Assessment of Solar Home Systems (SHS) for Isolated Rural Communities in Vanuatu Using Project Lifecycle/Sustainability Framework

By

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This report, "Assessment of Solar Home Systems (SHS) for Isolated Rural Communities in Vanuatu Using Project Lifecycle/Sustainability Framework," is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

Civil and Environmental Engineering

Master's International Program

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Preface

This report is submitted for the completion of a Master's degree in Environmental Engineering from the Master's International Program in Civil and Environmental Engineering at Michigan Technological University. It is based on field work done in Vanuatu while the author served as a Peace Corps volunteer in the community of Lamap on Malekula Island from September 2007 to December 2009.

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Acknowledgment

I would like to express my biggest thank you to the community of Lamap, Malakula Island for welcoming me into their lives and opening my eyes to their incredible, friendly culture, where everyone treated me like I was their own. Special thanks also goes to my counterpart John, James and their family for the amazing work they have done for their community, they are the true volunteers. Of course I can't leave out acknowledging all the friends who just likes to hangout under my thatched roof; Ronald, Filibert, Arnauld, and everyone else who provided countless entertainment, conversations, and fresh tuna in the morning. Lastly a thank you to all my male students who taught me what it's like to be 16 and live a life without any responsibilities whatsoever. *Tankyu tumas blo soem mi hao nao blo planem manioc.*

A special thanks goes to my advisor James Mihelcic for his unwavering support and guidance, and for having the vision to create the Master's International program in Civil and Environmental Engineering. I am grateful to be part of this most innovative engineering education that provides invaluable multidisciplinary perspective and developing country field work experience for the aspiring engineer.

Abstract

Vanuatu is a small island developing state with an archipelago of more than 65+ inhabited islands spread out over a 700km by 200km area in the South Pacific Ocean. The government of Vanuatu recognizes many potential social and economic benefits of rural electrification and prioritizes its development. But because of the geographical isolation among different islands and the under developed infrastructure, centralized power grid becomes an impossibility. Photovoltaic solar home systems (SHS) are thus increasingly utilized by both the Vanuatu government and foreign donors and as a practical and effective means to rural electrification.

This report adapted an assessment tool based on lifecycle-sustainability framework and applied it to assess solar home system (SHS) projects in rural Vanuatu. This follows from previous research in which the assessment methodology has been developed for and applied to water and sanitation projects. Three SHS project sites with different project basis were chosen for the case studies of this report. For these case studies the assessment was done both during and after the completion of the project and are compared using the lifecycle assessment methodology to help determine best practices for rural SHS projects in Vanuatu.

Recommendations of this report include modifications and weighted emphasis on the assessment tool for more relevance under SHS project context. Specifically, the separate classification of self vs. donor funding and privately owned vs. community projects is necessary for both the economic and political cohesiveness element of sustainability. In addition, rural area specific SHS component selection, design, and economic considerations are given. Emphasizing technical design error margin in the conceptual design life stage and system hardware robustness from environmental conditions and user abuse are found to be factors that can lead to system longevity.

Chapter 1: Introduction and Framework for Assessment

In the rural areas of developing countries, around 75% of the population or two billion people live without electricity (Zahnd, 2009). The same population has a growing desire for basic services such as lighting, water, health care, and education. This places heavy pressure on local governments to keep pace with the demand for electricity. However, the installation and maintenance of grid electricity in these often small and geographically remote, isolated populations is often near impossible. People not served by centralized power grid mostly rely on solid fuels and fossil fuels like kerosene and diesel for most of their energy needs. Fossil fuels are often imported, and their use leaves local economies vulnerable to global price fluctuations and disruptions in supply. Transporting these fuels to remote locations can be expensive and difficult, and their indiscriminate use can also be harmful to health and the environment. Moreover, maintenance of fossil fuel driven generators can also be problematic for people living in rural areas.

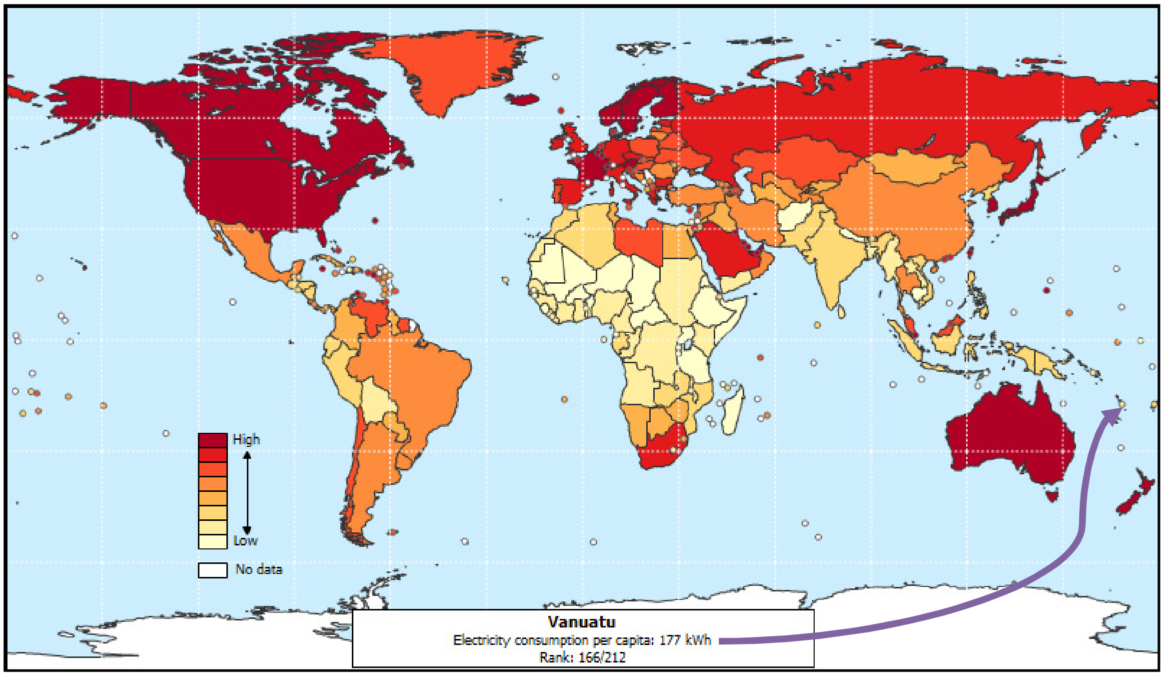


Figure 1.1: World annual per capita electricity consumption map. Adapted from (Electricity consumption per capita, 2008)

Accordingly, renewable energy systems have been increasingly utilized in most developing countries as means to rural electrification provision. In Vanuatu there are an abundance of renewable resources such as hydro, solar, wind, and biomass. These resources offer considerable potential to provide Vanuatu with a diverse energy supply sources and reduce its dependence on imported fossil fuels. However, the challenge is how to make a transition from the traditional energy supply source to the renewable energy sources. Currently there are a few small wind and micro-hydro projects in rural Vanuatu. Wider scale dissemination of these two renewable technologies in the rural areas has been limited due to the non-point-of-use power generation and the resulting need for a mini power transmission grid and the associated technical operation/maintenance requirement.

