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With time comes increased loads—An analysis of solar home system use in Lundazi, Zambia

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Abstract

Solar energy can bring a number of electric services to the user but also puts up a number of limitations in terms of usage. The design of the system will affect the output from the system as well as the technical life. This article is based on a case-study of a photovoltaic-Energy Service Company (PV–ESCO) project company in Lundazi, Zambia. The solar technology has enabled clients to improve light quality in their houses or shops, which is the most valued benefit according to clients. Clients to the ESCO have acquired a number of electric appliances since they received the service. Radio cassette players are commonly found in households both with and without solar services, while TV sets has been acquired first after they have received this service. To the clients the solar services have resulted in an improvement of the living standards. Energy use and charge was logged during a six-month period. Average usage range from 10 to 14 Ah/day. The load is concentrated to mornings and evenings, but the possibility to access energy services, such as light during the night, is appreciated by the clients. The average energy output from the solar module is 14.5 Ah/day. Increased panel effect, change of the cutting points of the regulator and improve the users knowledge on proper operation of the system are options to tackle the situation of increased loads put on the system.

Keywords: Solar home system; Rural electrification; ESCO; Energy use; Zambia

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1. Introduction

Stand-alone solar photovoltaic (PV) systems have been used in numerous rural electrification projects in Sub-Saharan Africa, for example Zimbabwe [1,2], Ghana [3], Senegal [4] and Mali [5]. Kenya has the largest numbers of systems installed [6], while South Africa has one of the most ambitious national projects in Africa. A steady reduction of the cost per installed Wp has taken place, which can be traced to a reduction of cost of the panel (Table 1). Even though solar PV technology was applied in various development projects in the late 70s it was not until the early 90s that more widespread use of the technology was started.

Typical systems found in solar PV projects consist of a solar PV module, a battery and a regulator that controls the charging and discharging of the battery. It is common that a set of light points are part of the system. The technical specifications are normally based on delivering basic energy services, which typically involve 2–3 h of light and the possibility to watch 1–2 h of television (TV) and listening to music. A system like this is often referred to as solar home system (SHS).

Experience from a decade of solar diffusion has shown that projects involving good-quality components have been more successful in creating a business than those aiming at supplying low-cost systems [18]. One reason is that people are less willing to pay if the systems are not delivering the suggested services. As a result, solar modules and regulators found in most projects involving diffusion of solar systems have been field tested and are durable components. In most solar projects funded with aid or government money, the standards of the equipment is fairly good as a consequence of historical experience with technical failures. Many projects also include a component where training of technicians takes place.

Even though batteries utilised in solar projects are of good quality, they require both maintenance and proper operation in order to last long. Low and variable charge currents,

Table 1
Price quotations from selected references

Year	Price quoted	Indexed (USD 2004/Wp)[a]	References
1972	50 USD/Wp	226.0	[7]
1973	100 USD/Wp	425.5	[8]
1975	20 £/Wp[b]	154.5	[9]
1976	20 USD/Wp	66.4	[10]
1978	11 USD/Wp[c]	31.9	[11]
1985	7 USD/Wp	12.3	[12]
1990	6.2 USD/Wp	9.0	[13]
1991	4 USD/Wp	5.5	[14]
1992	5 USD/Wp	6.7	[15]
1995	4.5 USD/Wp	5.6	[16]
2001	5.9 USD/Wp	6.3	[17]
2005	5.1 USD/Wp	5.0	[17]

[a] The prices quoted in the references were corrected for inflation using the consumer price index (CPI) and given in constant USD for 2004 per peak Watt.

[b] 1 £ = 2.2 $US average 1975.

[c] Presented in the reference in USD 1975 value.

along with occasional deep-discharge cycles without proper recharge, result in operational conditions that soon will reduce the life-span of the battery. Experience shows that the lifetime cost of batteries will eventually exceed those of the initial costs required to purchase a PV module [19,20]. Short life of batteries in addition to relatively high costs for a new battery result in that many solar systems are operated with poor batteries [21,22]. Even though maintenance and management of the systems can be secured through for example an Energy Service Company (ESCO), the operation of the systems is still made by individual users. An SHS is a technical system that requires consideration of a number of variables in the process of design and operation. In order to design and operate these systems with good cost effectiveness and to secure safe services to the users, the knowledge on user behaviours, technical performance and the interactions between these two is crucial.

The aim of the article is to analyse the use of SHS from both user experiences and technical performance and the implications that this will have on design of SHS in rural electrification projects. The analysis is based on results from a number of studies undertaken in Lundazi in the Eastern Province of Zambia.

Assessments and design of systems are normally based on information collected prior to actual installations. Once the systems are installed the challenge is to operate these as efficiently as possible, rather than to analyse the design specifications. In case there are any evaluations, these are usually focused on project management and processes of implementation rather than evaluation and examination of user behaviours and technical design. There are some published results on the actual measurements of loads, for example Nieuwenhout et al. [18] and Reinders et al. [22]. Two other load studies that are based on the users documentation of their usage and from that information assessing the energy usage is found in Morante and Zilles [23] and van der Plas and Hankins [24].

