to the town centre, and the low income dominantly coloured communities on the dusty outskirts in RDP and older formal housing.

The municipality's leadership indicated their willingness to engage with the researchers and granted permission to conduct research in the community. The municipal officers were also willing to provide data pertaining to electricity consumption in the town, and provided the contact details of the contractors managing their credit meter and prepaid meter billing databases. Meetings were also held with the principals at each of the main schools who agreed to allow their learners to participate in the research and the science teachers were to facilitate interactions with the learners.

A local resident was conducting measurements on the town's load data for a separate study and agreed to share the load measurements on the town's electricity consumption at the substation level. Innovative Energy Projects cc (INEP) were the ESCO responsible for the Eskom roll-out in the area, and were contracted to assist the research team with survey management and to conduct the first phase of the survey prior to their intended CFL roll-out.

Figure 6: The 'bo-dorp' or high-income area of Prince Albert

Figure 7: Power lines between houses in the low-income area of Prince Albert

Benefits to the community

There were several potential benefits – both direct and indirect – of the study to the community:

- A legacy of community development and personal growth through increased awareness of energy matters

- Meeting poverty challenges through increased knowledge of EE
- Temporary employment opportunities for the local community and training of interviewers and survey staff
- Training and awareness in EE and conservation (with associated economic and social benefits)
- Involvement of school learners and teachers in energy studies
- A small monetary donation was made to each of the two schools as a way of thanking the communities of the town of Prince Albert for their participation in the study. It was decided, in consultation with the local advice office, that this would be a more favoured approach as gifts to individual households would have been both costly and a source of animosity between those who participated in the household survey and those who didn't.

Data sources for Prince Albert study

The various data collection methods employed are described below, and include the load data, school learner audits and worksheets, focus group workshops, three-phase survey and municipal consumption data.

Half-hourly load data

Prince Albert's load metering equipment was installed by Eskom and on downloading the data from the website where the records were stored it was difficult to ascertain what CT (Current Transformer) ratio was being used to record the half-hourly load values. Consequently, although the readings spanned the period before and after the CFL exchange, they appeared to contain too much noise and unexplained stochastic variation to be of value in analysing both the impact of the intervention on consumption and the REs of the efficient lighting intervention. The challenge of measuring both of these phenomena was compounded by the relatively small impact of lighting on the town's consumption. Although the town is predominantly residential, there are a few large consumers such as the municipal water pumping, hotel, Spar supermarket, a dairy, prison and several guest houses and restaurants. The presence of these potentially substantial non-residential energy users meant that the overall load could not be used as a direct measure of residential electrical consumption in the town.

School learner survey and worksheets

The intention of the school-learner survey was to independently assess the energy use before and after the CFL exchange, and determine whether there were any significant differences between the number of hours of light usage (e.g. due to REs) before and after the intervention. The intention was for learners to participate in a project based on the information they collected in their own worksheets. The learners were selected in conjunction with the selection of households for the three-phase survey. The two schools in the town of Prince Albert were Hoerskool Zwartberg and Prince Albert Primary. A description of each of the schools is given in more detail in the section on the focus groups. The science teachers in both schools were approached to assist in the roll-out of the learner audit. As appreciation for the return of the completed worksheets on light usage, a small donation was given to the schools to contribute to the purchase of sports and other needed equipment.

A learner survey on household energy use was administered prior to the CFL rollout, and was intended to mirror the Phase 1 and 2 household surveys and examine the differences in perceptions between learners and adults. Additionally, worksheets were prepared to assess household usage of lights for the duration of a week, one worksheet prior to the CFL rollout and one after. The worksheets distinguished between the usage of CFLs, incandescent bulbs and other bulbs and the intention was to monitor usage changes in conjunction with the CFL rollout intervention. Therefore the intended outcome was to assess whether the impact of the installation CFLs bulbs on the light usage patterns could be assessed, and to quantify any REs, as well as assess the reliability of the household survey data as verified by the school learner survey and worksheet.

Electricity consumption data
The data on electricity consumption that was provided by the payment system contractors consisted of prepayment purchase data and credit meter data as described below:

(i) Prepayment meter data

a. Survey respondents' purchase history dating from early 2007 until end of 2009 including units, value in Rands and free units (in Prince Albert only households with special needs and who specifically apply receive the FBE allowance of 50 units per month).

b. Total town monthly prepayment sales, as well as weekly sales spanning 6 weeks prior to and after the CFL exchange.

c. Municipal accounts from July 2005 to September 2007 with monthly figures for all sales. The municipality lost essential staff after September 2007 and was therefore not able to provide data after that month.

Figure 7: Prepaid meter in a low-income household

(ii) Credit meter data

a. This information consisted of monthly purchase histories for survey respondents, including monthly consumption and billing information (only if households had not moved or changed accounts).

b. Municipal accounts from July 2005 to September 2007 as for the Prepayment data in c) above.

Focus groups
Methods of appreciative enquiry were employed to gather qualitative information in two separate focus groups held at the time of the Phase 1 survey (described below) and prior to the rollout. The workshop was conducted prior to the roll-out to assess the prevailing attitudes and

awareness towards EE. A further aim was to gain qualitative data on light usage, energy and EE awareness and behaviour.

Figure 8: Focus group workshop with learners from Hoerskool Zwartberg

The participants were learners from grades 8 and 9 in the Zwartberg High School and were generally from the wealthier households, and learners from grades 5 to 7 in the Prince Albert Primary school, who were from low income families. The differences within and between the two groups facilitated useful comparisons. The feedback from the learners was collected and summarised after the workshops. The original intention was to conduct a follow-up workshop with the same learners, but the timing conflicted with the learners' examination period, and it would have been logistically difficult to track learners who may have moved to the high school between years. A second workshop was therefore not conducted. Sufficient data was gathered from the first group and from the surveys and consumption data to complete the study.

Three-phase survey

Given the two year study period, a three-phase survey approach was adopted. Each of the phases involved design of the survey, development of a survey management plan, quality assurance procedures and interviewer selection and training. Additionally data capturers were hired and trained. A pilot survey was carried out on the 21st and 22nd of May, 2008 prior to the first phase of the survey. The intention of the pilot was to ascertain the appropriateness of the different types of questions, and gauge the general level of understanding of the community to be interviewed, as well as to pick up any error or misunderstood or unclear questions. A detailed pilot was only carried out for the first phase, as many of the issues were well-understood after the first survey, and difficult or irrelevant questions could be left out in the subsequent phases, without the need for additional pilots for each phase.

For the purposes of the survey, the town was divided up into five districts, with a target sample of 10% of each district. The five districts were Rondomskrik, Blouhuise, Oublok/Uit-en-tuis, Enslin Straat, and the South & Central Town. Demographically the first 3 represent the low income area of the town, the 4th a middle income area, and the final area a mix of middle and high income households. These districts were used as a proxy for tow main income groups in the data anlaysis, with the first 3 being considered 'low' and 4th and 5th considered 'high' for the purposes of data analysis. A total of 298 households were selected at random with proportionate representation from the 3 areas. Relocation of households was fairly common place, interfering with the continuity of the 3 phases. Houses that had relocated, or with new inhabitants were excluded from Phases 2 and 3.

The first phase (baseline) took place from the 10^{th} to 13^{th} July 2008,shortly before the CFL roll-out (and after the pilot survey) a week prior to the intervention, alongside the focus groups and school learner survey and worksheet. This phase was managed by INEP with the intention of capturing the baseline attitudinal and behavioural variables, and understanding the energy use patterns among the households. The questionnaire itself was developed in consultation with the INEP who had a number of years experience with DSM implementation, as well as ERC staff who had experience with energy surveys. The questionnaire was very comprehensive, as we agreed that a detailed understanding of the energy context for this sample would be necessary to enable a thorough understanding of the source of observed behavioural shifts.

The second phase was carried out in September 2008 shortly after the CFL rollout (but within the same winter season) to allow for sufficient burn-in time for the roll-out. The intention was to capture short-term attitudinal shifts as a result of the roll-out and assess whether there were any rebound affects that could be measured based on comparisons of the pre and post-survey data.

The third and final phase was conducted in September 2009 a year after phase two, to limit seasonal variation between the phases, and to capture longer term REs and behavioural changes compared to the baseline. The survey aimed to target about 10% of the households in the town, amounting to some 300 households (including a built-in buffer allowance for non-response over the three phases).

Anecdotal evidence
In addition to the formal data collection activities described above, qualitative insights collected through informal conversations with the townsfolk, advice office, municipal staff, interviewers and survey respondents was noted during the fieldwork activities and are included in the final reporting of the analysis.

Summary
Prince Albert turned out to be an ideal site for a micro-level study on the RE of efficient lighting roll-outs. The site was chosen based on its satisfaction of the study site criteria: Suitable EE intervention, consumption data measurements, and willingness of the stakeholders in the town to participate in the study. There were challenges in obtaining the consumption data for the households surveyed, but the obstacles were eventually overcome. The planned energy awareness workshop by NERSA never took place and we were unable to include a specific awareness intervention for this part of the research, so self-selection of awareness groupings based on survey responses was instead used at the analysis phase.

In summary Prince Albert met the majority of criteria as a study location for the efficient lighting intervention. Sufficient quantity and quality data could be collected to facilitate a useful set of data for the analysis of the impact of efficient lighting on energy consumption behaviour. The three phases of the survey were carried out with due cognisance of the external and internal factors that would impact collection and analysis of data could not be controlled for.

Alongside the survey data, which captured respondents' stated shifts in behaviour and attitudes, actual consumption could be monitored for the town, and prepayment purchase and credit meter data could be collected as described above.

The final data set therefore includes a unique combination of survey data, qualitative information from focus groups and anecdotal evidence, and actual consumption data, with validation by school learner worksheets and town load data.

Figure 9: Training of survey staff in Prince Albert

Figure 10: Phase 2 Interviewer training in Prince Albert

3.4.2 Zanemvula

Background

The Zanemvula project was selected for this study after representatives of the municipality expressed an interest in the research material and agreed to be willing collaborators. The project was a pilot project for SWH roll-outs in the low income sector with the intention of motivating future roll-outs and learning from the experiences. The houses are part of the national housing project under the RDP, and had no existing geysers. While this means that specific water-heating REs cannot be measured, it does broaden the scope of the study to towards examining the impacts of latent demand for energy services, which is a reality in the South Africa's current political economy.

Figure 11: Solar water heaters installed in Zanemvula

The location

Zanemvula is a newly established residential community on the outskirts of Nelson Mandela Bay, where houses were built and given to inhabitants of informal settlements. The residents were recently relocated as part of the reconstruction and development programme. The community is a mix of Xhosa-speaking black people and English speaking coloured people, many of whom had been relocated due to living in a flood plain area. Houses are standard RDP houses with prepaid meters and (surprisingly) abundant electrical appliance ownership among the households.

The municipality was interested in the potential impact of SWHs on electrification (current and future), as well as gathering implementation experience for future roll-outs that could be shared with other municipalities. Their aim was to be visionaries in the roll-out of services that make an impact on their communities through improving access to energy services and reduced dependency on the national grid and improved energy security for the region. General awareness of energy issues among the community was quite low.

The roll-out and short-term maintenance was funded by the municipality and the associated research conducted by the Nelson Mandela Bay University with external funding granted to assist with research.

The criteria for choosing an appropriate study site for measuring the RE of solar water heater interventions were similar to those for choosing Prince Albert as the site for the efficient lighting study. Factors that motivated the choice of Zanemvula were:

- Opportunity for conducting surveys in both high and low income solar water heating interventions.
- A competent and cooperative municipality willing to assist with data collection.
- Presence of a ‘virgin’ site in a community where both baseline and follow-up surveys could be conducted.
- Access to electricity consumption data
- Possibility of controlling for the impact of an awareness campaign (carried out by third parties) for the households who were to receive the new technology.

The roll-out of SWHs in the high income area of NMB was pending, while the low income pilot in Zanemvula was imminent, so the first condition could not be satisfied immediately.

Benefits to the community

The benefits to the community of the study were similar to those mentioned for Prince Albert. Additionally, community participation in the installation and roll-out of the project would enrich the knowledge and awareness levels within the community, and give the community a sense of ownership of the intervention.

Data sources for Zanemvula

The data collected for the study in Zanemvula included a two phase survey, electricity consumption data and an awareness workshop.

Two-phase survey

This research was 'piggy-backed' on the roll-out of SWHs in the Zanemvula district. An independent assessment of the intervention was conducted by a third party stakeholder, however the focus of their study was not on behavioural response, but rather on the qualitative impacts of this type of roll-out on the community.

The intention of their research was to highlight the effectiveness and identify challenges and solutions in the large-scale implementation of SWHs. Unlike the Prince Albert surveys, therefore, the questionnaires had a strong social focus, and contained detailed questions on health issues and water heating behaviour. The ERC assisted with the design of the questionnaires to ensure that the required behavioural, awareness and attitudinal questions were included in their survey. Awareness and attitudinal questions were added to both the baseline and follow-up survey. Every one of the 1263 houses in Zanemvula was offered a SWH, and every house that was selected for installation was subject to a baseline survey questionnaire. Only about 10% of these were included in the follow-up survey.

Electricity consumption data

The municipality provided prepayment data history for the houses that were earmarked for solar water heaters. The community of Zanemvula was recently established and many of the houses did not have electricity connections at the time of the baseline survey. The data supplied was therefore for a cohort of houses with an increasing number of connections to the network over the period of the study. The earliest prepayment records were in September 2008, and these continued up until September 2009.

Awareness workshop

A three-part workshop was held at Booysen Park Community Centre, Nelson Mandela Bay, and the one attended and discussed in the next chapter was the second of the three parts, held on 15th May 2009. The intention of the workshop was to raise awareness of the Solar Heater Energy Programme Pilot Project.

The workshop was facilitated by Fikiswa Mahote and Bonelwa Tubeni of Premier Attraction, who were both contracted by Sustainable Energy Africa (SEA); funding was provided by the British High Commission. Representatives from the municipality and the SWH suppliers also participated in the workshop. Zuko Ndamane, an advisor and site manager at the Kuyasa CDM project, shared his experience on the workability of energy interventions in low income communities. Approximately 50 members of the members of the community attended this workshop.

Figure 12: Solar water heater awareness workshop for residents of Zanemvula

The key issues addressed in the SWH awareness workshop were as follows:

- Energy, what it is used for, the main sectors, types of appliances and energy carriers (fuels).
- Water heating as an essential component of overall household energy service requirements.
- Advantages of renewable energy, and explanation of carbon revenues.
- Importance of awareness campaigns in all EE interventions.
- Background to the SWH roll-out: dealing with the impacts of climate change and load shedding.
- How to get the maximum benefit from solar heated water.
- Maintenance and installation considerations.
- Lessons learned in the Kuyasa CDM project in Kayelitsha township in the Western Cape.

Further opportunities were given to the community to ask questions or voice concerns and get responses from the workshop facilitators, the municipality, or the contractors supplying the SWHs. Further details of the workshop are contained in Appendix 7.

The key points and teachings of the workshop are reported in the following chapter because they contain valuable insights for future awareness programs on energy interventions, and they inform the kind of learning that is referred to by the inclusion of an awareness variable in the data analysis

Summary

Zanemvula (as with Prince Albert) tuned out to be an ideal site for a micro-level study on the electricity consumption response to low pressure Solar Water Heater roll-outs. The site was chosen based on its pending intervention and third party surveys (baseline and follow-up); availability of consumption data measurements in the form of prepayment history; willingness of the stakeholders in the town to participate in the study, and the presence of an awareness campaign connected to the roll-out. In summary Zanemvula met the majority of criteria as a study location for the impact of SWH roll-outs in low income areas, and adequate quantity and quality of data could be collected there to facilitate a useful set of data for the statistical analysis.

Alongside the survey data, which captured respondents' stated shifts in behaviour and attitudes, prepayment data was supplied by a cooperative municipality, and the awareness workshop could be used as a control factor for the measuring behavioural response patterns

The final data set thus includes a two-phase survey data, social study report, anecdotal evidence, and prepayment data.

In summary, Sections 3.4.1 and 3.4.2 describe the sites and data collection that took place in each of them. The advantages of both sites was that data could be collected consisting of a combination of consumption and survey data that could be analysed simultaneously. The disadvantage is that the specific results emerging from the analysis may be site-specific, and not necessarily applicable to any similar roll-out elsewhere in the country. As discussed earlier in the report, the creation of representative sample data was not the intention, nor would it be realistic.

3.4.3 Nelson Mandela Bay

A roll-out of 500 high pressure SWHs has been planned in Nelson Mandela Bay in a project funded by CEF. As for Zanemvula, the intention of the municipality and the funders is to conduct a comprehensive pre-feasibility study for large scale roll-outs of SWHs in middle and high income areas. The stakeholders responsible for the project were approached and agreed to share the comprehensive data they were collecting for the study. The monitoring activities include (for 50 households) both baseline and follow-up monitoring of water consumption, measurements of electrical usage of geysers, and overall household electricity usage at half-hourly intervals over an extensive period of time so that seasonality and natural variation can be accounted for. In addition to the water and electrical consumption data, survey interviews will be conducted by the ERC and the results analysed in conjunction with the measurement data to parallel the two studies described above. At the time of writing the physical roll-out had not taken place, and the research will be conducted during 2010.

3.5 Modelling household energy behaviour

The fieldwork and subsequent data collected in the sites described in the previous section were to be analysed in their own right. Additionally the data was intended for use in validating a systems dynamics simulation model of household electricity consumption, and specifically the response to EE interventions (see the diagram in Section 3.3 above). In this section we describe the approach used to construct the model.

The broad aim of this component of the work is the development of a simulation model capable of explaining the consumer response to EE interventions at the household level, and in particular how 'slack' arising from EE interventions can be absorbed. More specific aims of developing the model are:

1. To integrate the findings of previous research on household energy consumption and the attitudinal and behavioural factors affecting efficiency interventions.

2. To use the results of the literature survey to construct a model of how a household 'decides' (this might be implicit) how much energy to consume.

3. To modify the basic consumption model to include the effect of potential intervention programs, again using past literature as a guide.

4. To use the model to investigate and tentatively quantify the effect that different intervention strategies may have on energy consumption, for various different household 'types' e.g. low-income, high-income, and environmentally aware/unaware.

5. To use the model to identify the main causes of rebound following different interventions, and speculate about the appropriateness of policy options for residential EE with various combinations of price, technology and awareness

The simulation model of energy consumption was built at the level of the household using a systems dynamics representation. Systems dynamics allows for a simplified graphical depiction of how energy consumption choices might evolve within a particular household, and for exploration around the effects that different intervention strategies might have. The variables and relationships between variables included in the model were selected after a review of the literature on household energy consumption and intervention programs. The model has two defining features. Firstly, it is a preference model involving multiple criteria - a household's decision about how much energy to consume is based on achieving a 'suitable' balance (although what is considered suitable will differ between households) between three objectives:

- minimising cost;
- maximising standard of living/comfort; and
- minimising social and environmental impact.

Examples of impact include, but are not limited to, contribution to load shedding and greenhouse gases emitted by energy consumption. Secondly, it includes three broad possible types of interventions: price-changes, efficiency/technology interventions, and informational/ awareness campaigns.

In light of the above, after a thorough search on literature relevant to household energy decision making, a model was conceptualised in consultation with a modelling expert, and after a number of iterations and testing procedures, a final model was chosen. The final model was then parameterised using 'sensible' values for the parameters, and multiple runs of the model were conducted to assess the direction and sensitivities of the final consumption to the parameters of interest. The full model is described in Chapter 4. The model outputs revealed some insights into household energy behaviour, resulting in a number of hypotheses about behavioural response to interventions. The hypotheses could then be validated using the survey and consumption data.

3.6 Forecasting of impacts of rebound

This section describes the methodology used for constructing the LEAP model used to conduct exploratory forecasting of the impacts of EE interventions and REs on national energy demand. The model developed for the research on REs is a simulation model restricted to the forecasting of future energy usage patterns in the residential sector, and does not take into account the supply-side or cost criteria of the EE interventions or rebound mitigation options in any of the scenarios.

A number of scenarios are parameterised to explore the potential impacts on EE savings in the residential sector over the period from present time until the year 2030. Scenarios are also run with price and awareness interventions alongside EE in order to determine the extent to which REs may be mitigated using these options, and to suggest suitable policy options. A detailed description of this aspect of the research is contained in Nyatsanza (2010), and only a brief overview will be given in this report.

The research was conducted for a dissertation submitted as part of the fulfilment of an MSc degree, and the research was consistent with the overall objectives of the rebound study. The main aspects of the dissertation consisted of:

- a literature scan including a review of the context of EE in South Africa;
- updating and adapting an existing LEAP model of energy demand in South Africa, with a focus on the electricity consumption in the residential sector; and
- exploratory scenario analysis using the LEAP model

The scenario analysis comprised the building of a reference EE scenario using local estimates of penetration rates of EE interventions (particularly water heating and lighting). The reference scenario was then adapted using estimates of rebound from the literature to measure the extent to which EE savings can be eroded by direct REs. Further exploratory scenarios were then run to examine:

- the use of price increases to encourage EE; and
- mitigation of rebound using awareness interventions and tariff increments; and

An overview of the model, scenarios and assumptions are described in further detail in Chapter 5 (Section 5.3), and a summary of the results of the exploratory modelling are presented in Chapter 6 (Section 6.3).

3.7 Summary of methodological approach

The choice of a suitable methodology for undertaking the research contained in this report was not a simple one. The complexity and novelty of the phenomenon meant that extensive effort was dedicated to developing the final methodology. Ultimately an evolutionary approach was adopted. The evolution that took place was informed by a combination of literature searches, stakeholder consultation, internal workshops and trial-and-error. Additional considerations in the development of the approach included research on how rebound could be measured, what time frames would be suitable, and how study sites and intervention types were selected.

A range of techniques were used for the study that took place over a period of two years. Originally, in accordance with the research proposal, the methodology consisted of stakeholder interactions, a pilot study and focus groups alongside a pre and post-intervention studies over a range of energy end-use conversion technologies. Statistical techniques were used to analyse the data which came from various sources, including internally administered surveys, consumption data provided by municipalities and Eskom load meters. In addition to those methods, a systems dynamics approach for modelling household energy consumption behaviour was developed and the LEAP modelling framework was used to illustrate the national impacts of rebound in the residential sector as projected for 2030.

Using the case study data and a systems thinking approach, some of the key influential variables can be teased out and sensitivities quantified. The use of data analysis methods and the systems models (in their own right and in combination with each other) are also intended to further the range of methodological approaches in this field of study, while making a contribution to effective policy and sustainable energy planning in the South African context.

A number of criteria were considered in determining the research aims and the methodology. A spectrum of considerations was extracted, and included among others: relevance to policy and the current discourse around energy matters, benefits to the communities in the study sites chosen for the research, to questions of sustainability and social impact.

The analyses described later in the report will be used to suggest ways of improving the effectiveness of measures at the level of implementation, and very importantly, ensuring that the measures are acceptable (or even desirable) for the residential end-users. Quantitatively we aim to model the likely levels of rebound arising after mass roll-outs of new technologies such as CFLs or SWHs.

4. Data resources collected

Having described the methodology in Chapter 3, this chapter proceeds by describing what was gathered for each of the study sites using the various data collection methods.

4.1 Prince Albert

4.1.1 Focus groups

The full report on the discussions that took place at each of the two focus groups is given in Appendix 6 as a series of questions and summaries of the responses to each question. The majority of the learners in both workshops were very participative and willing to offer their opinions with a minority attempting to dominate the discussion. The facilitator ensured that the majority of the learners were able to respond. This section summarises the important findings of the workshops as they relate to the study of energy efficient lighting interventions in the residential sector. Separate results are presented for each of the two schools that participated, with Prince Albert Primary including learners from the poorer district of Prince Albert and Zwartberg School including learners from the wealthier districts of the town. It is noted that many power cuts had been taking place at the time of the focus groups, so that the focus of the discussion around energy often tended towards the impacts of power cuts on the households.

Focus Group 1 - Prince Albert Primary School

One of the notable differences between the two groups was the type of energy carriers used, with the learners from the poor areas of the town relying on diverse and multiple fuel carriers for many of their cooking, space heating and lighting requirements, for example using fuel wood and paraffin in addition to electricity. The households in these communities were also adept at stacking fuels[5] and using novel methods of maximising their usage of (say) fuel wood. The children reported that electric light was their preferred carrier for lighting with paraffin and candles providing an inferior quality of light, affecting the ability to complete their homework. Income was the main constraint in having consistent access to electricity for lighting. Some learners said that television was a useful source of education about energy saving.

Interestingly, when asked about the value of lighting in the home, learners felt compelled to share the impact of power cuts on their studying activities including the impairment of concentration due to paraffin and candle fumes, as well as the danger and inconvenience of candles and paraffin lamps. Security was also a concern with incidences of criminal activity being associated with power cuts. To optimise lighting efficiency, the family would congregate in one room, and utilise the light given by the television as a light source in the room, with the lights themselves being kept off to save electricity. Saving electricity was a widely accepted priority in among these learners.

Suggestions given for electricity saving included going to bed earlier, not leaving outside lights burning by mistake and switching to CFLs (concerns around price and brightness notwithstanding).

Focus Group 2 – Zwartberg High School

There was a clear shift in emphasis compared to Focus Group 1 from electricity for basic needs to the more luxurious usages of electricity for entertainment. Fuel stacking happened more out of preference than necessity, with certain households preferring gas to electricity for cooking, and to ensure availability of fuel during power cuts. Solar Water heaters were also taken up by certain families, with rechargeable lamps and LED torches replacing candles and paraffin as backups. Families seemed to be less adept at using candles and paraffin lamps as backups, with many incidences of accidents reported. Two learners indicated that their households had air

[5] Fuel stacking is a method used by households to shift to alternative fuel carriers when the principal fuel carrier is not available due to resource availability or financial constraints.

conditioners and back-up generators in case of power cuts. The number of light fittings was greater than that reported by the learners in Focus Group 1.

CFL ownership was definitely more prevalent in these households than in Focus Group 1. Some learners reported households using CFLs for outdoor security lights that could be left on for security reasons. Some experiences with CFLs were negative due to reported inferiority of light quality, and colour differences. Load shedding led to subsequent wastage in instances where light switches and appliances had been inadvertently left on, and power was restored when nobody was home or the members of the household were asleep. Ideas for power saving among these learners generally excluded lighting, and there were a few misunderstandings regarding the use of CFLs and EE of various appliances.

To summarise, the focus groups provided a number of qualitative insights that can be used to inform awareness-raising initiatives and the likely response to energy efficient lighting roll-outs. They also highlight the differences in the needs and concerns of households between high and low income households.

4.1.2 Lighting usage worksheet

The intention of the learner worksheet was to validate stated consumption behaviour by the adult head of the household against the actual consumption reported by the learners living in those households. One school teacher in each of the schools took ownership of the audit and managed the completion of the worksheets by the learners. The worksheets (see Appendix 12) consisted of rows for the various rooms in the house, and columns for the number of hours each of these lights were running on each day of the week. The same worksheets were filled out before and after the intervention by the same set of learners. The intention was to conduct an independent study on the worksheets submitted by the learners, and integrate the worksheet data with the survey data. Schools were offered an incentive in the form of a prize to the best learner's comparison of their usage before and after the CFL rollout. The data collection exercise was, however, thwarted for a number of reasons, and the project was not completed. Some of the reasons for the failure were:

- Only about 50 percent of the first round worksheets were given back in the second round, rendering half of the initial worksheets to be of no value.
- In some of the worksheets, the numbers couldn't be identified or didn't make sense at all.
- A high number of the follow up worksheets differed significantly in numbers of bulbs and in the room usage to the initial worksheets. As a result some of the rooms could not be taken into account and further reduced the numbers of reliable worksheets.
- In some of the remaining worksheet pairs the differences in the total usage were too high and these worksheets could also not be used as data. Learners were confused between minute and hours of usage, and it was not clear whether usage had been multiplied by the number of lights or usage per light bulb.
- The difficulties of interpreting the learners' responses and inconsistencies reduced the number of worksheets to the extent that there was insufficient data to conduct a reliable comparison.

