

A financial and economic analysis of two electrification projects

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Executive summary

Introduction

This paper forms part of a series of reports prepared during the course of the second year of the EDRC research project 'The role of electricity in the integrated provision of energy in rural areas'. The objective of this project is to develop policy proposals and implementation guidelines for rural electrification in South Africa.

The paper reports on an analysis of two electrification projects undertaken by Eskom. Both an economic and a financial analysis are performed, and the financial analysis is undertaken from both the utility's perspective as well that of a household. The objectives of this study are to:

1. quantify the financial and economic impacts of electrification at two different rural electrification sites, and to
2. examine the implications for electrification technology choice on a more general basis.

Approach

The two sites chosen are case studies undertaken as part of a larger research effort co-ordinated by the Energy and Development Research Centre at the University of Cape Town. Loskop, in KwaZulu/Natal, is a community of around 1000 households and has been completely electrified over the past few years. Grid electricity was already in the area and so the electrification project has primarily been an investment in reticulation infrastructure. Mafefe, in the Northern Province, is a dispersed area containing over 30 villages. Of these, four settlements were electrified in the first phase of the project by means of a 22 km extension of the grid. Approximately 650 households received electricity as a result. More households in other villages have been and will be electrified in subsequent phases.

The methodology used for the financial and economic analysis is a cash flow model, which calculates the net present value of annual cash flows, taking into account a range of costs, revenue and other benefits. In the economic model, additional benefits incorporated into the analysis are the consumers' surplus as well as health and safety benefits associated with reduced fire hazards and paraffin poisoning. Additional economic benefits may well exist, but these have not been incorporated into the model. The methodology used to estimate financial impacts on users has attempted to examine fuel displacement and fuel expenditure effects as a result of electrification.

Three potential technical supply options are considered here: the use of prepayment meters, load-limited supplies, and off-grid (solar) systems. Each option is considered in both the financial and economic analysis, and an attempt is made to identify the conditions under which each of these supply options is optimal from a financial and an economic perspective.

Results

The results indicate that the projects are not financially viable for the utility, and that the total net present value of required subsidies is in the order of R2 000 and R4 000 per household (for Loskop and Mafefe respectively). These results are shown in the table below. In the case of Loskop, the prepayment meter option appears to require the lowest subsidies, while all three options produce similar results in Mafefe. The difference between the two sites can be mainly attributed to the 22 km grid extension required at Mafefe and the fact that the community is significantly smaller.



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	<i>NPV per connection</i>		<i>Total NPV</i>	
	Loskop	Mafefe	Loskop	Mafefe
Prepayment	(R2 200)	(R4 100)	(R2.3 mill)	(R2.8 mill)
Load-limited	(R2 500)	(R4 000)	(R2.7 mill)	(R2.7 mill)
Solar systems	(R3 950)	(R3 950)	(R4.0 mill)	(R2.6 mill)

Financial net present value of the projects

The economic analysis reveals that both projects are economically viable, with high rates of return. This can mainly be attributed to the estimation of fairly substantial positive externalities, primarily health and safety benefits as well as a consumer's surplus. The results are summarised in the table below. It can be seen that for both projects the prepayment system generates the most economic value, due to the greater benefits associated with the use of a wider range of end uses/services.

	<i>NPV per connection</i>		<i>Total NPV</i>	
	Loskop	Mafefe	Loskop	Mafefe
Prepayment	R3 000	R2 100	R3.1 mill	R1.5 mill
Load-limited	R1 600	R1 000	R1.6 mill	R0.7 mill
Solar systems	(R1 350)	(R1 350)	(R1.4 mill)	(R0.9 mill)

Economic net present value of the projects

From the user's perspective, there are different impacts for lower- and higher-income households. Where electricity displaces candles and paraffin for lighting and dry-cell batteries for radios, a household will save money on monthly fuel expenses, if a prepayment meter tariff is applied. However, these savings will, at best, be minimal if a load-limited tariff is applied. For households which use a wider range of appliances, financial savings on lighting fuels and batteries will be more than offset by the additional expenses of other uses, particularly if cheap or free wood is displaced by electricity. For these households, electrification will result in an increase in monthly fuel expenditure. This conclusion tends to agree with qualitative observations that households carefully weigh up the convenience and quality of electricity use against the additional expense.

The analysis of the conditions under which each supply technology is optimal has shown that load-limited supplies are preferred, from the utility's perspective, at consumption levels of less than 150 kWh/month per customer and relatively short distances from the grid. For consumption levels higher than this, prepayment systems generate fewer losses. At low consumption levels (less than 50 kWh/month), off-grid supplies are optimal for even very short distances from the grid (as little as 20 m per connection¹). Where consumption is higher, off-grid systems only become financially attractive to the utility in the case of communities which are further from the grid. If the same analysis is performed from an economic perspective, then it is apparent that prepayment metered supplies are optimal over a much greater consumption and distance range, that the niche for load-limited systems is restricted to lower consumption levels, and off-grid systems are optimal at only much greater distances from the grid.

¹ This refers to the distance of the settlement from the closest grid line, divided by the number of households in that settlement.

1. Introduction

This report documents a financial and economic analysis of two of Eskom's electrification projects: Loskop in KwaZulu/Natal and Mafefe in the Northern Province. The objectives of the study are to:

- examine the financial implications of different technology options, for the utility as well as the end-users;
- examine the likely overall economic impacts of the electrification projects; and
- consider the conditions under which each of the potential supply options would be optimal.

The technology options which will be considered are (1) standard prepayment meters, with a 40A current limit, (2) load-limited supplies, and (3) off-grid solar technology.

The study forms part of a broader and longer term investigation in rural electrification in South Africa, ('The role of electricity in the integrated provision of electricity to rural areas') conducted at the Energy and Development Research Centre of the University of Cape Town. The sites chosen for the analysis are two case study sites which have been visited and studied as part of this larger research project. Much of the data for this analysis comes from the case study research, and this document should be viewed as being supplementary to the case study reports (Thom 1996; Annecke 1996).

The following section will briefly outline the methodology used in the analysis. A short section will then provide some background to the two electrification projects for readers who are not familiar with the case study documentation. The results of the financial analysis will be presented, examining the likely financial impact on the utility as well as customers. This will be followed by a presentation of the economic analysis and its results. The penultimate section will examine the conditions under which each of the technologies would have represented the least-cost solution, and this will be followed by some concluding remarks.

2. Methodology

There are three different types of analysis presented in this report. These are (1) a financial analysis of electrification from the utility's perspective; (2) a financial analysis from the end-user's perspective; and (3) an economic analysis. The methodologies used for each of these are briefly described below.

2.1 The financial analysis from the utility's perspective

This analysis uses a discounted cash flow model to calculate the net financial impact of the electrification project. Such a model expresses all costs and revenues as actual cash amounts, for each year of the project. A net cash flow is then calculated and discounted back to the initial year to provide the net present value (NPV) of the project. A discount rate of 15.5% is used, with an assumed inflation rate of 9%.¹ The value of the NPV represents the overall benefit or cost to the utility and takes into account the cost of capital through the use of the discount rate. If the NPV is positive, the project results in net financial benefits for the utility, while a negative NPV indicates a net financial loss.²

¹ These assumptions match Eskom's recommendations for electrification projects, which reflect the utility's cost of capital.

² An alternative, but equivalent, evaluation can be based on the rate of return (RoR). The RoR is the discount rate at which the NPV is zero. If it is greater than a certain benchmark (in this case 15.5%), then the project is attractive to the utility (that is, there will be no losses).

The cost elements which go into the calculation of the NPV include all capital and refurbishment costs, operational overheads, servicing and maintenance costs and the variable costs of electricity supply. The revenue elements include all initial payments (that is, connection charges) and revenues from electricity sales. Lastly, there may be a residual value to the assets, but if the time period is taken over a sufficiently long period this may be approximated as zero (as is done here, with a time period of 15 years).

Although costs are based on actual experience (or modelled, thereby extrapolating from experience), revenues depend on the pricing policies and tariff levels adopted. Although there are official tariffs for standard prepayment supplies, policies for the other technology options are less firm. For load-limited supplies and solar systems, assumptions have had to be made on the most likely pricing policies, and sensitivity analyses conducted.

The NPV of a project is generally used as an investment decision making tool, and is most useful when comparing different investment options. In this way it can assist in the assessment of different technology options, and is used for this purpose here. It also provides a quantification of the overall subsidy which would be required – this is equivalent to the absolute value of the NPV, should the NPV be negative. However, it should be noted that the level of subsidy so calculated is sensitive to the set of assumptions and will vary with pricing policies.

The NPV calculated in this way does not allow a comparison of different financing strategies. In Eskom's case, possible strategies include equity (that is, self-financing), loan finance (possibly on concessionary terms) or more general (and sophisticated) finance from the capital markets. Examples of this latter type include the Eskom 168 bonds and the Electrification Participation Notes (EPNs). Examining the effects of these different strategies is a different type of analysis and is not considered in this study.

2.2 The financial impacts on the end-users

The methodology used here is to compare the likely effects on the household's monthly energy budget, taking into account the effect of inter-fuel substitutions. Unfortunately the case studies have not allowed pre- and post-electrification comparisons to be made, and so data from a national household survey (SALDRU 1995) have been used.

The effect of fuel substitutions can be difficult to model, and simplifying assumptions have had to be made. However, it is hoped that this analysis can lay the basis for more detailed and accurate studies to be conducted when pre- and post-electrification results become available from EDRC's rural electrification case studies.

2.3 The economic analysis

The economic analysis takes the cash flow analysis (from the utility's perspective) and makes certain adjustments. The objective is to transform the analysis so that the results reflect the overall costs and benefits to the economy as a whole. In order to do this, the following steps are taken:

- In all cost elements, any taxes and subsidies are removed. Imported equipment is priced using a shadow-exchange rate and labour components are priced using a shadow wage rate,³
- Prices are replaced by an estimation of the users' willingness to pay. This usually takes the form of a demand curve, with the willingness to pay a function of the amount of electricity consumed;

³ In fact, due to the rapid changes to South Africa's economy, existing data to perform this exercise is considered outdated, and so financial costs have been used as estimates of economic costs.