Photovoltaic systems, such as Solar Home Systems (SHS), are being promoted by both governments and international aid organizations as a feasible and cost effective alternative for the basic electrification of rural households (Nieuwenhout, 2002). A number of successful SHS pilot projects received widespread attention such as Sukatani in Indonesia (Surya, 1992). After these success stories, solar home systems gradually came to be adopted as a viable option for rural electrification. According to estimates by GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit) and other institutions, over one million SHS have been installed worldwide, the majority in rural areas of Africa, Latin America and Asia (GTZ, 1992).

A commonly acknowledged major barrier to widespread use of SHS in developing country rural areas is the high initial system cost (Urmee, 2009). However, even with substantial subsidies, (such as the government programs in India (MNES, 1999) and Mexico (Jorhe, 1998)) or when access to loans is possible (World Bank loans in Sri Lanka and Zimbabwe (World Bank, 2000), government loans in Botswana and Namibia (Schoon, 1998)) the growth is still limited. In addition to the high entry barrier of SHS, it is not known how many existing systems are being operated properly. Monitoring costs as well as practical and methodological problems make it difficult to obtain reliable data on the effective service life of the installed SHS.

There have been numerous SHS project reviews and studies on determining the contributing and limiting factors to SHS project success and its dissemination (Martinot, 2001). Of particular note is the World Bank SHS 1993-2000 evaluation report where twelve large scale SHS projects were reviewed on their approaches, early implementation experiences and corresponding lessons learned. The World Bank report, along with other studies (Urmee, 2009), can be summarized as using four main themes for evaluating SHS projects: (1) institutional, (2) financial, (3) technical findings, (4) user experiences. These themes cover most of the aspects around deployment of SHS in developing countries.

This report contributes to the continuing effort to understand and improve developmental process of SHS by presenting an alternative way to plan, guide, and assess/evaluate projects using a project lifecycle sustainability framework. A project assessment tool based on life cycle sustainability framework was developed by Jennifer McConville (McConville, 2006) from her experience as a Peace Corps Volunteer in the water/sanitation sector. This assessment tool takes into account five sustainability factors: (1) socio cultural respect, (2) community participation, (3) political cohesion, (4) economic sustainability and (5) environmental sustainability and five project life cycle stages: (1) needs assessment, (2) conceptual designs and feasibility, (3) design and action planning, (4) implementation and (5) operation and maintenance. The life cycle sustainability framework provides a tool for development workers to approach a project in a different way, looking at the sustainability of each life stage.

Previously the lifecycle sustainability framework has been developed for and applied to assess water and sanitation projects located in three countries in Africa (McConville, 2006, Castro, 2009, Ocwieja, 2010). In this report the assessment methodology is applied to a different technology, geographical location, and project context. This including refining the details associated with the assessment method so it was appropriate for SHS systems.

Three different SHS projects in isolated rural communities of Vanuatu were used as case studies in the application of the life cycle sustainability assessment methodology. Each case study was scored based on interviews and information gathered during project site visits. By applying this method to three SHS projects, systematic comparisons can be made, as well as insights, guidelines, and lessons learned for future SHS projects in Vanuatu. Chapter 2 provides a brief description of fundamentals of SHS including discussions on the main components of a solar electrical system and technical design guidelines. Chapter 3 first provides background information and definition of developmental project life cycle and sustainability factors. The assessment tool is then assembled using the defined life cycle stages and sustainability factors in the form of a matrix. In Chapter 4 three case studies are presented and evaluated using the assessment tool. Chapter 5 provides some comparisons between the different case studies and conclusions and recommendations for future research.

Chapter 2: Solar Home System (SHS)

This chapter will discuss typical solar electrical system components and SHS design. The discussion will be limited to standalone, non-hybrid solar electrical system common in the deployment of SHS projects in developing countries.

2.1. SHS electrical components

A Solar Home System (SHS) is typically a small standalone solar electrical system with a single solar panel, a charge controller/regulator, a battery, and simple, low powered electrical appliances such as lights, small radio, mobile phone charger, dvd player and a small TV. Its basic function is to utilize the sun's energy to provide electricity for various electrical appliances in a household. A typical SHS configuration and layout is shown in Figure 2.1.

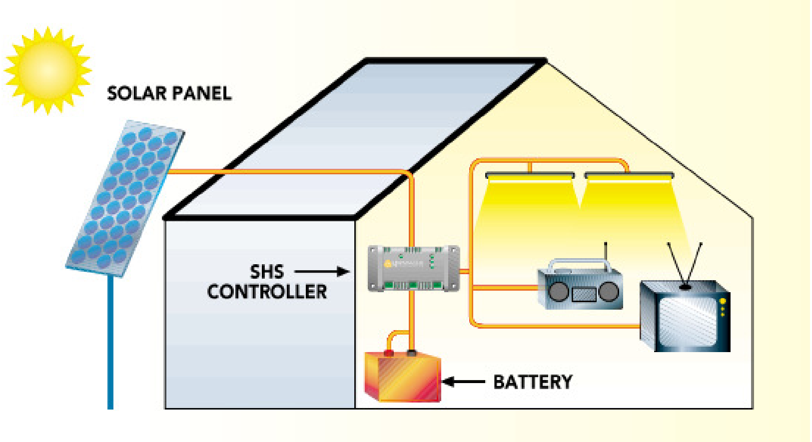
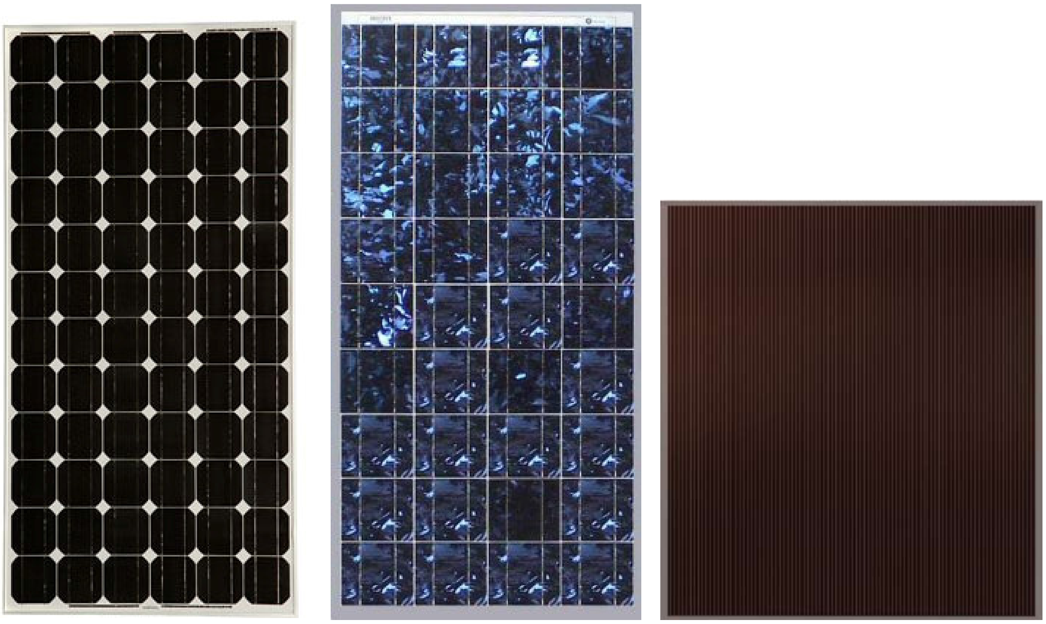


Figure 2.1: SHS components connection diagram. Courtesy of Morningstar Corp.