Although the teachers and learners were enthusiastic about participating in an energy study, a large number of school learners seemed to be overwhelmed by the task or were possibly not adequately instructed by the teachers. Unfortunately their worksheets were of no use for the project. Many external factors may have influenced light usage but learners would not have been able to capture these factors in the worksheets. For example changes in weather (cloudy versus sunny days), lighting reductions due to income constraints in the household, and absence of household members could have played a role in the light usage pattern of some households. The teachers were approached for some insight on the failure of the project and how it could be improved, but the response was not forthcoming.

4.1.3 School learner audit

A school learner survey was administered by each of the teachers at the two schools to the same sets of students who completed the worksheets. The information was collected and input, but no analysis was conducted on the data, as there was little information of value to the specific focus of our research. In summary, some lessons were learned in conducting of such studies that are peripheral to the learners' syllabus and extramural activities. Teachers and learners were not able to add value in the format we had proposed for this study due to resource and time constraints.

4.1.4 Three-phase survey

Qualitative observations on the survey approach and outcomes

Considerable time was invested in training of interviewers in the style of questioning, questionnaire content, and on quality checking of the completed questionnaires. It was only by the third phase of the survey that the interviewers were noticeably interested in and motivated by what the research made possible for South Africa, and the research community at large. Interviewer motivation was a challenge given the choice to use younger members of the community who had little to no experience in conducting such interviews. One of the insights for future studies of this kind is that interviewer motivation and a sense of contribution are important factors worth emphasising in the training of survey interview staff, particularly when the interviewers come from the community being studied. In Phases 1 and 2, payment for services and training were insufficient motivators for the majority of the interviewers. The quality of the data collected is dependent on the levels of interest and motivation of the survey staff. The fieldwork operations ran more smoothly when managed by the Prince Albert Advice Office than by third parties from outside the community, probably due to trust considerations.

The interviewer training held before each phase was a forum to check for errors and misunderstood questions. To minimise interviewer bias between surveys, and to capitalise on the interviewer-respondent relatedness that was created throughout the study, an attempt was made to use the same interviewers to interview the same respondents. This aim was not always fulfilled since some of the interviewers used in the first survey were not available for subsequent surveys. Given the shorter length of the questionnaires and improved skill of the interviewers in subsequent phases, a smaller contingent of staff could be utilised to complete the survey. The core interviewer staff remained the same throughout the study. Interviewer-specific biases were difficult to pick up in the captured data, although quality checks were carried out at the time of the survey. Although it is acknowledged that interviewer bias is present in the data, it is a factor that is difficult to account for in the final analysis of the data. Biases will have arisen due to the particular interpretations of the questions by certain interviewers. This is a bias that is expected to have been mostly eradicated by the third phase of the survey given the simplified questionnaire, well-accustomed respondents and improved management of the fieldwork.

Phase 1

In June 2008, a household CFL exchange took place in Prince Albert. A sample size of 245 participants participated in the first phase of the survey. The households were grouped according to income levels with 159 belonging to the lower income group and 86 belonging to the middle and higher income group.

The Phase 1 questionnaire was found to be lengthy, contributing to survey fatigue within the interviews, for interviewers and respondents. A compromise had to be made between fully capturing the required information and completing the survey within the specified timeframes. In retrospect, much of the data that was collected in the first phase falls beyond the scope of the study, but could be used for additional research around energy service requirements and consumption behaviour in towns such as Prince Albert.

Additionally Phase 1 was hurried, and that may have compromised the quality of some of the data, particularly in the high income area. The reason for the compromised quality was due to the fact that the interviewers felt uncomfortable conducting the fieldwork in that area, and preferred to leave those questionnaires to the end. Insecurity, lack of confidence of the interviewers, mistrust of the respondents, and the historical racial segregation in the town (alongside the greater complexity of electrical appliances in the higher income households) contributed to the poorer quality and quantity of responses in the high income areas.

Phase 2
The questionnaire in the second phase was streamlined to include fewer items relating to the overall energy profile of the household. The rationale for reducing the size of the questionnaire was to avoid interviewer and interviewee survey fatigue and to narrow the focus of the questionnaire to behavioural and attitudinal factors rather than broad energy consumption patterns that would have been tedious to keep track of over time.

Phase 3
The phase three questionnaire was further streamlined with the anticipation of survey fatigue, and retained only the key behavioural and attitudinal questions ascertained to be of importance in Phases 1 and 2. Additional questions with scale responses were added to assist with the categorisation of respondents. The purpose of these questions was to give quantitative responses to attitudinal variables to ensure a robust statistical analysis, for use in the validation of the hypotheses of the systems dynamics model

The key results of the survey data are reported on in Section 6.2.1.1 which includes results reported from the analysis of Phase 1 and 2.

4.1.5 Electricity consumption data

The Prince Albert municipality was approached early in the project, and agreed to provide whatever data they had at their disposal. The access to the data depended on availability of municipal staff to compile and extract the data. Originally, monthly summary accounts were provided on residential sales (and units) for the various tariff structures including both credit meter and prepayment sales. These figures were only available for the time up to September 2007, starting in 2005. After September the person accountable for the accounts had left and a suitable replacement had not been found at the time of final data collation, so the consultants appointed by the municipality were approached for assistance in accessing the raw electricity sales accounting information.

Prepayment data
The operator of the prepayment meter billing system, Syntell (Pty) Ltd, were contracted to assist the download of reports on prepayment consumption.

Given the time constraints, *pdf* reports were only generated for the households for which all three phases of the questionnaires were carried out. In addition, an historical monthly profile of sales per vendor was generated, and a weekly report over the period spanning the rollout was also compiled to see if there was any impact on the number of kWh units sold as a result of the roll-out.

The *pdf* reports were converted to Excel files using specialised conversion software, and these files were then manually integrated into one Excel spreadsheet. What is illustrated by this exercise is that valuable household consumption data is available from municipalities using similar vending systems, yet the data downloads are not suitable for direct measurement, and programming skills are required to convert the information into a usable format.

The procedure for converting the prepayment meter data into monthly consumption figures is detailed in the Appendix numbers 9 and 12.

When combining the reformatted prepayment data with the survey data, the following final modifications and categorisations were applied to the data:

- The study period was confined to be from 11/2007 to 10/2009 inclusive

- Observations with one or more of the following conditions were dropped from the data set (these responses were a negligible percentage of the total):
    a. Households that said they already had CFLs
    b. There was an indicator of a 'problem' with the household or unresolved data queries
    c. The household that had been given a solar water heater at a point during the period of the study
- Consumption values were categorised according to the timing of the 3 survey periods:
    a. 'Pre'-survey values used for months 11/2007 – 7/2008
    b. 'Post'-survey values used for months 8/2008 – 3/2009
    c. 'Follow-up'-survey values used for months 4/2009 – 10/2009.
- 'Don't know' was recoded to 'no' for certain questionnaire items (fairly few observations).

Credit meter data
The history of credit meter purchases of electricity was a crucial piece of data, as most of the high income households in the town still had credit meters. As explained in chapter 3, the credit meter purchases for households in the survey sample were eventually sourced from a consultant who had an archived copy of the credit meter data. The consultant provided the monthly purchase history for 15 of the 32 requested households. Households with account changes, or without a purchase history spanning the entire 4 year period of the requested period were excluded to ensure that no change of ownership houses were included in the analysis. Monthly purchase and consumption history was available from July 2005 to June 2009, spanning a period of exactly 4 years. The reformatting of credit meter data was a simple exercise given the relatively small sample, and the regularity of the data - the municipality regularly reads all meters at each month end, and the value of the units is supplied alongside the number of units consumed. The apparent inconsistency between the pricing of units sold under prepayment meter systems and credit meter systems is explained by the difference in service charges included in the electricity sales price between the two systems.

Load data
The Prince Albert load data was downloaded from the *Emeter* website and analysed, however the results were not of use due to lack of clarity on value of the Current Transformer (CT) ratios used to determine the load values in each hour. It was also unclear as to whether the measurements were for the whole town or only for residential users, so observed changes as a result of the CFL roll-out could have been smothered by large users, the town's water pump usage, weather changes, or natural variation in consumption. No noticeable shift could be seen when comparing the weekday averaged load profile 1 week before and 1 week after the CFL roll-out.

4.1.6 Feedback from fieldwork experience

This section contains a summary notes made during the fieldwork, and a summary of the reports prepared by the survey managers for the three phases. Full versions of these reports contained in the Appendix 12. The purposes of the section is to alert the reader an ESCO's experience of the CFL roll-out campaign, to highlight potential weaknesses and strengths of the survey data collection methods and to assist with the interpretation of the data collected.

An ESCo's perspective on Cfl roll-outs
Having interacted with many households in Prince Albert as well as in many parts of Eskom's Western Region, the experience of the ESCO, Innovative Energy Products (INEP) has shown that reversion to incandescent lamps is prevalent for the following reasons:

- Lack of adequate information and educational awareness around EE with up to 80% of retrofits targeted towards low income households throughout the country. Little regard is given to empowering households in the usage of the new technology, raising awareness of energy issues and the presence and impact of the toxins in the devices.
- Very little attention was historically given to ensuring the sustainability of the programme. Even if there were short term national demand and energy consumption reductions, impoverished consumers were unlikely to repurchase CFLs of their own accord. Efforts to ensure free replacement of failed lamps were minimal, and not well-advertised.

Fieldwork notes

(i) INEP

INEP (Innovative Energy Projects cc) assisted with the training of survey interviewers who conducted the survey, as well as translation of the questionnaires into Afrikaans, which is the dominant language spoken in the town. Some findings from the interactions with survey staff and respondents that were noted by INEP included:

- Homeowners were aware of free basic units, but were less clear on the number of free units they received. It was later discovered that the municipality does not automatically grant Free Basic Electricity (FBE), and only allocates it by application by the household and consideration of the need.
- Stated electricity purchases ranged from R10 to R2500 per month
- Users did not observe a change in consumption after the CFL roll-out, and installers' knowledge was not conveyed effectively to households
- The main (prioritised) sources of energy consumption were cooking, water heating and space heating (in that order)
- Electricity is by far the dominant source of lighting in the town, though many households use candles as a backup source of lighting.
- In a few instances, immediate reversion to incandescents took place as users found the brightness to be insufficient with the CFLs, even though the exchanged incandescent lamps were destroyed with users having to purchase new ones after the roll-out
- No major changes in the number of light fittings had been observed in the short period between Phase 1 and Phase 2.
- The major perception is that the intervention was a positive initiative
- CFL flyers were the main source of learning about EE
- Most households were willing to be trained in EE

In addition to the above, INEP said that the interviewers required much persuasion to complete the questionnaires with integrity, and there were instances where some of the questions were misunderstood by the interviewers. INEP expressed a view that external interviewers may have been more effective at conducting the interviews. However, using members of the community seemed to be instrumental in getting buy-in, especially among the poorer households, who felt more comfortable being interviewed by their own community. INEP's view was likely to be more accurate for the high income areas in which the interviewers appeared to lack confidence. There were also reports from interviewers and respondents that the questionnaires were too long. The experience of working with the local advice office was preferable to that of using an external manager, probably as a result of their being a pre-existing and trusting relationship between the advice office and the community.

(ii) PAAK

PAAK (Prince Albert Advies Kantoor/Advice Office), the NPO hired to manage the third phase of the survey, and who assisted with sourcing inteviewers reported that levels of awareness of energy saving had increased since the inception of the study in the community. They also found that the community were keen and willing to participate in the survey. PAAK themselves learned a great deal from the ERC staff about the global context for EE, and about CFL technology.

(iii) Feedback from Interviewers

Additional points noted from the interviewer training and fieldwork were:

- The community are angered by power cuts, and they expressed a willingness to ‘ease the pressure on the system’ and play their role in avoiding power cuts.
- On the whole, knowledge of climate change and environmental impacts was low, yet users were aware of their role in the national electrical system
- Some respondents had wanted the CFLs but had been excluded from the roll-out
- Solar water heaters had been received by ‘special-needs’ members of the community and these had made a positive impact on the lives of those who received them, including through reduced electricity consumption
- Response to the CFL roll-out was positive (largely because it was free).
- Respondents had not noticed a reduction in their consumption since the roll-out, probably because of tariff increases on 1 July 2008, and 1 July 2009.

4.2 Zanemvula

The primary fieldwork and data collection in Zanemvula was conducted by third parties in a collaborative effort with the ERC. Contributions were made to the design of the survey and the collation and cleaning of the survey data and prepayment meter data which are described brieflt in the first two sub-sections below.

The general findings from the awareness workshop are also summarised here for completeness so that its impact on the households can be understood in light of its inclusion as a potential explanatory variable in the final statistical regression model.

The data used in the analysis presented later in this report was the survey data combined with the reformatted prepayment electricity data. Some of the preliminary findings of the survey data and findings expressed in the reports from the researchers in Zanemvula are also presented in this section.

4.2.1 Two-phase survey data

The full survey data was captured by the researchers in Zanemvula for both surveys, and the captured set of questionnaire responses were supplied in Excel format. The data was cleaned, sorted and combined according to household *erf* number. The final data set consisted of Phase 1 survey data for approximately 1263 households, and Phase 2 survey data for the approximately 160 households that had received solar water heaters. Since the survey strategy was purposive (i.e. targeting the entire population), all households in Zanemvula were surveyed in the first phase.

4.2.2 Electricity consumption data

Electricity purchase data was provided for the entire population of households who had electrical connections installed either before or during the fieldwork.

A similar procedure for the Prince Albert data had to be followed to convert the data into a usable format for the analysis. The daily consumption figures were converted into monthly figures for the analysis with the assumption that new purchases are made when the prepayment credit is completely used up. Purchases that took place immediately prior to the installation date were ignored, and the final purchase for each household was also excluded as no assumption could be made about how long those units would last. In the early months of the analysis, from September through to December 2008, the number of households with electricity connections was limited, so these months were excluded in the final analysis. Households with daily average consumption exceeding 15 kWh were treated as outliers and excluded (on the assumption that they were businesses or unusual households inconsistent with the remaining data set).

4.2.3 The awareness workshop

The workshop was described in more detail in Section 3.4.2. It was a combined forum for informing the community about general energy matters, about the more technical details of SWH usage, and for community to ask questions or raise concerns about the project. The commitment of the municipality to the success of this roll-out was demonstrated by the effort they went to in holding the workshop. The response of the attendees was favourable, yet many of their concerns were less about understanding the prevailing energy issues than they were a forum for voicing concerns and negative experiences of the roll-out due to installation problems. A record of attendance was kept so that the households who attended could be separated from those that didn't, and the impacts of the awareness workshop on electricity consumption patterns analysed. It is inherently assumed that the awareness workshop would serve to maximise the benefit of having solar heated water, and therefore reducing the relative levels of electricity consumption. It is not clear whether the type of workshop is the most effective means of raising awareness about energy issues, and further research would be required to determine the relative effectiveness of awareness-raising techniques in impacting consumption behaviour.

4.2.4 Some initial contextual findings

There were 160 households that were surveyed in both baseline and follow-up surveys. All of these households received SWHs and some were newly electrified. The responses to the questions of interest were analysed using Cross-tabulation methods, and the focus was on attitudinal changes and behavioural changes since the roll-out of the SWHs, noting that there was a tariff increase as of 1 July in the year of the rollout (2009) and that Zanemvula was a new community established under the country's Reconstruction and Development Programme.

Many of the inhabitants had been relocated from informal settlements and would have been accustomed to paraffin stoves. Of these, 63% of the 49 households that originally used paraffin for cooking had switched to electric stoves. This switch should not necessarily be viewed as a consequence of the SWH installation (i.e. there is no causal indirect rebound resulting from the SWH roll-out), as many of these households were newly electrified since the first survey and therefore would have switched to electric stoves anyway. It is not clear whether the presence of newly acquired SWHs and the subsequent savings in fuel for water heating are correlated, as it was not the intention of the study to explore this specific relationship. In theory, the presence of solar heated water should reduce the demand for other energy carriers previously used to heat water, however according to the report on this implementation [NMBM Solar Water Heater Pilot Project, 2009] the latent demand for hot water was indicated to be present given the improved hygiene habits of the members of the households. Households who now have access to electricity will also perform space heating (as is the case for 16% of the households surveyed). These results indicate that the improved welfare of households may lead to increased energy consumption, particularly when the physical capital is disbursed without direct cost to the household.

When asked whether EE in the individual's household makes a difference to the current energy crisis, no notable change was observed in the responses to this question, however this is more indicative of an absence of awareness of the concepts of EE, renewable and sustainable energy, than legitimate sentiments toward the concepts. However, when questioned about personal responsibility for saving energy, 81% (38 respondents) shifted from stating in the baseline that it was the responsibility of other people to stating it was their own responsibility in the follow-up.

24% of the 85 respondents who thought that they should save as much energy as possible in the baseline stated that it was the responsibility of other people in the follow-up. Of the households that were newly electrified in the period between baseline and follow up 76% stated they switch lights off immediately they notice no one is in the room, with the remaining 24% who would not take immediate action (n=17).

There were few other notable shifts in behaviour or attitude between the baseline and follow-up surveys indicating that most of people attitudes and stated behaviours had not changed. The attendance at the SWH awareness workshop made no noticeable impact on attitudes and awareness compared to those who did not attend, and this is reflected in the general opinion about the value of the workshop.

5. Descriptions of models and modelling approach

The aims of this chapter are three-fold. Firstly, the systems dynamics simulation model is described in detail, including the approach to developing the model. Secondly, the general form of the statistical regression models used to analyse the data described in Chapter 4 are presented. The results from the regression models are presented in Chapter 6. The regression model is also used to test the hypotheses generated by the systems dynamics model described in the first section, once again using the Prince Albert data from Chapter 4. Finally, the LEAP model which provides the modelling framework for assessing the RE and EE mitigation potential is presented.

5.1 Systems dynamics modelling of household energy consumption

5.1.1 Rationale for systems dynamics modelling in the context of energy systems analysis

In energy systems analysis, consumer response is usually captured through elasticity parameters. Macro-economic studies indicate that energy demand tends to be price inelastic for high income households and for low income households with a more price-responsive mid-range. Elasticity measures are a used to represent the degree of response to a shift in a system. In energy systems analysis, elasticities are derived from econometric models of energy demand in the economy, with little focus on the micro-level response, despite obvious variation between the households represented by the models. System dynamics is a simulation methodology that can be used for:

- formulating the structure of a system where there are a number of different factors influencing each other to different degrees, and in different directions; it is a tool for conceptualising and representing a system that is dynamic, and where feedback is present;
- using the tool to enable a better understanding of the system being modelled, and draw conclusions about how the system behaves over time, and how it responds to perturbations.

For these two reasons, it was decided to attempt a representation of the system of household energy consumption behaviour that could be tested using data collected from the case studies of this research. The power of the approach is that it is a powerful method for applied thinking that can challenge the way systems are understood. Given that the dynamics of how decisions are made in a household are not well understood (and little attention has been paid to these dynamics given the historical focus of supply-side modelling with exogenously determined demand), an attempt was carried out in this research to facilitate a better understanding of energy behaviour at the micro-level. When aggregated to more than one household, such a model could be developed into an endogenously determined model of energy consumption that could be used for integrated modelling and analysis of energy systems.

Generalising the approach from rebound measurement to understanding behavioural response, deemed that the natural progression of the research required a more in-depth understanding of the drivers of energy consumption response. The approach can be connected to more conventional approaches though the notion of elasticity of demand which is a parameter in energy system optimisation models that is overlooked in importance. For example, if elasticity could be decomposed into a number of quantifiable constituents such as price, technology and pure behavioural response, then the model described below would have made a worthwhile contribution to research, and to applied systems modelling.

The full model, as constructed using the Vensim systems dynamics software, is shown in Appendix 12. In what follows, a description of each of the essential aspects of the model is given.

5.1.2 Modelling household energy consumption

As emphasised throughout this report so far, it can be seen that ‘slack’ arises in the budget for energy services when EE is introduced - but the slack in a household's budget for energy services may be absorbed by expenditure, either on other energy services or on other items (resulting in REs). A selection of literature was reviewed to ascertain which attitudinal, behavioural and awareness conditions will impact the way this slack is absorbed, and the subsequent level of rebound that arise. Ultimately, the aim is to demonstrate in reality how a situation of minimal or negative slack being taken up after the introduction of technical efficiency. As reported in Chapter 2, the ideal world is one where people not only save money as a result of the technology improvement, but where society benefits from the additional efficiency resulting from increased awareness in addition to a positive (reduced consumption) behavioural shift in attitudes toward energy use.

One of the questions the model in this work is intending to answer is: What strategies, and what combinations of these strategies will best mitigate REs?

Firstly, a selection of literature was reviewed to better understand the dynamics of household decision-making behaviour.

Previous (qualitiative) studies on household energy dynamics

Qualitative approaches (through participant observation, focus groups and interviews) are a key research method, and an internationally recognised and valuable way of predicting energy needs for the future and for developing supply and demand-side strategies for sustainable energy consumption. This ‘bottom-up’ approach contrasts with the traditional engineering or top-down approach to energy planning. For example, in poor households, household management and survival strategies are complex, and there is limited knowledge of how decisions on expenditure are made. For this reason it is imperative that policy options have a strong orientation towards demand and needs (Mehlwana and Qase, 1996).

To study social dynamics and patterning of fuel use in low income households, White, Mafokoane and Meintjies (1999) performed a qualitative anthropological study which included domestic appliance purchase and ownership, and processes of household decision-making. In the study sites chosen for the study (Soweto), metering and charging (billing) systems have an overwhelming influence on the manner in which electricity is used. For example, some households have attempted and succeeded in escaping the payment of the full costs of electricity consumed through illegal connections, consuming electricity wastefully and beyond their means (see page 10 and 11 of the Mail & Guardian newspaper, Vol 25 No 42 for a report on illegal electricity connections in South Africa). Houses with prepayment meters employ strategies to control their consumption – frugality, fuel switching and decisions based on perceptions of cost-efficiency rather than actual economy. Household fuel use is dynamic and reflective of people’s lives and experiences, and is generally income-responsive. Incomes and earning patterns markedly affect the choices people make (and are able to make) about their energy use. Appliance ownership in households reflects social and demographic variables. They are a mark of social status, represent ideologies and a manifestation of aspirations. Appliances have a utilitarian and symbolic use (e.g. concealing poverty – non-electric appliances being a mark of low status), and there are cultural norms that may prevent the take-up of new technologies e.g. tradition of cooking meat on wood-fires. Types and varieties of appliances are influenced by their cost and fuel availability. Appliance and fuel choice cannot be separated. Decision-making in households occurs within the constantly shifting interplay of power relations and are generally gender-dependent. Intra-household decision making processes are active processes of pushing and pulling, tugging and prodding, by interest groups within the household. When having to pay in full for fuel used, poor people do their best but within the limits set by knowledge and circumstances. There are constraints when it comes to purchasing and maintaining the quality of appliances, and by limited knowledge of how to best use fuels. Also, inefficient practices are sometimes adhered to because of social and cultural norms (and in areas where people escape paying the full costs due to illegal connections). Low levels of formal education results in a widespread lack of understanding about how electricity functions.

Modelling of household response to energy efficiency

Ruth et al. (2007) make use of an innovative simulation setting to analyse decisions about EE improvements in the residential and commercial sectors. They use a computer-facilitated gaming platform called PowerPlay to play out future scenarios. Observed behaviours are analysed to advance the understanding of consumer strategies by generating experimentally-based data on EE changes. The analyses can be used to substantiate or complement historical, time-series driven specification of energy models. The basic elements for the game with regard to households include minimizing energy-related spending, maximizing style and services, and minimizing environmental impact. At their disposal are product line selection and timing of purchases. Six groups of households are defined according to priority of objectives and income group, and each group is assigned weights for the 3 objectives. Results indicate that discrepancies arise between the actual choices made by households and the choices that would be considered economically optimal (also see Jaffe and Stavins). Efficiency investments can lead to inequitable outcomes with the poor cross-subsidizing wealthier households if pricing and tariff structures are not carefully constructed and adhered to; rapid investment in EE in regulated utility environment results in an underutilization of generation stock and a run-up of electricity prices. Co-ordination between supply investments and efficiency investment is required if efficiency programs are to be pursued. The methodology itself is useful for grasping underlying market dynamics and ripple effects in EE markets.

Strbac (2008) discusses the benefits and challenges of demand side management in the context of the UK electricity system. Some of the barriers to uptake by consumers include lack of metering and communication infrastructure, lack of understanding of the benefits of DSM and absence of adequate incentives. These factors reside under one of the themes of awareness and cost, though are not mutually exclusive in their impact. Some of the technological interventions proposed by Strbac include night-time heating with load switching, direct-load control, load limiters, time-of-use pricing, smart metering and appliances. Overall the implementation of DSM has been slow despite the concept not being new and the key technologies being available.

5.1.3 The structure and formulation of the basic consumption model

Previous literature suggests that households face three main objectives when making decisions about which energy-consuming goods and services to use (and thus about how much energy to consume):

- minimising the *cost* of consuming the energy,
- maximising the *comfort* derived from energy-consuming appliances, and
- minimising the *impact* of their energy consumption on the power system and the environment.

Not all households will accord equal importance to all three objectives. Some households (particularly low-income households) are constrained by budget limitations to the extent that only a minimal level of comfort is possible. Other households are almost unconcerned with price, consuming whatever is needed to provide a comfortable lifestyle. In the household energy consumption model presented here, these preferences are expressed in terms of two pieces of information for each household:

- goals which define desired levels of performance in each objective, and
- weights which define the relative importance of equal-size differences between the goal and performance levels on each objective (the ‘swing-weight’ interpretation common in preference modelling e.g. Belton and Stewart (2002)).

Both goals and weights will depend on socio-economic and other demographic characteristics of the household. But given a particular set of preferences (goals and weights) for the three objectives underlying energy consumption, households try to find an energy consumption level that in comes closest to satisfying their aggregated desires/needs.

Beginning from some arbitrary level of consumption, the household makes an assessment of its current cost, comfort and environmental impact. Cost is measured by multiplying the number of units of energy consumed by the unit price of energy. Comfort and impact are both measured (if only indirectly) by the number of units of energy consumed.

It is important to note that it is consumption in terms of units consumed that results in an impact, as opposed to amount of money spent on consumption. The benefit that households or individuals derive from consuming will depend on their socio-economic circumstances, and it is relative consumption that is correlated with consumption more than actual consumption. Impoverished individuals derive significant well-being benefits from increased consumption while wealthy individuals only derive marginal benefits, or even negative well-being from attaching much of the perceived well-being to high relative consumption and a focus on material wealth accumulation. (see Swim et al (2009))

Once goals and weights have been specified (see 5.1.8), satisfaction levels on each of the three objectives can be calculated as the difference between the current performance level and the goal. This difference is denoted by δ_j for objective *j*. For the minimising objectives (cost and environmental impact) the goal is subtracted from the performance level; for the maximising objective (comfort) the performance level is subtracted from the goal – so that underachievement relative to a goal is always positively signed. When a goal is achieved, the deviation is set to zero regardless of the performance level attained (so any overachievement beyond the goal is viewed equally by the household).

Thus, if g_j is the goal set for objective *j* and *C* represents the consumption level of the household, then

$$\delta_1 = \max(rC - g_{1,0})$$

$$\delta_2 = \max(g_2 - C, 0)$$

$$\delta_3 = \max(C - g_{3,0})$$

where *r* is the per-unit cost of energy. The decision about how much energy consume is then simply a matter of finding the consumption level C^* where the desire to increase consumption (and so gain more comfort) is exactly balanced by the desire to decrease consumption (and so save money and cause less environmental damage). In terms of the preference model, this occurs when any underachievement from the comfort goal is exactly balanced by the weighted sum of the underachievement from the cost and environmental impact goals i.e.

$$w_2\delta_2 = w_1\delta_1 + w_3\delta_3$$

where w_j is the weight associated with objective *j*. If the current consumption is below the equilibrium level C^*, then current consumption is increased incrementally until it reaches an equilibrium level. If the current consumption is above the equilibrium level C^*, so that cost and environmental considerations outweigh comfort considerations, then current consumption is reduced, again incrementally.