- External benefits are added to the analysis. These include the health benefits associated with decreased exposure to particulates, the lower risk of fires and burns, the benefits of reduced woodland denudation as a result of fuelwood collection, and the value of time savings from more convenient fuels and fewer wood collection trips.

The extent to which the externalities listed above actually exist, whether they can be monetised or not, and whether their value is already reflected in the estimation of the willingness to pay is discussed in more detail in Section 5.1.

Like the financial analysis, the economic analysis calculates a cash flow over a 15-year period, and discounts this to compute the NPV. The discount rate used, instead of reflecting the utility's cost of capital, is the social discount rate and this is set at 6% (this is a *real* discount rate and is the rate for rural projects recommended by the DBSA).

3. Background to the case studies

The two case studies selected for this analysis were Loskop and Mafefe. A brief background to each is provided below. In addition, some information on the different technology options is presented.

3.1 Loskop

Loskop consists of three settlements, Maqabagabeni, Mqedandaba and Msweleni (also referred to as Loskop extension). It forms part of the Okhahlamba magisterial district in KwaZulu/Natal, which is in the western part of the Natal midlands, extending from the Drakensberg mountains in the West to Estcourt and Mooi River in the East.

Land disputes and political divisions are prominent concerns in the settlement. Forced removals from Loskop in 1975/6 were followed by resettlements into Loskop in the late 1980s. At the same time, people who left under forced removals tried to return. These disputes have led to political polarisation, with different political groupings located in separate areas. Residents who have been in the area for generations are mostly settled in Maqabagabeni and Mqedandaba and are aligned to the African National Congress (ANC). This part of Loskop was electrified in 1993. On the other hand, Loskop extension (Msweleni) consists mainly of recently settled families, mostly aligned to the Inkatha Freedom Party (IFP), and this area was electrified in 1995.

The standard of services for the Okhahlamba district is generally poor, particularly in more remote locations such as Loskop. Although Loskop has a clinic, primary school, high school, public telephones and a large store (which also acts as a motel, post office and meeting place), access to these is often restricted by violent conflict. The clinic and primary school are in the IFP area, and the other facilities are in the ANC area. There are periods when residents are afraid to cross into each others' territory, thereby limiting access to these facilities.

It is estimated that there are approximately 12 000 people in Loskop, occupying around 1 000 homesteads. There is a high level of (male) migrancy, with the result that there are more women than men in the community. The average household size is more than seven, which is larger than the figures for Okhahlamba and KwaZulu/Natal. Nearly half of the residents are children or scholars, and the rest are unemployed (16%), wage earners (17%), home makers (14%) or retirees (9%).

The economy of Loskop relies predominantly on cash, mostly generated from migrant remittances and wage earners. There is only limited evidence of small-scale income-generating projects or informal businesses, and the dependency ratio for the settlement is high. Household income levels are low, on average R900 per month (equivalent to R140 per capita), and are particularly low for female-headed households, which also tend to rely more on remittances than regular wages. Formal employment in the area is dominated by two nearby factories which employ 300 people. Agricultural activity in Loskop is almost non-existent, which is

unusual for the area and is probably explained by the uncertainty over land rights and the endemic violence.

Electricity was first introduced into the area in 1987 when the motel-cum-store in Mqedandaba was electrified. The owner was required to pay a substantial connection fee and deposit. Later in 1987 a few more equally expensive connections were made. In 1990 Eskom approached the community, offering to electrify households with prepayment technology with only a nominal connection fee. In 1993 this plan was effected and the settlements of Maqabagabeni and Mqedandaba were electrified. This was followed in 1995 with the electrification of Loskop Extension.

3.2 Mafefe

Mafefe is an area of approximately 250 km² in the Northern Province. Although most of the area is mountainous and uninhabitable, the two most important river valleys contain fertile land and over thirty small villages are located at the base of the mountains. The total population of the area is in the region of 10 000 people, in around 1 700 households. The central villages are Ngoaname, Betle, Magapatona and Kapa, which together account for around 30% of the population.

The administrative centre of the community is in Ngoaname village, where there is a Tribal Office and Post Office. Other facilities in the area include a clinic and community centre (in Betle), ten primary schools, three secondary schools and an extension office of the Department of Agriculture. There are also at least three churches in Mafefe. Businesses in the area include three butcheries, two coal yards, 26 small shops, three bars/shebeens and one nightclub. The access road to the community is approximately 47 km long, of which 35 km is a gravel road in a bad condition.

There are serious political divisions in the community, particularly between the Mafefe Tribal Authority and its sister organisations on the one hand, and a group of community-based organisations (CBOs) and local council representatives on the other. For example, recently some development projects undertaken by CBOs in the area were effectively halted when the Mafefe Tribal Authority closed the community centre and confiscated vehicles used by these organisations.

Most people collect water from streams and rivers, although piped water and stand-pipes are available in some of the main villages. Energy use depends primarily on fuelwood, which is collected for free from the mountains. Other fuels commonly used are dung (mainly for baking), paraffin (particularly in lamps, but also in stoves to some extent) and candles. Torch batteries are commonly used to power radios. The use of car batteries is not widespread, probably because television reception is not available in the area.

Mafefe is an impoverished area which is highly dependent on state welfare payments, such as pensions and compensation for asbestos-related illnesses. The community also relies on remittances from migrants. Many households practise some form of subsistence agriculture, and in some cases produce is sold. However, this contributes relatively little to total household income and/or consumption. Employment opportunities in the area are limited to the few schools, shops, building construction or occasional development projects (including the electrification project). Poorer members of the community earn small amounts of cash by performing services (such as construction and washing) for other households. Women and female-headed households are particularly vulnerable to extreme poverty, due to a lack of access to social and political power, resources as well as income opportunities. Although studies have identified potential agricultural opportunities in the Mafefe region, there appear to be few commercial farmers in the area.

After an extended period of negotiation by the Mafefe Electricity Committee and Tribal Authority, first with the Lebowa electricity authorities and later with Eskom, it was agreed that Mafefe would be electrified. Eskom raised an amount of R675 000 from the Independent Development Trust (IDT) to pay for the extension

of the line into Mafefe (a distance of about 22 km). The four central villages in Mafefe were electrified in 1995, and in 1996 the line was extended further to electrify some villages to the north, of which Fertilis (Ga Mampa) is the largest. The plan is to electrify some of the other villages as well. Eskom decided to pilot the use of a 2.5A load-limited supply option in this electrification project. This analysis deals with the first phase of the project, that is, the electrification of some 690 homes and businesses in the four central villages. The fact that the 22 km of line extension will be used for subsequent phases has been accounted for by estimating a pro-rata portion of the cost of this line in calculating the costs for phase 1.

3.3 The supply options

Three technology options are considered in this analysis. Firstly there is the standard prepayment metered supply, with a current limit of 40A or 60A. This has been provided in association with a nominal connection fee (around R50 per connection) and a straight line tariff (that is, an energy charge with no minimum fee or monthly charge). It is the standard supply which has been used throughout the electrification programme, including Loskop.

The second option is a load-limited supply for domestic users which provides electricity up to a maximum current of 2.5A, thus effectively excluding thermal appliances (although special kettles and irons which can be used with this supply are available). Options of 5A and 8A, which allow greater use of thermal appliances, are also being considered by Eskom, but are not included in this analysis.

The third option considered here is the off-grid option. Essentially this means the use of 50 Wp solar home systems for households, and larger solar systems for schools and clinics. Solar systems have not been used, to date, as part of Eskom's electrification programme. However, it presents an attractive technology from a cost perspective, especially in more remote and smaller communities.

4. The financial analysis

This section will discuss the results of the financial analyses.

4.1 The financial impact on the utility

The financial impact on the utility will be discussed in terms of capital costs and overall net present value. Prior to presenting the results, the principal assumptions and cost elements will be presented.

Customers

In Loskop there have been approximately 1 000 domestic connections made since the project started. In addition, there are two schools, a clinic and a number of local businesses which have been connected to the grid. At the start of the programme there were only seven small businesses and over five years this has increased to 17 enterprises – a growth rate of two new enterprises per year. Although this rate of growth is less than that claimed as typical by Eskom ('between 10 and 20 new economic activities are created for every 100 homes we electrify' (Maree 1997: 4)), it is significant and can be expected to contribute to total consumption. For the purposes of this analysis, it is assumed that this rate of business creation continues.

	<i>Loskop</i>		<i>Mafefe</i>	
	<i>Initial connections</i>	<i>Growth p.a.</i>	<i>Initial connections</i>	<i>Growth p.a.</i>
Domestic	1000	0	650	0
Business	7	2	14	1
Other non-domestic	3	0	7	0

Table 1: Number of customers

In Mafefe, a total of 650 households were connected in the four villages which were electrified in the first phase of the project. Non-domestic connections include the Tribal Offices, Post Office, clinic, four schools and 14 small enterprises. A slightly lower rate of growth in businesses than has been experienced in Mafefe is assumed (one new enterprise per year), mainly due to the smaller population in this settlement, its physical isolation and low incomes. There is uncertainty regarding the potential for agricultural use of electricity in Mafefe. Although feasibility studies indicate that there is potential, it is not clear how easily this will be realised, and what the implications for electricity consumption are. Due to the uncertainties, water-pumping loads are excluded for the purposes of this study. It should be noted, however, that this type of load can add significantly to the overall consumption base, generating significantly more revenue for the utility. In addition, the commercialisation of agriculture in the area would increase available income in the community, and this may have some influence on electricity use patterns.

The cost assumptions

Capital costs for grid electrification are calculated as the sum of the 11 kV line extension, reticulation costs and connection costs. In the absence of accurate information for the case studies, the following assumptions have been used, based on information provided by Eskom Consulting Services (1996) and Eskom Distribution Technologies (Geldenhuys 1996).

