Efficacy of solar power units for small-scale businesses in a remote rural area, South Africa

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Abstract

Much work has considered the practicalities and affordability of solar systems for domestic energy supplies in remote rural areas. There is less understanding of its utility for small-scale business enterprises in such areas. We examined the patterns of use of two 12 V and one 24 V systems for small-scale enterprises housed in transportable containers. Monitoring of load shed and top of charge indicated that the 12 V systems were inadequate to meet the requirements of the enterprises. The 24 V operation performed a lot better. Despite some technical limitations the system offered a number of social, economic and environmental positives; primarily the offering of business products not otherwise available in the area, incomes to the entrepreneurs and greater connectivity with regional centres through office services such as cell-phone charging and faxing. Customers of the small-scale enterprises felt that their presence in the area saved them some money because they no longer had to travel as frequently to regional urban centres.

1. Introduction

The turn of the twenty first century has seen the world's human energy consumption at its highest point [1]. It has been argued that history reflects a relevant correlation between changes in energy use and advances in human welfare [2]. Whether this is the case or not, it is clear that the general opinion on energy relations in our modern world sees a positive link between energy and socio-economic well being [3], thus, the importance of energy to the continuation of human development cannot be understated.

The increasing human population coupled with the enlarged energy demands of the modern lifestyle have led to what is now a challenging period in energy planning to meet sustainable development needs [4]. Most modern methods of energy production in widespread use are known to have significant adverse effects on the environment [5]. Global climate change, air pollution and other primary and secondary effects associated with the production of energy have raised global concern on the subject of energy production [6]. According to the World Health Organization [7] as many as 160,000 people die each year from the side-effects of climate change. Side-effects range from malaria to malnutrition and diarrhea that follow in the wake of floods, droughts and warmer temperatures. In light of this, the fact that fossil fuels are providing almost 80% of the global energy demands provides cause for concern [8]. Atmospheric releases from fossil fuels comprised 64% of global anthropogenic carbon dioxide emissions from 1850 to 1990 [2]. Environmental issues aside, declining oil reserves and the dwindling supply of other non-renewable energy sources have added further incentive to find sustainable solutions [1].

However, such solutions would need to meet the requirements of growing populations in many regions, growing economies and increasing energy consumption per capita. Najam and Clevelend [2] demonstrated a clear relationship between the quantity of energy a nation uses and the size of its economy, although energy efficiency is increasingly important. In a predominantly capitalist world, development is seen as not only desirable but also essential. Energy is also central to the achievement of the Millennium Development Goals, particularly in terms of reducing poverty and ensuring environmental sustainability [9]. "*The development challenge in the energy sector is to promote access while simultaneously making a transition to a cleaner energy future*" [3]. The notion of sustainability should include socio-economic as well as environmental elements.

The challenges surrounding the supply of sustainable electricity are especially difficult for developing nations. A lack of resources, infrastructure and general poor living standards of the majority of the population make increasing the supply of, and access to, electricity problematic. In most of sub-Saharan Africa only 10–30% of rural areas have access to electricity [3]. Even where electricity is available, the large size of many sub-Saharan countries and the expense of electricity frequently limit its distribution to much of the rural population. Renewable small-scale energy production methods, such as solar and wind power, are deemed to be increasingly attractive alternatives to aid in the development of rural areas [10] and [11].

Solar energy has been hailed by some as the answer to the rural poverty and environmental problems experienced in the less developed world [1]. Its increasing utility is evident with the world market for photovoltaics (PV) growing by approximately 33% per year between 1997 and 2006 [12]. Developing countries such as Kenya have carried out successful solar rural electrification programmes which were largely based on market forces [13]. Other programmes being implemented in many sub-Saharan countries such as Zambia, Zimbabwe and Tanzania have yielded mixed results with recipients complaining of frequent load shedding because of either inadequate panel size or insufficient battery capacity [14]. Most of these dealt with the provision of renewable energy for domestic households. In South Africa, several rural solar energy supply projects have set up since 1994. Estimates in 2003 found more than three million rural households to be without access to electricity [15]. The 2002 South African White Paper on the promotion of renewable energy and clean energy development has been a key step towards incorporating sustainable energy production and making the service available to rural communities [16] and [17]. As with other countries, most attention has been focused on providing electricity for domestic, educational or agricultural purposes. However, there is also a need to supply electricity for rural businesses. The instalment of business infrastructure can potentially act as a development catalyst in rural areas [17]. This important aspect of rural electrification is often omitted in solar electrification programmes [13] and [14]. The productive use container (PUC) project, which is the focus of this study, is an initiative aimed to promote access to electricity for commercial services in remote rural areas.