2.1.1. Solar Panel

Solar panels or more technically photovoltaic (PV) panels are a solar home electric system's enabling component. Panels are made of wafers or cells of semiconductor material that use sunlight (photons) and the photovoltaic effect to generate direct current (DC) electricity. There are three main types of solar cells: mono-crystalline silicon, poly-crystalline silicon, and thin film materials (See Figure 2.2). The different cell technologies represent different energy conversion efficiencies and manufacturing approaches in trying to reduce the cost of photovoltaic generated electricity. The photovoltaic technology is constantly evolving in the direction of better conversion efficiency and lower cost. Each solar cell can generate a predetermined voltage and current under manufacturing and physical constraints. A solar panel is made up numerous series and parallel combinations of identical individual cells to generate the desired power output (current and voltage). Panels are assigned a power rating in watts based on the maximum power they can produce under ideal sun and temperature conditions. The rated power output is used to help determine how many panels are needed to meet the electrical load demands. Multiple panels combined together are called solar arrays. In a typical SHS household one solar panel of less than 120w is usually utilized. There is a linear relationship between solar panel cost and output power. The solar panel can approach 50% of the total initial equipment cost of a SHS.



(a) **(b)** **(c)**

Figure 2.2: Solar panel types: (a) mono-crystalline silicon, (b) poly-crystalline silicon, and (c) thin film.

2.1.2. Charge Controller

The primary function of the charge controller is to maintain battery health by preventing battery overcharge by the solar panels and full discharge by the electrical loads. Either condition will lead to severely reduced battery lifespan. Charge controllers come in all sizes, and protection and monitoring features. The selection depends on the size of installed solar panel(s) and the complexity of loads and future expansion possibility. Different charging and maintenance algorithms are employed depending on the state and the type of the battery. There are many electrical protection features in a suitably designed charge controller that are beneficial in SHS type of applications. Protection features such as reverse polarity, short circuiting, over-current, low-voltage-disconnect, and tropicalization of circuit board makes the system relatively fool-proof in the SHS setting.

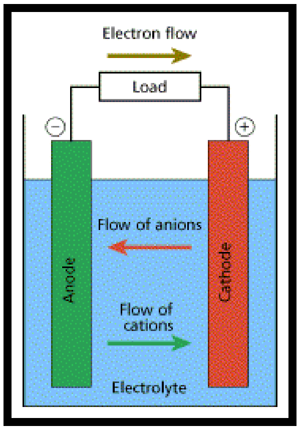
Figure 2.3: Charge controller specifically developed for SHS projects. Note the easy to understand labels and light indicators. Courtesy of Morningstar Corp.

2.1.3. Battery

Almost all solar electrical applications use a lead-acid type of battery chemistry to store energy. This is because of the battery's storage capacity to cost ratio, their wide availability, technical simplicity, and support infrastructure. A lead-acid battery is an electrochemical device that stores chemical energy and releases it as electrical energy upon demand. When a battery is connected to an external load, such as a light, chemical energy is converted to electrical energy and direct current flows through the circuit.

DISCHARGING PROCESS

$PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + H_2O$



CHARGING PROCESS (Reverse of Discharging Process)

$2PbSO_4 + H_2O \rightarrow PbO_2 + Pb + 2H_2SO_4$

Figure 2.4: Basic Lead-Acid battery operation and chemistry. Adapted from Battery FAQ, 2009.

2.1.4. Loads

Loads are electrical appliances that draw power from the battery, either directly or indirectly. Typical home electrical appliances are AC powered. To be able to use AC powered appliances in a SHS, a DC-AC power inverter will be required. The inverter itself acts as a load because of parasitic power draw (stand-by power consumption) and conversion efficiency losses. In this case all the AC appliances connect to the inverter, which get its power from the battery. In many SHS projects, an inverter is not included due to cost and system abuse concerns. In those cases increasingly available DC electrical appliances such as CFL and LED lights, small radios, portable dvd players and small DC powered TVs are connected directly into the 12v DC SHS circuit. It is very cost effective and efficient to deploy DC-only SHS due to the typical low power requirements of DC appliances and it also simplifies the system design.

2.1.5. Balance of system components

All other SHS systems components not included in the above main categories are termed balance of system (BOS) components. They include panel installation posts, mounts, hardware, wires, switches, circuit breakers, fuses, installation tools, digital multi-meters, future maintenance items, etc. These ancillary parts serve crucial function to the proper implementation and operation of the system, thus their quality is as important as the other main components of SHS. Other than the panel installation posts, the BOS components will have to be imported in developing countries. For a typical SHS project the cost of BOS components can sometimes be underestimated by project planners due to unfamiliarity of local pricing.

2.2. SHS Design

Solar electrical system designs are load (energy demand) based since all of the electrical energy has to come from the system (standalone system, not grid-tied or generator-solar hybrid). Thus, it makes sense to know what the electricity demand is to properly design and size the system.

There are two key parameters that govern the design; 1) solar resource (energy supply) and 2) electricity usage (energy demand). The fundamental design objective is to ensure that the supply meets the demand, under various environmental and cost constraints and uncertainties in both the energy supply and demand, and also to maximize component lifespan. It is important for the two key parameters to be determined and/or estimated as accurately as possible for ideal system performance. The basic design goal is to properly size the solar panel and the battery (or battery bank) so that the loads can be powered up 90%-99.99% of the time (Shepperd & Richards, 1993).

Systems with 99.99% power availability are critical-load systems. They are usually radio communication towers at remote mountain top locations where electrical grids are too costly to install and reliable and cost effective fuel delivery for an electrical engine generator is not possible. A seasonal vacation cabin can be designed with 90% availability for cost effectiveness. Most residential installations have availability in the range of 95% to 99%. The cost differential between the two can be as much as a factor of 3-4 (Sandia National Labs, 1995).

2.2.1: Solar Resource

Solar resource is the amount of sun light available to the solar panels to generate electricity. Commonly used technical terms for solar resource are the irradiance and insolation. Solar irradiance is the amount of solar power striking a given area. It is a measure of the intensity of the sunshine and is given in units of watts (or kilowatts) per square meter (w/m^2). At the outer edge of earth's atmosphere the solar irradiance measures at a constant $1,360w/m^2$. On a clear sunny day at noon on earth's surface on the equator, the solar irradiance measures about $1,000w/m^2$. The decrease in solar irradiance on the earth's surface is due to atmospheric absorption (See Figure 2.5). On rainy days with thick cloud cover, the atmosphere can absorb almost all of the solar energy.

Solar irradiation data are often presented as an average daily value for each month. On any given day the solar irradiation varies continuously from sunup to sundown due to the sun's angle and the change in thickness of the atmosphere that the sun light has to penetrate. The monthly and seasonal variations are mainly due to the earth's 23.4 deg inclination from the orbital plane as it goes around the sun. It can be explained similarly as in Figure 2.5, instead of the east-west orientation of sunrise-sunset, the sun's relative north-south position depend on the latitude of the installation location. Near the equatorial latitude, the sun makes very close to 0 deg incidence angle to any flat mounted panel, similar to the noon time sun as in Figure 2.5. Near the poles, very little sun light shines directly at the same panel.

