Solar Computer Systems: A Techno-Economic Field Investigation in Nepali Hill Schools

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ABSTRACT

Many Solar Computer Systems (SCSs) have been deployed in developing countries, with the aim of improving educational outcomes, and in some cases, providing autonomous energy supply to the community more broadly. A number of systems have been installed in schools of the Nepali hills. This paper describes a techno-economic field investigation into 8 case schools. The PV systems and loads, including computer systems, were examined; and system specifications, operation and diagnosis of any failures that had occurred were recorded. The findings from the investigation indicate that long-term sustainability of service from the systems is jeopardised by poor maintenance of the energy systems and an even higher high failure rate of the computer systems, primarily due to computer viruses. A simple economic analysis indicates that there is an opportunity to utilise low power laptops to improve system service while cutting cost of hardware.

Keywords* : *"Computers", "Developing Countries", "Education", "Photovoltaics", "Rural Electrification", "Solar"

SOLAR COMPUTER SYSTEMS IN NEPALI HILL SCHOOLS: A TECHNO-ECONOMIC FIELD INVESTIGATION

Introduction

Photovoltaics, Information & Communication Technology and Sustainable Development

In the field of education in developing countries, there has been a relatively new focus on Information and Communication Technology (ICT)[1], which is seen as a possible means to bridge the education gap between the developed and developing worlds, by providing better access to knowledge at low cost (Jie 2000, Farrand 2005, Herren 2006). ICT, however, requires electrical energy, which is not available in many of the poorest and most isolated communities (IEA 2011).

Because grid extension is very high cost per unit of energy when population density and demand are low, distributed electricity generation capacity has been installed in many developing countries over the past 30 years, and in many different forms. Fossil fuel gensets, wind, biomass, biogas and hydro generators have all been applied, but photovoltaics (PV) has been shown to be generally least cost for small isolated villages with low energy requirements (Reiche, Covarrubias et al. 2000; World Bank 2008). Common applications for PV electricity in rural villages have included water pumping, vaccine refrigeration, and lighting for clinics, schools and homes. A large body of

[1] ICT includes computing and communications technologies, notably including internet, digital education resources, mobile phone, satellite and wireless technologies.

literature has established that success of these applications has depended not only on the quality of the hardware, but also technical and institutional capacity to finance, install, maintain and use the systems effectively (Barnes and Floor 1996; Cabraal, Davies et al. 1996; Lorenzo 1997; Lorenzo 2000; Martinot, Cabraal et al. 2000; Martinot, Ramankutty et al. 2000; Nieuwenhout, van Dijk et al. 2000; van Campen, Guidi et al. 2000; Wilkins 2002; IEA PVPS 2003; Nieuwenhout, de Villers et al. 2004). A number of best practice guidelines have been produced (Architectural Energy Coorporation 1991; THERMIE 1998; World Bank 2008).

The majority of the literature on PV in developing countries has historically focussed on Solar Home Systems (SHS), consisting of a photovoltaic module, battery, charge controller to protect the battery, 2-5 lights and, in some cases, the facility to connect additional small DC loads. New applications for PV in developing countries have recently emerged, including mobile phone charging, computers, and micro solar products (i.e. solar lanterns). These new applications have different requirements in terms of hardware of the energy system, as well as technical and institutional capacity to use the technology sustainably (skills, knowledge, infrastructure and organisations). While a number of previous PV studies have mentioned computers as a potential load (Nieuwenhout et al 2004, Sproul 2008) and similarly a number of ICT studies have noted that renewables are a common source of electricity in areas beyond electricity grids (Brewer 2005, Fettweist 2008, Unwin 2009), there is a scarcity of literature documenting lessons learnt in using PV to provide energy specifically for ICT. This paper presents a field study that offers some potentially useful insights in relation to the technical and economic aspects of the problem.

For the purposes of this investigation, Solar Computer Systems (SCSs) are defined as any computer powered in by solar energy (photovoltaics).

The objectives of the investigation were as follows:

1. Investigate the current state of the SCS in a number of installations in the field.
2. Examine the techno-economic implications of equipment choice in SCS over the intended lifespan of such applications.