1.1. Productive use container (PUC) project

The PUC project involves the conversion of standard shipping containers into solar-powered business centers. The container (Fig. 1) was exhibited at World Summit on Sustainable Development in Johannesburg in 2002, and has since been implemented on a small scale [18].

Fig. 1. Operational PUC unit.

The pilot phase consists of six container units that support businesses which are run by local entrepreneurs. The containers are powered by 10 panels which produce a 220 V AC output. The structures are designed to accommodate 12 panels, leaving the option of increasing electricity generation capacity if necessary [19]. The solar panels charge deep cycle lead acid batteries which then relay the electricity to the business devices. These batteries need to be regularly fully charged in order to maintain long term function. There are two system sizes currently being used, a large 24 V system and a smaller 12 V system. These have different capacities and characteristics which make up a part of this study.

The number of businesses differs between the PUCs with some being a cooperative business (e.g. sewing) with a number of members, and other PUCs consisting of a range of different smaller businesses. The shops are occupied by a range of services which include food & catering, office support services (e.g. faxing, word processing, photocopying), leatherwork, sewing, women's boutiques, energy stores, laundry services and hair dressers. Part of the programme includes providing the entrepreneurs with training both in business practice and solar technology [19]. The electricity used is paid for by the entrepreneurs to the agency responsible for the provision and maintenance of the PUC.

This project sought to evaluate the pilot phase project with respect to the practicality of the PUC system, identify benefits and limitations, and suggest possible improvements.

2. Study area

A total of six PUC containers have been set up in northern KwaZulu-Natal, in the two north-eastern district councils of Uthungulu and Umkhanyakuda. Most of the sites are located in areas which are currently not part of the national electricity supply grid. Both districts have largely rural populations (>75 %), with high unemployment rates (approx 30 %). Education levels are low, with about one-third of adults having no schooling at all. Cash incomes from employment are limited due to the low skills base, and most households rely on state grants and remittances from urban areas, along with small-scale livestock husbandry, arable agriculture and collection of key resources from the wild (such as fire wood, construction timber and medicinal plants). Local energy sources consist mainly of paraffin, wood, candles and dry cell batteries [20].

3. Methods

The study included direct electrical monitoring of the PUC systems and a questionnaire survey of the PUC-based entrepreneurs and their clients.

3.1. Electrical monitoring

Three PUCs were monitored over a period of 140 days. The PUCs were selected to include a range of conditions with two sewing co-operatives (Mkhuze & Mduda) and one multi-industry

PUC (Hlabisa) being analysed. The Hlabisa system was a 24 V system while the others were both 12 V. Data loggers were used to record daily trends in battery voltage and inverter use. Battery voltage was of particular importance when monitoring when and for how long the system went into load shed and reached top of charge. Load shed provides an indication of overuse of the system; it is caused by the charge controller which reacts to excess use by temporarily shutting down the system. If reached too frequently it can damage the battery, and shorten its life span. The evaluation of battery health is further supported by monitoring the top of charge readings. Top of charge occurs when the battery reaches its full capacity and signifies a period where more energy is produced than is being used. The exact maximum value will differ between the two system sizes but the frequency and time of day that top of charge is reached is comparable. Solar systems should reach top of charge relatively frequently in order to maintain a healthy battery. Both load shed and top of charge patterns were analysed for frequency and daily trends. The data from these analyses were used to determine whether the system was over-or/under-sized and used optimally. Use patterns were monitored by observing the current output on the inverters. Values of maximum current, time used and daily trends were monitored. Daily fluctuations in the use patterns as well as the above variables were compared graphically. Comparisons between the 12 V and 24 V systems were made with regards to all of the variables.

The electrical monitoring data have been presented using histograms for different periods of the day, each of equal duration, i.e. 4 h and 48 min (i) pre-dawn (00:00–04:48) (ii) morning (04:49–09:36) (iii) midday (09:37–14:24) (iv) afternoon (14:25–19:12) and (v) night (19:13–23: 39). The electrical data sample size was limited by resources and logistics. There were only two data loggers available, which limited the data that could be collected at one time. The large distances between PUCs and technical nature of the data-logger installation meant that the study was limited to only three of the six containers. The load-shed trends themselves have the potential to be misleading as load shed can also occur when users have not paid for the electricity. Periods like this were assumed to have lasted at least one day and so any load-shed data spanning 24 h or more was omitted in the analysis. Despite this there is still the possibility that some of the recorded load-shed periods attributed to overuse are due to lack of payment. It was also assumed that as the period of sampling falls within the winter season, energy production values can be taken as belonging to the lower end of the annual spectrum. Any problems identified with the system not coping may be restricted to the low light conditions of the year, but as such represents a real test of the needs and efficacy of the systems at this critical threshold period of the year. The selected sampling period provides a stern examination of the PUC's capabilities.