The maximum irradiance is at solar noon which is defined as the midpoint in time, between sunrise and sunset. The term "peak sun hours" is defined as the equivalent number of hours per day, with solar irradiance equaling 1000 w/m^2 (See Figure 2.6).

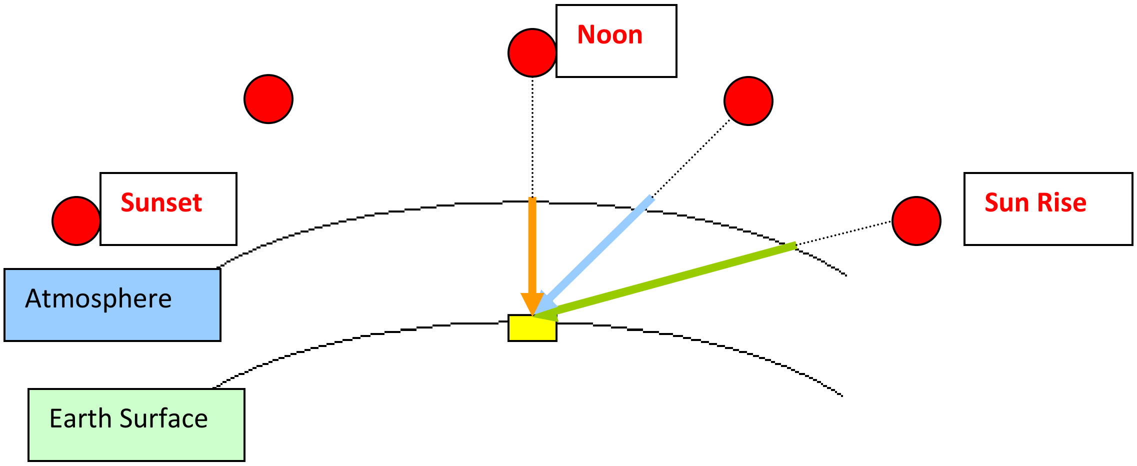


Figure 2.5: Length of different colored arrows represents different thickness of the atmospheric layer that the sun light has to penetrate. Thicker layer to penetrate equals more light absorption, resulting in decreased solar irradiance (Thickness of atmosphere exaggerated for illustration purpose).

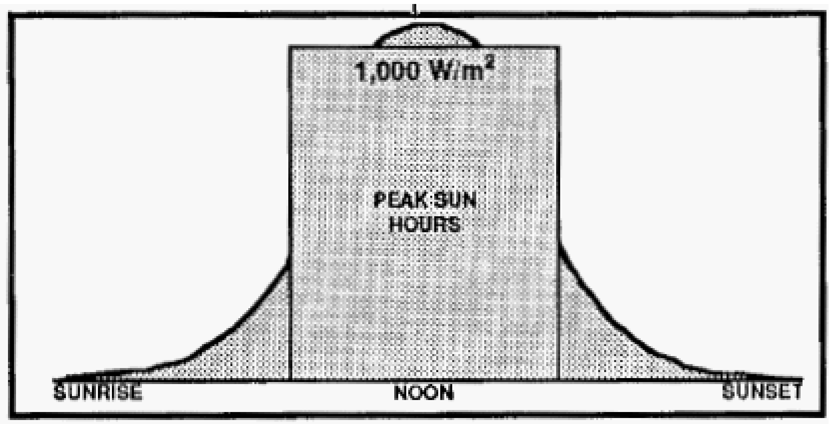


Figure 2.6: Illustration of peak-sun hours. Adapted from Standalone Photovoltaic Systems, Sandia Labs.

Solar insolation is the amount of solar energy received on a given area measured in kilowatt-hours per square meter (kwh/m^2)--this value is equivalent to peak sun hours. We are interested in the concept of peak sun and peak sun hours because the power output of all solar panels manufactured are specified in terms of the standard condition of peak sun (1000w/m^2) at 25 °C. A 100 watt solar panel will produce 100 watt of output only when the solar irradiance on the panel is 1000w/m^2 and temperature of the solar cell is at 25^{o}C. Haze or partly cloudy or higher temperature conditions will reduce the output wattage. For a location that has a solar insolation value of 5, it can be expected that a 100w solar panel will produce 100w × 5 = 500w-hrs of electricity per day, assuming the temperature of the solar panel remains at 25^{o}C.

Solar insolation data in the United States and a majority of the developed countries are usually obtained from sensors mounted near sources of interest such as airports, meteorological stations, research stations, universities, etc. There are also accurate computer simulation models for estimating solar insolation. Whenever possible, local solar resource data should be consulted.

2.2.2: Solar panel sizing

Assuming the solar resource data is available, the first step in the design is to determine the electrical load that the system has to support. This load estimate is one of the key factors in the design and cost of the stand-alone solar system. Usually a list of all the loads, their rated wattage, the expected daily number of hours of operation, etc, will be tabulated and summed up in several key design parameters such as peak current, total daily watt-hrs, total daily amp hrs. Based on the author’s experience most non-professional designers (hobbyist, do-it-yourself’s, Peace Corp Volunteers) will usually use only the total daily watt-hrs to determine the size of the solar panel. In some of the internet special interest sites the same sizing guideline can also be found. The basic formula is:

Size of panel (Watts) = Total daily load (Watt-hrs) / daily peak sun hrs (hrs)

This formula seems simple and straightforward and it can be derived with high school level electronics knowledge. However, some serious under-sizing of the solar panel will occur when you calculate the size of the panels this way. Fundamentally there is nothing wrong with the formula. It's what's hidden in the definition of 'watt' and the fact that most small DC power sources are current limited devices that's the source of the miscalculation. To understand why this formula will arrive at an undersized design, one has to look at the solar panel performance specification shown in Figure 2.7.

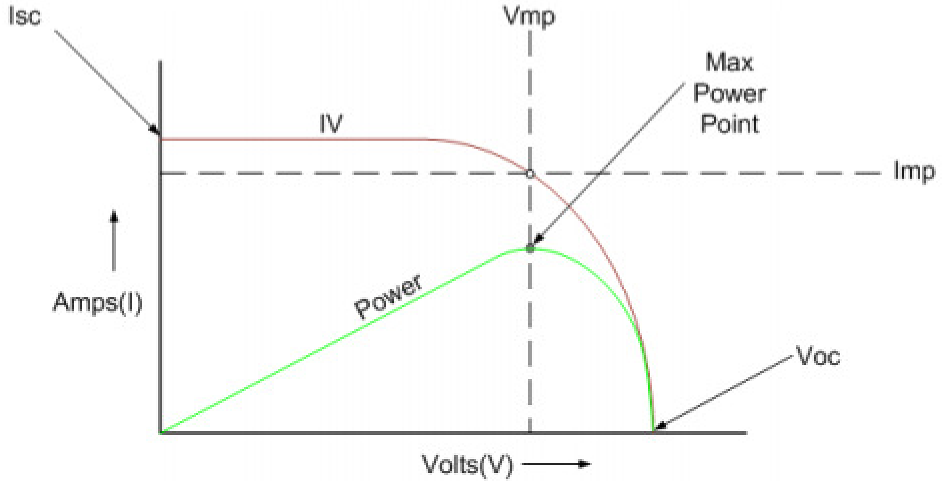


Figure 2.7: Solar panel performance specification: current-voltage curve. Adapted from Outback Power Systems.