1.1. The Zambia PV-ESCO project

The possibility to utilise commercial bodies for implementation in development interventions gained attention as an alternative to traditional top-down and bottom-up approaches in the early 90s [25]. As a result a popular approach in solar diffusion projects has been to support the creation of small electric utilities, ESCOs, to manage and maintain solar systems that are installed in clients' homes, shops or in institutions [c.f. 26–30]. From a general point of view, the ESCO approach attempts to have a local stake-holder that keeps a vested interest in keeping the solar systems in good working order and to maintain good customer relations. (Table 2).

Table 2
Details of system components

Item	Details	Notes
Solar panel	BP Solar 250/1	50 Wp, roof mounted, pole in special cases
Regulator	BP CGR1200	Max charge 12 A, max load 12 A
Battery	Raylite Leisurepak RR2	96 Ah
Lamps	Solar fluorescent	2 × 8 W, 2 × 13 W in non-covered holders
Battery box	Lockable metal box	
Installation	Installations made in conduit pipes, clipped to the wall. Switches and socket placed on the wall	

In 1996 the Department of Energy (DOE), Government of Zambia, began to discuss how small-scale solar technology could fit in the rural electrification policy of Zambia. These discussions led to a project called the Zambia PV-ESCO project that received funding from Swedish International Development Cooperation Agency (Sida) in 1999. The aim of the project was to support the operation of three ESCOs in the Eastern Province and learn from these experiences to see if solar electricity can be an appropriate technology to incorporate in the national energy policy of Zambia [31–34].

The DOE has a team of international consultants linked to the project. These consultants have made inputs to the project through presenting and trying to incorporate lessons from other solar PV projects and to design and take part in training. The University of Zambia (UNZA) have been involved in the technical and business management training.

There are three ESCOs operating a total of 406 SHS (August 2005). The project utilises a soft loan model where the local ESCOs are supported with credit capital in order to finance the investment. The ambition was to have the companies to repay almost the full cost of the hardware over a period of 20 years, but this had to be revised and the ESCOs will repay about 50% of the hardware cost.

The ambition from the start was to provide soft loans to the companies and these companies would then be responsible for design, purchase and installations of the systems. Due to formal reasons, the buyer had to be the DOE and the procurement of the systems was in the end managed by the tender board of Zambia. This process led to that the ESCOs only getting limited contacts with suppliers and limited possibilities to select the equipment they wanted. Experiences from Zimbabwe shows that the involvement of outside actors hamper the development of a local market [2]. By giving the control to the ESCOs, it is hoped that more conducive conditions for developing a market for solar equipment in Zambia are created.

The ESCOs taking part in this project are operating their systems and adjusting their fees according to the repayment of hardware and the operating costs. The ESCOs compete with the grid utilities, shops and organisations offering solar equipment. For example, the Ministry of Education has for a number of years offered teachers to get a solar system which can be paid through a deduction from their salaries. The repayment is done over a period of 3 years. At present these systems are relatively few and the diffusion is slow and erratic. Customers to the ESCOs often ask if they are able to purchase their systems and own it themselves, rather than paying monthly service fees. No such agreements have yet been reached.

1.2. Lundazi Energy Service Company

The Lundazi Energy Service Company (LESCO) is a local energy service company, licensed by the Energy Regulation Board (ERB) of Zambia operating 152 solar systems in the area around Lundazi since September 2001 (Fig. 1).

For those people living in the central town of Lundazi, grid electricity is an option that would be cheaper than the solar electricity, but most clients do not have any alternative supplier of electric power.[1] It is, however, a long process to receive a grid connection. There are households in the town that have opted for solar electric services. One of the

[1]Some basic electric services can be supplied through dry cell batteries, which are used by more or less everyone in the area. Batteries are sold both in town, and are usually also available in local shops in the villages or along the road.

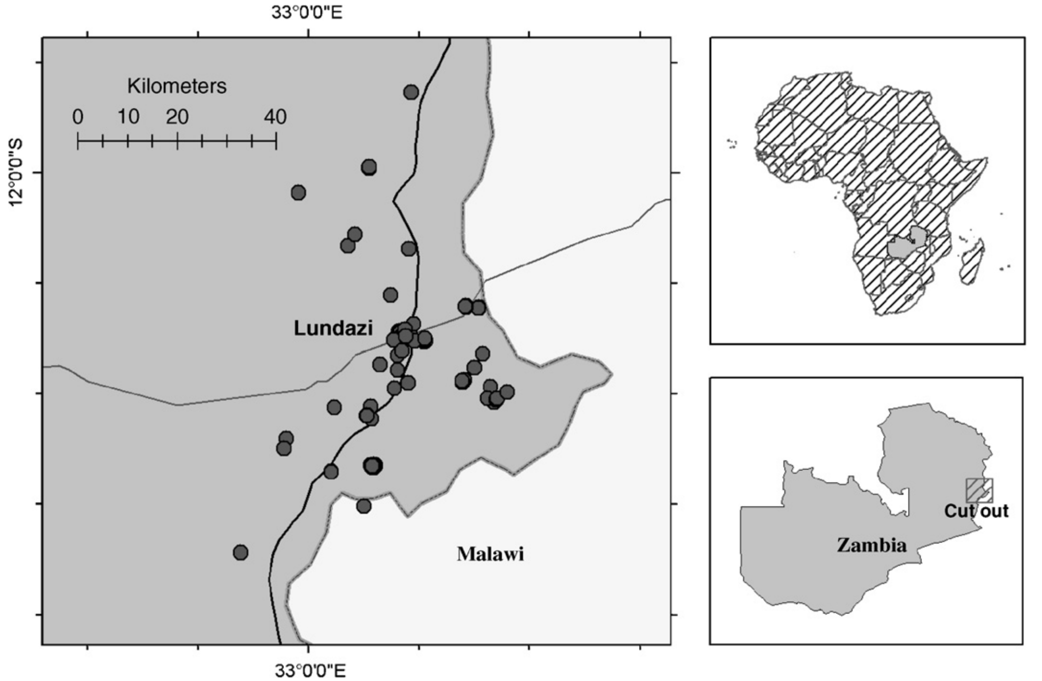

Fig. 1. Area where LESCO operates. Each dot represents a solar home system. Some locations have more than one dot.