5.1.4 Including the effect of external interventions

The aim of our model is to examine three broad interventions that are expected – and demonstrated in the literature – to lead to decreases in household energy consumption:

1. Price interventions: attempt to regulate energy demand by increasing the *effective* unit price of energy;

2. Efficiency interventions: attempt a controlled reduction of energy consumption by introducing new technologies which require less energy to fulfil the same service as a previous less efficient technology;
3. Information interventions: attempt to stimulate energy demand reductions by providing households with information about environmental issues related to energy use, and emphasising individual and collective responsibility for sustainable energy use.

In practice various combinations of these interventions are used. For example, in the Eskom DSM CFL roll-out to households, a paper flyer accompanies the new lights containing information about energy saving that may be used by consumers to raise their awareness levels. Similarly, municipalities that are supplying Solar Water Heaters to low income RDP households run awareness workshops in the community in which the roll-out is taking place. As mentioned above in 5.1.2, one of the questions the model in this work is intending to answer is: 'What is the appropriate combination of the above 3 strategies that will best mitigate REs?' Of course there are constraints on the implementation of the 3 strategies that could pertain to costs, or to practical considerations when carrying out the interventions. In this work the model is not used to test anything other than the impact of choosing various intervention strategies on household consumption. It seeks to find the appropriate mix of intervention strategies for different household types that will minimise the take-up of slack arising in the household budget, and therefore ignores any cost or practicality considerations relating to the actual implementation of these strategies.

The modelling of each of the interventions is described in turn below.

1. Price Interventions

Price increases affect the unit price of energy, without affecting any other part of the model. If the unit cost of energy is increased by $(100 \times t)\%$, the new cost incurred by the household is $(1 + t)rC$.

2. Efficiency Interventions

The introduction of a new, more-efficient technology decreases the amount of energy required by a household in order to perform an activity. Strictly speaking EE refers to using a new technology that makes more efficient use of a particular energy carrier (e.g. electricity) for a particular energy service (e.g. lighting). However much of the work around managing demand involves interventions that do not relate to the appliance itself, but for example to the structure of the building (which may lead to efficiency gains (passive interventions)), and fuel substitution (e.g. replacement of conventional water heating systems with solar water heaters where the main fuel source is solar radiation). For the sake of simplicity, in the discussions that follow efficiency interventions refer to the first and last of these three options, as this is where most of the emphasis of the empirical studies is placed.

Introduction of efficiency at point of use results in the reduction of final and useful energy demand in the system. From the household's point of view, the same basic activity is being performed, but less energy is being used in doing so. This necessitates a distinction between what might be termed the amount of energy demanded (or perhaps *apparent* energy consumption, denoted *D* – the demand for energy services such as lighting, space heating, hot water, etc) and the amount of energy consumed (or *actual* energy consumption, denoted *C*). The former measures the use of energy-consuming services, rather than the consumption of energy *per se*, and affects assessments of comfort and environmental impact. The latter measures the actual amount of energy consumed, and affects assessments of cost. In the basic consumption model presented here it is assumed for simplicity that energy demanded was equal to energy consumed. With the introduction of an efficiency intervention using $(100 \times s)\%$ as much energy as an old technology, we can write the amount of energy consumed as a linear function of the amount of energy demanded i.e. $C = sD$.

Efficiency interventions have the additional complexity that the service provided by the new technology may often not be precisely the same as previously experienced. There may also be teething problems upon the introduction of new technologies as users become accustomed to technologies that have remained the same for many years, with outright rejection and reversion being a possibility for some consumers. In the empirical studies of this research project examples of teething issues are new solar water heaters which may be less reliable sources of hot water than geysers; energy-saving lightbulbs (CFLs) may be perceived as providing an inferior light to incandescent lamps. Therefore, the level of comfort obtained is not simply *D* – the amount of energy 'demanded' to perform some activity – but can also be affected by dissatisfaction with the new technology. If a new technology is judged to offer a service only $(100 \times p)\%$ as good as the previous technology, the level of comfort is given by pD . This means that the difference between the current comfort and the desired level of comfort is in fact given by

$$\delta_2 = \max(g_2 - pD, 0)$$

Efficiency interventions also affect assessments of cost, since less energy is being used to provide the same level of energy service. The difference between currently incurred and desired costs is given by

$$\delta_1 = \max\left((1+t)rC - g_{1,0}\right) = \max\left((1+t)rsD - g_{1,0}\right)$$

A household's choice of how much energy to use is therefore determined by selecting a demand level D satisfying the following equality:

$$w_2([\max[g]_2 - pD, 0]) = w_1(\max[(1+t)rsD - g_{1,0}]) + w_3(\max[D - g_{3,0}])$$

3. Information interventions

Information interventions operate by exerting an influence on the relative importance (i.e. the weights) attached to the three objectives. Which objectives are affected is likely to depend on the type of intervention used. For example, feedback contrasting household energy spending with historical figures or neighbourhood norms may increase the relative importance of the cost objective. More overt campaigns highlighting the damage caused by wasteful consumption may have the effect of increasing the weight associated with the impact goal at the expense of the weights for other two objectives.

In the model developed here, information interventions are capable of changing a household's weights (changes in goals may also be modelled, but that is not done here), but only to a limited degree. That is, a maximum change is specified for the weight on the cost and environmental impact objective. All three weights sum to one, so that the comfort weight is indirectly influenced by changes to the other two. This maximum change essentially captures the salience of the information campaign through its ability to change a household's perceptions. While an information campaign is running, a household's weights will slowly change, from the initial weights, up to the maximum allowable change, provided that the intervention runs for long enough. Once an intervention ceases, the preferences start to fall back to their initial values. The statistical process governing the changes in preferences is one of exponential smoothing, which results in the decreasing marginal changes as the time following the introduction (or ceasing) of an intervention elapses. Further parameters of the intervention are the time taken for the maximum change in preferences to be attained, the length of the information intervention, as well as the time between information inventions. However these parameters are not varied as part of the current work and are left to future research. The time taken for the maximum change in preferences to be attained captures the effectiveness of a campaign; the other two parameters can be varied to provide a pattern of running an information campaign for L_{on} time periods every $L_{on} + L_{off}$ periods.

5.1.5 Additional components of the model

In addition to the basic consumption model and models of the three intervention approaches, there are a number of additional features of the full model that have been included but at this stage do not play a major role in any of the results because they are held constant or set to null values. The intention is that once the basic model is validated against the case study data analysis from the interventions in Prince Albert and Nelson Mandela Bay, then these additional elements may be useful as a means of fine-tuning the basic model. Specific elements include: households only becoming aware of their spending periodically (i.e. through some billing mechanism), with the inter-invoice period potentially affected by an intervention; capacity for increases in a particular household's energy demand being limited (for example, by the number of energy-consuming devices owned); and the determination of this capacity for consumption itself being an outcome of the decision-making process. Consumption increases are distinct from investment in equipment and technology. The focus in this study is on the usage of appliances that leads to an impact. Investment in equipment leads to impacts that are indirect (and considered to a lesser extent by consumers).

The full model is shown in

Figure 13.

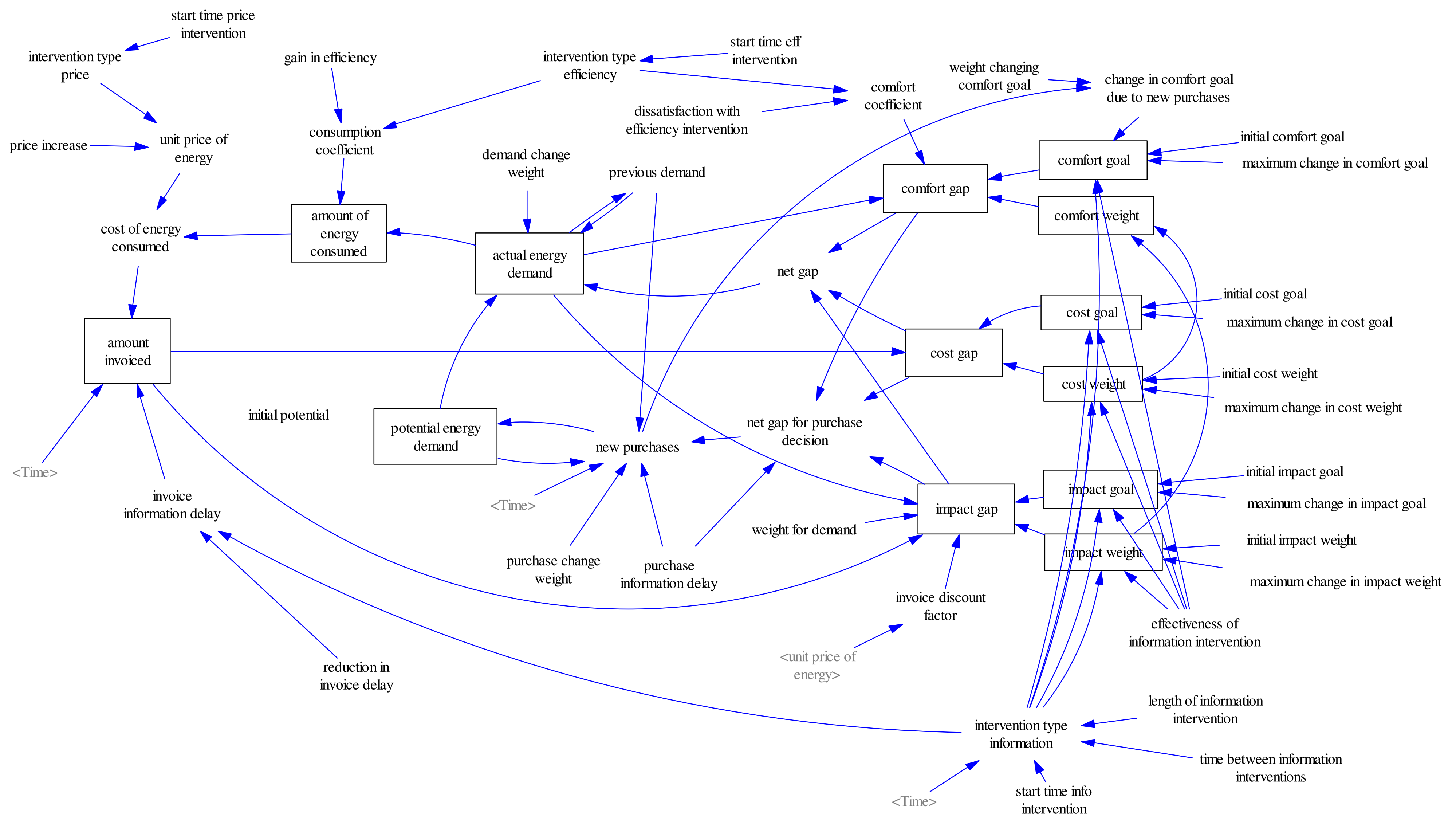

Figure 13: Systems dynamics model of household energy consumption behaviour

5.1.6 Intervention types

A range of likely but theoretical interventions were chosen to explore the theoretical impact on the consumption behaviour of an individual household:

1. No intervention (baseline or reference case).
2. A 10% increase in the per-unit price of energy.
3. A 10% efficiency saving (with no dissatisfaction with the new technology).
4. A 10% efficiency saving (with satisfaction level at a rate of 90% of the initial satisfaction level which we assume to be 1).
5. A 'feedback'-type awareness campaign: this has the effect of increasing the weight allocated to the cost objective by 0.1.
6. A 'greening'-type awareness campaign: this has the effect of increasing the weight allocated to the environmental impact objective by 0.1.
7. Both awareness campaigns run simultaneously.

5.1.7 Household types

Four distinct household types were chosen for inclusion in the model, with reference to two income groups (low and high), and environmental impact concern (no concern or some concern).

1. A low-income household with no environmental concern: this household has a low cost goal, and a high weight strictly penalising any spending above this goal. In the extreme, as the weight associated with the cost goal approaches one, the 'goal' becomes a hard constraint on spending. However here a modest level of comfort is also desired, with some importance (though less than half that allocated to the cost objective) attached to attaining this objective. The weight on the environmental objective is set to zero.
2. A low-income household with some environmental concern: the goal and weight on the cost objective are as for Household 1, but some importance is given to both the remaining objectives (comfort and environmental awareness) rather than just comfort. In this household, deviations from the comfort goal are considered to be twice as important as deviations from the environmental impact goal.
3. A high-income household with no environmental concern: this household has a high comfort goal, and a high weight penalising consumption below this goal. In the extreme, as the weight associated with the comfort goal approaches one, the household will consume at this level, regardless of the cost or impact of the consumption. However here some importance is also allocated to keeping costs at a reasonable level (though less than half that allocated to the comfort objective). The weight on the environmental objective is set to zero.
4. A high-income household with some environmental concern: as for Household 3, but with some importance reallocated from the comfort objective to the environmental impact objective.

5.1.8 Weights and goals

The goals and weights assigned to each of the household types for each of the objectives is given in Table 1 below, and have been elicited intuitively, and through trial and error (sensitivity) testing with the Vensim the simulation model. Because all results are to be expressed in relative terms (i.e. percentage changes), the actual units of measurement are unimportant, and have been expressed on a scale from 0 to 100.

Table 5: Preferences sets for the four basic household types

Household Type	Income	Environmental Awareness	Goals			Weights		
			Comfort	*Cost*	*Impact*	*Comfort*	*Cost*	*Impact*
1	Low	None	15	10	n/a	0.3	0.7	0
2	Low	Some	15	10	5	0.2	0.7	0.1
3	High	None	90	60	n/a	0.7	0.3	0
4	High	Some	90	60	30	0.6	0.3	0.1

The systems dynamics model has now been specified in totality. The model was then run experimentally to explore the impacts of the various interventions, and to compare the responses of the different household types. The results of these experimental runs are reported and discussed in Section 6.1.

5.2 Statistical techniques used for data analysis

The data collected for the two case studies was described in Chapter 4. Although the panel of 3 sets of survey data from Prince Albert (and the panel of 2 surveys from Zanemvula) can be analysed in their own right to measure the changes in attitudes and stated behaviour over time, the greatest research value can be derived from using the survey data to explain changes in consumption data. This exploratory analysis involves determination of which of the variables included in the survey are significant, and calculating the size and sign of the regression coefficients. Said another way, the principal methodological approach consisted of exploratory analysis of the factors explaining changes in consumption behaviour. Of secondary interest were the comparisons of the responses to the panel of responses in the two case studies, so these are only given brief attention in the final analyses. The focus of this section is thus on the linear regression models used to conduct the exploratory analysis of survey data combined with consumption data.

The fundamental question the models attempt to explain is: What are the factors that significantly explain changes in electricity consumption in households in the presence of EE interventions, and how do these explanatory variables interact with each other?

5.2.1 Data manipulation

In order to analyse the data, it had to be converted into a format that was amenable for use in a regression model, and could be coded to the requirements of the statistical package. The first challenge was to convert the prepayment purchase history into a set of monthly consumption figures. The procedure for this is described in more detail in the Appendix 12, and resulted in a time series of historical consumption for each household in the sample. This time series was the most important part of the data as it is the single dependent variable in the model.

Secondly, the survey response data for each phase of the survey had to be recoded to comply with the statistical modelling package (STATA) that was used for the analyses. Additional variables that had to be coded for use in the model were the price increments over time (so that the impact of these increases could be analysed), and a variable for the time of year (month or season) to account for seasonal changes in electricity consumption.

The final data set for each model was formed by merging the consumption data with the survey data and the additional variables.

The data manipulation was carried out separately for the Zanemvula and Prince Albert data sets. Additionally, within Prince Albert, the sample with prepayment meters had to be analysed separately to the sample with credit meters, as the format of the data differed between the two. The procedure for estimating monthly consumption figures from prepayment history resulted in outliers (excessive consumption), and these values were excluded from the analysis. Similarly, sections of the sample that exhibited excessive consumption were excluded on the grounds that these were not 'normal households', but rather operational businesses with higher electricity consumption than would be expected for a typical household.

5.2.2 General form of the regression model

Several techniques were considered for maximising the value of the combined survey and consumption data, including simple descriptive analysis methods (for the survey data). Some examples of the outputs and insights generated using these approaches are given in Davis (2009). However, for a complete analysis of the combined sets of consumption and survey data, a linear modelling approach was tested and found to be the most useful for analysing mixed data[6]. Similar models were fitted to the combined data from Prince Albert and Zanemvula, and for subsets of the Prince Albert data

The final model was selected using a step-wise method of parameter selection, with variables chosen intuitively. Many such models can be generated, and the results generated in this report reflect the thoughts of the analysts involved. Many other permutations of the model could be tested on the same data and using the same linear regression models.

The basic form of each model used consisted of a linear regression equation with a random intercept to account for between-household heterogeneity in electricity consumption. The dependent variable in all cases is the natural logarithm of consumption, which transforms the outcome to one that is normally distributed. The independent variables that are included in the model differ depending on data set selected for the analysis and the specific variables being tested for significance. All models used were of the following format:

$$\ln(C_{it}) = \beta_0 + \beta_1 x(1)_{it} + \beta_2 x(2)_{it} + \cdots + \beta_n x(n)_{it} + u_i + \epsilon_{it}$$

where:

i indexes household i and t indexes time/month t ,

C_{it} = average daily consumption by household i in month t ,

$x(j)_{it}$ = j^{th} variable representing one of the following for household *i* in month *t*:

i) demographic characteristic

ii) survey response question of interest

iii) price change (as % of original baseline price)

iv) indicator for intervention presence or

v) a particular two-way interactions between two of these variables selected together

β_j = regression coefficient for variable *j*

u_i is the random effect for household i ($u_i \sim N(0, \sigma_u^2)$,

ϵ_{it} is the random error term $\epsilon_{it} \sim N(0, \sigma_\epsilon^2)$.

Various sub-samples with respect to time ranges and/or household types are used where appropriate for the various models. The results for each model are reported in Section 6.2.

5.3 Demand modelling using LEAP

LEAP ('Long Range Energy Alternatives Planning System') is a descriptive accounting and simulation tool for energy and environmental policy analysis. It is an integrated modelling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy.

LEAP allows the user to capture data to represent an energy system and analysis is conducted by constructing alternative futures, one of which is a baseline scenario which is used for comparison with all the other scenarios. The baseline scenario usually represents the business as

[6] The data are mixed in the sense that continuous quantitative and discrete categorical data are present.

usual or growth without constraint scenario against which other scenarios can be tested. Ultimately all futures can be compared to one another and the "best" future can be used for policy suggestions.

LEAP can be used to simulate the behaviour of consumers and producers under various signals such as price increases, income levels growth, policies and GDP growth changes. It is a bottom-up tool which means that end use data can be aggregated to form a picture of the total demand. Supply options can also be investigated and LEAP has an integrated environmental and technology database which allows the user to investigate GHG emissions and also local pollutants for different technologies.

The study by Nyatsanza (2010) study uses LEAP quantifies energy savings from various energy efficiency initiatives as well as the potential impact of the rebound effect suggests measures which would encourage energy efficiency and mitigate the rebound effect. Parameters for the different scenarios were gathered from literature on South African energy demand and rebound effects.

5.3.1 LEAP model structure

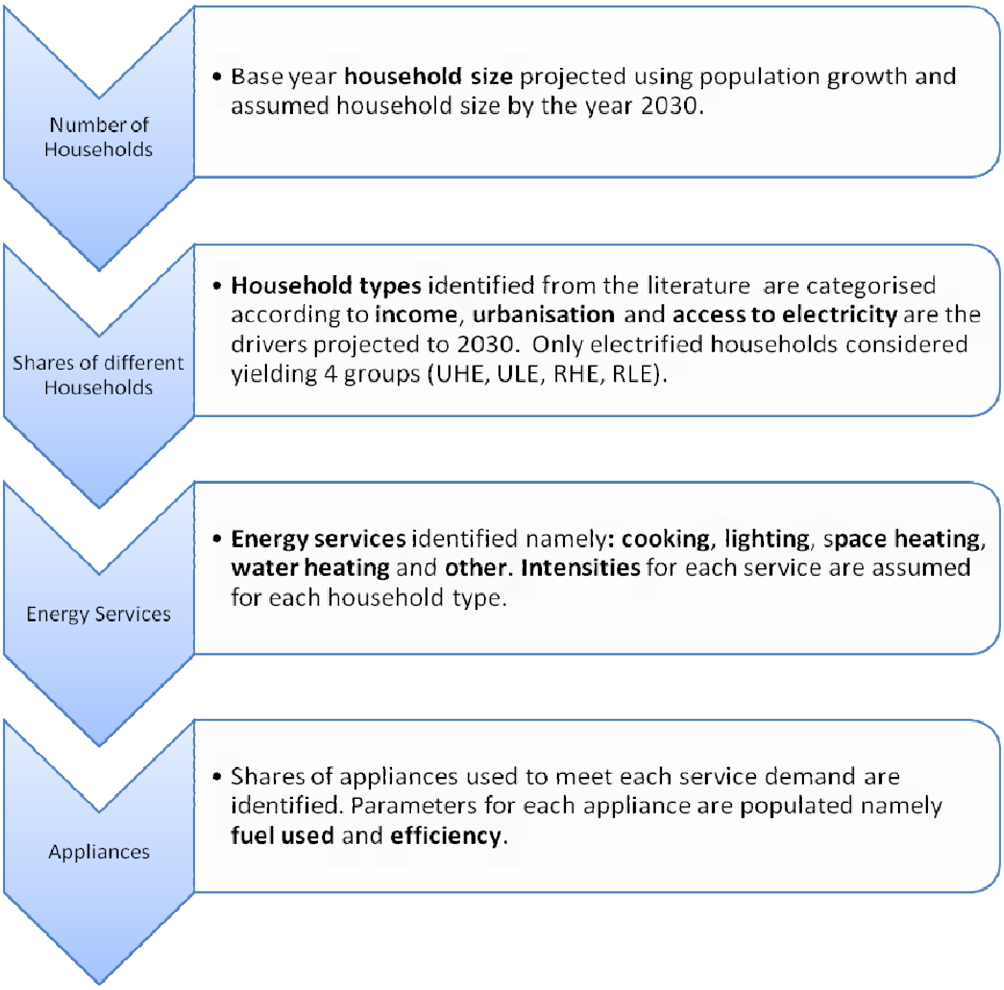

Figure 14: The LEAP modelling process.

5.3.2 Scenarios

In this section projections of demand are explored for different scenarios using the LEAP modelling tool. The scenarios to be investigated are:

1. Baseline growth without constraint scenario.

2. The impact of NERSA approved tariff hikes from 2010 to 2013.
3. The impact of maximum penetration rates of energy efficiency technologies assuming all technical savings are achieved.
4. The impact of maximum penetration rates of energy efficiency assuming **rebound exists**.
5. The impact of NERSA approved tariff hikes from 2010 to 2013 and maximum penetration rates of energy efficiency initiatives.
6. Mitigating rebound using awareness.

The following segments of this section describe the rationale behind modelling each scenario and also the assumptions used for each scenario.

Baseline scenario

The baseline scenario represents a growth without constraint scenario. In the baseline scenario, an energy efficiency enabling environment does not exist and minimal penetration rates of energy efficiency technologies are assumed. Technologies under consideration are CFLs, SWHs and geyser blankets. The baseline scenario will be used for comparison to the other scenarios. The penetration rates used in the baseline scenario were taken mainly from Winkler (2009).

Table 6: Assumed penetration for CFLs
Source: Winkler (2009)

HH	*2001 (%)*	*2013 (%)*	*2030 (%)*
Urban rich (UH)	8	15	17
Urban poor (UL)	1	9	17
Rural rich (RH)	6	11	17
Rural poor (RL)	0	9	17

Table 7: Assumed share of households using geyser blankets and SWH (intuitive assumptions)

Household	*2030 share of geyser blankets*	*2030 share of SWH*
Urban rich (UH)	10%	1.3%
Urban poor (UL)	4%	0
Rural rich (RH)	10%	0
Rural poor (RL)	8%	0

For the baseline scenario it is assumed that all technical savings for efficiency initiatives are realised and demand is impartial to external drivers such as the cost of electricity and GDP.

Tariff hikes scenario

Residential electricity demand is fairly inelastic in South Africa (Ziramba (2008) and Maphumulo (2010) but the NERSA approved Eskom tariff hikes from 2009 to 2013 are substantial. Below is a table showing the assumed tariff hikes for South Africa.

Table 8: Assumed future tariff increases (NERSA)

	2010	*2011*	*2012*	*2013*	*References*
High Income	30.00%	24.80%	25.10%	25.90%	(South Africa Online)
Low income	15.00%	15.00%	15.00%	15.00%	Own assumptions

Ziramba (2008) found evidence of a -0.02 short term and a -0.04 long term residential demand elasticity to electricity prices in South Africa. For the tariff increment scenario, a short term elasticity of -2% (4 years is considered short term) and a long term elasticity of -4% from the baseline scenario were assumed for the above tariff increments.

Energy efficiency scenario

The energy efficiency scenario attempts to illustrate the impacts of achievable penetration rates of CFLs, SWHs and Geyser Blankets according to Winkler (20096). It is assumed that all technical savings are achieved in the Energy Efficiency scenario and that no additional savings due to awareness or tariff hikes are onserved.

Table 9: Penetration rates of CFLs

Source: Winkler (2006)

Household	*2013*	*2030*
Urban rich (UH)	35%	50%
Urban poor (UL)	20%	40%
Rural rich (RH)	30%	50%
Rural poor (RL)	20%	40%

Table 10: Penetration rates of geyser blankets and SWHs for 2030

Source: Winkler (2009)

Household	*SWH 2030*	*Geyser blankets 2030*
Urban rich (UH)	50%	20%
Urban poor (UL)	30%	20%
Rural rich (RH)	30%	20%
Rural poor (RL)	20%	20%

Rebound scenario

The rebound effect scenario tries to illustrate the possible loses due to direct rebound on the energy efficiency initiatives under investigation. Empirical evidence of direct rebound from literature was used to explore the impact of the rebound effect.

The table shown below comes from (Greene and Greening 1998) review of over 75 estimates of rebound in literature. They restricted their study to examining the effects of fuel efficiency on a specific energy service rather than on fuel consumption (Greening, et al., (1998)).

Table 11: Rebound estimates

Source: Based on figures from Greening (1998)

Scenario	*Technology*	*Rebound*
Lighting rebound	CFL	12%
Water heating	SWH	40%
Water heating	Geyser blanket	10%

A higher estimate for rebound for SWH than for geyser blankets was used because higher rebounds are expected when an appliance can save more energy (this is because the price of the service is lower for a more efficient appliance). Also in some instances, solar water heaters will cater for unmet demand which means final energy intensity will increase for water heating (expected for the low income groups).

Impact of tariff increments on energy efficiency initiatives

Tariff hikes reduce the amount of financial gains from energy efficiency interventions therefore limiting the amount of funds that might have been recycled back into more energy consumption. Therefore tariff hikes have the potential of negating the rebound effect. In this scenario the tariff hikes in the table above were assumed and a short term and long term price elasticity of demand of -2% and -4% respectively according to (Ziramba, 2008) were assumed.

Impact of raised awareness on energy efficiency initiatives

If energy efficiency initiatives are carried out together with awareness campaigns, it is possible to anticipate even more energy savings than one would expect from efficiency initiatives alone. The Department of Minerals and Energy stated in the Energy Efficiency Strategy that major energy savings can only be achieved through changes in people's behaviour and that depends on informing them on what options exists (DME, 2005)

Assumptions used in the Municipal Electricity Efficiency tool developed by Sustainable Energy Africa were used to estimate potential savings from behavioural changes due to raised awareness on not only energy efficiency but also the energy situation in South Africa. Below is a table showing the assumed energy intensity drops for lighting and water heating due to raised awareness on energy maters.