Of interest to the study is the growth in the use of laptops and more recently low power laptops as an alternative to traditional desktop computers in rural applications (Computer Aid 2008), which is expected to have significant technoeconomic implications on the sizing of PV systems in the SCS. This investigation seeks to explore this further. The context in which this investigation was carried out was one of the world's least developed nations, Nepal.

From an energy service perspective, quality in solar rural electrification[2] can be defined as the extent to which the energy system reliably meets user's objectives (Nieuwenhout, de Villers et al. 2004). This implies that the energy system must be accessible, acceptable and available (WEC 2000)[3], and that suitable institutions must be in place to deliver the service (Retnanestri 2007). This study is limited to a preliminary scoping of the status of the technical and economic dimensions of quality in SCS installed in

[2] Electrification in this context refers to any provision of significant electrical supply, whether it be the convential grid or an autonomous system such as a Solar Home System.

[3] *Acceptability* refers to a relative cost-benefit (value) of technologies satisfactory to the consumer, as well as the cultural/environmental acceptability of technologies.

Accessibility refers to the ability of people to take advantage of technologies, having sufficient ability & willingness to pay and knowledge of the technologies and how to use them.

Availability refers to the presence of technologies (including maintenance & parts) and infers good quality and continuity of supply.

Nepal. The social and institutional dimensions that also influence the accessibility, acceptability and availability of the technology will be the subject of future work.

Rural Energy in Nepal

With a Human Development Index ranking of 138 of the 169 nations ranked by UNDP, Nepal is considered to have one of the lowest levels of development in the world (UNDP 2010). Energy is a major problem in Nepal, with a 2009 electrification rate of 43.6% (IEA 2010). For the majority of residents, particularly those in the hills and mountains to the west and east of the country, there is no access even to an unreliable grid. The country's rapid population growth and rising living standards are predicted to greatly increase energy demand and there is concern about how the country will meet these future needs (NEA 2009).

In an effort to address these concerns, the government launched the Energy Sector Assistance Program (ESAP) with the help of Danish aid. This program has centred upon improving quality of rural electrification through distributed generation projects and Remote Area power supply. The current initiatives of the program include construction of mini-grids, biogas and micro-hydro plants, deployment of solar cookers and a subsidy program for the installation of solar (AEPC 2008).

Of particular relevance to this study is the ESAP Institutional Solar Photovoltaic Subsidy (ISPS), which provides Nepali schools with funding for 75% of the upfront system cost of photovoltaic systems up to 1kWp.

Field Investigation

Methodology

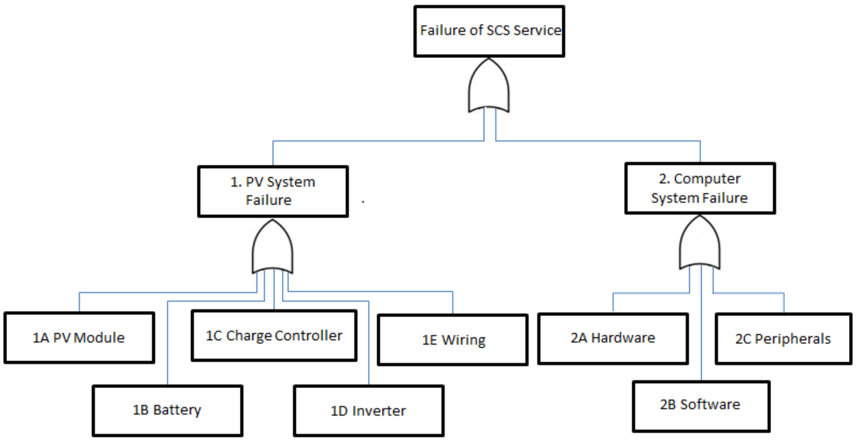
The fieldwork was carried out during a research trip in August 2009 and covered eight remote schools from the central and western development regions. The schools were identified by a local organisation Renewable Energy for Clean Environment and Development (RECED). The method of choice was that these systems were the only systems known to be using computers as loads. This resulted in sampling from four hill districts, namely Kaski, Gorkha, Kavre Palanchowk and Sindhuli.