3.2. Interviews

All of the business entrepreneurs currently operating in the PUC project (17) were interviewed. The main themes of the interview were to ascertain the (i) most common energy use, (ii) reasons for particular choice of business enterprise, (iii) choice of business by the entrepreneurs, and (iv) the reliability, adequacy and limitations of the system.

The interviews with the business clients aimed at identifying the benefits and limitations of the PUCs from a consumer's perspective. Five interviews were conducted for each business per PUC resulting in 75 interviews. The questionnaires sought to investigate the reliability of services provided by the PUC. The most desirable services were also identified, incorporating both services that are currently available and those that clients would like to have on offer. This provided an idea of local demand and possible future requirements regarding the performance of the PUCs.

4. Results

4.1. Energy production and use trends

There were no load-shed events for the 24 V Hlabisa system. The other two systems both experienced high numbers of load-shed incidents; 80% of monitoring days at Mkhuze and 44% at Mduda. It can be seen that the pre-dawn incidences of load shed are very high (Fig. 2). This indicates that appliances are being left on overnight or being used during the dark. Without sunlight to charge the battery it loses charge for the most part in the early pre-dawn period. The incidences of load shedding during the day could be due to overcast conditions, leading to insufficient solar energy being generated. The questionnaire data for Mkhuze supports the fact that load shed has occurred, but only an average of four blackouts per month are reported, whereas the datalogger information shows that it is much higher. The questionnaire data for the Hlabisa system supports the electrical information with no incidences of load shed being reported.

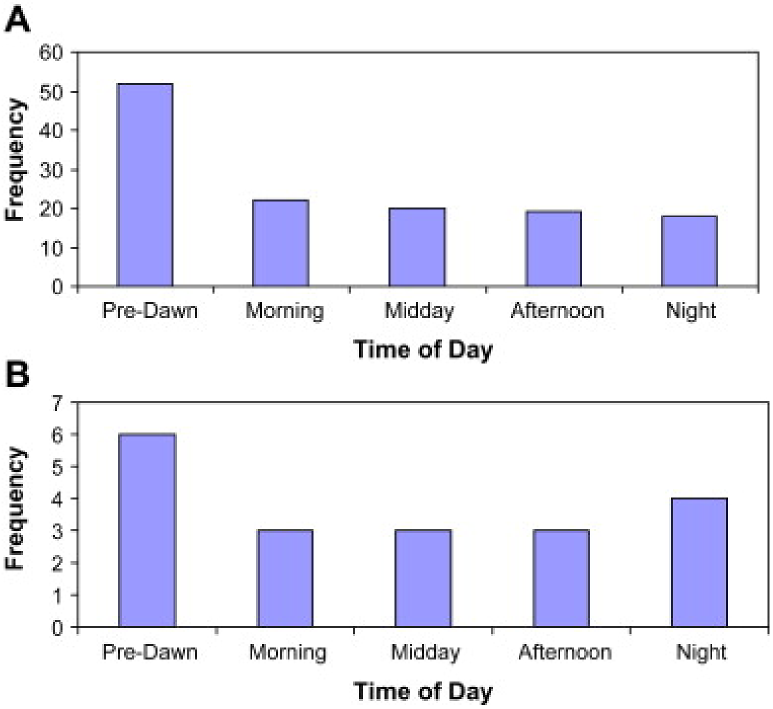

Fig. 2. Load-shed patterns for 12 V systems (A) Mkhuze and (B) Mduda.

The load-shed trends are explained by the use patterns (Fig. 3), which demonstrates that although systems are predominantly used during sunlight hours there is an element of use at night. This is especially applicable to the 12 V systems, resulting in load shed in the pre-dawn hours. The dark hours use at the Hlabisa system remains relatively consistent and could probably be attributed to the fridge (PV freezer) that was reported to be left on at night by the tuck-shop owner (a tuck shop is a small retail shop with flexible hours selling common food items and household consumables, such as bread, matches, soap, cool drinks). The sewing cooperatives are obviously also operating at night and are consequently putting too much pressure on the batteries. Interestingly, the questionnaire data reveals a contradiction with all operatives stating that they do not leave appliances on at night. The high midday and afternoon use frequencies are good as those are the hours of maximum solar production and probably correlate well with peak customer times. Ideally, usage at pre-dawn and night hours should be kept to a minimum.