Table 12: Assumed changes in behaviour and energy intensity

Energy service	*Behavioural changes*	*Reduction in energy intensity*
Lighting	Efficient use of lights	10%
Water heating	10^{o}C thermostat reduction	6%

6. Results and discussion of the analyses

This chapter presents and discusses the results generated from the models described in the previous chapter. In the first section, the systems dynamics model of household energy consumption is used to generate outputs using assumed parameter values, firstly for a single intervention, and then for combinations of interventions (technology, price and awareness). The final part of section 6.1 uses regression techniques on the data from the Prince Albert case study to validate the hypotheses generated through the simulation model.

The second section of this Chapter summarises the main findings from the statistical regression analysis of the combined survey and consumption data for the case studies in Zanemvula and Prince Albert. The third section discusses the outputs of the LEAP model of national demand impacts, and the final section provides a synthesis of the results.

6.1 Simulation modelling of household electricity consumption

The systems dynamics simulation environment described in section 5.1 was used in a series of experimental runs to generate the outputs that are presented and discussed in the first part of this section. The second part of the section consists of a statistical validation of the hypotheses generated from the model.

6.1.1 Discussion of the outputs

In this section, the outputs of the simulation experiments described in Chapter 5 are used to illustrate the effects of different intervention strategies on the consumption of electricity, for four different household 'types'. The simulation model is conceptual and the parameters values are assumed, with the interventions types selected as being representative of those scenarios that could prevail in reality.

The relative effects of each intervention on the amount of energy consumed are shown in the table below. Because of the distinction between energy consumed (the amount of energy required from a supplier in order to perform certain activities) and energy demanded (a measure of the number/type of activities performed), the relative effects of interventions on demand are also shown in parentheses.

Table 13: Impacts of energy efficiency interventions

	Household type			
	Low income/	*Low income/*	*High income/*	*High income/*
Intervention	*No environ-mental concern*	*Some environ-mental concern*	*No environ-mental concern*	*Some environ-mental concern*
None (baseline)	11.5	10.5	81	75
10% price increase	-6.5% (-6.5%)	-6.5% (-6.5%)	-2.9% (-2.9%)	-2.9% (-2.9%)
10% efficiency saving (same satisfaction)	-3.2% (+7.5%)	-3.2% (+7.5%)	-7.2% (+3.1%)	-7.2% (+3.1%)
10% efficiency saving (- 10% satisfaction)	0% (+11.1%)	-1.1% (+9.9%)	0% (+11.1%)	-1.1% (+9.9%)
Awareness/feedback: cost weight + 0.1	-4.3% (-4.3%)	-4.8% (-4.8%)	-3.7% (-3.7%)	-4% (-4%)
Awareness/green campaign: impact weight + 0.1	-8.7% (-8.7%)	-20.6% (-20.6%)	-7.4% (-7.4%)	-8% (-8%)
Both awareness campaigns run simultaneously	-13% (-13%)	-52.3% (-52.3%)	-11.1% (-11.1%)	-12% (-12%)

Note: The effects on the amount of electricity demanded (see definition in text) are shown in parentheses. The units of consumption are arbitrary, in reality they would be in KWh.

Impacts of the individual interventions

REs are evident for both the price and efficiency interventions. The magnitude of the rebound depends on the income-level of the household, and (in the case of less-satisfying efficiency interventions) the level of environmental concern.

For price interventions, greater REs are experienced in high-income households – for a 10% increase in price, consumption drops by only 2.9%, giving an effective rebound of 7.1/10 = 71%. This rebound is strictly speaking a pure price elasticity effect. In comparison, the rebound in low-income households is 35%. The reason underlying the rebound in response to price-based interventions is that the price interventions effectively instantaneously increase the gap between the cost goal and the currently incurred cost, while leaving the gap between the comfort goal and current comfort unchanged. This provides an incentive to immediately decrease the demand for energy. However, the comfort goal acts as a counterweight to this incentive, and induces some resistance to change. The extent of this resistance to change is a function of the importance allocated to achieving a desired level of comfort. It can be shown that in order to restore a balance between objectives, demand must decrease until the ratio of new to old demand is given by $\frac{1}{[w_{comfort} + (1+t)w_{cost} + w_{impact}]}$, provided that the change in demand does not result in any of the goals becoming fully achieved[7]. The expression simplifies further to $\frac{1}{1 + tw_{cost}}$ because of the constraint that weights must sum to one. Most importantly, final equilibrium demand decreases as w_{cost} increases. Therefore, households that place a greater

[7] This expression, and the ones that follow it, are only valid while no goals are fully achieved i.e. $\delta_j > 0, \forall j$. If any of the goals is achieved, non-linearities in the definition of the δ_j can cause different types of behaviour to occur. Usually these affect the expressions used to describe change in a simple way – for example, if the impact goal is satisfied here, the ratio of new to old demand becomes $\frac{1 - w_{impact}}{[w_{comfort} + (1+t)w_{cost}]}$. Any effect of achieving the specified goals is discussed in the text, where this has occurred.

importance on cost relative to comfort will experience larger decreases in energy demand, which is why the rebound is so much greater in high-income households placing more weight on the comfort objective. It is also clear why environmental impact considerations have no influence the effect of price interventions. In fact, the model suggests that increasing the impact weight at the expense of cost considerations would reduce the impact made by price-based interventions.

For efficiency interventions, REs depend quite strongly on the satisfaction with the new technology. If the new technology provides as satisfying a service as the old technology, the magnitude of the rebound followed the introduction of 10% more-efficient technology is between 2.8% (for high-income households) and 6.8% (for low-income households). The result is therefore the opposite of the price interventions: here, rebound is greater for the low-income households. The reason for this is that the efficiency saving instantaneously decreases the gap between the cost goal and the current cost, while leaving the comfort gap unchanged. This provides an incentive to increase the amount of energy demanded. It can be shown that in order to restore a balance between objectives, demand must rise by a factor of $\frac{1}{[w_{comfort} + sw_{cost} + w_{impact}]}$, which simplifies to $\frac{1}{[1-(1-s)w_{cost}]}$. This factor increases in w_{cost} , suggesting that households that place a greater importance on cost relative to comfort will experience greater increases in demand.

If there is dissatisfaction with the quality of a new efficiency intervention, this causes a decrease in current comfort assessments and hence an increase in the gap between the comfort goal and current comfort (in addition to decreasing the gap between the cost goal and the current cost as discussed above). Both these effects act as an incentive to increase demand, so that the increases in (general, not necessarily related to the new technology) energy demand are larger when a new technology is dissatisfying. In this case, demand rises by a factor of $\frac{1}{[pw_{comfort} + sw_{cost} + w_{impact}]}$.This factor cannot be written in terms of just a single objective weight, although it can be slightly simplified to $\frac{1}{[1-(1-p)w_{comfort} - (1-s)w_{cost}]}$. Note that this factor increases i.e. demand rises by more, if either $w_{comfort}$ or w_{cost} increases while the other is held constant (i.e. any weight increase is at the expense of w_{impact}). This explains why the increase in energy demand (and therefore consumption) following an efficiency intervention is lower when some weight is placed on environmental issues. In the simulated intervention – a new technology offering a 10% efficiency saving but with a 10% decrease in the satisfaction with the provided service – energy demand increased 9.9% in households with some environmental concerns and 11.1% if some weight was placed on the environmental goal. The net effect of these increases in demand is that the amount of energy consumed fell only 1.1% in environmentally-aware households, and not at all in households with no environmental concern (i.e. 100% rebound). For the range of values used, low-income and high-income households experienced the same changes in demand and consumption in response to this particular intervention, but the factor above shows that this is a consequence of have the efficiency saving $1-p$ equal to the dissatisfaction rate $1-s$ (i.e. $p = s = 0.1$). If $s < p$ i.e. satisfaction with the new technology is high, greater increases in demand (and hence larger REs) should be expected from households with higher weights on the cost objective (e.g. low-income households). If $s > p$ i.e. low satisfaction, greater effects should be expected from households with higher weights on the comfort objective (e.g. high-income households).

For the range of households simulated here, information interventions increasing the relative importance of achieving environmental goals led to larger decreases in energy demand than those focusing on increasing the relative importance of the cost objective. This effect however, is largely dependent on which of the environmental impact and cost goal is lowest. Both objectives act as incentives for a household to decrease its energy demand. For an intervention that increases the cost weight w_1 by Δ_1 and the environmental impact weight w_3 by Δ_3 (and hence decreases the comfort weight w_2 by $\Delta_1 + \Delta_3$), the absolute change in energy demand is given, up until the point where any of the goals are achieved, by $\Delta_1 g_1 + \Delta_3 g_3 - (\Delta_1 + \Delta_3) g_2$. For all households considered here $g_3 < g_1 < g_2$. This implies that for an equal size change in importance weights, the greatest absolute decrease in demand will be observed for changes to the (smaller) environmental impact goal. Absolute changes are equal in environmentally-aware and unaware households; the observed differences in relative changes are due to the smaller initial demand in households with non-zero weights on the environmental impact objective.

If any of the goals are achieved i.e. $\delta_j = 0$, then non-linearities in the basic equality

$$w_2(\max[g_2 - pD, 0]) = w_1(\max[(1+t)rsD - g_{1,0}]) + w_3(\max[D - g_{3,0}])$$

can cause some more extreme behaviour to occur. For the low-income, environmentally-aware Household 2, the second 'green' intervention changes the environmental impact weight from 0.1 to 0.2 and the comfort weight from 0.2 to 0.1. This is enough to cause energy demand to drop below 10 units, which satisfies the initial cost goal, effectively removing the middle term from the above equation. This means that the new demand is given by $D = w_{impact} g_{impact} + w_{cost} g_{cost}$, which causes a strong further decrease in demand, because w_{impact} is twice as large as w_{cost} . It may be that this combination of events (i.e. a low-income household that, once its cost objectives have been satisfied, reduces its consumption further in order to pursue environmental goals) is implausible – perhaps the more common response would be to try to increase their modest standard of living (i.e. increase the comfort goal, which would counteract the tendency for consumption to drop any further. The model, however, is useful in raising these types of questions.

The results above (specifically, that the change in energy demand following an information intervention is $\Delta_1 g_1 + \Delta_3 g_3 - (\Delta_1 + \Delta_3) g_2$, provided that none of the goals are fully achieved), also imply that the effect of a simultaneous cost/impact intervention will simply be an additive combination of the effects of the two interventions on their own. This is the case for Household types 1, 3 and 4 in Table 2; again, non-linearities introduced by the satisfaction of Household type 2's cost goal causes a strong super-additive effect, although this is almost certainly a practically impossible result (the net effect of the two interventions is to reduce Household type 2's comfort weighting to zero). A more sensible conclusion may be to identify this as an extreme situation in which the output of the model should not be trusted.

Impacts of combinations of interventions

The model can also be used to explore combinations of interventions i.e. situations in which more than one of the interventions are run concurrently. The effects of simultaneously running multiple interventions on energy consumption are shown in Table 3. Note that the figures in parentheses are the sum of the marginal contributions made by each intervention (from Table 2) and are not the demand figures (as was the case in Table 2). These results can be used to identify cases in which interventions are mutually reinforcing, leading to larger decreases if run together. The only combination of interventions for which this is consistently the case (across all household types) is if price interventions are run concurrently with information interventions focusing on increasing the importance weight allocated to the cost objective. This synergy was previously noted when examining the marginal effects of price interventions. Running efficiency and information interventions (of either type) can also cause super-additive reductions in consumption, but only for (the low-income, environmentally aware) household type 2.

Table 14: Effect of combinations of efficiency interventions on energy consumption

	Household type			
	Low income/	*Low income/*	*High income/*	*High income/*
Intervention	*No environ-mental concern*	*Some environ-mental concern*	*No environ-mental concern*	*Some environ-mental concern*
None (baseline)	11.5	10.5	81	75
Price*Efficiency	-9.4% (-9.8%)	-9.4% (-9.8%)	-9.7% (-10.1%)	-9.7% (-10.1%)
Price*Info (cost)	-11.4% (-10.9%)	-11.8% (-11.3%)	-7.4% (-6.6%)	-7.7% (-6.9%)
Price*Info (impact)	-14.7% (-15.2%)	-20.6% (-27.2%)	-10.1% (-10.3%)	-10.7% (-10.9%)
Efficiency*Info (cost)	-6.4% (-7.6%)	-14.3% (-8%)	-9.7% (-10.9%)	-10% (-11.2%)
Efficiency*Info (impact)	-11.6% (-11.9%)	-28.6% (-23.9%)	-14.1% (-14.6%)	-14.6% (-15.2%)
Price*Effic.*Info (cost)	-13.2% (-14.1%)	-14.3% (-14.5%)	-13% (-13.8%)	-13.3% (-14.1%)
Price*Effic.*Info (impact)	-17.2% (-18.5%)	-28.6% (-30.4%)	-16.4% (-17.5%)	-17% (-18.1%)
Note: The sum of the marginal effects of each intervention is shown in parentheses				

6.1.2 Discussion

The model described here gives a behavioural framework for understanding how households endowed with certain characteristics with regard to income, preferences and desires make decisions about how much energy to consume. In its basic form, this is done by solving a simple equality constraint balancing the conflicting objectives of achieving a suitable low cost and environmental impact on one hand, and achieving a suitable standard of living or comfort on the other hand. Intervention strategies influence energy decisions by impacting on the levels of achievement, and the relative importance, on the different objectives. From this simple framework, the model makes a number of testable predictions about the RE:

1. For price interventions, greater REs are experienced in high-income households.
2. Increasing the impact weight at the expense of cost considerations would reduce the impact made by price-based interventions.
3. For efficiency interventions, greater REs are experienced in low-income households.
4. Greater REs are experienced if an efficiency intervention involves a technology that does not deliver as satisfying a service as before. If the new technology is more satisfying, negative rebound is possible.
5. REs occurring as a result of unsatisfactory new technology decrease as more weight is placed on environmental issues.
6. If satisfaction with the new technology is high ($s < p$), larger REs are expected from low-income households. If satisfaction with the new technology is low $(s > p)$, greater effects should be expected from high-income households.
7. An information campaign will be more effective in reducing energy demand if it (a) increases the relative importance allocated to the targeted objective, and (b) targets whichever objective has the lower goal in terms of level of energy demand required to meet the goal (testing this hypothesis requires knowledge of goals *and* weights, which may be difficult).

The first phase of the model development involved setting up the household consumption model based on preferences for energy and energy services, and generating a number of testable hypotheses given that the initial model used estimates for the weights that were determined intuitively. In the next phase, the data collected from the Prince Albert study is to the hypotheses above (where possible). This testing is viewed as an opportunity to validate the model and to make any extensions or adjustments suggested by the data. Given a final model framework and estimates of demand effects (and REs), it may then be possible to estimate energy preferences (in terms of the three underlying objectives) for different household types (especially stratified by income), and to use these to inform energy-efficiency interventions in similar settings.

6.1.3 Validation of systems dynamics model

In this section the data set from the Prince Albert study is used to validate some of the hypotheses generated in the previous section. For each hypothesis the specific insight generated under the systems dynamics framework is stated. The subset of the data sample that was used to test the various hypotheses is then specified together with the equation of the linear model that was fitted to the sample. The significant results are presented for each hypothesis. The following section discusses the implications of the results generated from the modelling. It should be noted that only the complete survey and consumption data set was included for this modelling, and the analyses were therefore confined to households with complete survey data and prepayment meters. Houses with credit meters were not suited to the analysis due to the previously mentioned inconsistencies between the data sets.

Phase 3 of the questionnaires included a number of scale variable questions that were used to construct weights for the various household objectives, and linear models were formulated to specifically test the hypotheses of interest, including only relevant subsets of the total dataset. The scale variables were normalised where necessary. Although the individual models do not explain a large amount of the variation in consumption, the design is useful for testing particular interactions, and avoids the need to build a model with a large set of potentially confounding explanatory variables. There are advantages and disadvantages to this approach that will be discussed in the second section. In the hypothesis testing below, it should be noted that the emphasis is on ascertaining the importance of second order (interaction) effects, so the main effects should not be compared between the models of each hypothesis. The main effects need to be included in the model so that the interactions can be identified.

(i) Hypothesis testing

Variable definitions

In the models described for each of the hypotheses, the following variable definitions are required:

i = respondent index indicating the variable value for the i'th respondent

t = time index indicating the variable value in the t'th month

PC_{it} = price change (as % of original baseline price)

EI_{it} = indicator for efficiency intervention (CFL swop)

$W_{cost,I}$ = importance weight for cost objective

$W_{imp,I}$ = importance weight for impact objective

Sat_{it} = satisfaction with intervention (averaged over 5 satisfaction questions on 1-10 scale) (satisfaction is 0 before the intervention)

u_i = random effect (intercept) for respondent I ($u_i \sim N(0, \sigma_u^2)$

ϵ_{it} = random error term $\epsilon_{it} \sim N(0, \sigma_\epsilon^2)$

Explanation of hypothesis testing in the context of model validation

In each of the hypotheses tested below, the variable of interest is the co-efficient of the interaction variable in the regression equation, e.g. in the first hypothesis below, coefficient β_3 is of interest, and the assertion is being tested that this coefficient is significantly different from 0 (in the direction of the alternate hypothesis, H_1). For the hypothesis below, a validation of the hypothesis would occur if the coefficient is significantly less than 0. If the coefficient is significant, the interaction between the variables of interest exists, and the outcomes of the systems dynamics model are verified. Each of the hypotheses test is laid out below in a consistent format, with the model parameter estimates and interpretation given for each hypothesis.

HYPOTHESIS 1

For price interventions, greater REs are experienced in households placing lower weight on the cost objective (i.e. high-income households).

Sample

Only months July-Oct 2008 were considered in the 'before' period; only months July-Oct 2009 were considered in the 'after' period. Months prior to July 2008 were not considered because the data confounds effect of CFL intervention and price intervention.

Model

$$\ln(C_{it}) = \beta_0 + \beta_1 PC_{it} + \beta_2 w_{cost,i} + \beta_3 PC_{it} w_{cost,i} + u_i + \epsilon_{it}$$

Hypothesis equivalent to: H_1: $\beta_3 < 0$ against H_0: $\beta_3 \geq 0$

Results

Coefficient	*Estimate*	*Standard error*	*z-value*	*p-value*
β_1	0.096	0.156	0.610	0.540
β_2	-0.478	0.767	-0.620	0.533
$\boldsymbol{\beta_3}$	**-1.013**	**0.431**	**-2.350**	**0.0095**
β_0	2.130	0.259	8.210	0.000
σ_u	0.583			
σ_ϵ	0.282			

The data are consistent with the model (reject H_0)

Interpretation

After the price increase the average consumption decreases for all households, however those households that place relatively more importance on cost will reduce their consumption by even more than their counterparts who are less concerned about cost.

HYPOTHESIS 2

Increasing the impact weight at the expense of cost considerations would reduce the impact made by price-based interventions.

Sample

Only months July-Oct 2008 were considered in the 'before' period; only months July-Oct 2009 were considered in 'after' period. Months prior to July 2008 not considered because they confound the effect of CFL intervention and price intervention.

Model

$$\ln(C_{it}) = \beta_0 + \beta_1 PC_{it} + \beta_2 (w_{imp,i} - w_{cost,i}) + \beta_3 PC_{it} (w_{imp,i} - w_{cost,i}) + u_i + \epsilon_{it}$$

Hypothesis equivalent to: H_1: $\beta_3 > 0$ against H_0: $\beta_3 \leq 0$

Results

Coefficient	*Estimate*	*Standard error*	*z-value*	*p-value*
β_1	-0.210	0.042	-4.950	0.000
β_2	0.503	0.459	1.090	0.274
β_3	**0.587**	**0.215**	**2.730**	**0.003**
β_0	1.977	0.060	33.170	0.000
σ_u	0.582			
σ_ϵ	0.282			

The data are consistent with model (reject H_0)

Interpretation
Households who place a lower emphasis on their cost considerations versus their impact considerations will not respond to the increase in price levels. Said another way, those concerned about the impact of their energy consumption relative to the importance they place on cost are already consuming less and will not necessarily alter their consumption after a price increase. Another way of interpreting this is that households who invest less importance in cost will not alter their consumption when prices change

HYPOTHESIS 3
For efficiency interventions, greater REs are experienced in households placing greater weight on the cost objective (i.e. low-income households).

Sample
The full sample was used for this model so that the data spans the efficiency intervention

Model
$$\ln(C_{it}) = \beta_0 + \beta_1 EI_{it} + \beta_2 PC_{it} + \beta_3 w_{cost,i} + \beta_4 EI_{it} w_{cost,i} + u_i + \epsilon_{it}$$
Hypothesis equivalent to: $H_1\colon \beta_4 > 0$ against $H_0\colon \beta_4 \leq 0$

Results

Coefficient	*Estimate*	*Standard error*	*z-value*	*p-value*
β_1	-0.107	0.080	-1.350	0.177
β_2	-0.107	0.038	-2.830	0.005
β_3	-0.667	0.697	-0.960	0.339
β_4	**0.524**	**0.233**	**2.250**	**0.012**
β_0	2.013	0.232	8.690	0.000
σ_u	0.617			
σ_ϵ	0.429			

The data are consistent with the model (reject H_0)

Interpretation
Households who prioritise costs (which in the sample here are cost constrained households) will consume more after an efficiency intervention than those who say they are less concerned about costs. This is evidence of suppressed demand that potentially leads to rebound

HYPOTHESIS 4
Greater REs are experienced if an efficiency intervention involves a technology that does not deliver as satisfying a service as before. If the new technology is more satisfying, negative rebound is possible.

Sample
The full sample was used for this model such that price increases and intervention can be taken into account for the regression.

Model fitted
$$\ln(C_{it}) = \beta_0 + \beta_1 EI_{it} + \beta_2 PC_{it} + \beta_3 sat_{it} + u_i + \epsilon_{it}$$
Hypothesis equivalent to: $H_1\colon \beta_3 < 0$ against $H_0\colon \beta_3 \geq 0$

Results

Coefficient	*Estimate*	*Standard error*	*z-value*	*p-value*
β_1	0.061	0.023	2.690	0.007
β_2	-0.103	0.038	-2.730	0.006
β_3	**-0.021**	**0.017**	**-1.230**	**0.110**
β_0	1.803	0.059	30.750	0.000
σ_u	0.624			
σ_ϵ	0.429			

The data are consistent with the model (reject H_0)

Interpretation
Relative satisfaction with the intervention is associated with lower post-intervention consumption (i.e. smaller potential rebound)

HYPOTHESIS 5
REs occurring as a result of unsatisfactory new technology decrease as more weight is placed on environmental issues.

Sample
Only those people who are relatively unsatisfied with CFLs (overall satisfaction < 6/10)

Model
$$\ln(C_{it}) = \beta_0 + \beta_1 EI_{it} + \beta_2 PC_{it} + \beta_3 w_{imp,i} + \beta_4 EI_{it} w_{imp,i} + u_i + \epsilon_{it}$$
Hypothesis equivalent to: $H_1\colon \beta_4 < 0$ against $H_0\colon \beta_4 \geq 0$

Results

Coefficient	*Estimate*	*Standard error*	*z-value*	*p-value*
β_1	0.372	0.194	1.920	0.055
β_2	0.153	0.110	1.400	0.163
β_3	1.227	1.615	0.760	0.447
β_4	**-1.481**	**0.602**	**-2.460**	**0.007**
β_0	1.409	0.532	2.650	0.008
σ_u	0.788			
σ_ϵ	0.543			

The data are consistent with the model (reject H_0)

Interpretation

Households who were relatively less satisfied with the intervention, but who place more importance on environmental issues, consume relatively less after the intervention than houses with similar satisfaction levels, but who place less importance on environmental/impacts issues

HYPOTHESIS 6

If satisfaction with the new technology is high ($s < p$), larger REs are expected from low-income households. If satisfaction with the new technology is low $(s > p)$, greater effects should be expected from high-income households.

This hypothesis could not be tested as is difficult to compare efficiency saving % [‘p’] and dissatisfaction % [‘s’]

HYPOTHESIS 7

An information campaign will be more effective in reducing energy demand if it:

a. increases the relative importance allocated to an objective of the targeted objective, and

b. targets whichever objective has the lower goal in terms of level of energy demand required to meet the goal

This hypothesis could not be tested as the surveys did not contain responses on the weights and goals, and these are difficult items to assess.

ii) Discussion

It should be noted that the income category (as distinguished by the area in which the household was situated) was weakly correlated with any of the weights (especially cost). The implication is that income grouping by area is not necessarily a good proxy for actual income or there is no relationship between true income and cost weights.

The value of the above models is that they facilitate an exploration of the second order effects in understanding demand/behaviour. Common approaches to energy modelling generally only focus on first order effects, ignoring the fact that many of the first order parameters may not be independent. So the systems dynamics model construct, validated by survey and consumption data allows a greater understanding of the interplay between weights that users attribute to various factors, and their propensity to rebound.

The validation of the majority of all the hypotheses that were tested verifies assertions that were proven in the systems dynamics modelling that may not have been obvious. The success of the approach has both practical and academic merits.

A potential pitfall of the approach is that the model does not include a full set of the available explanatory variables, however it does simplify the analysis and the interpretation. Statistical power is lost when testing multiple hypotheses from the same data set, but using separate tests. More powerful tests could have been conducted with a full model that included all the relevant first and second order effects, and where all the hypotheses could be tested at once. The challenge with that approach would be to interpret the correlations between the various weights, and the fact that different subsets of the sample were derived to form subgroups for each test preclude the possibility of a full model (i.e. the time periods between each hypothesis were inconsistent).

6.2 Statistical analysis of the case study data

This section presents the high-level findings generated by exploring the datasets from the two case studies discussed previously. Firstly, a selection of the findings from the Prince Albert survey data is presented, followed by a discussion of the statistical regressionl outputs generated for two sub-sections of the sample, namely the prepayment meter households and the credit meter households. These were analysed separately due to inconsistencies between the dependent variable (electricity consumption) for the two sub-sets. The second part of this section presents the findings from the Zanemvula study, from an attitudinal change perspective and through statistical regression analysis of consumption.

6.2.1 Prince Albert

6.2.1.1 Results from survey data

A selection of qualitative comparisons of the survey panel data is summarised here. Some of the results have been drawn from Davis (2009), and the remainder from some descriptive comparisons contained in Appendix 8 to this report. These results are peripheral to the main statistical models but provide some interesting insights generated from the surveys. The majority of the results reported below are sourced from an initial comparison of the Phase 1 and Phase 2 responses:

- **Latent demand:** Less than 8% of the sample said they were not satisfied with the amount of lighting in their homes, and this did not change immediately after the roll-out, indicating lower than expected latent demand for lighting.
- **Penetration of CFLs:** The roll-out appeared to achieve a penetration rate of around 75%, and most respondents felt that the initiative was a positive one (from the sample of 245 households). There was no significant difference in the response between high and low income groups.
- **Perceived savings of electricity:** 93% of the sample reported no change (or unsure) in electricity consumption since the roll-out, however the tariff hike that had taken place between the two surveys will have eroded any savings. When asked how much was spent on electricity, an average reduction of R21 (statistically significant) was observed.
- **Illumination Comfort effects:** 11.2% more respondents said yes or don't know when asked if they had lights they left on for long periods of time compared to the baseline, while 26% admitted a shift in their attitude towards leaving unused lights on unnecessarily. Only a slight positive bias was observed for the high income classification with 26% (versus 16% low income) saying after the roll-out that they sometimes leave lights on longer.
- **Awareness:** 51% of respondents claimed to have an increased knowledge of energy matters since the baseline survey (17% no change and 32% unsure). 25% of respondents reported an increases awareness of how to save energy with 27% saying no change and 48% saying they weren't sure. The main source of learning was the CFL flyer (59%), television (36%) and other (6%).
- **Attitude to energy saving:** 17% of respondents claimed that they are not concerned, 7% say someone else is accountable, 34% wish to save as much as possible and 42% use what they need.
- **Future behaviour:** Roughly equal proportions of respondents said that when their CFLs failed they would revert to incandescents, purchase new CFLs, and use a mix of the two. The split appeared to be independent of income group classification.