Costs for line extension, reticulation and connection are presented in Table 2. Line extension costs per kilometre are lower for Mafefe (phase 1) than they are for Loskop since the same line extension was also used to electrify nearby settlements, and costs are calculated on a pro-rata basis. Reticulation costs are higher for Mafefe due to the more dispersed nature of the settlement.

Capital costs for off-grid systems are estimated as R3 400 per 50 Wp solar home system (Davis 1996a). Larger shops and enterprises are assumed to be supplied by privately owned generators, and so are not included in the impact on the utility. The cost of installing off-grid supply systems in schools and clinics is assumed to be R60 000 per installation.

<i>Grid supply option</i>	<i>Loskop</i>		<i>Mafefe</i>	
	<i>Prepayment</i>	<i>Load-limited</i>	<i>Prepayment</i>	<i>Load-limited</i>
Reticulation costs	R1 100/site	R850/site	R1 950/site	R1 500/site
Connection costs	R880/site	R580/site	R880/site	R580/site
Bulk supply costs	R30 000/km	R22 500/km	R25 000/km	R20 000/km
Solar home systems	R3 400 per system		R3 400 per system	
Clinic & school solar systems	R60 000 per system		R60 000 per system	

Table 2: Capital cost elements

Assumptions regarding the variable and fixed costs of grid electricity supply are presented in Table 3. The average supply cost, expressed as a cost per kWh is the average cost of generation, transmission and distribution for each project. It reflects Eskom's anticipated increases in average costs into the future. Although a slightly lower supply cost is justified for the load-limited option due to the effect of reduced peak demand as a result of the load limits, it has not been possible to quantify this difference.

Support costs for prepayment supplies are based on experience to date and are assumed to stay constant in real terms. A substantially reduced support cost is assumed for the load-limited supply option due to the intention of relying on local electricity committees. Since this idea is untested, however, the reduction in cost

must be viewed as optimistic and represents what the utility would probably like to achieve.⁴

Operation and maintenance costs for solar home systems are assumed to comprise of battery replacements (every three years), and periodic maintenance checks. The average cost is calculated to be R16 per system per month.

<i>Grid supply option</i>	<i>Loskop</i>		<i>Mafefe</i>	
	<i>Prepayment</i>	<i>Load-limited</i>	<i>Prepayment</i>	<i>Load-limited</i>
Average supply cost for grid	9.3c/kWh	9.3c/kWh	9.3c/kWh	9.3c/kWh
Average support cost for grid	R23/month	R17/month	R23/month	R17/month
Average O&M cost for solar	R16/month		R16/month	

Table 3: Supply and support costs

Consumption and tariffs

Revenue streams are calculated on the basis of tariff schedules and sales growth assumptions. Average domestic sales are assumed to grow as shown in Figure 1. The starting point for electricity sales is set at 50 kWh/month, which is typical for new electrification projects in rural areas. Sales growth is extremely difficult to forecast, even over the short term. Studies of consumption growth trends to date indicate fairly high growth rates of 10-20% per annum (Davis 1996b), and show a fairly linear pattern of growth,¹ at least over the first few years. For the purposes of this study, consumption growth is treated as a variable rather than an assumption. Not only is a sensitivity analysis conducted on consumption growth, but the analysis in Section 6 treats consumption (along with grid distance and settlement size) as an independent variable in determining the optimum technology choice.

However, the financial and economic analyses require a base case set of assumptions. It is assumed that growth is linear, since this assumption more closely fits experience in other electrified settlements,⁵ and that consumption grows steadily to a maximum over a 15-year period. For prepayment meters the maximum level of consumption (in year 15) is set at 200 kWh/month, which is close to urban consumption levels after only a few years. This gives an average level of consumption over 15 years of 125 kWh/month. Sales growth is assumed to be lower for load-limited supply options due to the constraints which these systems impose, and the base-case assumption is for consumption to reach a maximum of 100 kWh/month, giving an average over the period of 75 kWh/month. It should be noted that actual domestic consumption will be significantly higher than sales predictions due to the high level of revenue losses which are experienced. While figures were not available for the case study sites, current revenue losses to all of Eskom's prepayment customers account for 35% of total consumption. Since revenue losses are generally lower for rural localities, it is assumed that revenue losses start at 20% and decline to 10% over five years. Technical losses in the distribution system are assumed to be 10%.

Sales to businesses are assumed to grow from 500 to 1 000 kWh/month over 15 years. While this may appear high if one associates rural businesses with small traders, given the small number of businesses the average level of consumption is easily increased if only one or two larger users (such as mechanics, welders and water-pumps) are present. Sales estimates for schools and clinics are assumed to be

⁴ Experience to date with pilots of load-limited supplies indicates that these cost savings may very well not be achieved. However, this analysis is designed to compare the different technology options over the medium term, assuming that the anticipated cost savings are achieved. Consequently, load-limited supplies are given the benefit of the doubt.

⁵ The alternative growth pattern commonly used in this type of analysis is an 'S-curve'. However, it is judged here that this pattern gives rise to an unrealistically high rate of consumption growth in the first few years after electrification.

higher than the average household, and are set at 500 and 800 kWh/month respectively.

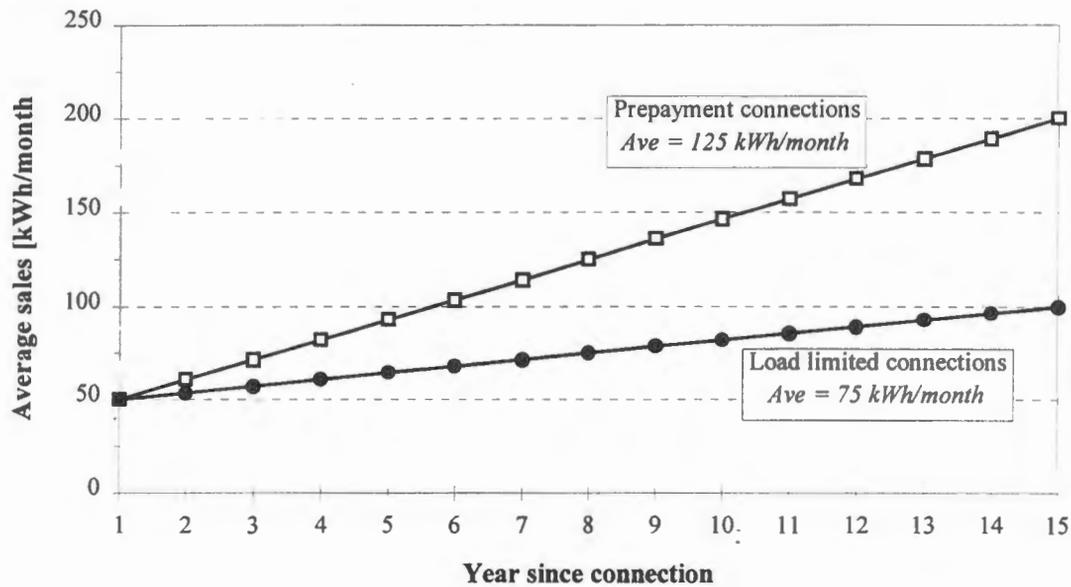


Figure 1: Sales growth for domestic customers

Tariffs for the prepayment supply and business connections are set at a R50 connection fee and a unit charge of 25c/kWh. For load-limited supplies, it is assumed that the connection fee is R10 and a monthly tariff of R10 is charged. The same tariffs are applied to the solar home systems.⁶

Figure 2 shows the average contribution of households, businesses and other non-domestic users to total revenue. It can be seen that where prepayment meters are used, domestic revenue accounts for over 80% of total revenue. Where load-limited supplies are used, revenue from domestic users is substantially reduced in absolute terms (due to a tariff of R10 per month), and revenue from businesses makes up a much larger portion of the revenue base. Naturally, these results are sensitive to assumptions regarding consumption growth, tariffs as well as the formation of new businesses. The greatest sensitivity is to pricing policies for load-limited supplies, especially given the current uncertainties around these policies.

⁶ Since Eskom has not developed a pricing policy for solar home systems, this tariff is purely hypothetical and is set at the same level as for load-limited supplies, recognising that the utility would find it difficult to charge more for an even more restricted supply. However, if the recommendation that solar home systems be subsidised to a maximum of R1500 per system is translated into a pricing policy, then this would require a monthly tariff of R25 per month for the 50 Wp systems considered here.

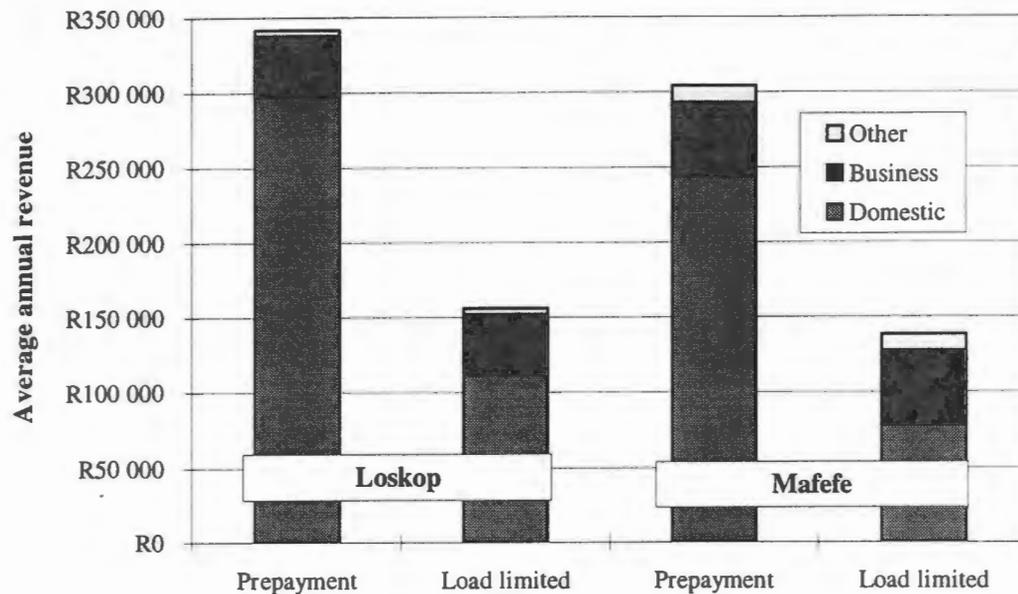


Figure 2: Revenue contributions by customer categories

Capital costs

The average capital costs of the three different technologies are presented in Table 4. In the case of Loskop, it can be seen that the load-limited supply option can be provided at the lowest capital cost, and off-grid at the highest. These costs are influenced by the fact that the grid was available in the area at the start of the electrification project. At a cost of R30 000/km for 11 kV line extension, every addition kilometre of grid extension required would have added around R30 per connection.