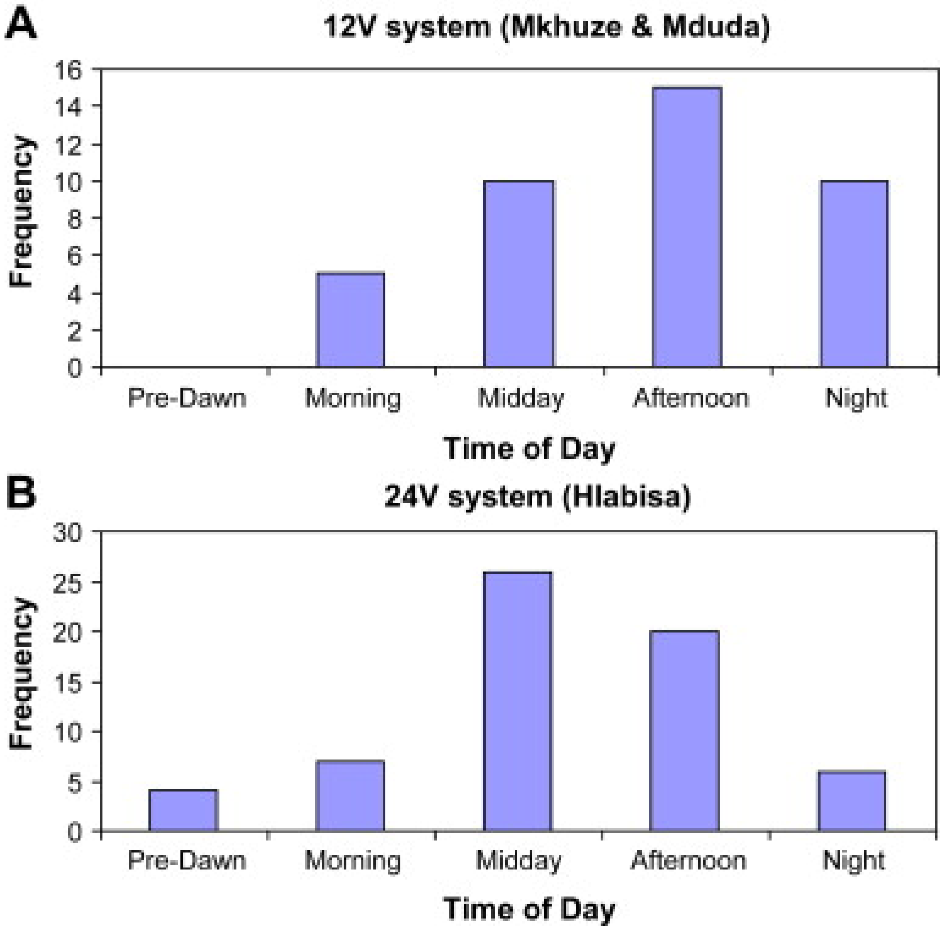

Fig. 3. Daily appliance use patterns of the (A) 12 V and (B) 24 V PUCs.

4.2. Top of charge

The load shed and use patterns (Fig. 2 and Fig. 3) indicate overuse with regards to the 12 V systems. This result is further backed up by readings of top of charge, which was only attained on 14% and 24% of days for Mkhuze and Mduda, respectively. The Hlabisa system reached top of charge on 28% of the days measured. The ideal percentage of top of charge values should be about 50%. Even the larger 24 V system doesn't come close to attaining this figure. These results further support the suggestion that the 12 V cooperatives, and Mkhuze in particular, are facing problems. When top of charge has been reached it has occurred predominantly around midday (Fig. 4). This is natural as that is the point when the solar energy is at its highest. Battery life is a crucial part of the solar system, the importance of maintaining it is revisited in the discussion.