This is a typical current-voltage curve of a 12v solar panel. Each point along the curve represent a wattage output of the panel because power (watt) = current (amp) × voltage (volt). There are 5 points of interest on the curve which are typically part of the technical specification of a solar panel. They are labeled I_{sc}: short circuit current, Imp: max power current, V_{oc}: open circuit voltage, V_{mp}: max power voltage, and max power point wattage: $W_p = V_{mp} \times I_{mp}$. Deviating in either direction from the max power point on the curve will result in reduced power output. Note that the max power point does not occur at 12volts. It is usually set at a much higher voltage (15-18v) to maintain the power output to at least 12v so it does not lose the ability to charge a 12v battery during partly cloudy or other less than ideal conditions.

Because power = current ×voltage, this means that the max power current for a given panel will be less than the current at 12v for the same panel wattage. This implies that a 12v solar panel at certain wattage rating cannot power an equal wattage load at 12v. For example a 60w load at 12v requires 60w/12v = 5amps of current. A 60w panel typically has max power current at only 3.5-3.8 amps. This means that the incorrectly applied formula using system watt-hrs to find the required wattage of the solar panel will result in an undersized panel.

The proper way to size the solar panel is to use the daily load total amp-hr and a well established guideline in solar research literature (Hund T. , 1999) of a minimum charge-amp-hr to load-amp-hr ratio of 1.3 (C:L ratio) to first find the charge amp hr required. The ratio of 1.3 is to account for wiring losses, battery charging efficiency, and to minimize the period that the battery spend in the deficit charged state.

Charge-amp-hr = load-amp-hr x 1.3

After the charge-amp-hr number is obtained in the above equation, the next step is to divide it by the daily peak sun hrs at the installation site to arrive at a minimum current in which the panel's (or a combination of series/parallel panels) max power current must be greater than or equal to. It is this minimum "max power current" that is used to size the solar panel.

Minimum max power current (amp) = Charge-amp-hr / peak sun (hr)

The C:L ratio may be one of the most important design parameters for batteries achieving rated cycle-life. The C:L ratio determines the number of cycles the battery spent in deficit-charge recovery and the time spent at regulation voltage every day (Hund T. , 1999). This is probably the most important solar system battery charging parameter for maintaining battery health [ref 3]. As the C:L ratio increases, the number of deficit-charge cycles decreases and the time spent at regulation voltage increases accordingly. It is very important for batteries in stand-alone solar systems to recover from this deficit-charge condition using only the limited charge provided by the panels each day. Deficit-charge recovery in solar systems is more difficult than in other deep-cycle applications because of the extended time that the battery spends in a discharged condition. In many solar systems the battery may not completely recover from LVD (low voltage disconnect) for weeks-to-months at a time.

2.2.3: Battery sizing

Battery sizing is a tradeoff between cost and system power availability. Battery is sized to provide daily load demand and storage of energy in case of non-sunny days, in which the battery has to provide all the power to the load demand. Usually the number of days of storage required depends on the application, the desired usage availability, and local weather. In residential applications in sunny, dry climate, 2-3 days of energy storage will usually suffice. In cloudy weather, 3-5 days will be more appropriate. There is no exact right answer to the number of days of storage needed. But in general the recommendation is to put in as much storage as one can reasonably afford.

Batteries are rated in terms of amp hours of storage capacity, under specific conditions. Batteries undergo electro-chemical reactions during charge and discharge so the physical environmental conditions and the charge-discharge rate all have an effect on available battery capacity. (Battery FAQ, 2009)

Most deep cycle batteries are normally rated in number of hours it takes to discharge a fully charged battery to 10.5 volts in 20 hours at 25° C, denoted as "C/20". Discharge rates of 100 hours (C/100), 10 hours (C/10), 8 hours (C/8) or 6 hours (C/6) are also common ratings. For example, a 100 Amp-Hr C/20 rated battery means that the battery can provide 5 amps of current (C/20 = 100/20 = 5) for 20 hours. The exact same 100Ah battery will have different capacity rating at other discharge rates. The difference in battery capacity due to discharge rate is termed the Peukert effect; the higher the discharge rate (or fewer hours the battery is fully discharged in), the lower the capacity (Figure 2.8). In Figure 2.8, n is the Peukert number specific to each battery. Most reputable battery manufacturers include the Peukert number as part of the battery specification.

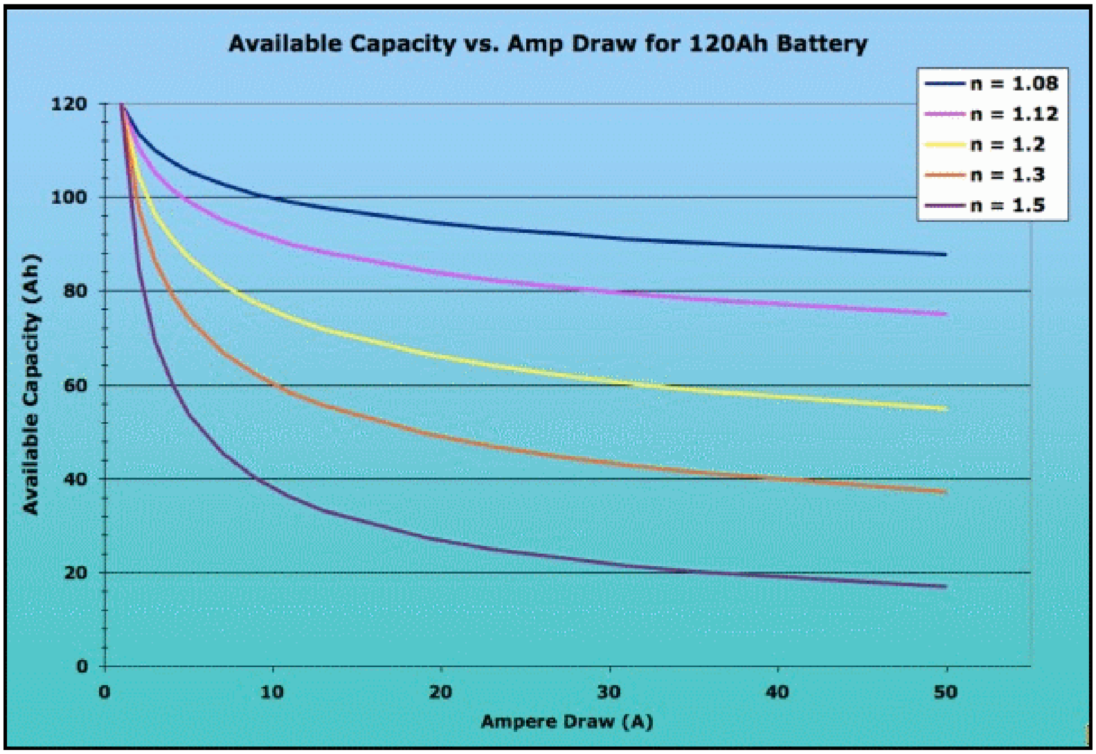


Figure 2.8: Peukert effect on available capacity. n= Peukert number of the battery. Adapted from battery FAQ.