Figure 1 - Locations of case schools visited during the field study
(Source: Adapted from CIA Factbook 2011)

During the fieldwork, the operational status of each SCS was observed and recorded through systematic system health check. This including testing of components and monitoring operation at each of the sites over a minimum of 24 hours. To further understand the context and use of SCSs in these applications, interviews and surveys were also carried out with stakeholders, such as maintenance staff, schoolteachers, students, as well as other members in the community who did and didn't use the computer systems.

A framework for field analysis of PV system health has been defined as part of the Tackling the Quality of Solar Rural Electrification (TAQSoLRE) Program (Diaz 2007). The framework identifies system components for reliability analysis using a fault tree. The fault tree, which focuses on the generation side of the system, i.e. excludes loads, is reproduced in the left hand side of Fig. 2. For the purpose of recording system operational status in this investigation, a second branch was added to the fault tree, which examine the computer system and include the associated modes of failure, as shown on the right hand side of Fig. 2.

Figure 2 – Adapted Simplified Fault Tree Analysis for SCS



At the first (top) level the fault tree identifies failure of an SCS system. At the second level, it is determined whether the failure of service is due to a problem on the generator side or the load side i.e. essentially a PV system failure or Computer System failure.

The third level of fault tree analysis uncovers the component that has failed. A complete or partial failure of a single component may not necessarily result in the complete failure of a system to provide service. Both partial failures of components (i.e. still offering some functionality) and complete failures (no function remaining) were therefore recorded.

Findings from the Field

A summary of the systems installed in each of the case schools can be seen in Table 1.

Table 1 – Installation Details from the field investigation

School Name (Location)	Students	Installation Date	Age at Visit (Months)	Installer	Maintenance	Donor	Total Installed PV (W)	Total Battery Capacity (Ah)	Computer Stations	Lighting
Jageshower (Borlang, Gorkha)	487	Feb-08	17	UNSW/Lotus Energy (PKR)	Santa Ram Shrestha Lotus Energy (PKR)	UNSW Staff and Students & Foreign Donor	420	590	1 x Desktop w/ CRT 1 x Laptop	8 x 11 W DC light
Saraswati (Borlang, Gorkha)	850	Jul-08	12	Himalaya Light Foundation (Light System only) Local teachers installed the computers and inverter system	None	Himalayan Light Foundation	80	100	2 x Desktop w/ CRT	4 x 11 W DC light
Child Welfare Scheme Nepal Vocational Training Centre (Pokhara, Kaski)	78	May-09	2	Lotus Energy (PKR)	Lotus Energy (PKR)	UNICA Netherlands	340	500	2 x Desktop w/ LCD	1 x 11W DC light
Shree Shiva Shakti (Mechchhe, Kavre Palanchok)	110	Dec-08	7	Dibya Urja Pvt. Ltd. (KTM)	Local Technician (Lotus Energy PKR)	Foreign Donation (Danish Highschool)	250	150	1 x Micro Laptop	1 x 11W DC light
Nagdevi Vidhalaya Secondary School (Mathi, Kavre Palanchowk)	223	Aug-07	3	Suradaya (KTM)	Local Technician	Computer - Government Solar System - American Donor	120	1200	2 x Desktop w/ CRT	-
Devisthan (Dalawatarn, Sindhuli)	~800	Aug-08	11	Suryodaya (KTM)	Local Technician	School/Community Funding	450	568	5 x Desktop w/ CRT	-
Shree Kusheshwar Bidhyapeeth Higher Secondary School (Dumja, Sindhuli)	~1000	Sep-07	24	Lotus Energy (KTM)	Local Technician	School/Community Funding	510	568	3 x Desktop w/ CRT	7 x 11W DC light
Shree Mavi Goth Bazaar (Ratmate, Sindhuli)	780	Aug-07	23	Lotus Energy (KTM)	Local Technician	School/Community Funding	340	150	2 x Desktop w/ CRT	2 x 40 W IC