reasons is that the installation fee for solar is less than for grid connections, another is considered by the clients to be more secure.

Typical daily use of electricity (12 V DC) for the LESCO customers is 10–15 Ah, which is equal to 3.5–5.0 kWh/month. With the monthly fee charged by LESCO in January 2005[2] of ZMK 35,000 (US$ 7.4[3]), this gives an electric tariff of more than 1 US$/kWh. Energy units are not appropriate in this case as the outputs from the systems are services rather than energy. Despite the high energy cost, most clients find the monthly fee charged reasonable. There is an installation fee of ZMK 250,000 (US$ 53), which is charged in connection to the installation. Even though no additional systems have been installed since 2001, there has been some relocation of existing systems. Reasons are found in clients moving to other areas, or inability to pay for the service.

Apart from the manager there are three technicians, one office assistant and one administrator working at LESCO (February 2005). The technicians are scheduled to make monthly inspections on all systems. During these inspections the solar modules are visually checked and if necessary cleaned from dust, an ocular inspection of the lamps, switches and cables is made, along with readings of the acid-specific gravity of each battery cell. The clients are also asked if the system is working satisfactorily. The monthly inspections are

[2]The monthly fees are supposed to be adjusted to the inflation rates in order for the ESCO to be able to cover their repayments for hardware. The 12-month inflation rates in Zambia have been in the range 17–24% during the last 5 years [35].

[3]1 US$ = 4700 ZMK August 2005.

documented and records are kept in each location and in the main office. The manager argues that they would be able to operate the double number of systems in the area without needing to have more personal. It is the responsibility of the client to report any malfunction to the LESCO office. The technicians should thereafter attend to the problem within a stipulated time of two working days. Broken lamps should be replaced by clients at their own cost, while lamp fittings and regulators should be replaced by LESCO.

1.3. Description of SHS found in Lundazi

All the systems installed in Lundazi are based on the same components and are all of the same size. The winning bid came from a contractor in Lusaka and installations took place on three occasions between September and December 2001. The cost was US$ 899 per installation [31].

The systems are based on a monocrystalline 50 Wp solar module (BP 250/1) that in most cases is found mounted on the roof. In about 20% of the cases this was not an option and the modules are mounted on poles. The modules have a tilt up from the horizontal axis of between 10° and 20° and with a tilt facing within 30° of true north. Each system is equipped with a charge and discharge regulator (BP GCR1200) that has functions for low-voltage disconnection and reconnection. A three-colour LED charge indicator is found on the regulator.

The regulator is placed inside a locked box together with the battery. The battery (Raylite RR2) has a nominal power rating of 96 Ah and should withstand at least 250 cycles to 80% depth of discharge (DOD). There is an indicator on the battery that gives a crude assessment of the charge status of the battery. The battery found in the systems has an excess capacity, as the tender documents stated that the minimum capacity of the battery should be 100 Ah. With this size of battery, the system will have almost 7 days of autonomy with normal load starting at a fully charged battery. One reason was that the systems should be possible to expand with a larger solar PV module without needing to switch regulators or batteries. Rules of thumb is that this should be in the range of 3–5 days for systems in Sub-Saharan Africa [see for example 36,37].

Four lamps are supplied together with the system, two 13 W and two 8 W. The lamps are standard solar fluorescent lamps in non-covered lamp holder. The positions of the lamps are decided by the client at the time of installation so that they are positioned differently between the different clients. Only few houses have lamps outside the house. Lamp switches are put on the wall, and all wiring is made in conduit pipes clipped to the wall.

There is a double 12 V DC socket supplied. Two plugs are supplied and the clients are advised not to make own connections. The technicians are normally willing to assist in the installation of plugs or to make suggestions on installations. The installations follow the Zambian standards of design and installations of SHS [38]. All of the installations have been inspected by officials from ERB.

2. Methods

The results presented in the article are based on two questionnaire surveys on the use and changes in the daily lives as a consequence of access to solar electric services and logs of actual loads in three households along with solar irradiation readings. This study was carried out as part of an individual research project at the Human Ecology Section, Göteborg University, Sweden. It has been implemented and funded independently from the Zambia PV-ESCO project.

2.1. Surveys

Two surveys have been carried out that covered all the installations that have been made in the Zambia PV-ESCO project. The first survey was made in 2001 and covered households that had made applications to sign contracts with LESCO ($N = 31$) but had at that time not received an SHS. The second survey covered all of the systems that LESCO were operating in June and July 2002 ($N = 152$). In each of these surveys the closest neighbour was included. These were selected as the closest house along the road when the fieldworkers arrived to the client. The neighbour group does not represent the typical household in the area, and is included here to illustrate experiences with electric appliances and living standards when there are no solar services available.