As shown in Figure 2.8, a 120Ah rated battery with Peukert number = 1.2 (yellow line) becomes a 60Ah battery when the current draw is 30Amps.

In considering battery sizing in SHS applications, there is an important distinction between rated battery capacity and usable battery capacity. The Peukert effect comes into play in solar applications when the peak load current demand exceeds the nominally rated C/20 discharge rate. In those cases the designed storage capacity of the battery will ‘shrink’, resulting in more depth of discharge, lowering the battery voltage further, which in turn results in even more current draw (power = volt × amp, if voltage lowers current has to increase to keep the same power level), thus initiating a negative feedback loop of yet more ‘shrinkage’ of the battery capacity, and so on.

There is another factor that makes sizing batteries a non-straight forward task. The usable battery capacity is further limited by the battery life vs. depth of discharge trade off. Figure 2.9

shows the number of charge/discharge cycles a battery will provide before failure as a function of depth of discharge. Note that the y axis is in logarithmic scale.

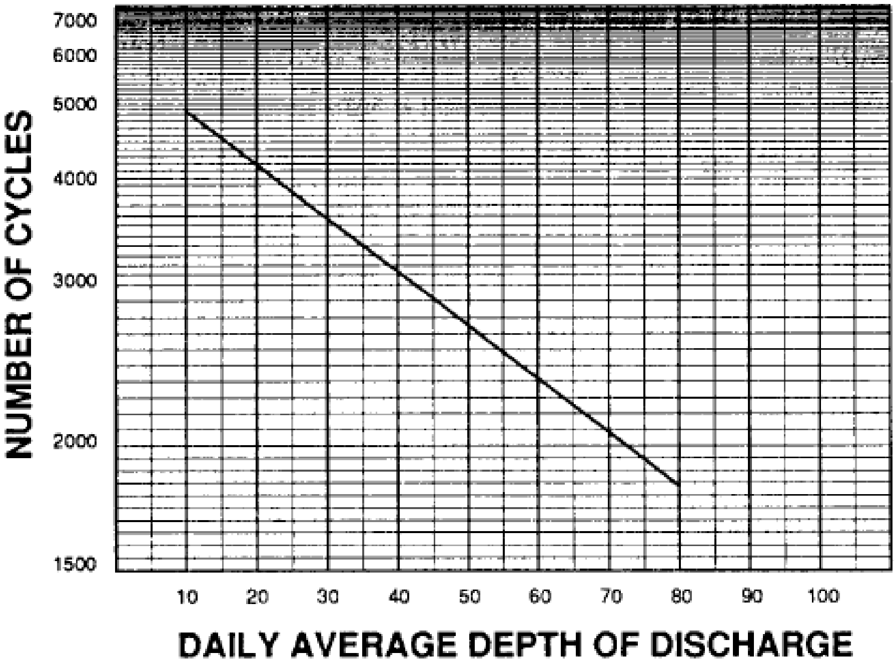


Figure 2.9: Battery life cycle vs. depth of discharge (DOD % capacity). Adapted from Sandia labs.

There is usually a compromise between battery life and available capacity, together with replacement cost considerations. A multi-dimensional optimization coupled with life cycle cost analysis might be performed to better aid the choice of battery size. At the end, non-technical considerations might still overrule technical designs recommendations. A commonly accepted compromise for usable battery capacity is 50% DOD (Deep Cycle Battery FAQ, 2009).

2.2.4: Estimating local solar insolation and importance of panel orientation

Most of the time solar insolation data is simply not available in developing countries. This critical design parameter directly affects the ability of the designed system to provide power to the loads. For an outsider system designer, south pacific conjure up images of sunshine and white sandy beach. But this is often not the case, especially in Vanuatu. To have a reasonable educated estimate on the solar insolation value, meteorological data can be consulted. Figure 2.x shows the number of rainy days in different geographical parts of Vanuatu. The northern island weather station is located at latitude of 13deg south, and the middle islands weather station (Lamap, author's location) at 16 deg south, and the southern island weather station at 19 deg south.

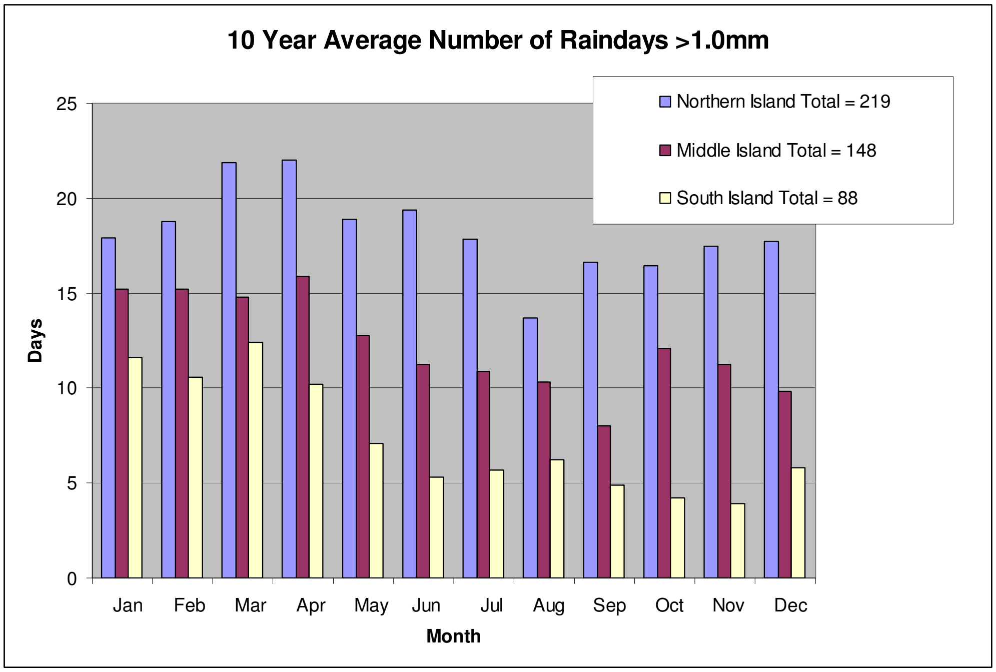


Figure 2.10: Ten year average number of rain days for different geographical region in Vanuatu. Data source: Vanuatu National Meteorological Department.

As Figure 2.10 shows, there is quite a bit of variation in the amount of rain days between the northern islands and the southern islands. In addition, windward sides of most south pacific islands generally receive more rain than the leeward side. These observed climatic differences are due to mountain terrain of small volcanic islands and south east trade winds in the southern hemisphere. The above stresses the importance of using local weather data. Even though there is no provable direct inverse correlation between the number of rain days and the number of peak-sun hours, it is safely to assume that on a rainy day the likelihood of cloud cover is high. (Although data not shown, there is a direct correlation between number of rain days and total amount of rainfall) It can be estimate based on observation that the number of peak-sun hours on a rainy day to be between 1-2.5.