In Mafefe, the 22 km of 11 kV grid extension accounts for as much as 25% of the total capital cost for load-limited supplies, contributing around R640 per connection. In this case, it can be seen that off-grid supply technology is slightly cheaper than prepayment systems in terms of capital cost per connection, and the load-limited supply option is the least-capital intensive of the three supply systems.

	<i>Cost per connection</i>		<i>Total capital costs</i>	
	<i>Loskop</i>	<i>Mafefe</i>	<i>Loskop</i>	<i>Mafefe</i>
Prepayment	R2 200	R3 700	R2.3 mill	R2.6 mill
Load-limited	R1 600	R2 800	R1.6 mill	R1.9 mill
Solar systems	R3 400	R3 400	R3.5 mill	R2.5 mill

Table 4: Approximate capital costs

Overall net present value

The overall NPV of a project represents the overall loss or gain for the implementing agency, given the future revenue streams and cost of capital. If the NPV is negative, it quantifies the present value of the subsidies which will be required.

Table 5 presents the NPVs for the three technologies at the two sites, expressed as a total amount and divided by the number of connections. In the case of Loskop, it can be seen that the financial results for all of the options are negative, that is, subsidies will be required. It should be noted, however, that, if prepayment supplies are provided, the financial impact is less than those required for load-limited supplies – R2 200 per customer compared with R2 500 per customer. If solar systems are provided, then the required subsidies are much larger – in the region of R4 000 per customer.

At first glance these results appear surprising, given that load-limited supply options are designed to substantially reduce Eskom's exposure to losses, and a 14% increase in financial losses seems counter-intuitive. There are a number of underlying reasons for this result. Firstly, the very low tariff for load-limited supplies results in very small revenues being received. Secondly, sales are assumed to grow to levels of 200 kWh/month if prepayment supplies are provided (giving an average of 125 kWh/month). Although these levels may appear high in comparison with current statistics, it should be noted that a fairly long time horizon is adopted, and it is further assumed that revenue losses are reduced substantially over time. Lastly, the cost savings due to load-limited supplies are actually quite small, since the site was only a short distance from the existing grid. While capital costs are reduced by 30%, this reduction is only 7% of total capital, refurbishment and operating costs incurred over the lifetime of the project. In fact, greater savings are realised through the assumed 25% reduction in support costs, accounting for a 17% reduction in overall costs.

In the case of Mafefe, all three options result in similar losses, with solar home systems having the slight edge. The difference between this result and the one for Loskop can largely be explained in terms of the line extension cost. Not only does this add to the total costs of grid extension, but a greater difference in the costs of prepayment and load-limited supplies is realised. However, it should be noted that if a large number of upgrades (from 2.5A to 20A) are anticipated, then these capital savings may not actually be achieved. Lastly, if 20 Wp rather than 50 Wp solar systems are installed, then the costs of off-grid would be reduced by over R1 000 per system, making this supply option the cheapest option by a substantial margin.

In fact, the IDT provided R675 000 towards the Mafefe electrification project, and this amount should be added to the overall NPV. Taking account of this grant, the losses for the prepayment and load-limited systems reduce to approximately R3 000 per customer.

	<i>NPV per connection</i>		<i>Total NPV</i>	
	<i>Loskop</i>	<i>Mafefe</i>	<i>Loskop</i>	<i>Mafefe</i>
Prepayment	(R2 200)	(R4 100)	(R2.3 mill)	(R2.8 mill)
Load-limited	(R2 500)	(R4 000)	(R2.7 mill)	(R2.7 mill)
Solar systems	(R3 950)	(R3 950)	(R4.0 mill)	(R2.6 mill)

Table 5: Financial net present value of the projects

Naturally, the NPVs are sensitive to the main assumptions in the analysis. In particular, the assumptions regarding consumption growth, tariff policies and cost elements will affect the overall results. Since the central question of this study is to examine the conditions under which each technology is preferred by the utility, a useful sensitivity analysis to conduct is one which identifies the variation to the base case assumptions which results in a different technology being chosen.

In the case of Loskop, the base case analysis showed that the prepayment metered option was optimal. The load-limited option would be preferred if one of the conditions listed in Table 6 is satisfied. The only change which is considered plausible is if the load-limited tariff is increased from R10 to R14 per month. However, indications are that, if anything, the price will be lowered rather than increased. These results suggest that for this case study, the original conclusion is robust (that is, that the prepayment option is preferable in Loskop).

<i>Variable</i>	<i>Change to base case assumptions</i>	<i>Comment</i>
Capital costs	Prepayment capital costs are increased by 30%	Considered unlikely
	Load-limited capital costs are reduced by 30%	Considered unlikely
Tariff	Prepayment tariff is decreased from 25 to 22c/kWh	Considered unlikely
	Load-limited tariff is increased from R10 to R14/month	Possible, although pressure is to decrease price
Support costs	Prepayment support costs increase from R23 to R27 per customer per month	Unlikely, since pressure is to reduce cost
	Load-limited support costs decrease from R17.50 to R13 per customer per month	Considered possible, although very uncertain
Domestic consumption	Ave. prepayment consumption is decreased from 125 to 100 kWh/month	Considered unlikely
	Ave. load-limited consumption is decreased from 75 to 35 kWh/month	Considered unlikely

Table 6: Change to base-case assumptions for load-limited to be preferred over prepayment option for Loskop case study

The same sensitivity analysis was run for the Mafefe case study, with the exception that the changes were designed to make the prepayment system preferable to the load-limited option. The results are summarised in Table 7. It can be seen that all of the changes are small, and considered possible. Consequently, the result that the load-limited supply option is preferable to the prepayment option is considered extremely sensitive to the main assumptions.

<i>Variable</i>	<i>Change to base case assumptions</i>	<i>Comment</i>
Capital costs	Prepayment capital costs are reduced by 5%	Considered plausible
	Load-limited capital costs are increased by 5%	Considered plausible
Tariff	Prepayment tariff is increased from 25 to 26c/kWh	Considered plausible
	Load-limited tariff is reduced from R10 to R9/month	Considered plausible
Support costs	Prepayment support costs decrease from R23 to R22 per customer per month	Considered plausible
	Load-limited support costs increase from R17.50 to R18.50 per customer per month	Considered plausible
Domestic consumption	Ave. prepayment consumption is increased from 125 to 135 kWh/month	Considered plausible
	Ave. load-limited consumption is increased from 75 to 80 kWh/month	Considered plausible

Table 7: Change to base-case assumptions for prepayment to be preferred over load-limited option for Mafefe case study

It is interesting to note that the financial losses calculated here are less than those estimated by other studies (Davis 1997; Els 1994). This can be explained as a consequence of two factors. Firstly, in the case of Loskop the capital cost per connection is substantially below Eskom's current average of over R3 000 per connection. This is mainly because no 11 kV grid extension was required to reach the community. Secondly, this analysis has included the effect of non-domestic loads, which contribute to the overall revenue. This second effect is significant – in Loskop and Mafefe the NPV is approximately 25% and 15% less (respectively) without business consumption.

It is concluded that the electrification projects sustain financial losses for the implementing utility, whichever technology is used. Where the site is relatively close to the grid, prepayment supplies are the most attractive for the utility, mainly due to the pricing policies which are associated with the different options. Where the site is further from the grid,⁷ other supply options become more competitive.

4.2 The financial effect on users

There are four financial effects which new electricity users experience. Firstly, there are the connection costs. Since these are once-off costs and where the charge is kept to a relatively small amount (in the order of R50), the cost is relatively minor. However, it should be recognised that the very poorest households will find even this a substantial amount to budget for. Secondly, there are the costs of appliances. These can be large, particularly if a wide range of appliances are purchased. Table 9 shows the penetration of appliances in newly electrified households. Although appliance purchases may be thought of as once-off costs, where they are purchased on credit (usually hire-purchase), the financial costs will be spread over an extended period. Thirdly, there is the additional cost of electricity purchases. As the range of appliances in the home expands, and as the use of these appliances grows, so the cost of electricity purchases will increase. Set against electricity costs, there is fourth effect: the reduced expenditure on fuels which are displaced by electricity.

Calculating the financial impact on users is difficult for a number of reasons. As consumption grows and appliance purchases increase, so the additional costs incurred will change over time. Costs in the early years may in fact be relatively high as a household accumulates additional appliances. As consumption grows, monthly expenditure on electricity will grow, taking a larger share of the overall budget. The approach taken here is to present typical costs for the use of individual appliances. The capital costs of appliances are dealt with by amortising them over a three year period, so that an estimate of monthly costs can be calculated. Costs for a range of appliances are shown in Figure 3.