6.2.1.2 Regression analysis of consumption

This section explores the degree to which electricity consumption is explained by the items captured in the survey, as well as the intervention and price increases that happened over the study period.

The inconsistency between the time periods for which the prepaid and credit meter data were available meant that the two sets could not be combined and were therefore analysed separately. The credit meter data was based on monthly readings from the households since July 2005. The actual meter readings were used for consumption, but the price data excluded the connection fee implicit in the prepayment data, making the purchase and price information incompatible with the prepayment purchase data. Although the survey data was consistent between the two types of households (metered and prepaid), the consumption data was not, so for the linear modelling exercises separate analyses had to be conducted. The model outputs for each of the analyses are presented below.

Prepaid meter results

The intention of the model is to explain shifts in electricity consumption since the efficient lighting intervention and determine which variables are useful in explaining household consumption. The final linear model fitted to the full data set of household with prepaid meters shown in the table below. The model was tested using different versions of the model whereby estimated daily consumption figures above 15 kWh, 25 kWh and 50 kWh per day were deemed outliers and were excluded from the analysis. These outlying estimates don't fit the profile of a typical residential household, and were thought to be influential in the model if included. The large values could have arisen in the estimation procedure used to calculate daily consumption, particularly if a household had made large purchases on successive days, inflating the average consumption figures. In the case of the Prince Albert consumption model, the analysis proved to be robust to the inclusion or exclusion of these values. The model with the 25 kWh outlier threshold is described below.

The Final Model includes the following significant variables:

- afterinv: indicator variable for period following intervention (this is a variable that tells the model whether the consumption is being observed before or after the CFL roll-out)
- AprJun, JulSep, OctDec: quarterly indicators (relative to baseline quarter JanMar) (this variable tells the model in which quarter of the year the consumption figures are being observed relative to the first quarter)
- all_1: number of people in house
- statdcons: claimed electricity consumption (this is stated spend [all_2] divided by average unit cost) (square root transformed to suck in right tail)
- mall_3a: average wood usage (square root transformed to suck in right tail)
- all_6: Indicator for yes response to 'Energy efficient home makes a difference' – not significant anymore, with price change in model
- all_8v2: Indicator = 0 if willing to swap incandescent for CFL at higher price, otherwise = 1
- strtprice: unit price of electricity at beginning of period (a kind of tariff category)
- chprice2: % change in unit price in electricity, relative to the unit price in the first (pre-increase) time period (unit price in first period is calculated as an average over period 11/2007 – 6/2008)
- int2: interaction between indicator of post-intervention and claimed electricity consumption (afterinv * statdcons)
- int3: interaction between indicator of post-intervention and wood usage (afterinv * mall_3a)
- int7: interaction between indicator of post-intervention and indicator of (un)willingness to swap incandescents for CFLs at higher prices (afterinv * all_8v2).

Table 15: Prepaid households – significant coefficients for the household electricity consumption model with a CFL intervention

lnconsmp	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
afterinv	0.149	0.084	1.77	0.077	-0.016	0.314
AprJun	0.095	0.025	3.85	0.000	0.047	0.144
JulSep	0.087	0.026	3.28	0.001	0.035	0.138
OctDec	-0.057	0.023	-2.42	0.016	-0.103	-0.011
all_1	0.038	0.009	4.41	0.000	0.021	0.055
statdcons	0.025	0.004	6.63	0.000	0.018	0.032
mall_3a	-0.024	0.005	-5.19	0.000	-0.032	-0.015
all_8v2	-0.118	0.043	-2.72	0.007	-0.203	-0.033
strtprice	2.949	0.348	8.48	0.000	2.267	3.630
chprice2	-0.068	0.037	-1.85	0.064	-0.141	0.004
int2	-0.021	0.004	-5.04	0.000	-0.029	-0.013
int3	0.022	0.006	3.63	0.000	0.010	0.034
int7	0.181	0.052	3.49	0.000	0.079	0.283
_cons	-0.073	0.191	-0.38	0.703	-0.448	0.302

Discussion

The impact of the intervention came up as moderately significant (p=0.077) and with the opposite sign to what would be expected, however the coefficient value can not be interpreted directly because of the presence of significant interaction effects.

The quarter of the year is significant with the April/June and July/September quarters having significantly higher consumption relative to the January/March base quarter. The coefficients were fairly equivalent at 0.095 and 0.087 respectively. A lower consumption than the base quarter is observed on October/December (-0.057). These seasonal effects are as expected.

Electricity consumption is also positively related to household size.

There is a significant interaction between stated electricity consumption and the presence of the intervention to the extent that the *actual* consumption gap between those who claim to use lots and those who claim to use little narrows after the intervention. The implication of this is that since the intervention (or possibly due to survey-induced awareness) users have a more accurate awareness of their actual usage patterns. Int2 is significant indicating that for the sample of households, the correlation between stated electricity consumption and actual electricity consumption is stronger before the intervention than the same relationship before the intervention (Figure 15).

A significant interaction (Int3) exists between the intervention and the usage of firewood (Figure 16). In particular, after the intervention, those who use wood increase their electricity consumption relative to those who don't. This is potentially evidence of rebound or suppressed demand for those whose access to electricity is limited by income (generally wood-users in Prince Albert are from poorer communities, who rely on wood as an alternative fuel for cooking and space-heating when money is scarce). Gains in efficiency as a result of the intervention may have resulted in increased consumption of electricity for those who spend more on wood. Efficiency can lead to a substitution away from alternative fuels towards the energy carrier where the efficiency gains have been made, particularly among poorer households.

Another significant interaction (Int7) that emerged from the model was between the presence of the intervention and the 'CFL-aversity' of the user (Figure 17). Those who were unwilling to pay a premium for CFLs tended to increase their consumption after the roll-out of free CFLs relative to those who were willing to pay a premium for the CFLs.

The implication of this is that the likelihood of rebound is impacted by the willingness of the consumer to take the initiative in energy efficient behavioural change. The result confirms the hypothesis that those willing to engage in energy efficient behaviour will have a smaller propensity to increase their consumption after an intervention.

The variable 'strtprice' is analogous to a tariff category (the model does not recognise specific tariff categories but calculates the effective unit price of electricity paid by households at the start of the study). Increases in price are relative to an individual household's effective starting price. In reality tariff increases result in different effective increases depending on the characteristics of the household, such as access to free basic electricity and tariff category. Prepayment tariff categories are determined with reference to historical consumption. The model simplifies the analysis by simplifying the consumption data. This approach avoids the need to take into account several complex tariff categories and historical changes in categories for individual households. As expected, the starting price is positively and significantly related to consumption.

As expected, electricity consumption is negatively related to price increases. The parameter 'chprice2' gives an indication of the elasticity of demand with respect to price. For the sample used here, the price elasticity of demand is moderately significant ($p=0.064$) with a value of -0.068. So for every percentage increase in price a decrease in consumption of 0.068% is expected, representing a highly inelastic demand for electricity with respect to price.

Typically (as is the case for many models of energy consumption) there is a large amount of intra-household variation in consumption (represented by the large rho value (0.557) and a relatively low explanatory power of the model (overall R-squared = 0.3454).

The graphs illustrating the significant interactions are shown below.

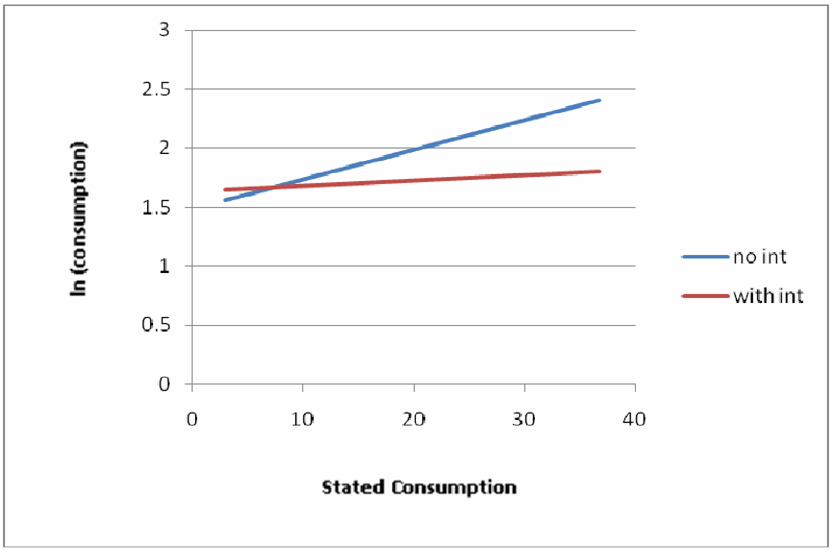

Figure 15: Interaction between users' stated electricity consumption and the presence of the CFL intervention (int2)

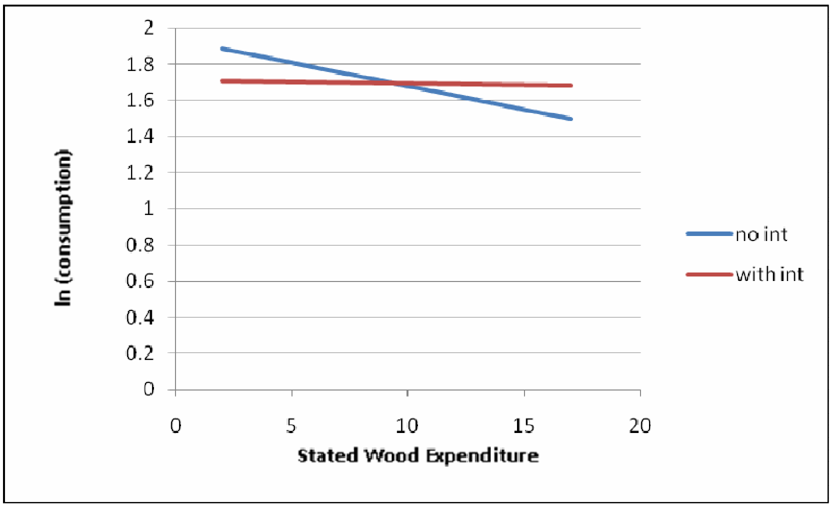

Figure 16: Interaction between stated wood fuel purchases and presence of the CFL intervention (int3)

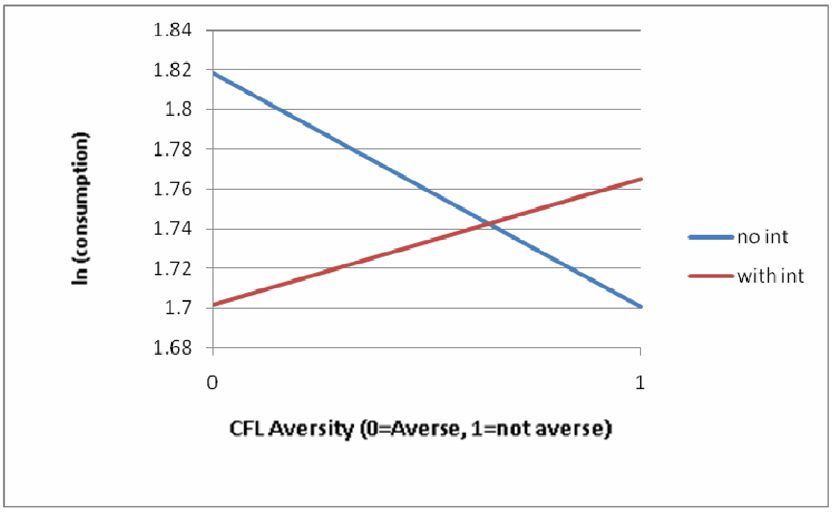

Figure 17. Interaction between consumption behaviour and CFL-aversity (int7)

Credit meter results

The final linear model fitted to the surveyed households with credit meters is shown in Table 16 below. The intention of the model is to explain shifts in electricity consumption since the efficient lighting intervention and determine which variables are useful in explaining household consumption. The model was tested using a number of different time spans, to see how robust the regression was to the inclusion of more or less prepayment history. The final model utilised the full set of data for 4 years starting in July 2005, spanning the intervention period and ending in June 2009, and consumption figures were coded in accordance with the survey phases.

The Final Model includes the following significant variables:

- afterinv: indicator variable for period following intervention (this is a variable that tells the model whether the consumption is being observed before or after the CFL roll-out)
- mall_1: number of people in house (centered around mean HH size of 3.42)
- IfFree: Indicator = 1 if willing to swap incandescent for CFL but only for free, otherwise = 0

- all_9: number of light bulbs (?)
- all_inc: household income
- int1: interaction between indicator of post-intervention and number of people in household (afterinv * mall_1)
- int7: interaction between indicator of post-intervention and indicator of willingness to swap incandescents for CFLs but only for free (afterinv * IfFree)

Table 16: Credit meters – significant coefficients for the household electricity consumption model with a CFL intervention

lnconsmp	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
afterinv	0.088	0.067	1.33	0.185	-0.042	0.219
mall_1	0.058	0.037	1.58	0.114	-0.014	0.131
IfFree	0.264	0.093	2.84	0.004	0.082	0.445
all_9	0.012	0.007	1.68	0.092	-0.002	0.025
all_inc	0.000	0.000	2.46	0.014	0.000	0.000
int1	-0.040	0.023	-1.76	0.079	-0.085	0.005
int7	-0.222	0.128	-1.74	0.082	-0.473	0.028
_cons	2.530	0.157	16.08	-	2.221	2.838

Discussion

Some of the observations from the model are that electricity consumption is positively related to number of light bulbs in household, and electricity consumption is positively related to income (income figures are not usually very reliable, but seem more to be more reliable for these households who are generally wealthier than those in the prepayment set). As for the majority of the regression models attempting to explain variation in prepayment household consumption, there is a large amount of variation in consumption within households (high *rho*), and the models have a fairly low explanatory power (low R-squared). Although the overall explanatory power is low, the regression techniques can still be used to elicit the size and direction of relationships between consumption and the variables of interest (for individual variables and for 2-way interactions between them).

The positive coefficient for mall_1 indicates that electricity consumption is positively related to household size. The negative coefficient for int1 indicates that the interventions led to relatively larger reductions (or smaller increases) in electricity consumption for larger households than for smaller households (i.e. the intervention had a more visible effect in large households than in small ones)

The positive coefficient for IfFree indicates that electricity consumption is higher in households who said that they would swap CFLs, but only if free. The negative coefficient for int7 indicates that this effect is only present before the intervention – after the intervention people who will only swap CFLs for free consume roughly the same as others. Note that this interpretation is different to that for pre-paid households.

One version of the model was built using a subset of the data commencing from July 2007 (1 year prior to the intervention), and the significant coefficients were the indictor of willingness to take on CFLs at a lower price than incandescents and the interaction between the presence of the intervention and willingness.

6.2.2 Zanemvula

The data collected in Zanemvula is used to explore the impact of a SWH roll-out in the low income sector. The data collected was described in Sections 3.4.2 and 4.2. Firstly the results of the key attitudinal and behavioural responses from the survey data are compared pre and post intervention. Secondly a regression analysis of the combined survey and electricity consumption data is presented and discussed.

Comparison of pre and post responses

T-tests were conducted on the responses to questions asked in both the pre and post surveys to see if there were any significant changes in the responses. A selection of the findings is as follows:

1. The demographics of the sample remained fairly consistent between the surveys as indicated by the absence of significant differences in numbers of people per household and the number of members earning an income. The consistency in demographics allows for meaningful conclusions to be drawn with regard to the responses to questions around energy consumption, behaviour and awareness. The difference in reported electricity expenditure was not significant despite there having been a price increase. There are several plausible explanations for this:
    - The effective price increase for this user group may have been smaller than for other tariff categories.
    - Households cannot afford the increases so simply reduce their needs for electricity (elasticity in demand present)
    - The price increase was absorbed by the presence of the SWHs which take up some of the households' energy budget
2. There was no appreciable change in the proportion of respondents who understood the terms 'renewable energy', 'sustainable energy' and 'energy efficient'.
3. The number of times the households heat water was significantly reduced from 3.1 to 2.5 ($p=0.00005$) which can be attributed to the presence of the SWH.
4. There was a significant increase in the proportion of households using hot water to wash clothing from 3% to 26% ($p=0.00000$)
5. The increase in the proportion of households using hot water to wash dishes was from 88% to 93% however this increase was not statistically significant (the proportion was already high indicating a prior utilisation of hot water for washing dishes, and limited potential for impact of the intervention).
6. The proportion of households using of hot water for bathing was unchanged at 96%, in spite of the respondents indicating that the personal hygiene habits of the household members had improved.
7. The average number of appliances per household had increased from 5.1 to 6.0 ($p=0.00008$) indicating the presence of indirect rebound, however it is not clear from the sample data if the link between the intervention and appliance ownership is causal as many of the households are newly electrified. The presence of SWHs may have led to budgetary slack that could have resulted in increased ownership of appliances.
8. The question of hot water usage for cooking was characterised by a significant reduction from 71% to 43% of households who said yes ($p=0.00000$). In the follow up survey some of the respondents may have interpreted this question as inquiring into whether solar heated water was used for cooking or not, to which many respondents answered no in a separate question in the survey. However, half of the surveyed households used solar heated water for speeding up cooking, but only 45 households used the pre-heated water for hot beverages due to the unfavourable smell, taste and colour of the water. The health impacts of consuming water that is heated and stored in plastic or fibreglass cylinders are uncertain.
9. Other stated behavioural changes such as switching off of unused lights, opinions about the impact of EE and attitudes to energy saving showed no demonstrable change. Attendance at the workshop made no significant impact on the responses to any of these questions, even

though the majority of attendees experienced it as useful of informative (61%). Only 26% of the households surveyed pre and post had attended the workshop. Although theoretical knowledge has not changed, the majority of households appear to be trying to save energy where possible. A separate Zanemvula report [Wlokas, 2009] also showed a reversion to incandescent light bulbs over the period of the survey, indicating the capital cost barrier to repurchasing CFLs when they fail.

Regression analysis of consumption

The final linear model fitted to the data set is shown in Table 17 below. The data included the control group who had not received solar water heaters by the time of the follow-up so that the impact of the intervention could be separated from the other explanatory variables. The intention of the model is to explain shifts in electricity consumption since the SWH intervention and determine which variables are useful in explaining household consumption. Households with daily consumption figures above 15 units per day were deemed outliers and were excluded from the analysis. These outlying households don't fit the profile of a typical residential household, and would be influential in the model if included. The large values could also have arisen in the estimation procedure used to calculate daily consumption, particularly of a household had made large purchases on successive days, inflating the average consumption figures.

The variables of interest are:

- sht_inst: indicator variable for presence of solar water heater
- month5, month6, month7: indicators for months of May, June, July
- bas_hhs_st: household size. This variable has been mean centered (expressed as units above or below the mean household size of 3.314)
- bas_19_104: indicator that person answered 'Other people should save more energy!' to the question on 'Attitude to energy'
- bas_28: indicator variable for the use of hot water for tea/coffee
- bas_34: number of electrical appliances owned
- int5: interaction between presence of solar heater and household size

Table 17: Statistically significant coefficients for the household electricity consumption modelling the impact of the solar water heater intervention

lnconsmp	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
sht_inst	0.057	0.043	1.34	0.180	-0.026	0.140
month5	0.092	0.027	3.37	0.001	0.039	0.146
month6	0.124	0.026	4.76	-	0.073	0.176
month7	0.090	0.026	3.47	0.001	0.039	0.141
bas_hhs_st	0.062	0.014	4.32	-	0.034	0.090
bas_19_104	-0.116	0.055	-2.12	0.034	-0.224	-0.009
bas_28	-0.272	0.076	-3.58	-	-0.421	-0.123
bas_34	0.027	0.008	3.32	0.001	0.011	0.043
int5	-0.047	0.028	-1.67	0.094	-0.101	0.008
_cons	1.626	0.080	20.32	-	1.469	1.783

A number of interpretations follow from the above outputs:

- There is a significant negative interaction between solar heater installation and household size, indicating that a reduction in electricity consumption following the SWH installation is only present for larger households (>3 members). For 'average' sized households (average for this sample is approximately 3) the effect of the SWH on electricity consumption is negligible, and smaller households (<3 members) may actually increase consumption, indicating the possible presence of a backfire effect. The magnitude of RE is inconclusive from the type of analysis that is being conducted, however the data does suggest that rebound is present because pure substitution of electrical heating of water with solar heated water should lead to a commensurate reduction in electricity consumption, and the data indicates no such reduction. The reduction as a first order effect is not significant implying that the addition of solar heated energy meets a suppressed demand for water heating, and does not substitute consumption of electricity.
- Electricity consumption is significantly higher in the winter months (May, June, July).
- Electricity consumption is higher in larger households.
- Those households claiming that 'Other people should save more energy' used significantly less electricity than those who gave other responses (the other responses were: 'I use as much energy as I need', 'It doesn't concern me', 'I feel I should save as much as possible')
- Those who heat water for use in tea/coffee used significantly less electricity than those who don't. As mentioned in the previous section this question may have been confused by the respondents as applying to solar heated water, rather than hot water in general. The result most likely indicates that those who are willing to put up with the unpleasant tastes or smells (and unknown health impacts) of consuming solar heated water do in fact save electricity by doing so.
- Electricity consumption increases as the number of electrical appliances owned by the household increases.
- There is a substantial amount of variation in consumption within households; this is a fairly typical outcome in energy consumption data (high *rho* value).
- The impact of the price increase in July 2009 may be present, however it is difficult to separate from the seasonal monthly effect. It could be argued from this result that the price increase could dampen the seasonal effect of winter months (especially August)

6.3 LEAP modelling

The figure below shows the residential electricity consumption projections of the scenarios described in section 5.3. Table 18 shows the energy savings from the different interventions.

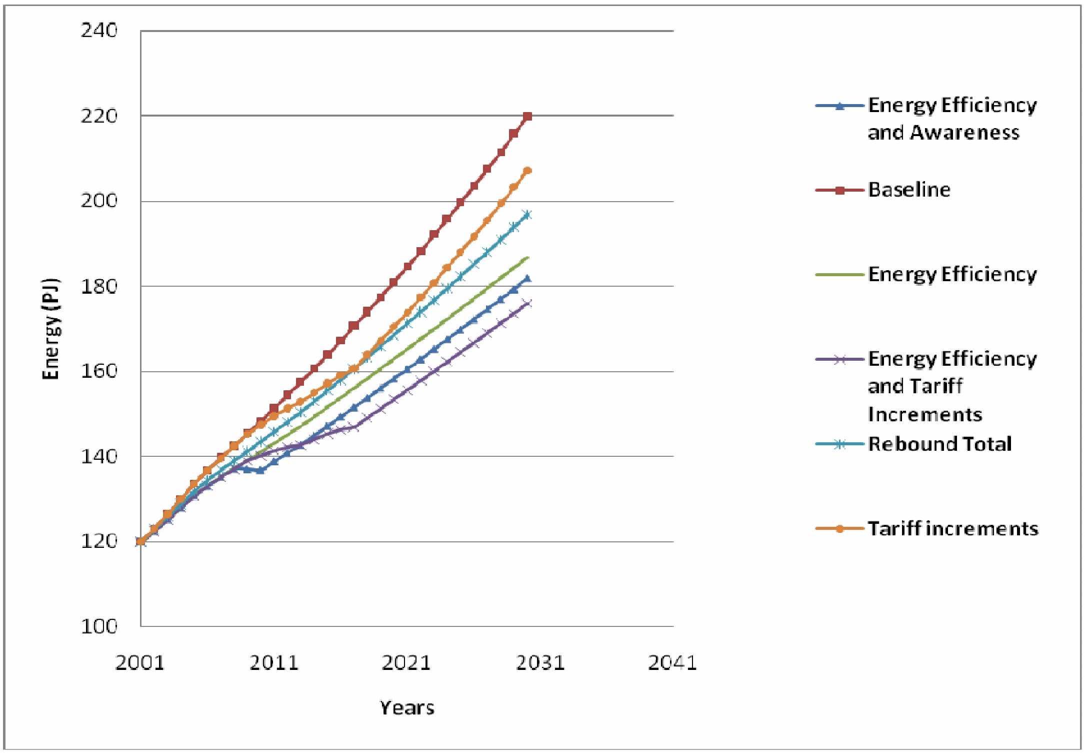

Figure 18: Projected energy efficiency scenarios for the South African residential sector.

Table 18: Illustrative energy savings from a range of interventions

Scenario	*Cumulative energy savings (2010 to 2030) (PJ)*	*End year energy savings (PJ)*	*End year energy savings (%)*
Tariff hikes	189.1	12.7	5.78
Energy efficiency	397.6	33.2	15.0978
Energy efficiency with rebound	274.6	23.1	10.5048
Energy efficiency and raised awareness	495.2	38.1	17.3261
Energy efficiency and tariff hikes	566.5	44	20.01

From the results it appears that tariff increments alone would not make a significant impact on energy demand with the assumed elasticities. If the suggested efficiency initiatives are implemented and all technological savings are achieved, a saving of approximately 15% from the projected baseline can be anticipated which is above the 10% targeted by the DME in the 2005 Energy Efficiency Strategy. However, if rebound is included the savings are just above 10% (although targets in the EE strategy are for the year 2015). The suggested energy efficiency targets are achievable but still quite optimistic as they are based on the highest penetration rates in the world (mainly in first world countries like Germany). This means that if the impacts of rebound are disregarded and such optimistic penetration rates are not achieved then the 10% electricity reduction in the residential sector might not be achieved.

Therefore using raised awareness on not just energy efficiency but also on the crisis situation of South Africa's electricity situation and raising the cost of electricity will help promote energy efficiency and also mitigate the rebound effect. Furthermore additional savings due to behavioural changes can be expected. The recommendations concur with findings elsewhere in this report which indicate that awareness campaigns be carried out concurrently with efficiency initiatives and also any cost savings from efficiency gains be taxed or priced by the Regulator in order to avoid rebound effects.

6.4 Synthesis of the analysis

In this Chapter, a range of analyses have been presented and discussed. We summarise and synthesise the various results in this section.

Firstly, the generic model of an individual household's consumption has been parameterised and simulated in a systems dynamics framework. The outputs of the simulations are encouraging in that they are outcomes that would be expected intuitively. The approach has allowed the creation of a rigorously defined model describing consumption behaviour. The value of the model lies in its ability to illustrate the combinations of various intervention strategies (price, efficiency and information) on household energy consumption (for households that differ by levels of income and environmental impact concerns). The response of households when the new technology fails to deliver a satisfying service can also be modelled in the framework. The approach offers a tool for testing how interventions carried out in combination with one another (2 or 3 together) can be super-additive or sub-additive, and estimates of the relative individual and combined impacts of each intervention can be quantified. The benefit of simulation modelling is obvious given that such testing would be difficult to conduct in reality because of the dynamic nature of energy consumption, and problem of heterogeneous samples. Additivity of combinations of interventions can be used to inform strategies for maximising EE. Furthermore, the model can used to formulate strategies that target specific household types which can be specified using weight preference parameters for comfort, cost and environmental impact.

After developing the systems dynamics model informed by qualitative research, and iterative simulation testing, the hypotheses generated by the model were tested against the Prince Albert case study data. This data contained sufficient information to test hypotheses relating to efficiency interventions, price increases, satisfaction with new technology, and preferences of the different households. The testing of the systems dynamics hypotheses was done by means of regression analysis on the combined consumption and survey data set. Six out of the seven hypotheses generated by the systems dynamics were found to be validated by the data. The seventh hypothesis could not be tested due to survey data limitations (these limitations could have been avoided with hindsight).

The second part of this chapter (section 6.2) analysed the case study data on CFL interventions and SWH interventions in Prince Albert and Zanemvula respectively. Qualitative analyses of the survey data revealed some interesting insights about the impacts of these interventions on attitudes and stated behaviour of households for each of the sites. Quantitative analyses involving the fitting of regression models to the combined survey/consumption data were also carried out and these revealed the relative importance of a range of factors that explain electricity consumption behaviour in the houses surveyed, including price elasticities. The regression models were used to test the interactive effects of household characteristics and the interventions on consumption behaviour.