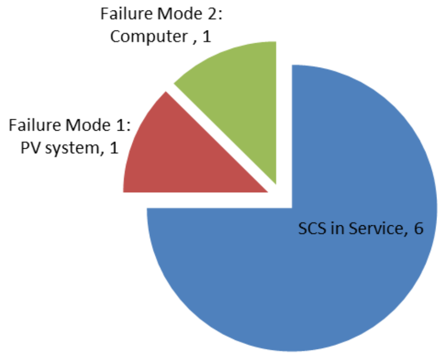
The first point of observation is that all systems are relatively new, the oldest only two years old. This indicates that local use of SCSs is rather recent. From discussion with users it was noted that generally only a single computer was used at each system, as there was generally one that was faster, and it was uncommon for two people to need to simultaneously use computers. It was also noted that in only 2 schools did students use the computers. A survey of stakeholders revealed that the majority of people believed that administrative work related to the school and community organisations was the most valuable use of the computers.

There was a remarkably high penetration of traditional desktop PCs, noteworthy given the higher power consumption of these devices. The large majority of the computer systems were provided second hand, and have already shortened lives.

Reliability Results of Fault Tree Analysis

From the upper level of the fault tree analysis it was observed that 2 of the 8 systems had experienced a complete failure of SCS service. In one instance this had been due to the failure of the PV system (Saraswati) and in another it had been due to a failure of the computer system (Dumja).

Figure 3 – Upper Level fault tree assessment of systems



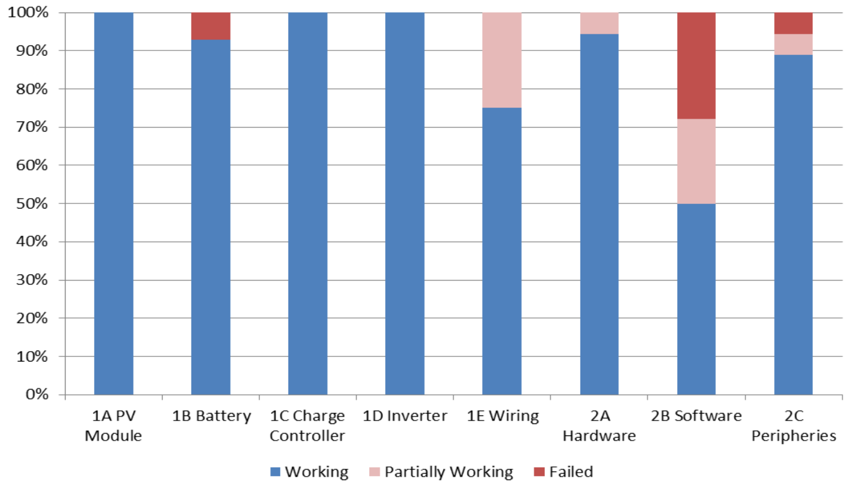
The failure at Saraswati was due to a failed battery some time ago. Unfortunately the long-term non-use of the system meant that the computer, peripherals and inverter had subsequently been damaged due to poor storage and rodents. Subsequently a new battery had recently been bought but was being used only for DC lighting and mobile phone charging. At Dumja the failure of SCS service was caused by a virus that affected all of the desktop computers.

At the lower level of the fault tree we performed a survey of the status of the components and the results are presented in Fig. 4 below. It can be seen that the most common type of failure in the installations is computer software related. The cause of the failures was most commonly computer viruses, which were evident in 50% of the systems. Since the majority of these computers were not internet connected, the source of these viruses could only be data transfers from disks and USB storage devices. A number of systems did not have even simple virus protection software, and the majority of those that did had out of date licenses so were ineffective. An antivirus boot disc would be highly useful in any future field visits, enabling a technician to restore the affected computers.

Wiring faults were the second most common type of failures, although wiring problem only resulted in partial, not complete, system failure. These were typically caused by inadequate contacts between circuit components, and resulted in some failed joints as well as oxidised contacts on both cable joints and battery contacts.

There was evidence of rodents interfering with the system in all but one case (CWSN). The lower end consequence was batteries covered in droppings and at the higher end were severed cables. It had been observed in the staffrooms and computer rooms that scrap paper, dust and general rubbish would build up around the system (it was observed the school cleaner in one case was hesitant to touch the system) and this fostered rodent infestation.

Figure 4 – Lower level fault tree assessment of systems.