For the author's location, with 148 rain days out of 365 days a year, and assuming that on non-rain days 5 peak-sun hours per day, you arrive at an average yearly solar insolation of 3.4 ([1*148+5*217]/365 = 3.4) . For the worst months Jan-Apr, the average monthly solar insolation is 2.9. There exists some uncertainty in estimating the solar insolation data this way, but it is considerably better than an outsider's amateurish estimate of '5 peak sun hrs for most tropical islands'. There are other ways to estimate the solar insolation in the absence of measured data or detailed simulation model (Nieuwenhout, 2006; Li, 2008), with plenty of ongoing research in this important area.

Once the solar insolation data is determined, the next step will be to determine the physical orientation of the panels. In general for a fixed mount panel (most all small solar systems), you would tilt the panel toward the peak-sun (true north in the southern hemisphere, true south in the northern hemisphere) at the same latitude angle as the installation site. If there is higher load demand during winter (shorter days, less sun, more time lights are on) you would change the tilt angle to latitude +15 deg in the southern hemisphere, and vice versa for the northern hemisphere. Usually if a solar system has constant load demand, (no seasonal variations in load usage) it is designed for the worst case solar insolation month, if one exists. In those cases you would want to tilt the panel such that it gets the most power during that month. It is typical for a panel to have a minimum of 15deg tilt regardless of the installation latitude. This is to take advantage of self-cleaning capability when it rains.

Figures 2.11 shows the effects of seasonal variations in solar insolation together with the orientation (tilt) of the installed panel. The difference in solar insolation between summer and winter can be up to 2-3 peak sun hrs a day! The difference between a simple horizontal flat mount and a tilted at latitude mount can also be very significant. Note the special case of Seattle area. In both the winter and summer it makes almost no difference whether the panel is flat or tilt mounted. The total insolation is about the lowest due to rain and perennial cloud cover. This illustrates the importance of proper panel orientation and regional climatic differences.

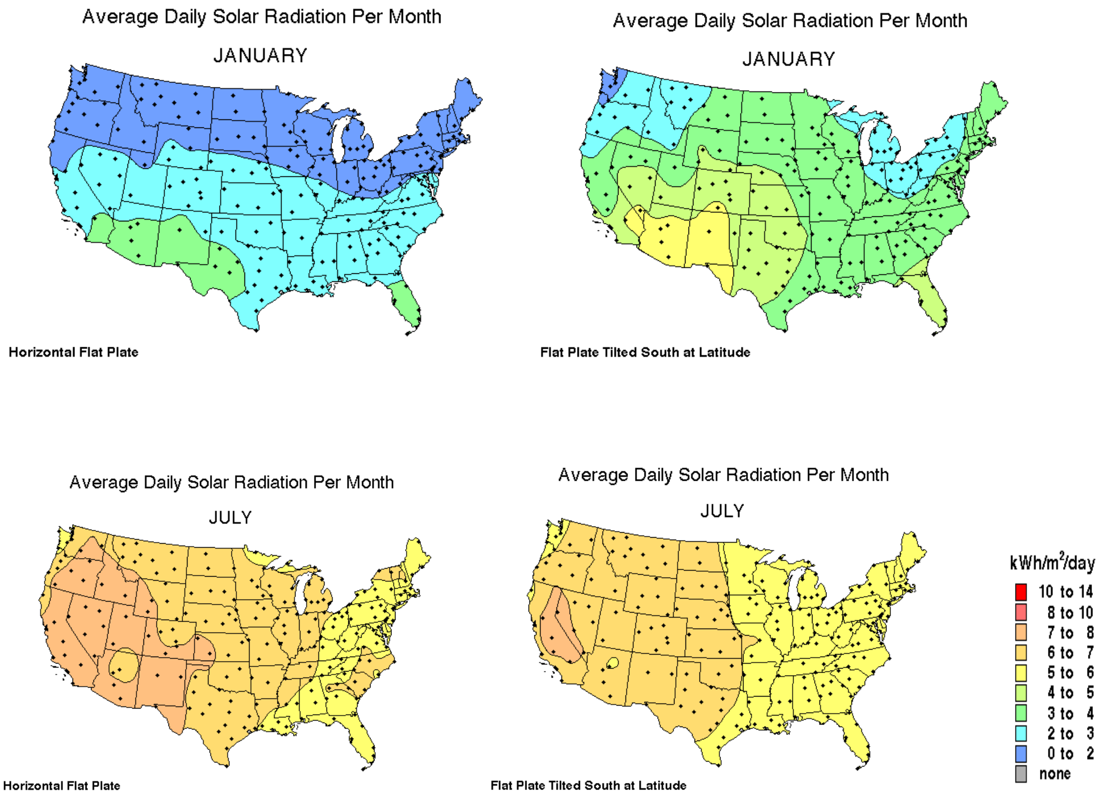


Figure 2.11: Seasonal and tilt angle effects on solar insolation. Adapted from NREL data.

In Vanuatu a lot of the amateurish home installations have the panels simply flopped up on to either a traditional thatch roof or a tin roof. Often times the roof does not face the north, and even if it does it is often at the wrong tilt angle. This huge installation oversight is guaranteed to lead to an underperforming and short-lived system (due to battery under charging), especially if the solar insolation is marginal to begin with, which is frequently the case in the Northern parts of Vanuatu. Even if the design and the installation are professionally done, microclimate can still play a huge role in performance of the system in the installation locale. There is a field study of a radio communications tower in Albuquerque (Hund & Stevens, 2000). The conservative design already reduced the local site insolation number by one hour from nearby measured insolation data to account for the mountainous microclimate. After two years of actual recorded data it shows the measured solar insolation value at the installation site is 28% lower than the already conservative estimate.

2.2.5: SHS Design worksheet

In the rural setting of a developing country, the two key design parameters of a SHS are rarely certain. A SHS design aid in the form of a spreadsheet is developed to see the effects of changing load on numerous design parameters such as required battery capacity as a function of storage days and depth of discharge, peak-sun hrs and their corresponding C/L ratio. This worksheet can also be used to quickly identify required panel and battery sizing, and to also investigate best-case worst-case usage scenarios. Descriptions and instructions on how to use the design worksheet are included in Appendix I.

Chapter 3: Project Assessment Methodology: Life Cycle-Sustainability Matrix

The life cycle assessment matrix (McConville, 2006; McConville & Mihelcic, 2007) used in this report provides a tool for development workers to approach a project in a different way, looking at the sustainability of the project over each life cycle stage.

The objective of this report is to put life cycle-sustainability assessment into practice by applying the methodology to evaluate rural area SHS projects in Vanuatu. The results will assist engineers and other development workers in recognizing factors that affect sustainability, effectiveness, viability, and gain insights on ways to mitigate them over the course of the project life.

This assessment tool will allow engineers and development workers to quantify the sustainability of their projects through a series of checklists. The results will reveal strengths and weaknesses in project approaches, and provide guidance toward a more sustainable approach to planning and implementing SHS projects.

In the following sections a brief introduction to the basic concepts of project lifecycle and definition and components of sustainability will be discussed. Much of it will be adapted from the materials developed in other research. For a more complete analysis the interested reader is referred to a Masters report (McConville, 2006) for details of the life cycle–sustainability development project assessment methodology.