A team of fieldworkers including both men and women were trained to fill in the questionnaires according to the answers given by the respondent. The questionnaire took about 30 min to complete and included both open-ended and closed questions. The fieldworkers were introduced to the client by one of the LESCO technicians who would then leave during the work with the questionnaire. The field workers had all been involved in the Zambian 2000 census and had thus some experience in working with questionnaires. They were all knowledgeable in the local languages and had at least secondary education.

2.2. Load and irradiation logging

Results from the surveys have been reported in Gustavsson and Ellegård [39] and Gustavsson [40]. These show that the clients are usually relatively well off and could possibly best be described as a higher-income group in the rural setting. The households normally possessed a number of electric appliances, and the oral information on usage suggested that the systems were operated above the design specifications.

Load measurements were carried out on three systems. The households were randomly chosen from three sets of user groups, 'high', 'medium' and 'low' users, which were formed using the survey information from June the previous year. The 'high' user had a TV, a video and a radio cassette player in the house, while the 'medium' user had a TV and a radio cassette player. The 'low' user only possessed a radio cassette player. Apart from these appliances all three households had four lamps that came with the installation.

A one-channel data logger, Tinytag Plus IP68, was installed on the high- and low-user households. A shunt (50 mV, 5 A) was used on the load side of the system to log voltage drop corresponding to the load currents. The 8-bit logger gave a measurement accuracy of 0.08 A, and readings were made with an interval of 5 min.

At the 'medium'-user house a more sophisticated logger, Campbell Scientific CR10, was used. In addition to load measurements, readings of battery current and the voltage on the battery, panel and load were taken. The interval between readings was set to 5 min. Even though the accuracy in the readings is higher, the measurements are treated in the same way as with those from the TinyTag loggers. The logger also kept logs of the ambient temperature in the battery box. The system at the medium-user household was moved after some time and installed at another client closer to the town.

A record of the sun irradiance was collected at the LESCO office roof. The meter was connected to a TinyTag data logger. The information collected was considered applicable for the area where LESCO have installed solar systems, which is about a radius of 40 km around the town of Lundazi.

The information was downloaded from the data loggers to a laptop computer and sent by e-mail to the author by an assistant living in Lundazi.

3. The use of the solar systems by rural dwellers

The majority, 90%, of the solar system users are households, and about 6% of the systems are installed in shops. The remaining systems are found in schools, offices buildings and health centres.

The typical client and his neighbour lives in a concrete or brick house with a steel sheet or asbestos roof. There are a median number of 6.5 persons living in the house, but the household sizes range from single up to 15 people. In the typical case (median values) you will find one adult man, one adult woman and three children in the house. Of the children two are in school-going ages and one below 5 years of age. More than 90% of the households have at least one member who has a formal income. These households are also involved in farming activities. The clients are working as teachers, civil servants, Zambia National Service (ZNS) employees and policemen. As these occupations normally include living in camp-like settings, their neighbours will have similar occupations and backgrounds. A simple wealth index was used to investigate possession of non-electric related items.[4] The index showed that the clients have a higher median index (0.67) than their neighbours (0.5). The same somewhat higher index was obtained for potential customers.

3.1. *Appliances connected to the system*

Appliances connected to the solar system were radio cassette players, black and white TV sets, fluorescent lamps and videos. Benefits that stem from the improved lighting conditions were considered by more than 50% of the respondents to be the most important benefit from the solar system. Based on the survey results the median hours of light for both clients and neighbours were 3 h per day, with the difference that the neighbours use mainly kerosene lamps or candles for lighting.

A typical kerosene wick lamp gives about 10–40 lm, and ordinary candles are normally less than 5 lm. This is contrasted to a solar fluorescent lamp (8 W), which can reach 400 lm [41,42]. Children in households with solar electric services were able to study after dusk, while children in households with kerosene or candles did not study at night to the same extent. This was exemplified in questions related to how children studied in the households. A majority (97%)of the neighbours and clients considered a good light source 'important' or 'very important' for the children to be able to study at night. Complaints from the children concerning the light were more frequent among the neighbours than client households [43].

[4]The wealth index was calculated from the information on ownership or existence of the following items/characteristics: existence of book other than bible in the house, ownership of bicycle, existence of extra room in the house where nobody sleeps, existence of sofa in the house, if the house has glass in the windows, and lastly ownership of motorcycle. The index was then computed from number of yes answers divided by 6.