Regular maintenance of the systems was limited to filling the batteries with deionised water. Battery contact oxidation had not caused complete failure yet but as the systems get older it could potentially play a much larger role in system health. The systems generally had a single person in charge of maintenance of the systems (typically a teacher) who had been present at installation. No school had a clear plan on what would happen if this person left the school.

Techno-Economic Analysis of Equipment choice

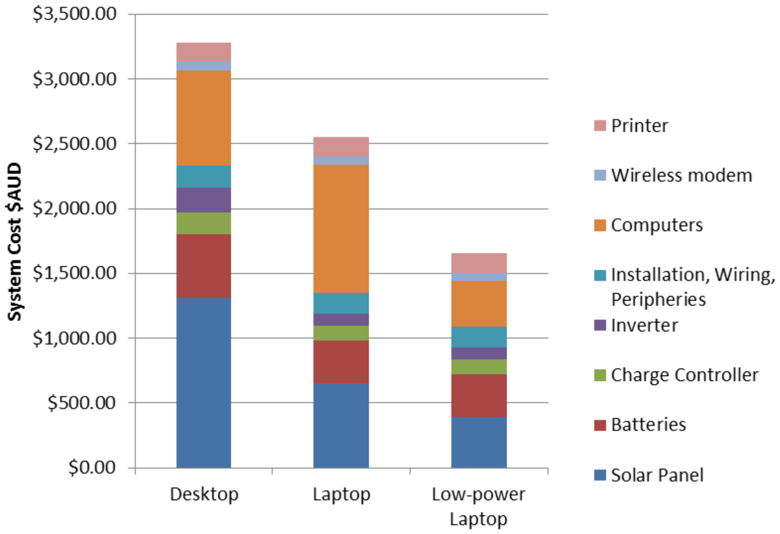
Upfront hardware cost is a key determinant of rural energy service affordability in developing countries. There is a large variation in energy consumption of traditional desktops, laptops and new low power laptops, so although desktop computers may have low upfront costs to the communities, a larger PV system is required to supply a larger load. A techno-economic analysis of SHS has therefore been undertaken to determine the least cost technology over the system life cycle.

A typical system, representative of those found in the villages was designed and costed. The hypothetical systems included a computer[4], PC Canon IP1880 printer and USB modem. The size of the PV system required to run the loads was calculated on the basis of an estimated 4 hours daily operation, and appropriate PV modules, inverters, batteries and charge controllers were selected.

Due to the local context of this investigation, Kathmandu would likely be a central source of all componentry for these systems. During the field trip prices for equipment, installation and service were attained from suppliers in Kathmandu (Lotus Energy & New Road 2009). The results of the capital cost analysis for different computer components of the SCS are shown in Fig 5. For an Australian audience, the prices have been converted to Australian dollars.

[4] Desktop - SD Tech Base Desktop w/ Maxview CRT monitor
Laptop - Acer Aspire 4315
Low Power Laptop - Asus Eee 900

Figure 5 – Upfront capital costs of systems



The results indicate that a low power laptop would provide a substantially cheaper alternative, both in terms of computer and energy system, with system costs half that of a desktop computer. It is interesting to note that although a standard laptop is more expensive than a desktop, it would also prove a significantly cheaper option, since a smaller PV system is required, providing an upfront saving of AU$730. Even if the desktop was provided for free (for example in the case of a donation or government distribution program) the system with a laptop would only be AU$9 more expensive.

As almost 90% of the SCS systems encountered in Nepal included desktops, this is a very significant finding. The most common justification for the use of desktop computers was that they are often cheap or donated for free, more reliable and spare parts are highly available and are cheaper than those for laptops. In order to incorporate reliability into the techno-economic analysis, a life cycle costing exercise was subsequently undertaken. A simple life cycle analysis was carried out using summated cost over 20 years at a 10% discount rate. Assumptions on component lifetimes are given in Table 2.