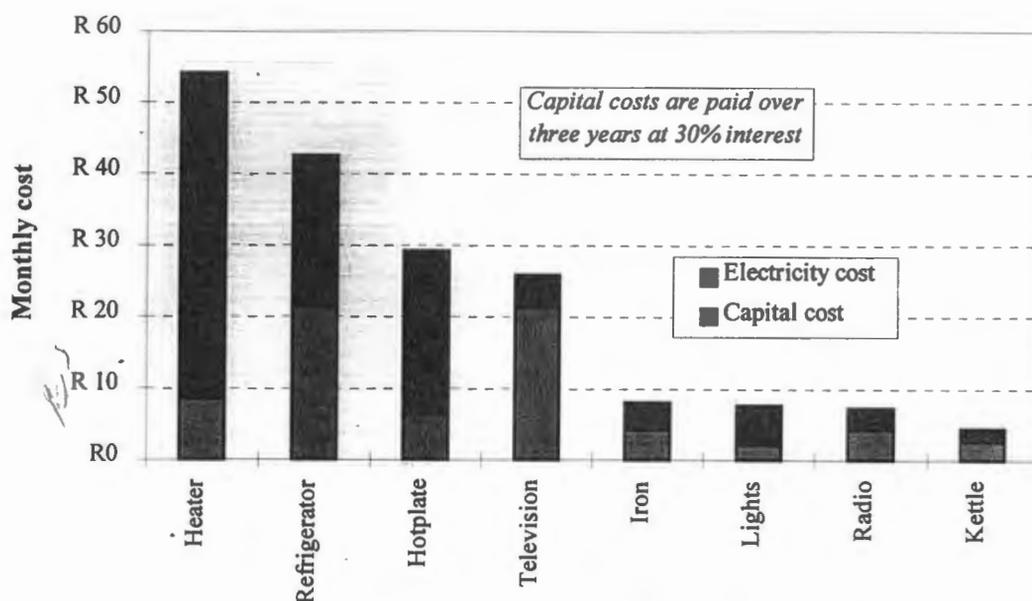


Figure 3: Monthly costs for different appliances

⁷ 'Distance from the grid' is referred to here as the distance from the grid, corrected for settlement size, that is, the distance from the grid divided by the number of households. This parameter incorporates both distance effects as well as settlement size effects.

Heaters, refrigerators, hotplates and television sets are the more expensive appliances, in some cases because of the capital cost (refrigerator and television), and in others due to the electricity costs (heaters and hotplates). Naturally, if a household owns a heater or a hotplate, then controlling the use of that appliance can be a way of limiting electricity costs. This pattern of use is fairly common, particularly for cooking, where a household may purchase a hotplate but continue to use paraffin and wood. Under these circumstances, it is common that electrical appliances are only used when their virtues of convenience and speed are considered important.

Televisions are often one of the first appliances introduced into the newly electrified home. Their popularity can be explained by a number of factors. Although relatively expensive items, households can often afford single large purchases where one member of the family sends remittances from employment in an urban area. In addition, if control over this type of income is in the hands of men, it is possible that expenditure on entertainment will receive a higher priority than expenditure on kitchen appliances. Thirdly, the acquisition of a television brings something completely new into the household, that could not be powered easily before electricity was available. Its value extends beyond the contributions in terms of entertainment and information, and may well assume a symbolic importance in terms of 'modernity' and being in contact with events beyond the immediate locality.

Other common appliances such as irons, lights, radios and kettles are less expensive, from both a capital cost and an electricity cost point of view. Naturally, the cost of lighting will depend on the number of lights, the need for extension cords or other wiring, and the length of time that they are used. Nonetheless, their overall costs are small, much better light quality is provided, and savings on other fuels are significant. This combination of factors explains why electrical lights are almost universally used. It should be noted, however, that in many newly electrified homes, wires are not extended to adjacent rooms or buildings, effectively restricting electrical light to a limited part of the dwelling. This is probably the reason why many electrified households continue to use candles and paraffin for lighting.

The extent of appliance ownership gives some indication of the way in which appliance costs and associated electricity use would impact on the household's budget. In Loskop, ownership of basic appliances is widespread, with the exception of refrigerators and geysers (which require piped water). It should be noted that although hotplates are widely owned, they are used in conjunction with other fuels, notably wood and paraffin.

<i>Appliance</i>	<i>Loskop</i>	<i>Comment</i>
Electrical hotplate	80%	Although widely owned, most households continue to use non-electrical cooking equipment
Kettles	60%	Kettles are used for making tea as well as heating water for bathing
Electric irons	70%	Ironing is done on alternate days. Approximately 30% of households heat solid irons on paraffin stoves.
Televisions	65%	Many television owners had battery operated sets before electricity arrived.
Radios	80%	Many radios are still powered by dry cell batteries.
Electrical heaters	5%?	Only a very few households own single bar heaters.
Refrigerators	33%	Refrigerators are commonly used to store food commodities for sale, such as meat, beer, cold drinks and ice-lollies. Some residents rent out refrigerator space to their neighbours.

Table 8: Appliance ownership in Loskop

Other information on appliance ownership suggests that appliance ownership is strongly related to income, and that the extent of appliance ownership in Loskop is above average. Table 9 shows the ownership of electrical appliances from the SALDRU survey, stratified by income group (Davis & Ward 1995). It can be seen that appliance ownership tends to double with each increase in income group (with the exception of radios, which are widely owned).

	<i>Geyser</i>	<i>Stove</i>	<i>Kettle</i>	<i>Fridge</i>	<i>TV</i>	<i>Radio</i>
Low	0%	10%	12%	12%	19%	79%
Medium	2%	27%	25%	28%	33%	85%
High	8%	53%	45%	65%	67%	91%
Total	5%	37%	32%	43%	47%	87%

Table 9: Appliance ownership for rural electrified households

Savings introduced by displacing other fuels also depend on the range of appliances owned and extent of their use. Electrical lights displace paraffin and candles, and can be expected to introduce savings in the household budget. Where the use of an electrical hotplate displaces collected wood, then electricity introduces a new expense into the household, even though it may have a range of non-financial benefits such as displacing the need to collect wood, shortening meal preparation times, and reducing exposure to smoke from fires. Where electrical hotplates displace paraffin stoves, gas stoves or purchased wood, then savings can be expected. Similarly, running a radio off mains rather than batteries will result in savings, although it is not uncommon that households will continue to use a battery operated 9V radio rather than purchasing a new radio that can run off the mains. Appliances such as televisions and refrigerators introduce new energy services into the home and so will not displace any expenditure (unless a television had been run off a 12V battery prior to electrification).

Quantifying these savings can be difficult, due to the dynamic nature of fuel displacement and the difficulties of measuring the changes. Most data on fuel expenditure does not differentiate between, for example, paraffin used for cooking and paraffin used for lighting. However, examining expenditure patterns before and after electrification can provide some approximation of the overall effects. Unfortunately, this information is not available for the case studies under examination. Instead data from a nationwide survey is used in the analysis below.

Table 10 shows the results of an analysis of energy expenditure of rural households from the SALDRU survey (Davis & Ward 1995). Fuel expenditure patterns of electrified and unelectrified rural households were compared. It was found that, for those using a fuel, there were net savings on non-electrical fuels if a household had electricity. This saving can be expressed as an equivalent electricity cost (taking into account different appliance and use efficiencies), and so the net saving can be calculated. This figure reflects the saving on a fuel as a result of electricity displacing some of its use. It can be seen that savings are largest from the displacement of candles. In addition, displacement of wood, paraffin and batteries generates savings of a similar order of magnitude. Overall, savings on displaced energy are small but significant for low income households – approximately R25 per month. However, when one considers the cost of electricity required to supply these services, the net savings are modest – in the order of R10 per month. If the costs of appliances are considered, then these net savings are removed altogether.

<i>Fuel</i>	<i>Expenditure displaced</i>	<i>Approx electricity equivalent</i>	<i>Net saving</i>	<i>Contribution to total net saving</i>
Candles	R5.15	R0.50	R4.65	38%
Wood	R7.02	R3.50	R3.52	29%
Paraffin	R10.19	R8.00	R2.19	18%
Batteries	R1.84	R0.00	R1.84	15%
Gas	R0.15	R0.05	R0.10	1%
Coal	R0.15	R0.25	(R0.10)	-1%
Total	R24.50	R12.30	R12.20	100%

Table 10: Financial effects of fuel displacement on a rural household

If the additional costs associated with new electrical services are considered – for example the additional expenses associated with television use and other energy services – then the evidence suggests that a household's energy budget is increased as a result of electrification. For example, data from the SALDRU survey, presented in Table 11 shows that total energy expenditure increases after electrification for all income groups examined.

	<i>Monthly fuel expenditure</i>		<i>Fuel expenditure/Total expenditure</i>	
	<i>Electrified</i>	<i>Unelectrified</i>	<i>Electrified</i>	<i>Unelectrified</i>
Low	R50	R30	9.1%	7.1%
Medium	R55	R45	6.3%	6.5%
High	R80	R55	5.1%	5.7%
Total	R65	R40	6.1%	6.4%

Table 11: Overall fuel expenditure

These results are premised on the use of prepayment meters and a straight line tariff. Where a household uses a load-limited supply, with a flat monthly fee of say R10, the results are quite different. As can be seen from Table 10, the displacement of lighting fuels and dry-cell batteries is likely to reduce a household's energy expenditure by possibly R10 per month. This is the same as the assumed monthly charge of R10, and so these households would spend approximately the same amount of money on energy as a result of electrification. Although electricity provides greater convenience and quality, particularly for these limited end-uses, it must be recognised that the poorest households may prefer to use candles and batteries rather than electricity, at least during those periods when cash is especially scarce. The requirement that a flat monthly fee must be paid *every* month will pose additional difficulties for these households, whose survival strategies often rely on very carefully considered allocation of limited and variable cash resources. Since these patterns of allocation are adjusted as a family's cash resources change, the fixed monthly charge for electricity further constrains their survival strategies.

In summary, access to electricity is likely to increase overall fuel costs in a household, particularly where new energy services are introduced, such as television, and where electricity replaces less expensive fuels, such as collected wood or coal. Evidence from the case studies suggests that households carefully weigh up the advantages of the convenience, speed and cleanliness of electricity against its perceived expense. For the poorest of households, which are unlikely to use electricity for a wide range of applications, not least because of the expense of new appliances, electrification will result in net savings to their monthly fuel expenditure only if they are on a prepayment tariff.

5. The economic analysis

The financial analysis of these two electrification projects captures the financial effects, as seen by Eskom. However, there are a range of other costs and benefits experienced by other parties, generally termed external effects. Four types of externalities will be considered here:

- consumers' surplus effects,
- environmental and health effects of greater electricity use,
- multiplier effects of greater electricity use, and
- productivity improvements resulting from higher service levels.