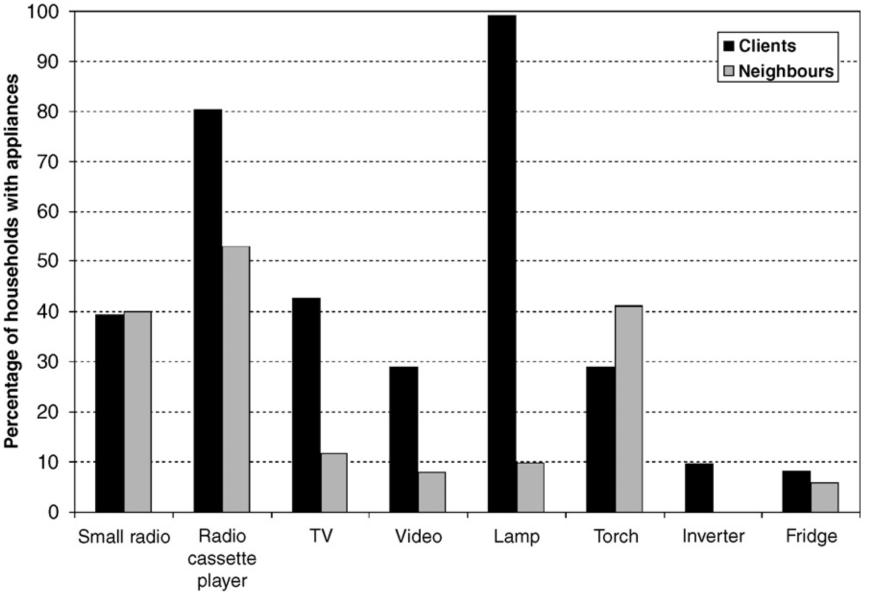

Fig. 2. Appliances in households in 2002 (clients and neighbours).

In the study 2001, there was only one potential client who reported that he only had a torch or a small radio, whereas all others possessed larger electric appliances in their homes. The most common appliance among the respondents at that point was a radio cassette player. Few had TV sets or VCRs and these appliances were in most cases brought with the household as they had moved from a previous setting where they had grid connection. The majority (53%) of these respondents reported that they had earlier lived in areas with grid electricity.

One year later many clients had acquired a number of new appliances. Not counting the electric lamps the most common appliance in the houses are still radio cassette player, which is the case for both customers and clients. In the client group this is followed by TV sets (42%), which are found in few (10%) of the neighbours' houses (Fig. 2).

The median number of appliances that can be connected to the solar system has increased from one to two among the respondents compared between the two years.[5] Access to TV for example has increased from 20% prior to having solar electric service to almost 50% after 1 year. For VCRs the increase was from 20% prior to accessing solar services to 30% after. Among the neighbours, 27% of the households ($N = 60$) did not have any electric appliances in their houses in 2002.

When clients have purchased TV sets and/or videos they have in most cases opted for 12 V systems, rather than 220 V with inverters. In the baseline study 50% of the television sets found were 12 V, while none of the videos were operating on 12 V. In the survey carried out 1 year later, almost 85% of the TVs and videos found were 12 V. Typical 12 V DC video and black and white 12 V DC TV found in the area are rated about 13–17 W. The access to electric appliances increases significantly along with household's higher wealth index.

[5]Appliances considered are radio cassette player, TV, video, inverter, fridge, etc.

Inverters are not commonly found. One of the reasons is that these are not permitted by LESCO to be connected to the system. An inverter is considered to drain the charge of the battery and encourage bypassing the regulator. Connected inverters are reported to the managers by the technicians and could lead to warnings and in the end even to the termination of the contracts. This has not happened yet. Car batteries used as a source for electricity was not found in many households. One of the reasons is possibly that bringing the battery to town for recharge is difficult due to lack of transportation.

In 2001 the experience of using and operating a solar system was limited among the respondents. A number of respondents reported at that time that they considered getting stoves, irons and fridges to run on their systems. LESCO still often gets questions on how the systems can be modified or improved in order to run a fridge or a stove. The answer given is that cooking is not possible on a solar electric system, while special fridges are available to use with solar, although costly. Clients are still quite eager to see if they would somehow be able to run a fridge on the solar system. Apart from being used in the household, a fridge could create income-generating activities such as selling cold drinks.

3.2. System usage patterns

The information collected from the data loggers shows that a load is put on the systems during the mornings from about 6 to 8 a.m., and then in the evenings from 6 to 9 p.m. (Fig. 3).

The constant load found during the day is one difference between the 'high' and 'low' users. The 'high' user also extends the time during the evenings when there is a load put on the system. The 90% percentile shows that the average values will differ between days, especially for the 'medium' and 'high' users. In the case of the 'low' user the periods in which loads are put on the system is very much the same, but the average load is slightly higher. Time series of the energy use per day show these daily variations more clearly (Fig. 4).

The average energy use per day is 14.5 Ah for the 'high' user, and 10.0 Ah for the 'low' user. Daily variations are largest for the 'high' user where the load can reach more than 20 Ah/day. The 'low' user has a relatively steady daily use. One of the reasons is that the 'low' user did not have any TV or VCR that could make any drastic rise in the energy usage.

The survey showed that those who have TVs, VCRs and radio cassette players have a median usage of each of these appliances of 2 h per day. The average values are affected by some households reporting very large usage. Lamps have 1 h longer usage per day. The clients report that lights are used in the mornings while preparing food and in the evenings for comfort and light for studying and reading. In most cases, lamps are switched off when there is no one in the room. At night the systems are also used intermittently when light is on for a short period. The possibility to access immediate light at night was brought forward as a positive aspect by a number of clients. The alternative is to light candles, or oil/kerosene lamps. In one case, a medical officer described that as a result of the more convenient and improved light he was now able to treat patients at night. The same case is with a number of teachers who are able to give night classes and extra teaching.

TV and VCRs are typically used in the evenings. This is seen in the load curves as a rise between 6 and 7 p.m. in the evening from almost zero to daily maximums. The national broadcast news at 7 p.m. in the evenings is watched commonly and reported by many respondents to be the most attractive broadcast.