The final part of the chapter summarised the main findings of the LEAP modelling exercise. The projections were conducted relatively independently of the work in the first two sections of the chapter, however the work illustrates the kind of exploration that can be achieved using a simple projection tool, and development of scenarios. The project's time limitations meant that it was not possible to complete the analyses in the first two sections prior to the LEAP model. Therefore the residential sector projections of South African electricity demand could not fully incorporate the combined learning from the systems dynamics model and the statistical analysis of case study data. However, the projection model does succeed in estimating the likely impacts of REs and behavioural response and demonstrates how interventions can be taken into account in the model by modifying the elasticity of demand.

7. Conclusions and recommendations

This chapter concludes the report by summarising what has been achieved over the course of the study. It then makes some recommendations for energy policy and planning based on the outcomes of the research, and discusses where the value in future work in this area resides.

7.1 What has been achieved

This research has explored an approach to researching the issues surrounding in the roll-out of EE interventions in the residential sector. The main aims laid out at the beginning of the study were to identify the many factors impacting residential energy consumers' behavioural response to technology interventions and to identify numerical ranges for the estimates of these impacts. Simultaneously the study was to endeavour to find ways of mitigating what was thought to be an adverse response to EE by consumers.

The data that has been generated throughout the course of the study can be analysed in many different ways. The research has produced a systems dynamics simulation model of household energy consumption behaviour with feedback, and compiled two extensive data sets from which a number of explanatory models of energy consumption and associated insights have been generated. The model and the data remain available for further exploration of household energy demand.

In summary, the research has revealed that some of the factors impacting residential energy consumers' preferences – and thus their behavioural response to technology interventions – include:

- The derived benefit of energy (usefulness) for the consumer.
- Awareness and attitudes of consumers towards energy consumption, and the associated feedback on their own consumption.
- The economic context (at the level of country and individual household) in which interventions take place. This context includes household income and prices of electricity and electricity conversion technologies).
- The energy consumer's experience of the new technologies.

Strategies that can be used to influence the behavioural response to an energy technology intervention are the price of running the appliance (electricity tariff) and information feedback (awareness) which in turn affect the preferences and behaviour of consumers, in a feedback loop that can be neatly portrayed using systems dynamics.

The findings in this study are in agreement with Smil (2003) who writes that 'failures or limitations of efficiency gains predicated on changes of our behaviour spring from our preferences and feelings'. It is clear from this study and others that availability of technical fixes that would not require behaviour change does not guarantee their take-up, even when they are guaranteed to save money. The reasons for this are that consumers are not perfectly informed, and even where they are informed, they do not necessarily make perfectly rational choices based on minimised cost or environmental impacts. Even voluntary take-up (which has not been the case for the interventions in this study) depends on the readiness of consumers to adopt more efficient technologies (especially if life-cycle costs were included as the overriding goal).

Consequently, even when awareness of EE is promoted, and there are regulations, appliance labelling, subsidies, etc, the uncertainties around EE potential are large, and the ability of DSM programme managers to verify the intended savings is limited, as much of the impact is irreconcilable due to the huge uncertainties in the dynamic of energy demand and consumption. Durability of technology is as important as durability of attitudes and behaviour. Smil states further that in a paradigm of ostentatious consumption, there is a palpable absence of concerns about the environmental impact of high energy consumption. The absence of concerns leads to a gap between intended harnessing of potential gains and the actual gains achieved when implementing and investing in efficient energy use practices. Perhaps beyond technology and awareness there is a huge potential for exploring the fundamental barriers to changing behaviour that are embedded in our value systems. The opportunities for transforming consumption behaviour are abundant and obvious, yet the take-up remains miniscule, even at the lower end of the cost-benefit scale for interventions.

Some of the specific contributions of the research include: the collation of two unique and extensive data sets, a detailed methodological record of novel approaches to energy demand and consumption modelling, and the recording of a number of valuable insights which have emerged in the process. Each of the three contributions is summarised below.

7.1.1 Data collected

In Prince Albert, a three-phase survey panel of more than 200 households with historical consumption data, spanning a CFL rollout with distinct income groups, has been collected. In Zanemvula a two-phase survey panel with consumption data, spanning a SWH rollout in the low income sector, was collected. The information collected here has an important application in the national political economy where energy reserves are low, and social upliftment is a priority.

In addition to the quantitative data, a wealth of qualitative data, from the literature and from the study scoping and data collection activities has been recorded. This combined data presents significant opportunities for further analysis than could be conducted in the time allocated for this research. The data sets could be made available for further research and analysis. Examples include a detailed energy context study for both sites and detailed analysis of the panel of survey data.

7.1.2 Methodological successes and contribution to energy modelling and research methods

A significant contribution of this study is the development of a novel methodology for data gathering and modelling, based on both quantitative and qualitative information. The methodology ultimately consisted of a five-pronged approach from which the learning is synthesised in a non-linear and organic fashion. The five overlapping prongs are:

1. scoping, stakeholder interaction and literature review;
2. data collection and analysis;
3. systems thinking and simulation design;
4. validation of systems thinking using data; and
5. quantification using energy modelling software.

A detailed record of the methodology used has been made to enable a critical evaluation of the techniques that have been applied to the research, the value of alternative approaches has been proven, and an overview of the outcomes was given in Section 6.4.

Various successes and failures of this approach are identified and are discussed in detail below. The successes are clear from what has been documented in the report. A notable disadvantage is that the data collection can be laborious and time-consuming, and the existing data sources are not amenable to energy analysis (probably a throw-back to an era of abundant cheap supply of electricity).

Simulation models were used to estimate the impacts of multiple interventions on households with different preferences. To accomplish a real-life study of this sort would have been extremely challenging, so the benefits of a simulation approach have been illustrated, as a tool for learning, and as a tool for generating testable results.

Strengths and limitations of the approach

The final methodology employed for this study has challenged conventional wisdom for quantification of energy demand response. The approach that was originally proposed in the terms of reference for the project was found to be simplistic in light of the challenging nature of the research question. The original stated approach was ignorant of the many complexities that have been teased out during the course of the project. Conventional wisdom would seek to measure in energy units the level to which consumption would 'bounce back' once technical efficiency has been 'achieved'. The term 'achieved' is used quite broadly, since earlier inefficient technologies and the newer technologies tend to co-exist unless stringent regulation has been put in place. In particular, new ways of integrating of socio-behavioural and techno-engineering methods have been employed.

Ultimately a micro-level, in-depth, interactive and monitored study invoking qualitative and quantitative methods was chosen for the case-studies. In so doing the behavioural response to EE was examined, and the factors that affect this response were determined. Examples of such factors include demographic characteristics, the type of the intervention, and the nature of implementation (including active factors such as education and training). Obviously the cost of consuming a particular energy service will also play a role (including or excluding capital outlay).

The benefits of the micro-level case studies are twofold:

- A wealth of data was collected in two isolated study sites from which those variables that had the largest explanatory power can be ascertained (through statistical analysis).
- Analysis can be undertaken on how the importance of the variables might differ between study sites, and also the likely differences in the sensitivities.

The strength of the site-specific study approach is that one can test new research methodologies and get a sense of the important factors that impact household response with regional and geographic variables held constant. An improved understanding of behavioural response can contribute to a better understanding of the likelihood of rebound and potential of mitigating actions. The other advantage of using specific study sites is the fact that an area can be isolated, and surveys carried out with relative ease and in a cohesive manner. Also, billing data can be obtained from individual municipalities, which would be a challenging task in the case of a national study. Combining the survey data with electricity consumption data added a dimension to understanding the impact of differences between perceived (reported) consumption, and actual consumption as obtained from sales data (converted to consumption data).

The weakness of the site-specific study is that it precludes some of the possibilities of drawing conclusions at a national level about behavioural response. For that, a much larger and geographically diverse study would have to have been carried out, and the complexities of data collection, survey management and heterogeneity of the sample would be overwhelmingly large.

The limitations of the LEAP forecasting results are that:

- The modelling done is illustrative and not descriptive.
- Rebound figures were based on studies done in developed countries. Rebound is generally expected to be higher in developing countries therefore caution should be taken regarding the estimated rebound losses in these scenarios.
- The forecasts of energy demand depend on the assumptions used for the baseline study. There is a general lack of household end-use data which to accurately portray the sector. Therefore it is recommended that an updated baseline scenario be made out of the 2011 census data. Data on the current progress of energy efficiency initiatives is not readily accessible to the public. Therefore an accurate portrayal of the current situation of the energy efficiency situation in South Africa was challenging to achieve.

- Although the DME has set its energy efficiency targets for the year 2015, it is not clear how they aim to achieve this exactly since specific targets for different technologies are not stated. The penetration rates of energy technologies used in the forecasting appear to be optimistic compared to the current rates of procurement.

Summary

In summary, the research amounted to a methodologically challenging study which leads to the answering of many important questions around (bottom-up) energy demand analysis and household energy consumption behaviour. It is clear from the initial attempts to quantify REs that heterogeneous sample groups are difficult to create with regard to consumer behaviour and measuring the impacts of technology and awareness. A wide range of factors influence consumption and the factors interact with each other and with the dynamic and constantly shifting characteristics of households. This study has made progress in mastering the complexity and uncertainties surrounding energy consumer behaviour. Pure behavioural response to EE can't be measured in the conventional sense without many assumptions and conditions in place.

7.1.3 Insights generated

In building a methodology that aimed to study REs, it became clear that the challenge was more to do with the dynamics of EE response within the general theme of consumption analysis. It became clear that second order effects of technology, price and information are significant although typically ignored in previous micro-level studies. Super- and sub-additivity of intervention strategies in combination can be usefully tested in a simulation environment using a combination of feedback simulation in the form of systems dynamics and energy consumption forecasts. The nature and direction of the additivity is revealed through systems modelling approaches that mimic the behaviour of decision-makers.

Energy data alone falls short in providing an understanding of the impacts of interventions on household consumption, and systems dynamics models can make a contribution to this type of understanding. Models can test outcomes in theory that could not easily be tested in reality due to the impracticality of creating homogenous sub-samples and controlled experiments relating to energy consumption.

7.2 Recommendations

On the basis of the findings, the following recommendations are made. These are presented in terms of:

- methodological approaches to collection and analysis of data;
- achieving energy savings potential, mitigation of rebound and effective intervention strategies;
- regarding end users and DSM managers;
- energy planning in a dynamic society.

7.2.1 Methodological approaches to analysis and collection of energy data

It has been demonstrated in this report that the study of energy demand and consumption requires a holistic approach. The study of energy consumption behaviour, particularly in the residential sector, is a multidisciplinary science that can be radically enhanced by drawing on engineering, psychology, economics, sociology and anthropology. Therefore both the approach to research and the type of data that is collected ought to reflect the holism and multidisciplinarity. The analysis of energy consumption behaviour, particularly at the level of the individual, is arguably as important, if not more crucial than the question of how to best meet those energy needs. Moreover, any future research in this area needs to target the interface between supply and demand.

In South Africa particularly, there is a need to challenge the current paradigm within which energy data is collected, and where possible make use of existing systems for gathering the required information. Relative to developing countries, the country is in a good position to make this shift. An example illustrating this point is demonstrated in the Prince Albert case study, where extensive effort had to be invested in converting a useful and valuable data resource into a format that can be used for energy modelling and statistical analysis. This example is indicative of the kind of challenges facing energy analysts. The effort was required because of the fact that inherently the systems designed for recording energy usage are accounting systems designed to record total historical consumption, reflecting the historical and presently entrenched paradigm of supply-centric approaches to energy planning. Such data should capture the intricacies of changing patterns by users, and the impacts of important variables such as time (seasonality), location (geography) and price. Indeed this is linked to the type of feedback that consumers receive, which is even less than that collected by municipalities for managing their accounts, and contributes to the lack of engagement by consumers with their energy consumption behaviour, and ultimately contributing to phenomena such as the RE and failure of the best intentions of technologists.

The collection of energy data does not necessarily require new resources or surveys, but rather that the sources which already exist (such as censuses and municipal prepayment systems) be adapted to be more amenable for use by energy analysts. A shift is required such that data relating to energy usage, behaviour and consumption, as well as the systems used to collect such data, will meet the requirements of research in the realm of energy demand analysis. This will have direct and indirect positive repercussions through supporting participants in the supply, delivery and consumption of that energy with their decision making around energy.

7.2.2 Achieving energy savings potential, mitigation of rebound and effective intervention strategies

Some of the recommendations contained in this section are drawn from the literature, and others from the analytical methods used in the study. In summary, an integrated approach that makes use of pricing (for example through carefully structured escalating block tariffs), user feedback, combined resource saving (e.g. energy and water simultaneously), technology development and roll-out, and educational programmes will help EE initiatives to fulfil their potential to contribute to resource sustainability and climate change mitigation objectives. In the headings that follow the technology options can refer either to information feedback or devices that improve technical efficiency. In either instance, the technology should be designed with the user preferences in mind, and much of the effort should be invested in successful procurement of the technology in the roll-out to end-users.

Price, awareness and information feedback

A ‘user-pays’ strategy will assist with the linking of price to cost (e.g. through time of use tariffs and avoidance of free-ridership). In conjunction with a ‘user-pays’ pricing strategy, incentives that target the competitive aspirations of individuals (especially children), reporting on peer behaviour and shorter pay-back periods, will together contribute to meeting the objectives.

Prepayment meters in their current form have a limited effectiveness as feedback tools. As demonstrated by the case studies analysed in this report and by the experiences of previous researchers, these meters do not lead to significant reductions in consumption or more efficient energy behaviour practices. Part of the failure can be attributed to insufficient incentives through pricing to adopt efficient behaviour.

Perceptions can also be influential. It is necessary to be aware of the channels of information flows (say in social networks), and that perceptions can be altered through the means of disbursement of awareness and the content. For example, Amory Lovins coined the notion of a ‘Negawatt’, resulting in a more positive slant on EE than trying to pick up the wasted energy. Positive re-enforcement of good practices through feedback will also be of use.

Awareness-raising can take place by developing an energy and EE literacy programme which can be enhanced through education and training during technology transfer and by establishing information programs that are regular, ongoing and responsive. Education should include understanding EE broadly and the technology specifically; the focus of education should be on changing behaviour from energy and appliance use to encouraging sustainable use instead, such as fuel switching or 'reversion' and awareness (costs, and externalities such as health from pollutants and greenhouse gases).

Embedded technologies
If technology is embedded (in situ) in new building designs and structures, then the hurdle of take-up is already surmounted and the potential to revert is limited (e.g. if new houses were regulated to have ceiling insulation and solar water heaters). Here planners can make use of the 'ratchet effect'. Embedded technologies also minimise the number of decisions users need to make.

Technology selection, dissemination and procurement
Many people are averse to change or unable to overcome perceived and real barriers to changing behaviour, and making energy efficient technology tools readily available and easy to buy will increase their take-up. Where this is too costly or difficult to achieve, the role of regulation and in-situ technology can be harnessed.

The roll-out of interventions (technology and awareness, and even pricing) should give due consideration to various performance criteria, in which the relative costs of the interventions and benefits are weighed up prior to the roll-out. It is essential to undertake robust and informed analysis in the energy policy and planning environment, with due consideration given to the unintended consequences of interventions (especially direct, indirect, economy-wide REs). Specifically, the one-size-fits-all approach should be avoided, and a special kind of risk management framework that takes into account both known and unknown consequences of new technology through managing the risk and uncertainty associated with interventions.

Interactions between technology, price and awareness/attitudes need to be well thought out before undertaking interventions and awareness programs, and these interactions can be understood in the manner developed in this study. A summary of the main policy options and motivations are included in Table 19.

Table 19: Policy options and motivations

Policy options	*Motivations*
Raise awareness through media advertising and community engagement.	Informing consumers of their choices and energy matters and increasing the effectiveness of EE.
Mandatory efficiency standards and appliance labelling	Ensuring a culture of EE and raising awareness.
Integrate EE with other developmental programmes	Increasing the amount of funds available for EE, and integrate with other resource saving initiatives.
Integrate rebound effects in energy planning	Implement mitigative measures that entrench confidence in EE.
Tariff increases	Ensuring that technological savings and potential cost benefits from an EE investment can be realised and to discourage overconsumption of energy.

7.2.3 Regarding end users and DSM managers
In practice, energy planners and even stakeholders with a commercial interest in disbursement of new technologies need to be aware of a number of factors that will impact the response when considering the roll-out of the intervention. It would be helpful to use the insights gained in this study to anticipate behavioural response. Simple as it may seem, consideration essentially

amounts to viewing the intervention from the perspective of the consumer and taking into account:

- lack of information about energy matters otherwise referred to as ignorance and perception barriers;
- partial understandings or misunderstandings;
- prioritisation of capital investment over lifetime costs, and preferences for short payback periods among residential consumers (i.e. high discount rates for investments in EE);
- lack of interest in understanding the available choices, including the fact that existing technologies may provide a perfectly adequate service (or comfort level);
- propensity to rebound: unmet demand, unmet comfort goals, dissatisfaction with new technologies;
- pricing of energy (that may exclude externalities);
- the inability of consumers to observe the benefits of their investment or behaviour change.

The need to implement DSM as an emergency measure to alleviate supply constraints is not without its problems. As illustrated for efficient lighting technologies in the following table, each technology has advantages and disadvantages from the perspectives of both households and other stakeholders involved in the implementation of EE. The table is based on the findings of this current study and, where possible, the specific advantage has been counter-posed with a corresponding disadvantage. It is recommended that these factors be considered in the development of future roll-out programmes.

Table 20: Advantages and disadvantages of CFL roll-outs

Advantages	*Disadvantages*
Relatively easy to roll-out on a large scale, with multiple procurement methods (door-to-door, voluntary take-up, exchange points).	A 'one-size fits all' solution for households may not be appropriate. Different users have different needs with regard to comfort, cost and environmental impact preferences.
Savings on lighting conversion efficiencies are substantial and immediate.	Lighting is a relatively small component of electricity consumption and savings are not always visible to the household or the national load profile.
The door-to-door roll-out of CFLs together with awareness flyer serves to raise awareness about energy matters.	Awareness flyer does not give a complete view of the economic and environmental impacts of using CFLs.
Capital outlay for CFLs has decreased, availability is widespread, and quality of the energy service has improved.	REs can be substantial if there is suppressed demand for energy services for indoor lighting and security. New technology gives people a false sense of accomplishment in saving energy or avoiding greenhouse gas emissions, leading to negative reinforcement of EE initiatives.
Some users may experience feel-good factors from taking up efficient technologies.	Users are not fully empowered to get the most out of the technology and are not given provided with adequate information. Roll-out programmes generally do not consider sustainability objectives of lighting efficiency, and there is no mechanism for recycling, leading to potentially hazardous mercury oxide pollutants and other trace elements in the electrical ballasts that may leach into ground water from landfills, or toxic emissions at the point of disposal or breakage.
CFLs have longer lifetimes than incandescents so there is an associated convenience benefit of not	CFLs do not have dimmer-switch functionality and are not readily compatible with some of the less

having to replace lights frequently.	common light fittings.

7.2.4 Energy planning in a dynamic society

As discussed previously, roll out of EE interventions should not be considered as an isolated response to attempting to reduce the energy intensity of activities in any one sector. This report has already discussed the importance of coupling these with awareness-raising in an attempt to achieve behavioural changes and reduce the RE. The energy and climate change challenge goes further and points to the need for a multi-faceted, co-ordinated and dynamic response to transforming how society views and uses energy services.

7.3 Future research

Historically, rebound has been viewed as undesirable. However it has been demonstrated from the Zanemvula case study that its presence may be indicative of the improvement of the energy welfare improvements for those living in relative energy poverty. Future research is needed to discern between desirable and undesirable rebound in the context of energy needs analysis. Such an analysis can be conducted in conjunction with pricing strategies.

Further, the LEAP modelling framework can be improved using insights generated the case studies and systems dynamics modelling to obtain more realistic projections in the South African context. Indeed the approach can be applied in other countries as well.

7.3.1 Further work: what next?

Some of the next steps in this research are as follows:

- Completion (by December 2010) of the high income solar water heater study in Nelson Mandela Bay.
- Stakeholder workshops as proposed by SANERI with the intention of sharing the implications of this research on rebound and developing policy options in the public domain.
- Generation of research papers based on the contents of this report.

Beyond the scope of report, further quantitative studies (on the impacts of interventions and on the preferences of different household types) in conjunction with further fine-tuning of the household consumption model could be of value in informing policy and planning work in residential EE arena. The modelling approach is sufficiently versatile to be applied to other sectors of energy consumption (commercial, transport and industrial). Some specific progression includes:

- a proposal to Eskom and other stakeholders to fund the development of consumer energy behaviour empowerment initiatives;
- micro-level studies of rebound in other sectors: transport, industry and commerce;
- studies that explore what takes place at the interface between supply and demand of energy services.

Part of the accomplishment of this research has been in undertaking a fresh exploration of phenomena in the field of energy analysis, and thereby generating new approaches to researching consumer behaviour.

One of the key focuses of this project has been to understand the potential impact of REs and demand response in general on the supply system. This supply-centric approach is prevalent and has dominated historical thinking on energy planning. Recently the approach has begun to shifting to a demand-centric focus on energy planning, and this project has illustrated that research on demand is not only an interesting research area, but that demand and demand-response to supply interventions are areas that have not been sufficiently well understood to enable integrated thinking about sustainable energy planning. If there is to be a shift away from decentralised supply of electricity (for example), with the advent of smart grids and decentralised energy systems with increased renewable energy supply proportions, then the importance of explaining the behaviour of the demand agents increases exponentially. This project has defined – and illustrated by case studies – the kinds of demand-side factors that need to be taken into consideration in the planning of energy supply and EE strategies. It has also highlighted the value of interdisciplinary studies of energy consumption behaviour, and that the meeting of an exogenously determined demand led by engineering of technology and systems is no longer sufficient for meeting the challenges facing society in meeting its energy needs in a sustainable manner, especially amid the context of constrained supply.

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Appendices

Appendix 1: Stakeholder list

Further organisations and individuals were approached for collaboration, advice, and suggestions of study site, and invited to collaborate where appropriate: The organisations and individuals we spoke to included (among others).

- Andrew Etzinger, Eskom
- Trevor Gaunt, UCT's Department of Electrical Engineering
- Andrew Molalathoko, Load Research project contact person
- Marcus Dekenah Load Research project
- Nicola Cross (University of Tshwane study, Load Research)
- The Programme on Energy and Sustainable Development (PESD), based at Stanford University offered to participate in an advisory and reviewing capacity
- South*South*North
- Eskom's CTAD (Corporate Technical Auditing Division)
- Harold Annegern, *Enerkey*
- Barry Bredenkamp, National Energy Efficiency Agency
- Community members, trainers and trainees, data capturers, survey staff, survey and fieldwork managers in various communities

Appendix 2: Draft value tree

The value tree organises criteria from 'most abstract/vague' on the left ('success of intervention programme') down increasingly detailed levels of a hierarchy of objectives/criteria to the 'operational' lower-level criteria on the right. Here 'operational' is meant in the sense of being (a) measurable (even if only on some subjective scale e.g. Beaufort scale) and (b) clearly linked to preferences (so there should be agreement about whether more or less of a lower-level criterion is preferable, and why, even if there is disagreement about the importance of the criterion).

Note: 'cost' ('effect on economic well-being') is often shown as a single criterion on a value tree – here there is some more detail showing how overall monetary effects might be calculated. Treating 'cost' as a single criterion, this leaves 6 lower-level criteria (as is, there are 14). Later on, any prospective alternatives/ interventions are measured on these 6 (14) lower-level criteria – assessments on the higher-level criteria (up to the final 'overall/success' assessment) are derived by aggregating the lower-level assessments.

Reliable energy services

- Users 'feel good' about the intervention
- Feeling more comfortable
- Is the customer satisfied with their end use level?
- Quality of energy service provided by the new technology

Saving money

- Economic savings by households
- How does the post-intervention intensity (in J/m^2, or maybe J/m^2/something I can't make out) relate to a benchmark/standard?
- Saving money
- Is it cost effective?
- Decreased monthly kW/h and monetary spending
- Having lights at the end of the month

Comparison to best practices

- Differences/changes in household energy mix
- Percentage of technological efficiency achieved

Indirect effects

- Increase in energy efficiency industry in SA
- Jobs created through the intervention
- Does the local economy benefit?
- Is a maintenance service locally available?
- Can X be (or is X) locally manufactured?
- Sales of energy technologies (assume this is what is meant by 'techs') increase

Saving electricity

- Fewer blackouts, more spare grid capacity
- Lower burden on the national electricity grid

- Saving electricity

Timeline of realising benefits

- Timeline of realising benefits – specifically efficiency

Savings in CO_2 emissions

- Implications on carbon emission predictions
- Does it save CO_2 emissions?
- Emissions ($C0_2$) saved/avoided

Awareness of energy efficiency

- More energy efficiency awareness in households

After the removal of multiply-mentioned attributes and some further organisation, the following distilled list was obtained:

Reliable energy services

- Users 'feel good' about the intervention
- Feeling more comfortable/satisfied (Is the customer satisfied with their end use level? Quality of energy service provided by the new technology)

Saving money

- Economic savings by households
- How does the post-intervention intensity (in J/m^2, or maybe J/m^2/something I can't make out) relate to a benchmark/standard?
- Saving money (Decreased monthly kW/h and monetary spending; Having lights at the end of the month)
- Is it cost effective?

Indirect effects

- Increase in energy efficiency industry in SA (Sales of energy technologies (assume this is what is meant by 'techs') increase)
- Jobs created through the intervention
- Does the local economy benefit?
- Is a maintenance service locally available?
- Can X be (or is X) locally manufactured?

Saving electricity

- Fewer blackouts, more spare grid capacity
- Saving electricity

Savings in CO_2 emissions

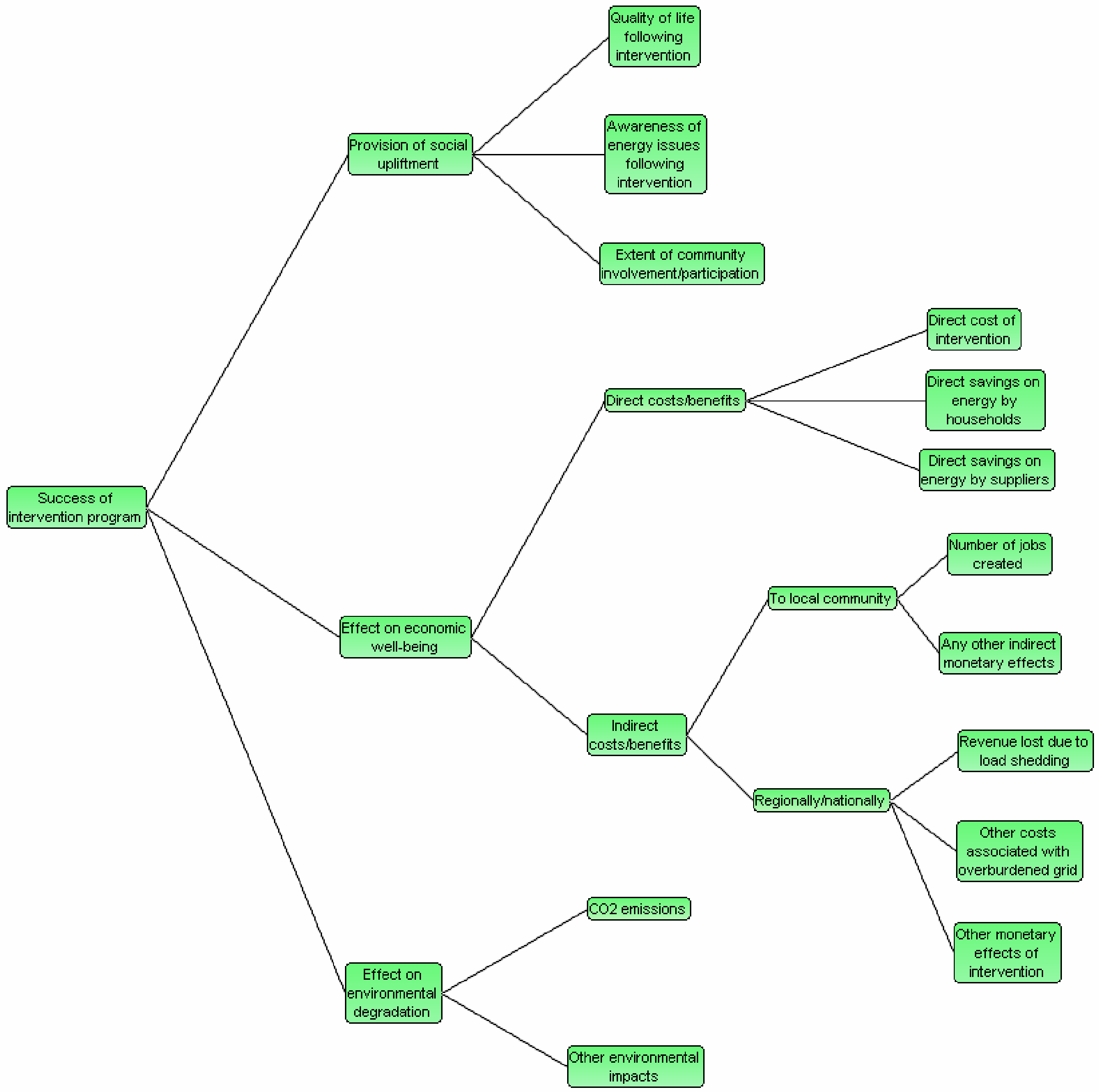
- Emissions ($C0_2$) saved/avoided

Awareness of energy efficiency

- More energy efficiency awareness in households

Some of the deleted items that may come into the measurement of other items are:

- Differences/changes in household energy mix (poss. Indirect effects, else consider 'why' this criteria is important i.e. what does it cause to occur?)
- Percentage of technological efficiency achieved (affects savings of money and electricity)
- Timeline of realising benefits – specifically efficiency (poss. need to apply a discount rate throughout)



Example of a value tree for assessing the effectiveness of energy efficiency interventions

Appendix 3: Original methodology

Key research questions

1. What are people's current levels of awareness and attitudes towards energy conservation and energy efficiency?
2. How do awareness and attitudes translate into action?
3. How do 1 and 2 differ according to income/LSM group, type of dwelling, number of household members?
4. Can reliable measurements of energy usage in the base scenario can be obtained though a school learner projects?