5.1 Defining the externalities⁸

Consumers' surplus

The concept of consumers' surplus embodies a number of important benefits which consumers perceive electricity as bringing. Essentially, the consumers' surplus is the difference between the price a person actually pays (for example, 25 c/kWh) and the amount that person would have been willing to pay for electricity. Generally, a person values the first units of electricity (normally used for lighting) most highly, and incremental units thereafter less highly. Since electricity prices are generally fixed at one level, or decline slowly, there is often a transfer of value to consumers for which they are not paying. Since this represents real economic value, it should, in principle, be included in a cost benefit analysis of electrification.

In practice, measurement of the consumers' surplus is difficult. However, proxies can be usefully employed. Electricity usually displaces more expensive lighting fuels, the price of which is a proxy for consumers' willingness to pay for that service. Consequently, the difference between household fuel expenditure on those services before and after electrification represents part of the consumers' surplus. This corresponds with the area marked B in Figure 4. Likewise, if consumption increases as a result of electrification, then an additional benefit accrues to the consumer (area C in the figure).

The willingness to pay for electricity may be greater than avoided energy expenditure due to the added convenience which electricity provides; that is, the consumers' surplus would be greater than the two components just described. However, these qualitative differences are difficult to calculate.

The methodology described by Davis and Horvei (1994) is used here to calculate the consumers' surplus. It is a function of the unit price paid for displaced fuels, the quantity of fuels displaced, the price of electricity and the consumption of electricity. The areas denoted B and C in Figure 4 represent the consumers' surplus. The area marked A represents the direct financial revenue from electricity consumption.

⁸ This section is adapted from Van Horen and Davis (1996), and this source is acknowledged.

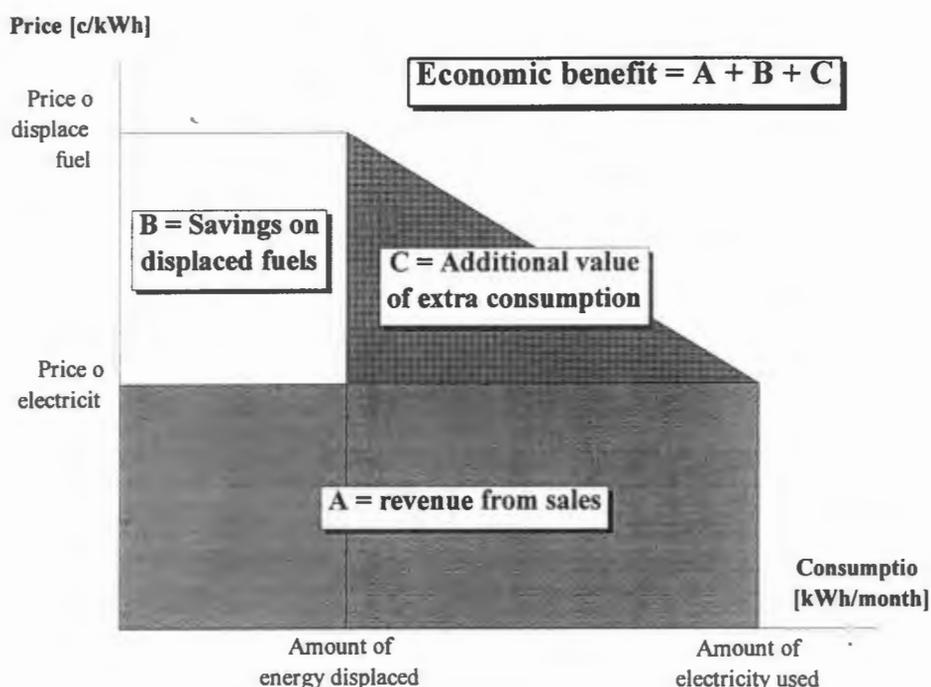


Figure 4: Calculation of consumers' surplus

Although crude, an analysis of the differences in energy consumption and expenditure between electrified and unelectrified households, based on an extensive survey conducted by the Project for Statistics on Living Standards and Development (SALDRU 1995), allows an estimation of urban and rural households' willingness to pay for small amounts of electricity. These results are shown in Table 12. Using this methodology and the data for rural households, it is possible to estimate the consumers' surplus for the electrification projects.

For solar home systems, the consumers' surplus is taken as the same as for load-limited supply options at a monthly consumption of 50 kWh per household. This is equivalent to a willingness to pay of R20 per month. In fact, this estimate is less than the actual willingness to pay, which should reflect those benefits in addition to savings on other fuels. Health and safety factors are considered below, but the priority given to better quality lighting and access to television is difficult to quantify in monetary terms. However, since the same methodology is used for all three technologies – that is, these intangible benefits are excluded in all cases – comparisons between technologies should still be valid.

Energy displaced	Equivalent price		Monthly saving (R/month)
	(kWh/month)	(c/kWh)	
Rural household	60	40	R24
Urban household	70	38	R27

Note: these results are based on an analysis of extensive survey data (SALDRU, 1995). As households use electricity for more end-uses (that is, as energy displaced increases), so the equivalent price decreases.

Table 12: Energy savings in electrified households

Health and environmental benefits of electrification

A range of environmental and health costs arise from the consumption of other forms of energy in unelectrified households. There are likely to be benefits in the form of avoided costs of using non-electric forms of energy. These 'external costs'

include air pollution from coal and wood fires, poisoning in infants who accidentally ingest paraffin, social costs of wood collection in rural areas, and fires and burns caused by candles and paraffin.

These effects can be assessed only with an understanding of fuel-switching processes at the household level. Based on the experience accumulated in the electrification programme to date, there is reasonable clarity about the end-uses for which electricity is the most effective means of satisfying demand. Most important is the fact that the provision of an electricity connection does *not* necessarily lead to the use of electricity for the more energy-intensive end-uses. Rather, the substitution effect is most pronounced for the higher-value services such as powering lights, radios, televisions and small appliances. This is summarised in an aggregated fashion for rural households in Table 13.

Energy service	Electricity supply system			
	None	Off-grid (solar)	Load-limited	Prepayment
Cooking	wood, paraffin, dung	wood, paraffin, dung	wood, paraffin, dung	electricity, wood, paraffin
Space heating	wood	wood	wood	wood
Water heating	wood, paraffin	wood, paraffin	wood, paraffin	wood, paraffin, electricity
Refrigeration	none	none	none	none, electricity
Appliances	none	none	iron, kettle	many
Radio, TV	batteries	solar	electricity	electricity
Lighting	candles, paraffin	solar	electricity	electricity

Table 13: Expected substitution effects of electricity in rural households

The incremental effects of moving from one service level to the next can be summarised as follows:

- *No service to solar system:* electricity will replace the use of candles and paraffin for lighting, and batteries for television and radios.
- *Solar system to load-limited system:* additional electricity use is likely to occur for the use of small appliances such as an iron and possibly a kettle.
- *Load-limited to prepayment system:* the extent of additional electricity use is highly dependent on household income. A certain amount of cooking on electrical stoves is likely, which together with kettles may also be used for water heating. Other appliances are possible. A very small proportion of households is likely to install hot water geysers which will substantially increase electricity consumption and replace other means of water heating.

From this, it is evident that the environmental improvements associated with moving from one level of service to another are fairly modest. Nonetheless, it is possible to make some monetary estimates of the incremental benefits of moving to various service levels, based on a recent economic study of the above externalities (Van Horen 1996). Table 14 summarises the data used in this study regarding the external costs of various environmental effects, as well as estimates of the abatement effect caused by electrification

Externality	External costs (R per h/h p.a.)	Estimate of % abatement		
		Solar	Load-limited	Prepayment
Air pollution: coal	R307	0%	0%	0%
Air pollution: wood	R944	0%	0%	15%
Paraffin poisoning	R90	10%	25%	50%
Fires & burns	R491	25%	35%	50%
Fuelwood collection	R291	0%	0%	10%
Total	R2 123	R132	R194	R461

Table 14: Environmental costs and percentage abatement under various scenarios
(Source: external costs from Van Horen 1996)

These estimates of cost abatements can be used to calculate the additional benefits generated by electrification.

Multiplier effects of electrification, including impacts on small enterprises

A commonly held view is that infrastructure services in general, and electricity in particular, are important contributory factors for the growth of small business and agricultural enterprises. It is frequently stated that electrification is a 'necessary, but not sufficient condition' for economic growth. Efforts to quantify the multiplier effects of electrification, however, are notoriously difficult, mainly because there are many contributory factors to the growth of small enterprises, of which electricity is but one. Clearly, where electrification is accompanied by investments in other necessary infrastructure services such as communications, roads, transport, credit provision, marketing and so on, the benefits from electrification will be significantly enhanced.

Similarly, econometric estimates of the multiplier effects of expenditure on electrification are usually highly generalised and subject to great uncertainty. One of the important results of electrification expenditure is that household expenditure on electrical appliances increases, and this represents a considerable boost to economic activity (Eckert et al 1993).

Notwithstanding this uncertainty, it is clear that the *direction* of change is positive: in particular, economic activity is greatly assisted by the provision of electricity supplies. Based on its experience with the electrification programme since its launch in 1991, Eskom estimates that, for every 100 households which are connected, between 10 and 20 new economic activities are started (Eskom 1996). In addition to the fact that the Loskop experience suggests that this is an optimistic estimate, at least for rural areas, data is not readily available on the average value added by new enterprises, nor on the importance of other factors in contributing to this growth. As a result it is not possible to quantify these effects in monetary terms with any confidence.

In considering the effects of the supply options, it is likely that the provision of any grid electricity (as opposed to off-grid supplies) is likely to have the greatest effect. With grid, it is possible to power appliances such as refrigerators and small motors. For heavier duty applications such as welding or carpentry, however, a higher level of service is required (60A, three-phase). A critical factor in this regard is not so much the level of service in the household itself (that is, load-limited or prepayment), as the capacity for the bulk connection system (that is, the medium-voltage distribution lines and transformers) to accommodate upgraded reticulation systems should those be demanded by even a small percentage of consumers.