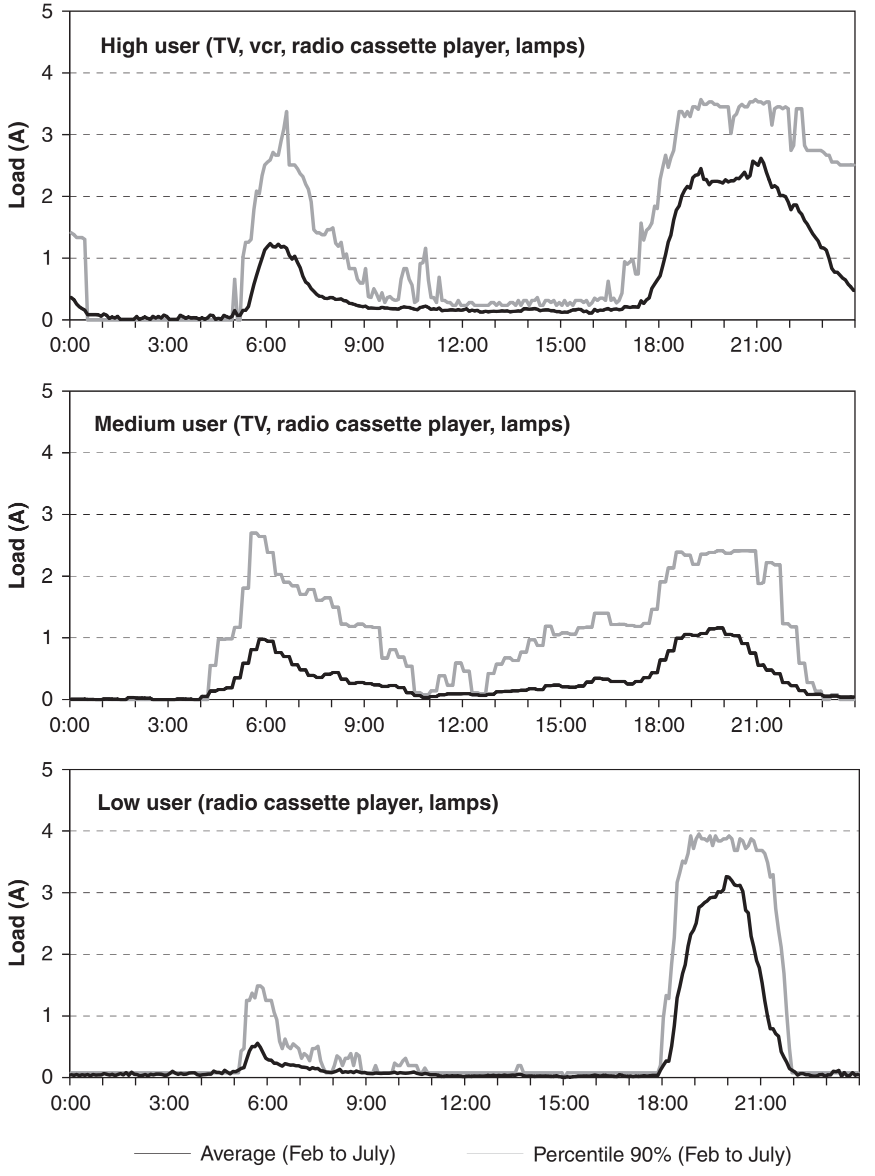

Fig. 3. Daily energy loads, patterns of three households.

4. Charge of the system

For the solar systems to cope with sudden drops in the charge of the battery, it is recommended that the panel should generate a slightly larger average output than the typical usage. In cases where the load is more or less the same as the daily charge, the system will become more exposed to changes in the charge patterns. If the battery becomes