1-4 were used to design the pre-intervention study. We envisaged around 200 households (10% of the town) split appropriately into LSM and experimental and control groups. The proposed intervention was a CFL roll-out as per Eskom DSM mandate. The survey sample group was to be split into an experimental and control group. The experimental group would receive formal training in energy efficiency and awareness while the control group receives no direct training (other than that associated with the CFL roll-out, and awareness material external to the study, for example Power Alert and media campaigns). NERSA had originally planned to conduct an energy awareness and training workshop in the town that would have coincided with our study, however this did not arise due to logistical constraints within the municipality, and an absence of a local champion to facilitate the workshop. A decision was taken to ask relevant questions that would assess the levels of awareness of the survey participants, and allow the participants to 'self-select' into groups depending on their responses to these questions.

Electricity consumption

In view of the literature surveyed in Chapter 2, the following strategies for data collection were originally envisaged, but were later abandoned due to cost and practicalities:

- The diary method should be used, along with data loggers to establish hours of use.
- The monitored group should be a subset of the surveyed group (nested sample).
- The selected households need to be 'average energy users' and representative of the households in that demographic group; if the households are self-selected, they may not be representative.
- Placement of data loggers should consider possible bias relating to the type of service to be monitored; e.g. in the case of lighting, which lights are used more/less often? What is the risk of theft of equipment (loggers and technology) in certain areas? Households may limit access to certain parts of the home for personal reasons, and there may be concerns relating to the aesthetics of data logging equipment.

Intervention

The following ideas were suggested to control for various intervention types:

- Monitor and evaluate the energy efficiency intervention regularly.
- Adopt a flexible approach, adapt according to the household's needs as study progresses.
- Ongoing technical and educational support should be integrated into the programme.
- Facilitate and co-ordinate between households and stakeholders and amongst stakeholders, to prevent research fatigue.

Proposed methodology

From a modelling perspective the methodology for obtaining a quantitative view of the size of the RE will be to have a control group and an experimental group, each group divided into 3 socio-demographic groups (qualitative insights will also be drawn from this data). An illustration of the proposed approach is given in the figure below.

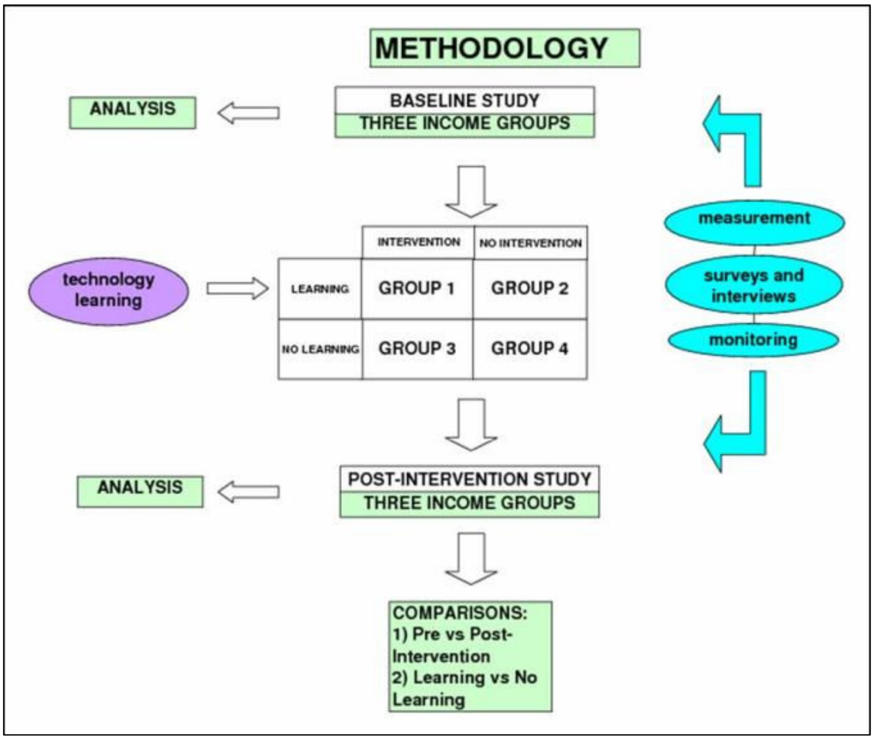


Figure 19: The original methodological framework developed for estimating rebound effects with and without awareness

Appendix 4: Prince Albert Background

The population consists of a total of 10,512 (7352 urban and 3160 rural) residents (as of 2001) which includes 172 African, 9137 Coloured, 1192 White and 11 Indians/other. Of all the households, 64.7% use electricity for cooking, 30% wood, 3.7% gas, 1.1% paraffin and 0.4% coal. Of the economically active population, the employment rate is 65%. This information (and more) contained in the Integrated Development Plan Review 2004/5 for implementation 2005/6 (http://www.capegateway.gov.za/Text/2005/8/prince_albert_municipality_idp_2005_-_2006.pdf).

Problems and potential in infrastructure:

'The region experiences constant power cuts which are caused by poor maintenance of the electricity system by ESKOM.' (Prince Albert IDP 2007-2011)

'Some people are using renewable energy, the area has a lot of wind and solar energy which could be used locally and produce surplus to the national power grid.'

The Municipal Service Provision Summary Chart

Facts

- Electricity is provided adequately in Prince Albert municipal area.
- Electricity is provided on farms but still a backlog of 27.4% exists.
- Gas & Wood, Coal, Paraffin is used on farms for heating purposes
- Wood is used all over for heating purposes during winter

Trends

- Eskom provide the whole area with electricity
- Exploring new energy sources in the area

Potential

- Diminish the 27.4% backlog that still exists.
- To research other sources of energy (Wind & Solar)
- To provide the whole area with energy

Project Stakeholders

Gert Bothma, Municipal/Infrastructure Manager, Prince Albert

Community Leaders – politicians and representatives of the community and local initiatives

School Principals

School Learners

Lodine Redelinghuys, DSM Manager, Western Region

Households selected for survey

Charles Marthinus, INEP, ESCO and survey manager

ERC staff

Stephen Davis, project co-ordinator

Jocelyn Muller, focus group workshop facilitator

Gisela Prasad, survey methodology and study design advisor

Eugene Visiagie, methodology adviser for schools data collection initiative.

Appendix 5: Zanemvula background

The municipality's intention was to avoid increased electricity demand and future enhancements of transmission grid capacity upgrades by implementing energy efficiency and energy substitution interventions. Since the business as usual development scenario would involve the purchase of electric geysers or heating of water with electricity, the municipality aimed to be on the cutting edge of sustainable development, utilising the abundant solar resource, and setting an example to other urban areas in South Africa.

Background to the solar water heater intervention

(Sourced from: *How to Implement Renewable Energy and Energy Efficiency Options: Appendix D – Solar Water Heater Manual*)

Nelson Mandela Bay Metro (NMBM), through their Electricity and Energy Business Unit, are pioneering a renewable, clean and energy efficiency project in which the private sector will provide the relevant 'services', supported by the municipality. A call for renewable, clean and energy efficiency projects was put out by the NMBM in February 2006 and three bids offering a range of wind, solar, DSM, cogeneration and landfill gas technologies were accepted.

The Metro agreed to support these projects on two levels. They will provide financial support through the negotiation of pricing structures that will ensure the projects' financial viability. They will also provide administrative support, such as the inclusion of relevant projects within the municipal billing system.

The basic premise underlying the model is that the Metro will not incur any costs other than the purchase of 'green' electricity (at a premium). It will make use of supplementary finance mechanisms available to green energy, to offset the cost of this electricity and in so doing reduce the price differential between renewable energy and Eskom grid electricity.

The SWH installations are rudimentary, normally with one tap – the intention is to empower members of the community to do retro-fit plumbing. Not all houses have baths / showers, and are not necessarily built with bathrooms in mind. There were ongoing installation and maintenance hiccups that required attention, for example leakages from the stop-cock system, requiring users to turn off the inlet taps to avoid water wastage. Pipes are made of a malleable plastic that is easy to bend, and temporary plastic taps are fitted. The reason for mentioning these facts is to demonstrate the range of factors that may impact household's attitudes to and perceptions about energy interventions.

From prior experience, Georgina Smit noted the following practicalities to consider when rolling out SWHs:

- The differential between summer and winter varies considerably between regions. A study in Kwanokhatula near Riversdale demonstrated much less solar heating in winter, whereas the NMB roll-outs should have a smaller seasonal differential in solar resources.
- Large pipe length from SWH system to tap could lead to increased water consumption without the appropriate awareness and direct user intervention to conserve the initial output of cold water for other uses.
- Theft of copper pipes a potential problem. New systems have plastic coated copper pipes that are less conspicuously valuable.
- Water is mainly used for bathing as opposed to preheated cooking water.
- Old and young differed in their desire / need for hot water. Kettles were generally used for heating water prior to SWH installations

The roll-out in this instance was predominantly a municipal initiative – with research conducted alongside the intervention aiming to highlight the importance of social aspects and consumption patterns related to hot water. The surveys objectives were distinct from the objectives of the rebound study, yet are valuable so have been included where relevant. In summary, the following points are worth noting:

- The research was social and included questions on health, perceptions of the project and the desire for hot water
- The community wasn't physically ready (houses were incomplete, etc), and the SWHs could not be installed until the houses were structurally read and electricity had been installed.
- SWHs have a positive impact on households and the gender roles in households – they alleviate time constraints for the person responsible for the day to day running of the household thereby resulting in stress relief and improved hygiene of the household members
- Zanemvula was a new community, so the baseline is not entrenched, nevertheless there was a sense of improvement in access to services
- Maintenance of systems is covered by the municipality for 1 year, with the expectation that a member of the community is trained to maintain the systems at the expense of individual home owners (including any upgrades of plumbing, etc)

Appendix 6: Focus group workshops

Focus Group 1

Prince Albert Primary School learners

Date: 19 May 2008

Venue: School Hall

Time: 11h00-13h00

Summary of responses to questions:

Q1 What do you value most about having electricity in your home?

All the learners appeared to have access to electricity, although they did not all use it. Some of the learners reported that they still used wood for cooking and for space heating in winter using a 'swart' (wood) stove. They all preferred using electricity for cooking and boiling water (for washing and tea/coffee) because it's easier and much quicker. They said that if you used wood to boil water on the wood stove it takes much longer to boil than using a kettle. Very few learners had kettles and when talking about boiling water for either washing or tea/coffee would talk about using the wood stove. One or two learners had geysers. Many people have wood stoves and save electricity using the wood. A few people use a two plate gas stove for cooking, water heating and ironing when there are power cuts or load shedding. They said that people living in the RDP houses and the informal settlement predominantly use wood and paraffin for cooking, space heating and water heating. One the children said that people in the informal settlement cannot afford to buy electricity even though they are electrified since many households do not have an income.

The learners said they also preferred the lights (electricity) as they thought that it was 'better light' and that you could see better. It was agreed that this was especially important when doing homework. Many felt that using candles and/or paraffin affected their concentration.

They also like being able to watch TV and thought that learnt 'things' like how to save electricity. One boy said that in the past it was difficult to watch TV, if you wanted to watch TV you had to have battery which first needed to be charged at the local garage.

One young girl said that she liked being able to use an airbrush to do her hair. One person said that he likes the convenience of a fridge because the food doesn't spoil as easily/quickly.

In winter many people scrape the coals from the wood stoves onto a metal sheet and then they put this in the living area to heat the room. They put salt onto the coals to prevent it from smoking and make a 'pypie' to blow the fire to prevent it from dying down. Often the coals are used to bake 'as koek', ironing, making 'rooster brood' and 'vetjies'. The children did say that there have been incidents where people experienced chest problems due to smoke inhalation. In winter it was common to use the 'swart ystertjie' or gas top for heating the iron. Sometimes they also heated water and put this in ordinary cold drink bottles to be used as a 'warm water bottle' in winter.

Q2. What do you value most about having lights in your home?

This question was reinterpreted by the learners and instead the aspect of lighting described was load shedding and power cuts. They felt that load shedding has affected their studying and homework. They felt that they couldn't see properly when doing schoolwork because there were shadows. They can't see as well using candles and paraffin and that their concentration is affected.

Most of learners said they use electricity for lighting most of the time, except when there is load shedding. They also felt using candles was inconvenient. One girl said that you firstly need to find candles, then the matches, and when it's dark you need to scratch around to find these. One child uses candles most of the time to save electricity and save money. One said that he does not like using electricity for watching TV and listening to music. He depends on the light from the TV then.

The said that many fires are caused from candle use. One person recounted a story about a lady that fell asleep with the candle and the wind blew over the candle and she woke up with the house on fire. She hurt herself when she smashed the window to get herself and her children out. This happened during load shedding which is usually between 4-6pm every night but it often stays off for longer. Another story was told of an old lady who died when a candle was knocked over also during load shedding. They said that these accidents were happening in brick homes and not in the informal settlement. A learner said that he felt that people from the informal settlement were accustomed to using candles and therefore knew how to use them safely.

During load shedding they have noticed an increase in crime and someone mentioned that a woman was raped during this time when the street lighting was out. They all considered the lack of alternatives to electric lighting to be a security, health and safety hazard.

Q3. Please share with us the way that you use lights in your house?
Generally these households appear to be using their lights sparingly. Lights are usually switched off as soon as it becomes light enough to see and on again at night around sunset. Usually only one light is used at a time and this appears to be the one in the kitchen.

Most of the children use the TV for lighting the lounge area. A few use their outside lights and some only use these when they have guests. One boy was an exception and said they leave all lights on most of the time at night. On average one/two lights are used for about 3/4 hours per day on average. At night it seems common to only use the kitchen light whilst cooking and this get switched off at about 7pm, after which most of the learners only rely on the light from the TV for the lounge area. In all the other rooms the lights are usually off. They only switch on the lights in the bedroom when preparing for bed.

One boy was acutely aware of saving electricity and using the lights efficiently. In his household they were educated to switch lights off when they leave a room and it was his duty to switch all the lights off before leaving the house in the morning. They had two energy efficiency lamps, one in the lounge and one outside. No one else in the group had purchased energy efficient lamps. Some of the learners have outside lights that are switched on when the sun sets and switched off, when they go sleep.

Water heating is done on the stove or kettle, this water used for washing and making tea/coffee.

Q4. When you think about lighting in your home, what are some of the dilemmas/challenges that you experience?
They said that sometimes they forget to switch the outside light. Outside lights also sometimes gets stolen - maybe for tik. They also joked about some of the social problems related to having or preferring no light when wanting to 'knyp die kat in die donker' and spoke about the many teenage pregnancies.

Q5. What opportunities for change can you think of that would make the most difference to the way that lights are used in your home?
They said that perhaps they could save energy by going to bed earlier. One person also suggested buying the battery operated touch lamp. They said that they should all remember to switch off lights when leaving a room. One person suggested switching to energy efficient lights. But many felt that the energy efficient lamps are too expensive and also not readily available (I did not hear that myself). One boy said the quality is not the same and many agreed except one who said that he compared the lights (since they have two) and he thinks that the light from energy efficient bulbs is brighter.

A boy also mentioned saving electricity by using wood instead but a girl countered this by asking about the environmental costs of wood use. There a general feeling that pre-paid meters are cheaper per unit than metered payments (don't know if I agree with this). This was mainly discussed in relation to being able to purchase in energy in smaller quantities and when money is available. They told me about some people that are especially having pre-paid meters installed and then doing illegal connections.

Focus Group 2

Science Club- Zwartberg and Prince Albert Private School Learners

Date: 20 May 2008

Venue: Zwartberg High School Hall

Time: 14h00 – 16h00

Summary of responses to questions:

Q1. What do you value most about having electricity in your home?
In these households electricity is the main source of energy. The learners generally agreed that they most valued being able to cook with ease and having lights for being able to see properly in the dark. A few mentioned that they liked not having to shower using cold water, but were happy to have geysers for heating the water. For these learners being able to listen to music was important and many of them had music systems with CD players. Having electricity available for charging cell phones was also appreciated since most had these too. More than half the children had play stations and the majority had computers too. The computers are used for homework, but predominantly for playing games. Electricity made the use of these appliances possible and this aspect was valued by the learners.

A few households had gas stoves but many had a combination of gas and electrical stoves. However, the people with a combination of gas and electrical stoves only made use of the gas appliance when there were unscheduled power cuts, which happens frequently when it rains, and also during scheduled load shedding. With load shedding everyone had made additional purchases to meet the households lighting needs and amongst the items purchased were gas lamps, battery operated touch lamps, rechargeable lamps, paraffin lamps, candles and 'skud lampe'. Other sources of energy are mainly used in winter for space heating. Amongst the energy sources used for space heating, wood was mentioned by a few learners mainly for use in fireplaces in winter in the lounge, where the families commonly spend most of their time together. Very few learners sill had the 'black' stove or wood stove. The other appliances used for space heating are electrical heaters ('water' heaters, oil heaters).

One of the learners mentioned that they had a solar water heater. Some other appliances owned were fridges, deep freezers, most households have fans with lights. Two people had air conditioners in their homes.

Although the learners in the group did not families did not own generators, many knew of many people who did own generators. The group also seemed familiar with other sources like solar panels and wind turbines and knew of a few people who used these in the area.

Q2. What do you value most about having lights in your home?
All of the learners used electricity for lighting most of the time. When we did a count the learners said that on average they owned between 10-15 lights per household.

Learners valued being able to read at night, being able to see clearly and being able to do their homework at night. In their view, candles aren't as good as incandescent lights because it flickers and it is not as bright. They said that it was bad for your eyes and that their parents eyes are weak and that this was caused by candles/paraffin lighting, before they had access to electricity. They also said that candles were dangerous and that you can burn yourself. Another mentioned an incident where a room was burnt out when a candle fell over. One boy said that he knew of many people whose homes had been destroyed by fires caused by candles. Only one learner mentioned a positive aspect and said she liked playing piano by candlelight.

Q3. Please share with us the way that you use lights in your house?

Generally the households appear to use about two/three lights at a time for two hours in the morning and two/three lights for three/four hours in the evening. Most lights are switched off when there are no occupants in the rooms. Except in the most common areas that are lit for longer periods. In the morning it's the kitchen and in the evening it's the kitchen and the lounge. Energy efficient (EE) lamps are used mainly outside and are generally left on at night for security reasons. Many have additional sensor lights on the property too. On average people own one/two EE lamps that are used either in the lounge or for outdoor lighting.

Q4. When you think about lighting in your home, what are some of the dilemmas/challenges that you experience?

The learners have either experienced or know of people who have had light bulbs exploding, especially with load shedding. They also mentioned that with load shedding a common problem has been that they forget to switch off lights and appliances and that when the electricity comes back on they have had TVs and music systems blaring, lights that had been left on etc. They mentioned that saving electricity is a problem, a challenge is switching to EE lamps. One boy reported that his mom said that 'I don't care if we waste electricity, I don't want that bad light'. They said that they did not like the colour difference, the EE white light vs incandescent yellow light. Most of the learners said that they preferred the yellow light from the incandescent light and that the white light from the EE lamp felt 'cold'. They said 'yellow is nice and warm like the sun'. They also said that the light from the EE lamp was dimmer than the incandescent. They also thought that perhaps they could save electricity by unplugging cell phone chargers and acknowledged that most of them as well as their families leave the chargers plugged in. They would also prefer to have light switches instead of using the strings for turning on their lights, since most of their lights were part of a fan/light combination fitting.

Q5. What opportunities for change can you think of that would make the most difference to the way that lights are used in your home?

Generally they mentioned different options for saving electricity in the household and didn't only look at lighting. They did mention that they could use solar panels for lighting and solar water heaters too. Another energy saving measure that they thought of was showering instead of bathing. They thought boiling a cup of water in the kettle at a time instead of filling the kettle was a good idea. One boy said that using the microwave for boiling one cup of water would be better.

Q6. What have you learnt?

One of the learners said that he has heard that the EE lamps use less energy when fitted upside down. A few mentioned that they had learnt that the microwave uses less electricity than a kettle.

Appendix 7: Zanemvula awareness workshop

Questions and concerns from community:

1. Will geysers work as well in winter as summer?
2. Will geysers be connected to showers?
3. Guarantees and warrantees (5-year factory guarantee from service provider and 1-year maintenance plan for minor leaks etc covered by municipality). Self-inflicted damage is not covered.
4. Concern about water overflow from geysers, and whether the municipality will cover the cost of the wasted water used. Implication of increased water consumption of 4 litre overflow per day (this may not impact the households water bill due to the free allowance, but will be wasteful to the water supply in a large-scale roll-out)
5. There were many questions about leaking geysers
6. Concern about water stop for geyser affecting other tap flows.
7. Concern about whether certain plastic pipes are strong enough to handle the hot water.
8. Complaint that councillor's office was not responsive.
9. Question about water bills

Answers from Steyn van der Merwe:

1. Most houses in pilot did not have showers, so tender did not allow for that.
2. Guarantee explained

The presentation by Fikiswa Mahota covered the following:

1. Energy and what we use it for (services rated according to level of energy required – from water heating most to lighting least).
2. Groups that need energy in society (sectors – domestic, service, transport, agriculture, food processing)
3. Types of energy appliances / fuels e.g. gas, paraffin, electricity with a few energy saving tips e.g. boiling only as much water as needed. Also solar stoves and geysers were mentioned and the advantages of solar energy. Participants were amused that solar energy is free!
4. Types of energy: solar water heater compared to electric geyser (disadvantages not mentioned e.g. no/little hot water when cloudy)

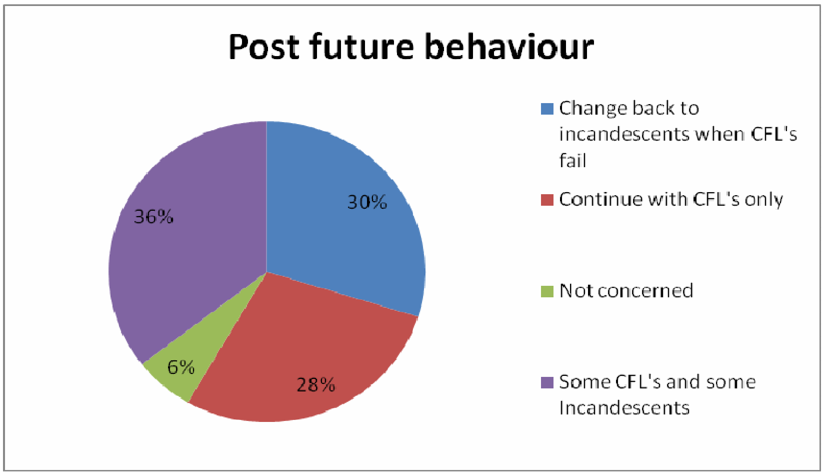
Further items touched on by the suppliers contracted to install the SWHs and by Zuko Zwane were:

1. The best times to use hot water – lots in summer and little in winter
2. If price is not a concern, the social norm of taking a bath will be preferred over a shower.
3. Kuyasa has some community owned maintenance and upgrade mechanisms in place.
4. Residents of Kuyasa are purchasing less electricity since the SWH roll-out there (video shown on Kuyasa project)
5. Demonstrations using physical models of the SWHs and the evacuated tubes were used to demonstrate usage, safety and functionality
6. Participants were encouraged to be proud of their new assets, even though they had not directly paid for them

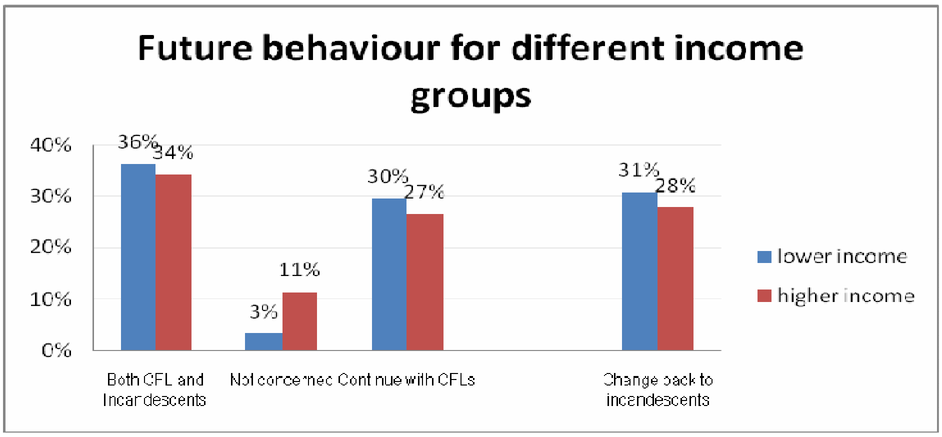
Appendix 8: Prince Albert survey data analysis

Post roll-out future behaviour

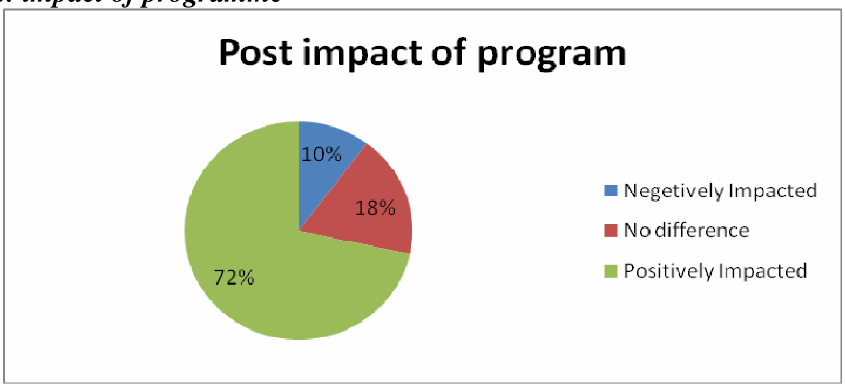
The possibility of take-back ranges between 30% and 72%. The worst case scenario happens when those that are not concerned and those that use both CFLs and incandescent light bulbs use the later only.