For the purpose of this analysis, it can be stated that electrification certainly has a positive effect in terms of growth of small business and agricultural enterprises, but it is not possible to quantify the size of this impact for present purposes.

Improved labour productivity and study conditions

The use of electricity in a household can have several effects on the productivity of inhabitants. Firstly, improved lighting, as well as access to television, brings about

considerable improvements to the quality of the working environment of students and scholars. The ability to study at home, although also dependent on other factors such as the number of people in the household and the number of rooms available, is certainly enhanced through electrification. Secondly, improved lighting and air quality (to the extent that the latter occurs) can also increase the quality of life of inhabitants and this has a positive effect on their productivity in places of employment or income generation.

On the other hand, increased access to electricity and television can also bring about negative effects, such as exposure to advertising and films which encourage the consumption of unhealthy commodities. It has been suggested that consumer demand patterns may change for the worse in terms of their public health effects, and that electrification and consequent increased television viewing can contribute to this (MRC 1995).

The quantification of these effects in economic terms is difficult or impossible. This is not necessarily a problem in this study, however, since some of these effects will already be reflected in consumers' willingness to pay, and are therefore at least partially accounted for in the consumers' surplus. Consumers are aware of the fact that electricity is a superior means of meeting their energy needs than alternatives, and that it is cleaner and less hazardous, and so their willingness to pay already embodies some or all of these effects. The same applies to the improved environmental and health effects of electrification – in the present analysis, these have already been (at least partially) accounted for in the consideration of environmental externalities. It is unlikely that additional benefits over and above those already addressed earlier, would be highly significant in relation to other effects.

5.2 A cost-benefit analysis

Table 15 presents the results of the cost-benefit analysis for the two case studies. The first point that should be noted is that the negative financial net present values have been transformed into positive economic values. This indicates that even if electrification generates losses for the utility, it has fairly high economic rates of return.

In the case of Loskop, it can be seen that the prepayment supply option results in much greater economic benefits than do either of the other two supply options. This can be explained in terms of the additional consumption which prepayment systems allow. This in turn results in greater environmental and health benefits.

Similar results are noted in the case of Mafefe, where it must also be noted that the optimum supply option is no longer the load-limited supply, but the prepayment system. This raises the question as to what conditions make each supply option optimal. This will be considered in Section 6.

	<i>NPV per connection</i>		<i>Total NPV</i>	
	<i>Loskop</i>	<i>Mafefe</i>	<i>Loskop</i>	<i>Mafefe</i>
Prepayment	R3 000	R2 100	R3.1 mill	R1.5 mill
Load-limited	R1 600	R1 000	R1.6 mill	R0.7 mill
Solar systems	(R1 350)	(R1 350)	(R1.4 mill)	(R0.9 mill)

Table 15: Economic net present value of the projects

The comparative economic value of these projects is indicated in the real economic rates of return, which are around 15% in the case of Mafefe, and 30% at Loskop. These rates of return are higher than generally found in many other types of infrastructure investments.

It is instructive to examine the contributions which different cost and benefit elements make to the overall results. Figure 5 shows the results for Mafefe. For prepayment supplies, actual revenue makes up only 40% of the total benefit. The

remainder is made up of the health and environment benefits (a further 40%) and the consumers' surplus (15%). The benefits of avoiding the cost of more expensive solar installations at schools and clinics accounts for only a small proportion of the total benefit. In the case of load-limited supplies and solar systems, the consumers' surplus is the largest contributor to total benefit, and this is largely because the actual prices charged are significantly below the estimated willingness to pay.

It can be seen that the health and environment benefits, together with the actual revenue received, are much greater for prepayment supplies, and this is what makes this supply option optimal from an economic perspective.

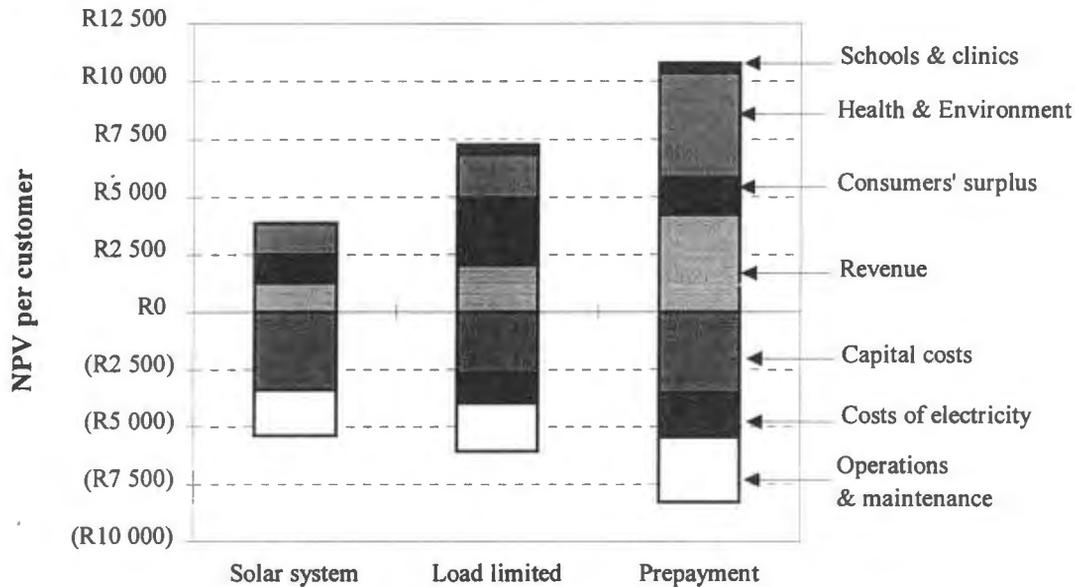


Figure 5: Cost and benefit elements

6. Conditions for optimum supply option

The financial analysis from the utility's perspective has indicated that the optimum option for the two case studies, taking into account all capital and operating costs, as well as all revenues, is either the prepayment supply (in the case of Loskop) or the solar home system option (in the case of Mafefe). However, the economic analysis has shown that the prepayment system generates the greatest net economic benefit in both cases. It is instructive to vary some of the main variables in order to understand the conditions under which each supply option is the most viable. The two variables which are examined here are (1) distance from the existing grid and (2) domestic consumption. Each variable will be normalised against the number of household connections to account for scale effects, that is, the distance from the grid *per connection*, and the consumption *per household* will be used.

The analysis can be performed from both a financial and an economic point of view. The former identifies the technology which will minimise losses for Eskom, and these results will be influenced by the pricing policy adopted. It should be noted that the same pricing policy has been adopted for solar home systems and load-limited supplies. This means that the choice between these two technologies is based on cost considerations only. Adopting different pricing policies for these two technologies will naturally affect the results. The economic perspective looks at the supply option that will maximise overall net benefits, and will not be influenced by pricing policy. Both perspectives are presented below. For the sake of simplicity, only the Mafefe case is examined here.

6.1 The optimum option from the utility's perspective

Figure 6 shows the optimum supply option, from a financial perspective, as a function of distance from the grid and domestic consumption. It can be seen that the option of a full supply with a prepayment meter is the preferred option where the average expected consumption is more than 150 kWh/month, unless the grid is relatively far away (over 30 km in the case of Mafefe). The option of 50 Wp solar home systems is preferred where the grid is further away, or where consumption is low. Load-limited supplies only appear to be viable where the distance from the grid is short, and where the average consumption is not expected to grow much beyond 100-150 kWh/month. Despite this limitation, it is highly likely that there are a large number of rural settlements which will fall into the category where load-limited supplies are the optimum option for the utility.

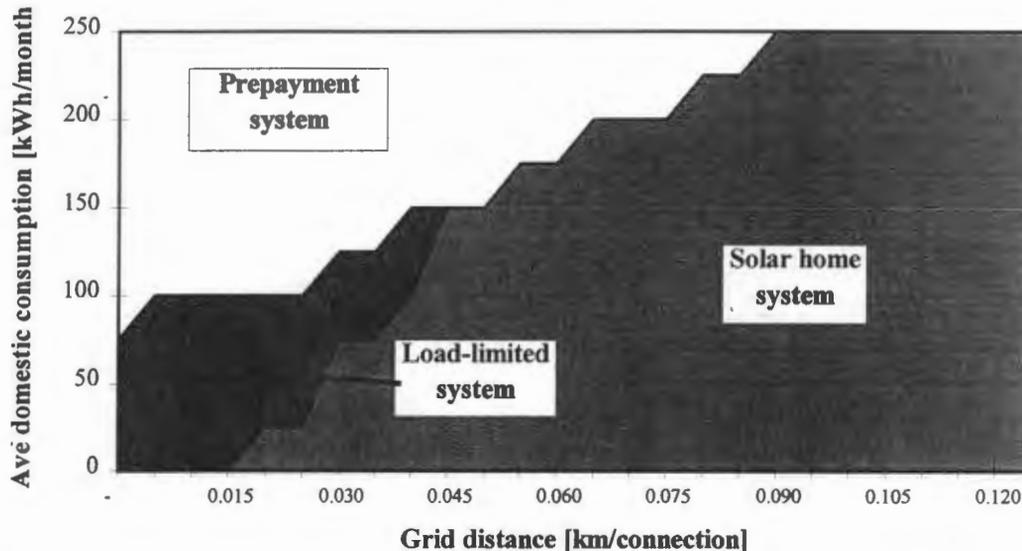


Figure 6: Optimum supply from a financial perspective (using Mafefe data)
Multiply grid distance by 690 to get actual distance for Mafefe

6.2 The optimum option from an economic perspective

The above analysis can be repeated from an economic perspective. Figure 7 shows the optimal supply choice if the two parameters domestic consumption and distance from the grid are varied. If this result is compared with Figure 6, it can be seen that choosing the supply option from this perspective tends to disfavour load-limited and off-grid systems, which bring only limited external benefits to the household and community. In fact, load-limited systems can be considered as economically optimal in only a very small niche – where average consumption is less than 75 kWh/month and where the distance from the grid is less than 150 m per connection. Prepayment systems become viable at lower consumption levels and greater distances from the grid, and this can be understood in terms of the greater benefits which prepayment systems have compared with other options.