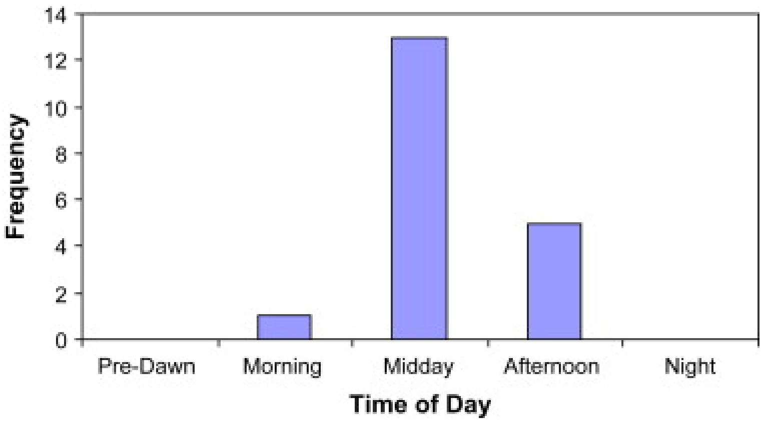

Fig. 4. Top of charge frequencies for all systems

4.3. Common use of energy

The nature of most (79%) of the businesses had been established in response to local demand. Sewing was the most commonly found business being present in all PUCs, followed by the office support services enterprise. This is interesting given the high energy usage displayed by the sewing cooperatives in the electrical data (Fig. 2 and Fig. 3). The high power requirements are obviously out-weighed by the local demand for the industry. Extra services (such as dry cleaning, computer training and a cinema) were requested by 57% of the clients interviewed but from the high number of, and variation in these requests, it can be concluded that there are no clear services of high demand not already represented in the PUCs. This also relates to the accessibility of similar, and usually cheaper, services in larger centres which residents visit every month or two. We expect that demand for PUC-based services would be higher in more remote areas.

4.4. Benefits

The PUC system has overall been very well received by the clients that use it. All of the people interviewed, both clients and operators, saw it as a positive development and were very enthusiastic. When asked how far away these services were previously available 71% of clients responded that they used to travel much further, usually 20–30 km. In this capacity the PUCs acted as valuable social centres; informal meeting spots that could serve to strengthen social ties. The provision of basic electrical services such as cell-phone chargers, word processing, printing and faxing serve to uplift resources of these remote areas. An unexpected benefit highlighted in the literature was that of increased connectivity [15]. The cell-phone charging and telephone facilities have provided a means for communities to strengthen connections both within and external to the immediate area, thus strengthening family networks and building social capital.

The systems have also been of benefit to the entrepreneurs, providing an average monthly income of R842 (±309). Tuck shops were found to be the most lucrative enterprises followed by office support services and then the popular sewing industry coming in at third highest. Most of the money spent at the PUCs would previously have been lost from the immediate rural economy, a fact which adds to their importance in raising rural standards.

4.5. Practical limitations

The most obvious and arguably most pressing limitation revealed is that of the 12 V cooperatives. As mentioned before, the gap between 24 V and 12 V systems was significant. The 12 V systems are clearly being over utilised. From the operator questionnaire data 82% of the respondents felt that the system would not be able to handle an upgrade to additional or more powerful appliances. The electrical data, especially for the 12 V systems supports this. However, certain systems might have been overloaded as other systems within the PUC may not have had charge credit?

Another limitation of this and many other solar systems is that after dark hours are not available for regular work. This could limit the productivity of the entrepreneurs and also lowers the number of business options that can be run in a PUC. This point is discussed later.

One of the limitations with regards to the 24 V Hlabisa system is the fact that the actions of one can impact on the whole PUC. If, for example, the sewing business uses too much power it could lead to load shed and a disruption of the other businesses activities. The Hlabisa system did not enter into load shed but this could potentially be a problem if higher demands are placed on it. The 12 V systems are definitely unsuitable for multi-business PUC's.

5. Discussion

The PUC project, as shown by the results, has a few problems requiring attention, with the main concern being the high frequency of load shed and insufficient frequency of top of charge conditions. One of the most vital aspects of a solar system is the battery [4]. Prolonging its life span is one of the major factors in determining success of rural solar electrification [12]. A study conducted in Ghana cited battery capacity as one of the main limitations of the solar systems [13]. The overnight night use trends observed at Mkhuze and Mduda (Fig. 2) need to be limited for the project to be viable. The contradictory questionnaire data stating a far fewer number of blackouts could be put down to misinformation by informants, or perhaps an energy leak somewhere in the system that causes evening shutdown. The former is more likely as such a leak would probably mean a load-shed occurrence every day. The long term performance of the PUC system is yet to be seen, but clearly its advantages would be significantly diminished if it is not operated to optimum efficiency. It is clear that attention must be given to maintaining the batteries in order to reap more of the benefits.