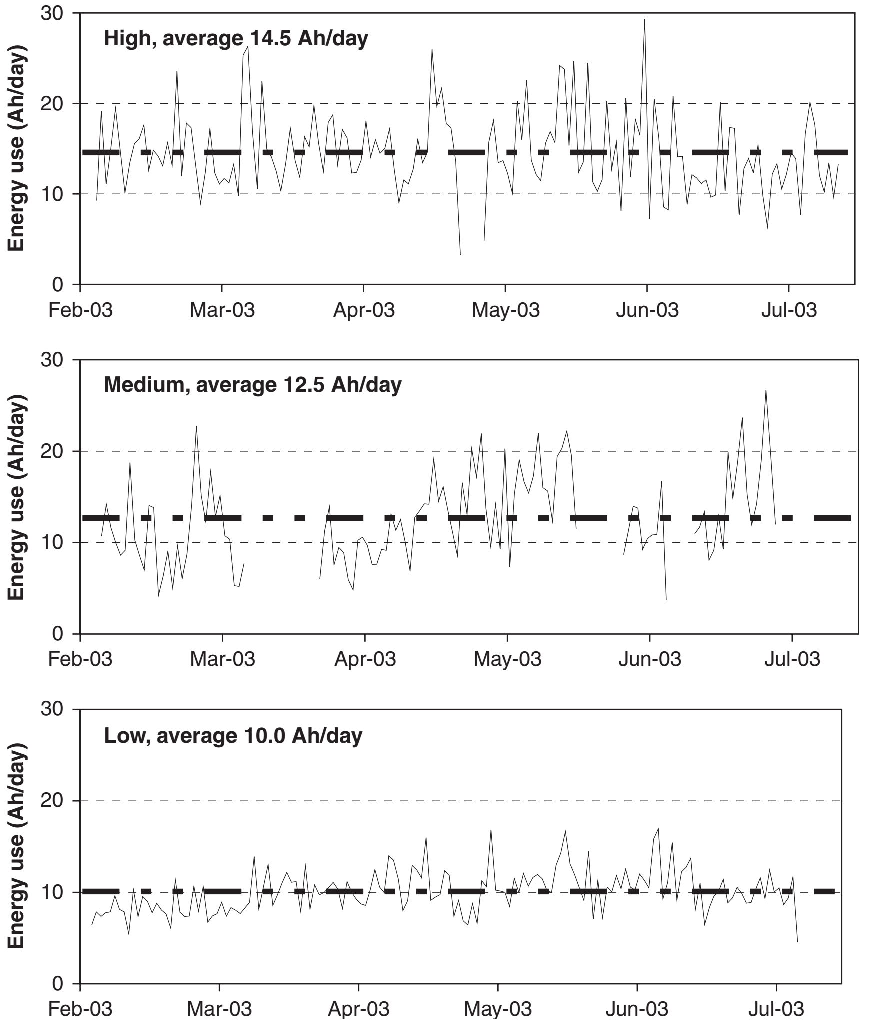

Fig. 4. Daily load (Ah/day) of three client households.

drained it will take a long time to regain charge as there is little extra power supplied from the panel.

4.1. Solar irradiation in Lundazi

The irradiation logging on the roof of the LESCO office gave a median solar irradiation over the period of loggings of 5.1 kWh/m^2/day, but also displayed seasonal variations (Fig. 5).

Looking at the seasonal values for median solar irradiation for the rain period between November and March this was 5.3 kWh/m^2/day. During the dry and cold season between April and August, a median value of 4.6 kWh/m^2/day was found. The hot season

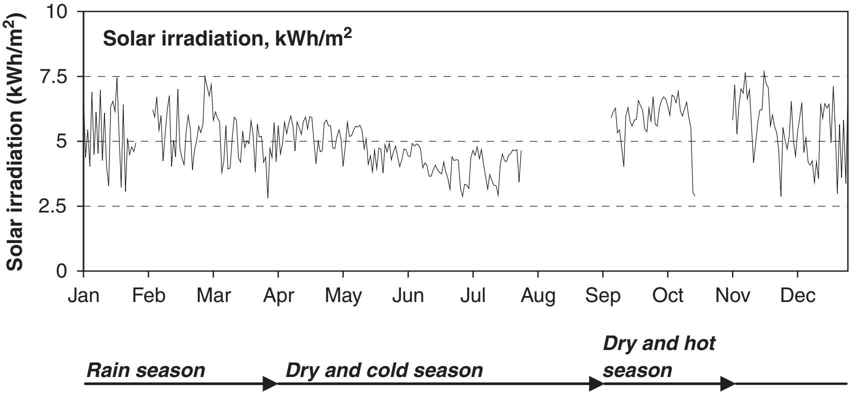

Fig. 5. Solar irradiation (logged on roof in Lundazi).

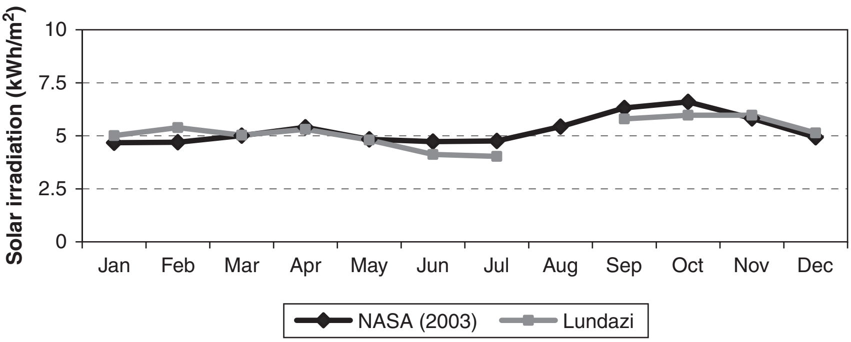

Fig. 6. Comparative solar irradiation NASA (latitude S12–13° and longitude W33–34°) and Lundazi.

between September and October reached a median value of 6.0 kWh/m^2/day. Comparative data from NASA [44] indicate that the values collected on location in Lundazi show some local variations but generally follow the more general trend in the area (Fig. 6).

4.2. Charge current from PV module

Information on the panel current was collected in the medium-user household. An average of 14.1 Ah/day was generated in the solar panel (Fig. 7).

The batteries are normally operated on a relatively low state of charge (SOC), thus the efficiency in the recharging process can considered to be high. Only about 8% of the days that were measured resulted in charge energy of less than 10 Ah.

The solar system will be possible to operate under relatively good conditions in Lundazi. The load must, however, be balanced to the charge available. In the case of the 'high' user their average energy use actually exceeds the daily energy charge. Median values are often more appropriate in terms of comparing values that have large variations. Comparing the median values for charge and the three different user cases reveals a slightly higher charge than usage for all cases (Table 3).