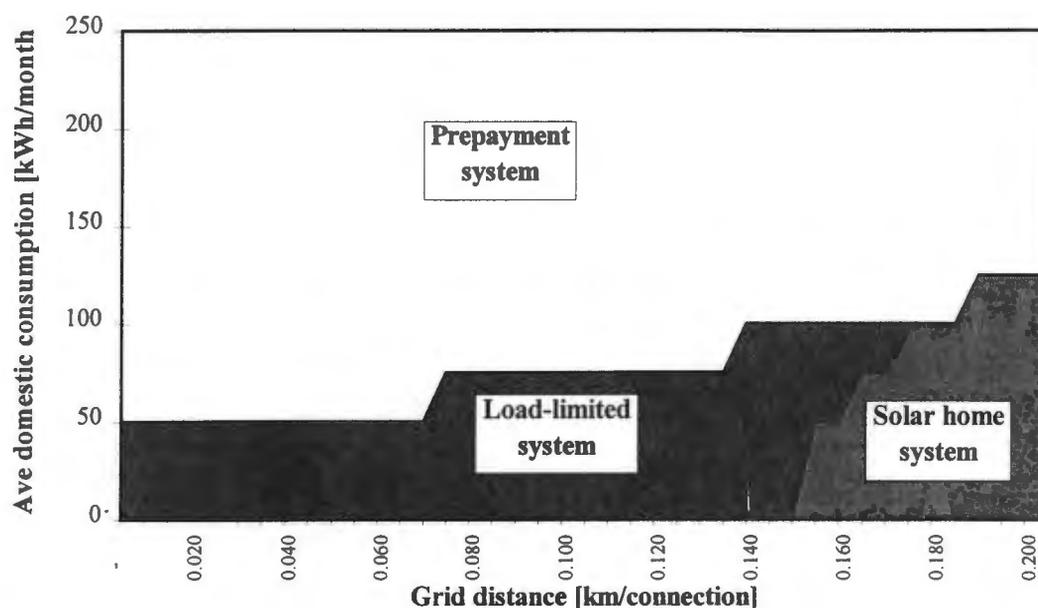


Figure 7: Optimum supply from an economic perspective (using Mafefe data)
 Multiply grid distance by 690 to get actual distance for Mafefe
 Note: X-axis scales are different from Figure 6

7. Conclusions

This paper has presented the results of a financial and economic analysis of two electrification projects. Unfortunately, the lack of certain data elements, together with the fact that neither of the sites have had electricity for long, has meant that certain assumptions have had to be made, and in some instances generic rather than specific information has been used. This has meant that certain parts of the analysis have had to be rather general, and it is hoped that as more information becomes available, the analysis can be refined.

In addition to reporting on the financial and economic consequences of these two sites, the analysis has attempted to generalise the results by looking at the conditions under which different technologies become preferable from both a financial and an economic point of view. The two critical variables used have been distance from the grid and domestic consumption (both normalised to take account of settlement size). Variables not considered have included the size of non-domestic load and the pricing policies used. Both of these will influence the results, although it should be noted that the size of non-domestic load will only affect the choice of grid vs. off-grid, not the choice of prepayment vs. load-limited, since it is assumed that non-domestic load is never supplied with load-limits. Also, changes to pricing policies and tariff levels will affect the financial but not the economic results. It should be noted that the results reported in this study are indicative only and do not represent the results of a comprehensive techno-economic study of the technology choices at stake – this is a much larger study and it is hoped that this report will stimulate the discussion leading to such a study.

The analysis of these case studies confirm the results of other work that electrification results in financial losses for the utility. However, most studies to date (Davis 1997; Nees 1993; Els 1994) have looked solely at the effects of household electrification. It is important to note that the size of these losses is reduced by 15-25% when non-domestic loads are included in the analysis. If productive uses of electricity can be encouraged, this will have a beneficial effect on the financial performance of electrification projects.

Despite the financial losses due to electrification, it is apparent that there are external benefits which are not captured by the prices paid. In particular, there are

substantial health and safety benefits, as well as a consumers' surplus, which add substantially to the estimation of the total benefit. Although fairly general assumptions and national averages have had to be used in this analysis, the results indicate that fairly good economic returns can be expected from electrification. Since the multiplier effects associated with electrification (both backward and forward linkages) have not been quantified in this exercise, it must be concluded that the results obtained are a conservative estimate.

Lastly, this analysis has provided some insight into the optimal choice of technology for electrification projects. Although the niche identified for load-limited supplies is quite limited, it must be acknowledged that there will probably be many potential projects which fall into this category. However, the savings assumed in the analysis relate to savings in operating costs as well as capital costs, and it is not yet certain that these savings will actually be realised. If the option of load-limited supplies implies overheads that are just as expensive as prepayment supply, then this technology will be far less attractive. As is to be expected, solar home systems are most attractive where distances from the grid are large, communities are small, and consumption is low. The analysis has attached some figures to this conclusion, as shown in Figure 6.

Approaching the issue of technology choice from an economic rather than a financial perspective provides different results. It is to be expected that more versatile supplies provide greater economic benefits, and the results reflect this. Effectively, this further constrains the conditions under which load-limited and off-grid supplies become attractive. It must be stressed that these results do not represent a comprehensive techno-economic study into technology choice, but merely provide some indicators of the likely outcome, based on case study experience.

From the user's perspective, access to electricity is likely to result in increased energy expenditure. Although some savings are realised through the displacement of more expensive fuels by electricity, these are more than balanced by the increase in commercial energy used in the home. This result is in agreement with qualitative observations that households carefully weigh up the expense of electricity against the value of the service that it provides. Households appear willing to pay more money for greater convenience, quality and the use of new energy services in the home. In the case of the poorest households on a prepayment meter, where electricity use is restricted to a very few applications, electrification is likely to result in actual financial savings on a monthly basis. These households are heavily subsidised by the prepayment meter tariff structure. However, the use of a load-limited supply and fixed monthly tariff (and it must be recognised that load-limits are directed at these households), is likely to impose an additional financial burden on them, as well as restricting the coping strategies used by these households during times of particular financial stress.

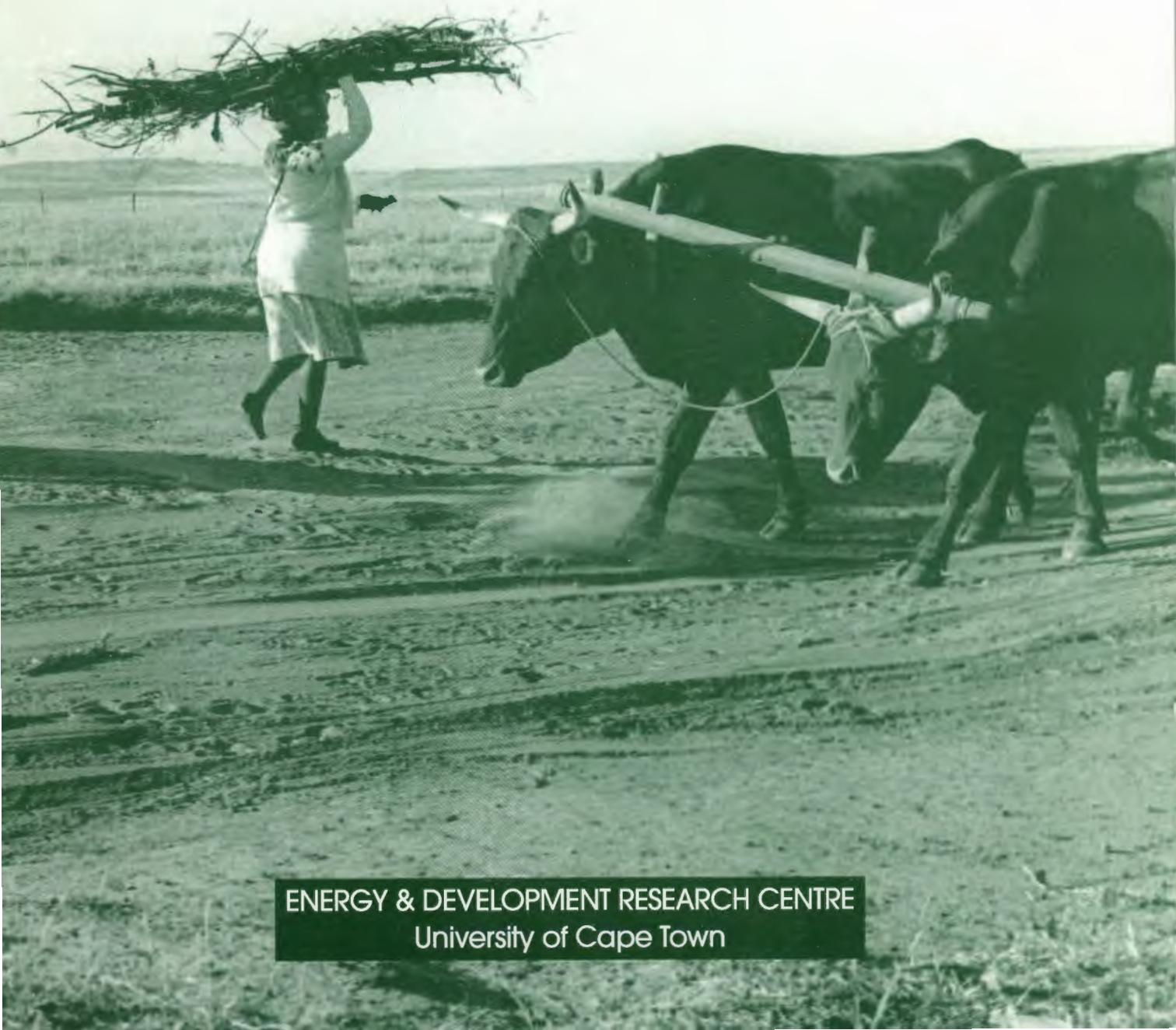
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