The inability of the 12 V systems to provide power at night could take away some of the potential benefits of electricity to the users. Many of the studies involving home-based solar systems have found that one of their major economic advantages was being able to work at night [13]. Studies in Zambia, Zimbabwe, and Kenya have shown that indoor activities, such as weaving, were one of the main economic benefits arising from the instalment of solar systems [21]. However, in the Zambian example the same link was found between night usage and poor performance with a reported 61% of the systems having problems with power supply [14]. It seems to be the case that smaller solar systems cannot be used effectively at night which reduces some of their advantages. The 12 V PUC system might not be a home-based system but any work that the entrepreneurs might have wanted to do at night is no longer an option.

Despite these limitations the PUC project provides some benefits to the users and area. This system brings with it a combination of social, economic and environmental positives which could serve as a foundation for encouraging further sustainable development [2]. Aspects, such as the increased connectivity with cell-phone charging facilities are advantages which are not initially very obvious. This particular aspect has also been seen in rural Kenya [13], and there is no reason why it should not apply in other rural settings. The strengthening of social ties resulting from this can do much to benefit the community. On the down side, for the poor rural dweller it means factoring in the added expense of cellular credit.

The availability of local electricity has previously been linked to enhancing literary and education levels [22]. To apply this to the PUC project is plausible, with reference in particular to the office support services that are available. With this communities have localized access to word processing and printing services amongst others. These might well serve to uplift the levels of computer literacy. The provision of electricity in rural areas has even been said to alleviate one of the problems faced by modern cities – rural to urban migration [4]. It is argued that the increased number of services available and enhanced quality of life provide more of an incentive to remain in a rural setting.

The application of solar energy in rural areas is only viable if the costs of on-grid power is either more expensive or the difference is negligible. Rural areas, especially in Southern Africa, are characterized by a widely dispersed layout [21]. In these conditions the PUC system has the advantage as no power grid infrastructure is required. The mobile nature of the shipping containers is such that centers can be established with relative ease, and for a much lower cost than if the grid was extended. The big 24 V systems cost approximately R42,000 including installation, R7000 more than the 12 V systems. The costs of extending the national grid to the extreme rural setting may well increase the merit of the PUC scheme. It is also ideal to make sure that any future PUC instalments are targeted to areas where there is both a demand for the services offered and the economic ability to purchase them.

The PUC project provides a positive means of introducing electrical services to the dispersed rural areas. Most other rural solar projects are based on solar home systems [12] and [14]. The focus on business opportunities makes the PUC model one of the few to target this niche. The PUC concept enables the provision of services which are vital in the eventual improvement of rural living standards. Developing nations will be hard pressed to meet the Millennium Development Goals (MDGs) without major improvement in the quality and quantity of energy services [3]. The PUC project provides the opportunity to take some real steps toward achieving these goals in rural areas. Even goals such as the empowerment of women are affected with 75% of PUC business being run by females.

5.1. Possible improvements

The PUC project has a lot of potential, with a few modifications it could become a real option for large scale rural application. The 24 V system performed markedly better than the 12 V system, and consequently upgrading all PUCs to a 24 V capacity would ensure that many of the load shed and top of charge problems are lessened.

Another possibility is to put more emphasis on best practice in the training programs. Management is one of the major flaws of solar projects [16]. The long term damage caused by bad practice may be quite an abstract concept to some rural entrepreneurs. The management training program needs to find ways of conveying the importance of managing use of the system. If this fails then perhaps the system can be programmed to be stricter in terms of night time use. For example if it could be tuned to permit a certain minimal level of electricity (e.g. fridges) but shutdown quickly if more is drawn. More research also needs to be done on the electrical appliances themselves. If specific energy saving appliances could be provided it might do much to reduce demand on the system. Additionally, some feedback to the users on the demand of specific appliances will increase awareness of how to improve practices to maintain charge when most needed.

Overall, our study has shown that there are number of benefits from the PUC system, but in common with most domestic orientated solar systems, there are some problems that need to be addressed. One of the most successful solar rural programs in the world is found in Kenya [13]. This stands out from other countries particularly because the drive for rural solar electrification was market based and not solely externally engineered [21]. If a way could be found to turn market forces into one of the main drivers regarding the expansion of the PUC project, it has real potential to succeed.

Acknowledgements

This work is dedicated to Doug Banks who tragically passed away in early July 2008; a significant loss of a brilliant mind and advocate of renewable energy in South Africa.

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