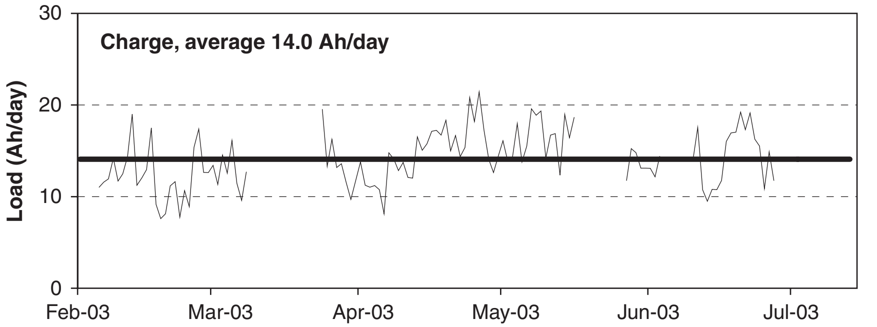

Fig. 7. Energy from panel, medium user.

Table 3
Median values for charge and energy use (Ah per day)

	Ah per day
Charge	14.0
‘High’ user	13.7
‘Medium’ user	12.1
‘Low’ user	10.0

The energy usage of the ‘high’ and to a lesser extent the ‘medium’ user results in extended periods for the battery to recharge itself. The days of autonomy considered suitable for Lundazi (Zambia) are 3–4 days, but as batteries often are operated on a low level of charge the concept of day of autonomy becomes beside the point. It is based on the assumption of a well-balanced system in terms of charge and loads. An increased panel effect would facilitate the load of the ‘high’ and ‘medium’ users. The ‘low’ user is balanced and the battery would regain its charge after a low-level voltage disconnection within about 14 days and still use energy services from the SHS as they are used to.

5. Discussion

The access to solar electric service leads to that more appliances are bought if affordable. The ‘high’ and ‘medium’ users in the study own what could be labelled standard appliances to be run on an SHS. Results from Gustavsson and Mtonga [21] showed that 1-year-old batteries found in the systems operated by LESCO have less than 80% of the rated capacity. Results from the load loggings show that the ‘high’ user is running the system beyond the design specifications. These customers will experience power cuts due to low battery voltage, and the batteries will not be given the possibility to regain high level of charge. In the long run this will affect technical lifetime of the battery negatively. There are a number of options to try to tackle this problem.

One option would be to adapt the system to the energy demand of the client. Those customers who want to use many appliances will have to increase the size of the module to ensure increased charge capacity. Unfortunately this option is difficult as LESCO only possesses systems of one size and does not have any spare modules. In the planning of the second phase of the PV-ESCO project a mechanism for financing systems of various sizes is suggested. In Lundazi the effect of the total module effect can be increased without needing to change regulator or batteries. The challenge is to make clients willing to pay the increased monthly service fee that goes with a larger system.

A second option is to train the users in how to assess the battery status and use this to adjust their energy use. This would require a technical modification so that the charge status can be assessed. The indicator on the battery, as well as on the regulator hidden inside the battery box, should be made visible.

In both the surveys and in interviews carried out with clients they explain that they have understood the limits of the system, and operate it in accordance. A set of written information material explaining how the system is supposed to be operated is given to the client along with the installation. In addition to this, the technicians also explain how the system is supposed to be operated. It seems that the information passed to the users was difficult to relate to as the users did not have any experience with solar systems before. The clients explain that their knowledge on operation was something they had learned through a "learning by doing" process. For example, one client explains that he looks at the strength of the light as an indicator of the battery charge. Another use the TV as an indicator, as the picture will change (narrow) as a consequence of the dropping voltage. A learning process that should be made in a number of steps according to the experience clients have of operating the solar system could be a more dynamic approach.

A third option would be to adjust the 'low-voltage' reconnection point to a higher value, thus changing the charging pattern of the battery. Controlled discharge tests, which were made on a number of batteries revealed that pole voltage would increase within a few hours after low-voltage disconnection and reach above the reconnection point [21]. As a consequence the blackout period would only be short. So if the regulator cuts the power in the evening, the pole voltage will recover in the morning and power will be available again. Changing the threshold points for the regulator would result in a longer period of blackout after a disconnection.

6. Conclusion

Electricity supplied from a solar home system will create opportunities to utilise a number of electric appliances and improve the living conditions of the users. The improved lighting condition that comes with a solar system is appreciated by the users. At the same time, it is expensive and people who can afford it are normally the better-off living in the rural settings. Their vested interest is a central component in securing local maintenance of the solar technology.

The data presented in the article show that clients appropriate and use a growing number of appliances. In many cases the capacity of the solar systems will be exceeded, which eventually will result in deterioration of the batteries through operation on long periods of low state of charge. Thus it is crucial to consider not only the possessions of electric appliances at the initiation of a solar project, but also the users' possibilities to acquire new and additional items. Lamps, a radio cassette player, a TV and VCR are appliances that eventually will be owned by solar clients.

One alternative to meet the increasing load demand on the system is to increase the panel effect, hence increasing the charge capacity. Another strategy is to draw on the clients' interest to learn how to improve the performance of the system. A transfer of knowledge could be made in steps as the users obtain growing practical experience. At present the information is passed on mainly at the time of installation. This should be combined with creating a possibility to assess the charge of the battery from outside the battery box.

A solar system has the potential to supply many of the basic energy services that is desired in the rural setting. Successful operation cannot be secured through technical fixes but requires both skills and knowledge on the technical limitations of the system.

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