Table 2 – Installation Details from the field investigation

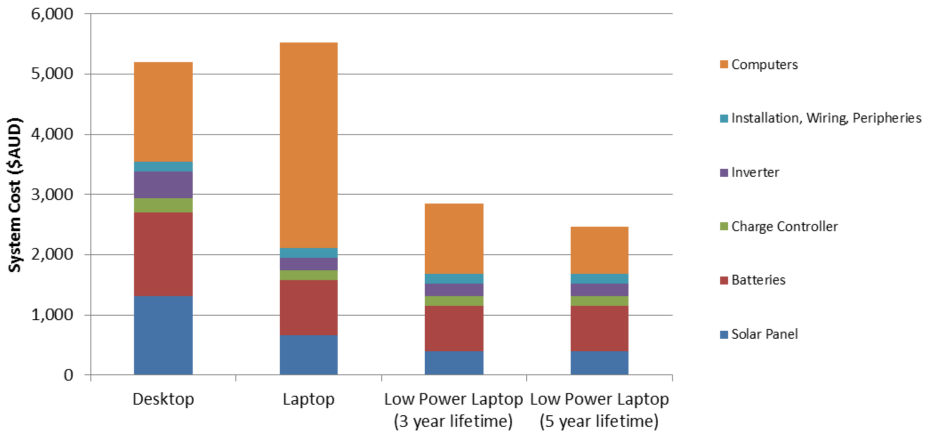
Solar panels	20 years
Batteries	4 years[5]
Charge Controller	10 years
Inverter	5 years
Wiring	20 years
Desktop Computer	5 years[6]
CRT monitor	5 years[6]
Laptop Computer	3 years[6]

It should be noted that availability of spare parts was not within the scope of this investigation and could become a significant factor in relation to repairability as systems age. The results of the life cycle costing are shown in Figure 6 below.

[5] The Batteries were assumed to be at a reasonable level of quality, but the life time would be shortened based on the fieldwork findings that the batteries would often reach Depth of Discharge of 50%.

[6] This data was based on product lifetimes in developed countries (Cleyhands 2001, Friedlander 2002). It is necessary to consider that developed countries will on the one hand have a higher turnover of equipment due to less protection from weather, user inexperience and the prevalence of viruses.

Figure 6 – Equipment costs over 20 year lifetime.



It can be seen that over 20 years, system costs become dominated by battery and computer replacement, putting into perspective the cost of solar panels over their long lifetime. Low power laptops again prove the most suitable option from a cost perspective, due to their low upfront cost and small PV capacity requirements. SCSs with laptops become the most expensive option, because their shorter lifetime requires a large number to be purchased (6 over a 20 year system life), while they also have the highest upfront cost. In project design, initial capital costs are often used as the basis for decision making. This lifetime assessment has quantitatively shown that such practice will not give the best results.

While this investigation included a limited sample of SCSs in Nepali Hills Schools, it provided some useful preliminary insights into the technical and economic aspects of SCS projects. Desktop computers with CRT monitors form the large majority of computers used in the studied SCS. Given that these are high energy users, there exists an opportunity for low power laptops to decrease system costs or improve service availability.

Preliminary Recommendations for future SCS systems

While this investigation was localised to the hill schools of Nepal some of the observations made here may be relevant in other applications of SCS. Following are some recommendations of the application of this technology for rural development.

- It is recommended to install single computer systems at multiple schools, rather than multiple computer systems at a single school. It was found that the first computer a school had the greatest benefit, and that with multiple computers only the fastest would be used.
- Encourage the adoption of low power laptops. These computers can adequately meet the school's basic computing requirements for recording figures and printing examination papers while requiring a significantly reduced capital cost and more efficient operation.
- Provide adequate virus protection or alternative operating systems that are less susceptible to viruses.
- Shift the funding focus from initial capital costs to future sustainability. The current Nepali government subsidy for solar in schools covers 75% of the upfront cost of equipment and installation. This encourages schools to purchase a system but gives no support for ongoing costs of system maintenance, training or organisational capacity building.

Conclusion

This paper has described a techno-economic field investigation of SCS in the hill schools of Nepal. For a number of case schools the SCS systems were examined; and system specifications, operation and diagnosis of any failures that had occurred were recorded. The investigation found that even though the studied systems are relatively new there is already an alarming level of failure, particularly in regard to the computer systems failing due to virus exposure. The implications of this is such that new programs should take particular heed of load side failure mitigation when supporting computers for development applications. In economic terms the opportunity to utilise low power laptops was identified as a way to improve system performance while reducing upfront and life cycle costs.

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