Among the different income groups, the lower income group are most likely to use both CFLs and incandescent light bulbs according to what is convenient in terms of cost. Compared to the lower income group, a larger proportion of higher income group participants are not concerned (3% for the lower income group 11% for the higher income group). This is expected since having more money affords them some level of indifference. The short term take-back effect will be more evident in the higher income group and long term relapse will be evident in the lower income group.



Post roll-out: impact of programme

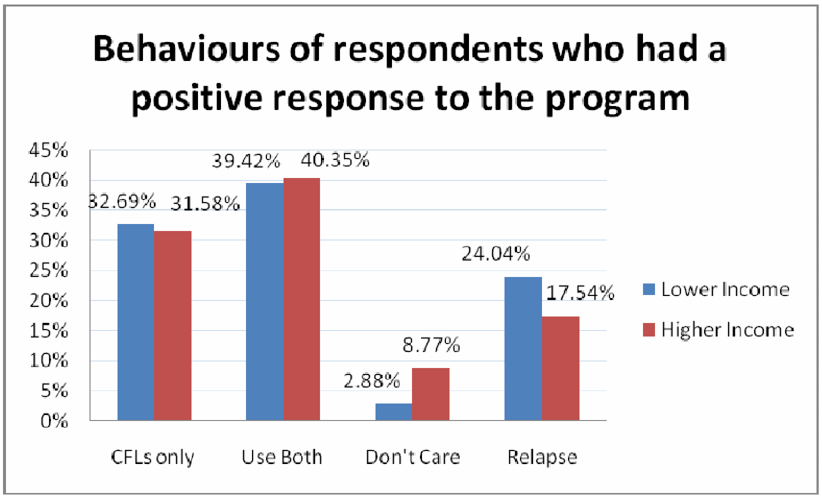


low income	*num*	*%*
Negatively impacted	14	9.52%
No difference	29	19.73%
Positively impacted	104	70.75%
total	147	100.00%

high income	*num*	*%*
Negatively impacted	9	11.54%
No difference	12	15.38%
Positively impacted	57	73.08%
total	78	100.00%

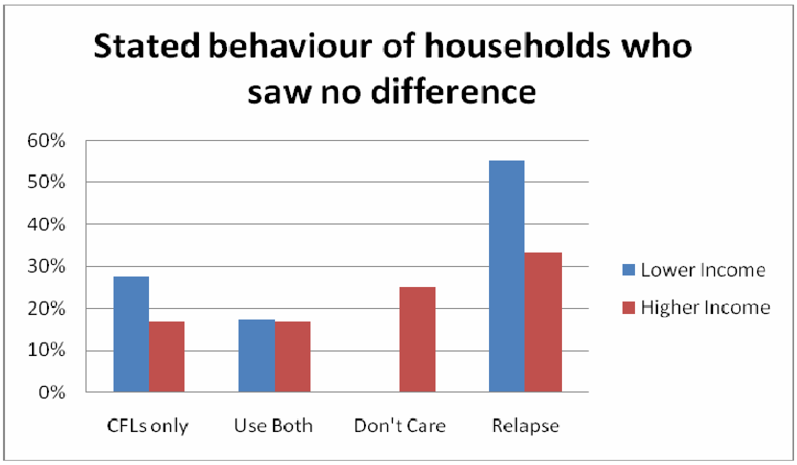
Stated behaviour of respondents who experienced a positive impact to the programme

104 low income respondents and 57 high income respondents said that the CFL exchange programme had a positive impact. Although the CFL exchange programme overly had a good response, 22% of participants who had a good response to the programme would change back to incandescent when CFLs fail, the main reason being the price of the CFL. As expected, a larger portion of participants who would revert belong to the lower income group given this reasoning (24.0% of the low income respondents in this category compared to 17.5% in the high income category). 40% of participants who had a good response would use both CFLs and incandescent light bulbs. 33% from the lower income and 32% from the higher income group would stick with CFLs. This shows that the possibility of relapse even when CFLs perform better than incandescent light bulbs is very high and needs to be addressed. A significantly higher portion from the higher income group (8.77%) do not care compared to 2.88% from the lower income group.



Behaviour of respondents who felt that the intervention made no difference

29 lower income respondents and 12 higher income respondents saw no difference. Half the participants, who saw no difference, would revert back to incandescent light bulbs with a larger portion of these belonging to the lower income group. 3 out of the 12 higher income respondents in this category are not really concerned which again shows how having a higher income affords some level of indifference.

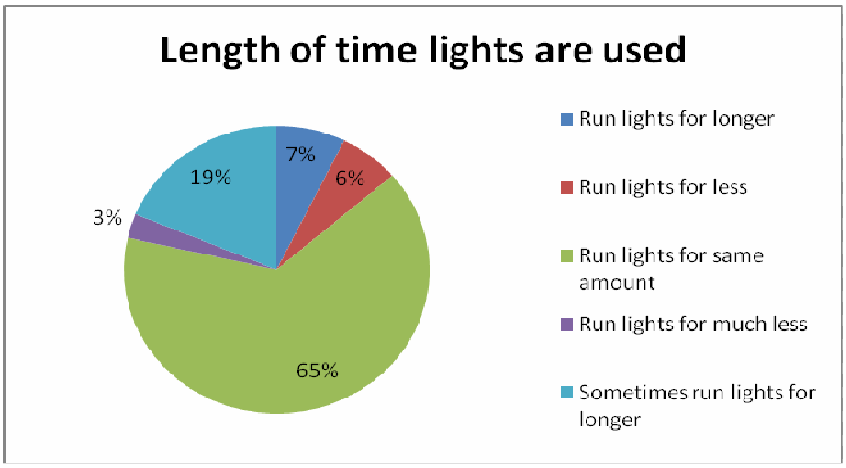


Behaviour of households who did not like the performance of the CFLs

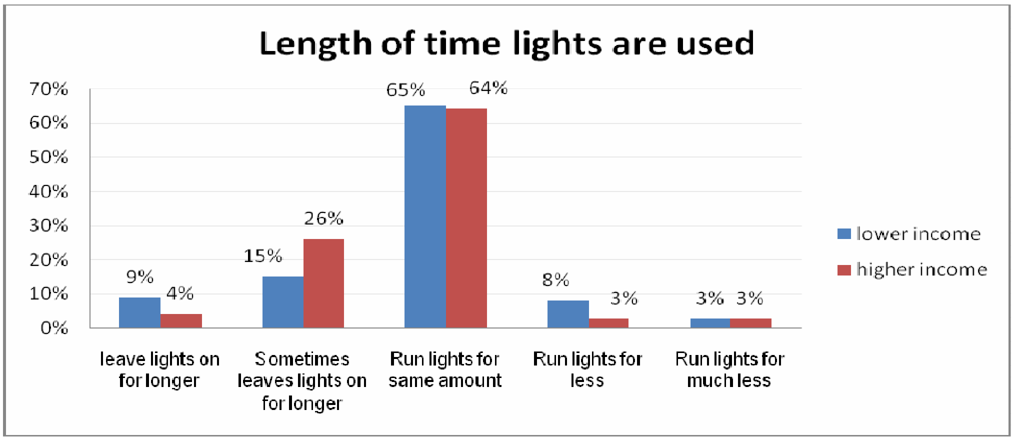
14 low income respondents and 9 higher income respondents said they did not like the performance of the CFLs. As expected most of the participants who did not like the performance of the CFLs would revert back to incandescent with 7 out of 9 respondents from the higher income group changing back to incandescent and 5 out of 14 from the lower income group reverting back to incandescent. 7 respondents from the lower income group would use both whilst only 1 participant from the higher income group would use both.

Most respondents who did not like the quality of the light from CFLs installed more light fittings

Phase 2: Stated light usage behaviour after the intervention

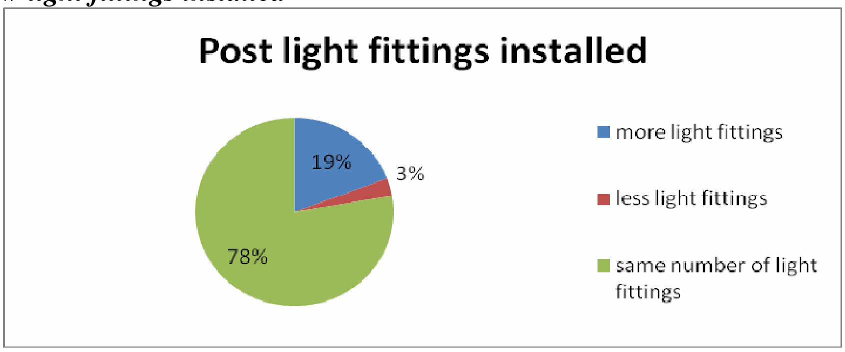


This is a measure of direct rebound. If lights are left on for longer, the benefits of having efficient lights diminish but sometimes when energy efficiency measures are taken coupled with either price increments or awareness campaigns, the rebound effect is negative which is ideal. 7% said they run lights for longer (assumed security/outdoor lights) whilst 19% of respondents said they sometimes run lights for longer. Direct rebound is however hard to measure using a survey because there is a difference between perceived versus actual length of time the lights are left on.

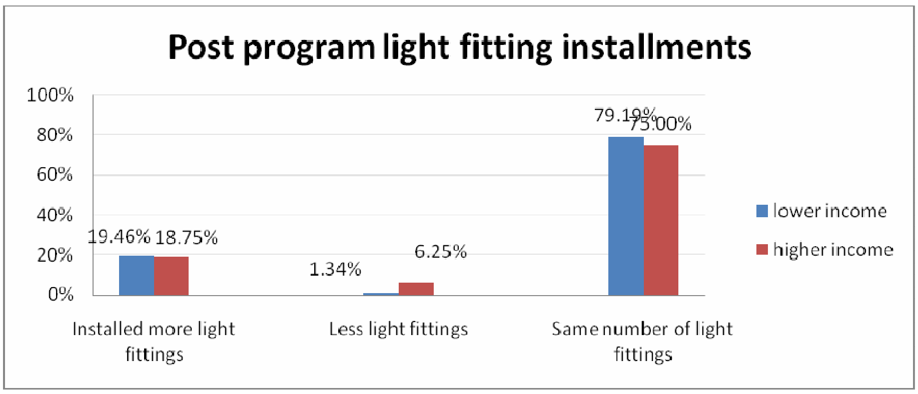


The above graph shows a small element of suppressed demand in 1st category. Also high income less concerned than low income about leaving the lights on longer.

Phase 2: New light fittings installed

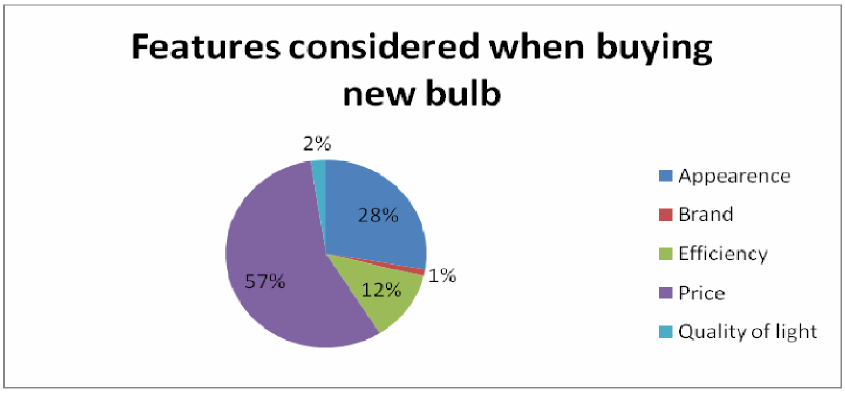


As a result of the CFL exchange programme (CFL lighting at the price of incandescent light bulbs), some participants installed new light fittings. Most participants did not install new light fittings. Due to the awareness campaigns some respondents did in fact reduce the amount of light fittings (possibly misunderstood the question).



Features considered when buying new bulb

The main feature considered when buying new light bulbs is the price of the light bulb, which means that if the CFL exchange programme is not followed through with awareness campaigns to show that using CFLs over a longer period of time will reduce the cost of lighting, or replacement programs (will also help with safe disposal of the CFLs) the CFL programme will not be successful in the long run.



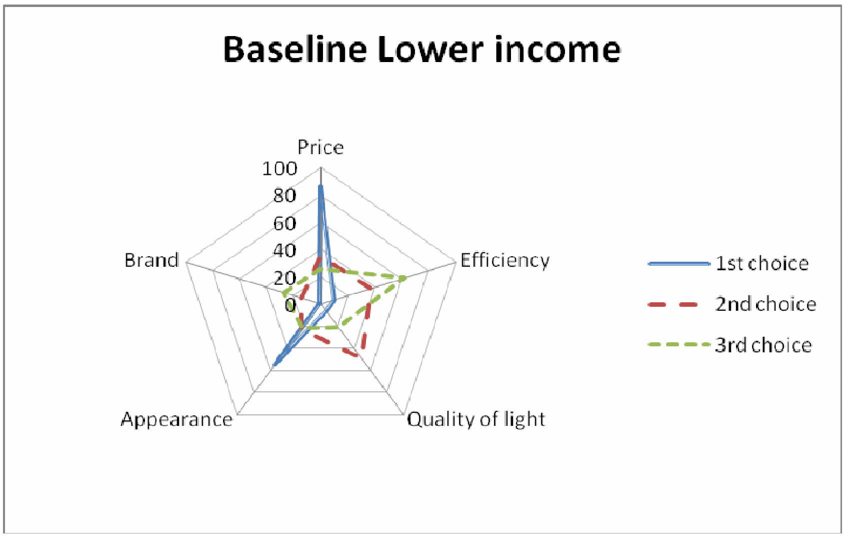
Further analysis based on income levels

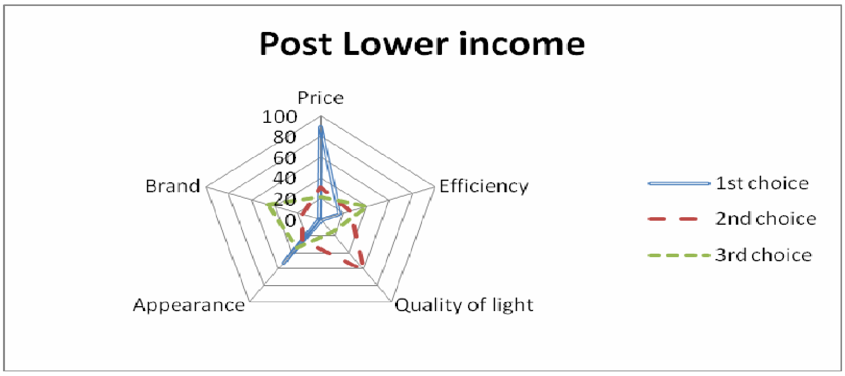
Lower income					
Baseline	*Price*	*Efficiency*	*Quality of light*	*Appearance*	*Brand*
1st choice	86	10	6	55	1
2nd choice	35	37	49	23	14
3rd choice	26	62	21	22	27
4th choice	9	32	23	17	77
5th choice	3	17	59	41	38

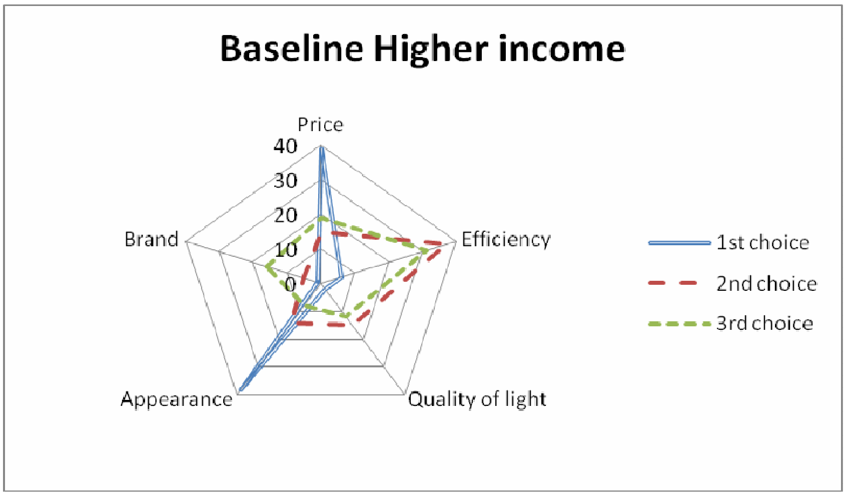
Lower income					
Post	*Price*	*Efficiency*	*Quality of light*	*Appearance*	*Brand*
1st choice	89	16	1	52	1
2nd choice	31	26	61	25	16
3rd choice	22	41	16	34	46
4th choice	13	71	9	8	58
5th choice	5	6	72	40	36

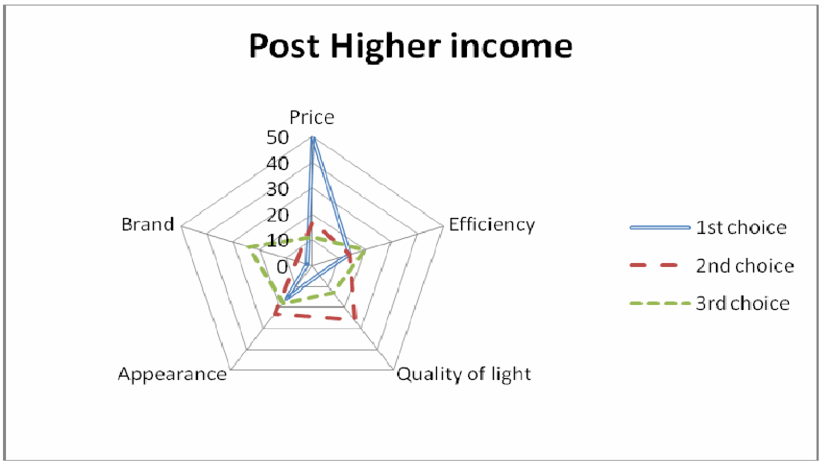
Higher income					
Baseline	*Price*	*Efficiency*	*Quality of light*	*Appearance*	*Brand*
1st choice	39	6	2	38	1
2nd choice	15	37	15	14	5
3rd choice	19	31	12	8	16
4th choice	9	10	12	9	46
5th choice	4	2	42	17	21

Higher income					
Post	*Price*	*Efficiency*	*Quality of light*	*Appearance*	*Brand*
1st choice	50	14	4	16	2
2nd choice	17	14	26	23	6
3rd choice	11	20	13	18	24
4th choice	3	32	11	2	37
5th choice	4	6	30	27	18


Baseline Lower income
Price
100
80
60
40
20
0
Efficiency
Quality of light
Appearance
Brand
1st choice
2nd choice
3rd choice


Post Lower income
Price
100
80
60
40
20
0
Efficiency
Quality of light
Appearance
Brand
1st choice
2nd choice
3rd choice


Baseline Higher income
Price
40
30
20
10
0
Efficiency
Quality of light
Appearance
Brand
1st choice
2nd choice
3rd choice



From these radar diagrams, it can be seen that awareness has risen with efficiency becoming more prominent as a first choice compared to the baseline.

Appendix 9: Prepayment data conversion

The Raw Data

The following procedure was carried out to summarise the prepayment sales for the households of interest:

1) The data was edited by a student to correct the date/time stamps and to put it into 1 consolidated spreadsheet.
2) Created an index of all the data entries running from number 1 to 134 showing name, address etc...
3) Duplicate entries for the same dates for the same customers were aggregated into total for that day. This was done using a pivot table, sorting by the date, and then copying it back into a spreadsheet. The indexes for the entries were retained.

   Number of data points went from 22928 to 22319.

   The pivot table was also useful to give totals for each customer of the units, expenditure and FBE over the period.
4) The average length of time between subsequent metered data was calculated. This was done using an IF statement, saying that IF the previous data entry is for the same customer ID, what is the number of days between the previous entry and this one. These were all averaged. The average was found to be 4.3 days.
5) The number of entries per household was tabulated using IF statements.
6) The length of time covered by the collected data was tabulated using IF statements.
7) This was placed in the INDEX along with the totals from the pivot table.

Next

1) Created a table of dates. The date range was from 2007/11/08 until 2009/12/14. A total of 767 days.
2) It was decided to divide this into six month periods as excel has a limitation in the number of columns allowed.
3) An if statement was used to create a time-based table, reflecting for each line of data, the average usage for a particular date range. Ie: from 2007/12/01 to 2007/12/05 reflecting a daily usage of 3kWh. So in the table under from the first to the last date in that range it would show 3kWh.
4) The table was then ‘compressed’ using a macro. This meant for each consumer, only 1 line of data exists to cover the whole period. So from 2007/12/01 to 05 it might show 3kWh, and from 06 to 09 it might show 4.5kWh. So the consumption data has been put into a linear form for each customer.
5) What is good about the linear form is that over a time period, you can see the total consumption for all the customers.

Layout of table:

1) There is an index of customers along with their totals over the period for which there are readings (given also).
2) There are then 4 worksheets, labelled 1, 2,3 and 4 for the periods:
   - 2007/11/01 to 2008/06/30
   - 2008/07/01 to 2008/12/31
   - 2009/01/01 to 2009/06/30 and

- 2009/06/30 to 2009/12/31

There is also a summary table at the end detailing the total monthly usage, and average household use for the covered months.

The table also gives some other stats which might be useful.

Appendix 10: Statistical Models

Zanemvula: Final regression model

Random-effects GLS regression Number of obs = 1985

Group variable (i): erf Number of groups = 410

R-sq: within = 0.0239 Obs per group: min = 1

between = 0.0863 avg = 4.8

overall = 0.0937 max = 7

Random effects u_i ~ Gaussian Wald chi2(9) = 83.85

corr(u_i, X) = 0 (assumed) Prob > chi2 = 0.0000

sigma_u = .46148726

sigma_e = .41157832

Rho = .55697897 (fraction of variance due to u_i)

Zanemvula: Attitudinal models

	2-Way Summary Table: Observed Frequencies (Zan_SvyOnly_97_BaseFUQs_temp) Marked cells have counts > 10					
	FU_5 Paraffin stove	FU_5 Electric and Paraffin	FU_5 Electric stove	FU_5 Electric and Gas	FU_5 Electric and fuel wood	Row Total
Paraffin stove	16	2	31	0	0	4
Row Percent	32.65%	4.08%	63.27%	0.00%	0.00%	
Fuel wood	1	0	1	0	0	
Row Percent	50.00%	0.00%	50.00%	0.00%	0.00%	
Paraffin and Fuel wood	0	0	0	0	0	
Row Percent						
Electric and Paraffin	0	0	8	0	0	
Row Percent	0.00%	0.00%	100.00%	0.00%	0.00%	
Electric stove	4	4	87	1	1	9
Row Percent	4.12%	4.12%	89.69%	1.03%	1.03%	
Gas stove	0	0	2	0	0	
Row Percent	0.00%	0.00%	100.00%	0.00%	0.00%	
None selected	0	0	0	0	0	
Row Percent						
Electric and Gas	0	1	1	0	0	
Row Percent	0.00%	50.00%	50.00%	0.00%	0.00%	
Totals	21	7	130	1	1	16

Statistic	Statistics: Bas_5(8) x FU_5(5) (Zan_SvyOnly		
	Chi-square	df	p
Pearson Chi-square	38.95026	df=28	p=.08177
M-L Chi-square	32.59784	df=28	p=.25091

Bas_18: Bas_Energy efficiency in household makes dif	2-Way Summary Table: Observed Frequencies (Zan_SvyOnly_97_Base Marked cells have counts > 10			
	FU_18 Yes	FU_18 Don`t know	FU_18 No	Row Totals
Yes	119	16	2	137
Row Percent	86.86%	11.68%	1.46%	
Don`t know	16	2	0	18
Row Percent	88.89%	11.11%	0.00%	
No	5	0	0	5
Row Percent	100.00%	0.00%	0.00%	

Statistic	Statistics: Bas_18(3) x FU_18(3) (Zan_SvyO		
	Chi-square	df	p
Pearson Chi-square	1.020610	df=4	p=.90665
M-L Chi-square	1.863861	df=4	p=.76078

2-Way Summary Table: Observed Frequencies (Zan_SvyOnly_97_BaseFUQs_temp)
Marked cells have counts > 10

Bas_19: Bas_Attitude towards energy saving	FU_19 I use as much as I need	FU_19 other people should save more	FU_19 I should save as much as possible	Row Totals
I use as much energy as I need	1	8	9	18
Row Percent	5.56%	44.44%	50.00%	
It doesn't concern me	0	2	8	10
Row Percent	0.00%	20.00%	80.00%	
Other people should save more energyl	1	8	38	47
Row Percent	2.13%	17.02%	80.85%	
I feel I should save as much as possible	2	20	63	85
Row Percent	2.35%	23.53%	74.12%	
Totals	4	38	118	160

Statistic	Statistics: Bas_19(4) x FU_19(3) (Zan_Svy		
	Chi-square	df	p
Pearson Chi-square	6.910906	df=6	p=.32917
M-L Chi-square	6.586701	df=6	p=.36077

2-Way Summary Table: Observed Frequencies
Marked cells have counts > 10

Bas_20: Bas_Switch lights off?	FU_20 Turn it off immediately yourself	FU_20 Switch the lights off later	Row Totals
Does not apply	13	4	17
Row Percent	76.47%	23.53%	
Turn it off immediately yourself	137	6	143
Row Percent	95.80%	4.20%	
Switch the lights off later	0	0	0
Row Percent			
Wait for someone else to turn the lights off	0	0	0
Row Percent			
Leave them on	1	0	1
Row Percent	100.00%	0.00%	
Totals	151	10	161

Statistic	Statistics: Bas_20(5) x FU_20(2) (Zan_SvyO		
	Chi-square	df	p
Pearson Chi-square	9.815763	df=4	p=.04366
M-L Chi-square	6.594100	df=4	p=.15897

Bas_33: Bas_Hot water efficiency	2-Way Summary Table: Observed Frequencies (Zan_SvyOnly_97_BaseFUQs_ten Marked cells have counts > 10 FU_33 I heat as much as I need to use	FU_33 I fill the pot or kettle	FU_33 I don't consider how much I need	FU_33 don't know	Row Totals
I heat as much water as I need to use for the task	124	6	3	1	134
Row Percent	92.54%	4.48%	2.24%	0.75%	
I fill the pot or kettle	11	0	0	0	11
Row Percent	100.00%	0.00%	0.00%	0.00%	
I don't consider how much I need	1	0	1	0	2
Row Percent	50.00%	0.00%	50.00%	0.00%	
I don't heat any water	3	5	0	0	8
Row Percent	37.50%	62.50%	0.00%	0.00%	
Don't know	0	1	0	0	1
Row Percent	0.00%	100.00%	0.00%	0.00%	
Totals	139	12	4	1	156

Statistic	Statistics: Bas_33(5) x FU_33(4) (Zan_Svy Chi-square	df	p
Pearson Chi-square	67.35017	df=12	p=.00000
M-L Chi-square	30.58715	df=12	p=.00228

Prince Albert: Final prepayment model

Random-effects GLS regression Number of obs = 2588

Group variable (i): id Number of groups = 119

R-sq: within = 0.0537 Obs per group: min = 3

between = 0.3980 avg = 21.7

overall = 0.3454 max = 24

Random effects u_i ~ Gaussian Wald chi2(13) = 230.26

corr(u_i, X) = 0 (assumed) Prob > chi2 = 0.0000

sigma_u =.46148726

sigma_e =.41157832

Rho= .55697897 (fraction of variance due to u_i)

Prince Albert: Final credit meter model

Random-effects GLS regression Number of obs = 638

Group variable (i): id Number of groups = 14

R-sq: within = 0.0290 Obs per group: min = 43

between = 0.1498 avg = 45.6

overall = 0.0965 max = 46

Random effects u_i ~ Gaussian Wald chi2(7) = 21.56

corr(u_i, X) = 0 (assumed) Prob > chi2 = 0.0030

sigma_u = .39227687

sigma_e = .43732343

rho = .44586051 (fraction of variance due to u_i)