3.1 Project life cycle stages

The general concept of project life cycle is well established in the industry and international standards have been developed (Estes, 1993). There might be various definitions and names given to each project life cycle stage, but they generally fall under the broad categories of project initiation, planning, execution and controlling, and closure. Project lifecycle does not necessarily follow a linear progression; some part of the project lifecycle may be iterative and actions and decisions in one project lifecycle stage may influence others.

Precise definition of project lifecycle stages and their definitions are customized for specific industry and project environment for proper application. For a development project it is appropriate to divide project lifecycle into five stages as shown in Figure 3.1.

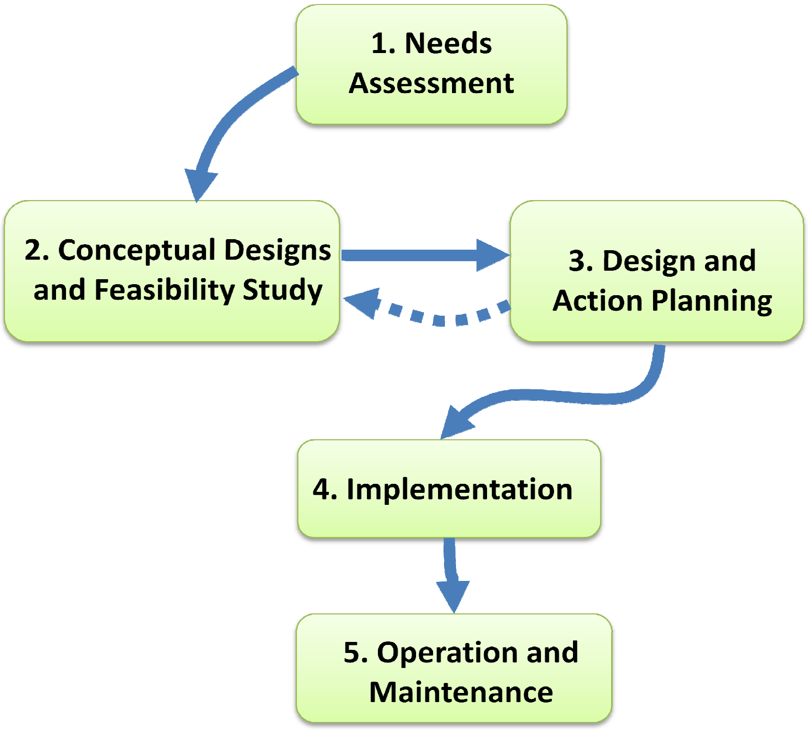


Figure 3.1: Five life cycle stages for development work. Solid arrows indicate the flow of the life cycle process. The dotted arrow indicates the potential for iteration between stages 2 and 3. Adapted from McConville, 2006.

1. Needs Assessment
   Each development project begins with a needs assessment, which determines the motivation for intervention and the extent of need. The purpose of a needs assessment is to determine if sufficient demand exists for the project and to begin collecting the necessary background information for project development.

2. Conceptual Designs and Feasibility Study
   The conceptual design phase is an iterative process in which alternative plans are developed and assessed for feasibility and acceptability. The objective is to select an appropriate technology that is technically sound, economically feasible, and acceptable to the community. This life stage may begin with a brainstorming session to identify potential solutions. Multiple conceptual designs will be considered, preferably covering a range of improvement levels, from small changes to the existing system to introducing new technology. The feasibility of each conceptual design will be determined based on social, economic, and environmental constraints, and advantages and disadvantage of each technology.

3. Design and Action Planning
   The selected design is finalized and an action plan prepared for project implementation. A detailed technical design is developed, including sketches, schematics, construction and operation budgets, and resource inventories. The action planning phase occurs in conjunction with project design, since action plan constraints may affect the final design. The action plan is defined by three steps: identification of tasks, assigning roles and responsibilities, and sequencing tasks in a timeline.

4. Implementation
   Project implementation includes both the pre-construction and construction processes. Pre-construction involves the procurement of supplies and financing, site preparation, and potentially the manufacture of construction supplies. Implementation also includes technical training and community education components.

5. Operation and Maintenance
   The operation and maintenance life stage considers the use of the project. It includes operational, management and financial issues. An organization with the capacity for adaptive management and ability to make adjustments for unexpected problems will typically oversee operation and maintenance programs. This stage may include continued technical training and education to support use of the system.

3.2 Sustainability factors

Sustainability has become a wide ranging concept that can be applied to almost any scale and context. The World Summit on Sustainable Development offers an abridged definition by recognizing the existence of three interdependent and mutually reinforcing pillars of sustainability: economic development, environmental protection, and social development (United Nations, 2002). Sustainable development occurs at the intersection of these three interests (See Figure 3.2). The first two pillars of sustainability are consistently defined throughout literature, but social sustainability has been widely interpreted. It has been implicated in issues of cultural sensitivity, conflict resolution, community-building, institution-building, and political stability (Estes, 1993). For this report social sustainability is divided into socio-cultural respect, community participation, and political cohesion. These factors are discussed in more detail in Table 3.1.

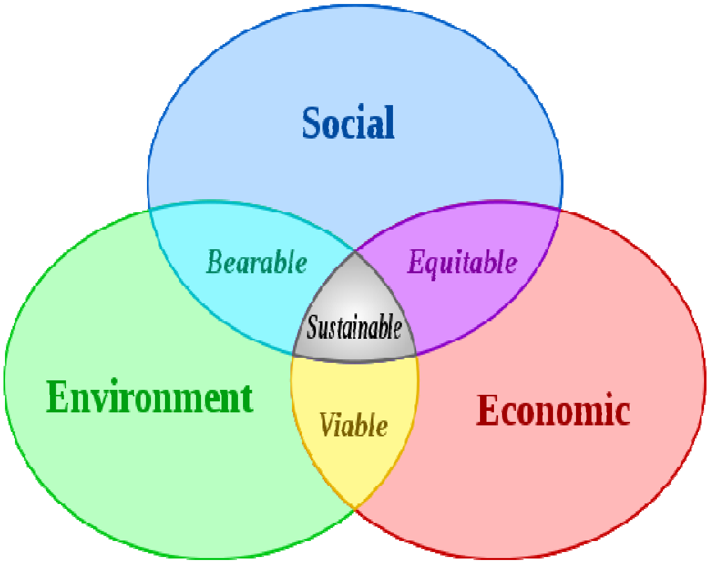


Figure 3.2: Three pillars of sustainability, sustainable development occurs at intersection of all three. Adapted from Wikipedia.

Social Sustainability	**Socio-cultural Respect**	A socially acceptable project is built on an understanding of local traditions and core values.
	Community Participation	A process which fosters empowerment and ownership in community members through direct participation in development decision-making affecting the community.
	Political Cohesion	Involves increasing the alignment of development projects with host country priorities and coordinating aid efforts at all levels (local, national, and international) to increase ownership and efficient delivery of services.
Economic Sustainability		Implies that sufficient local resources and capacity exist to continue the project in the absence of outside resources.
Environmental Sustainability		Implies that non-renewable and other natural resources are not depleted nor destroyed for short-term improvements.

Table 3-1: Five Factors in Sustainable Development. Adapted from McConville, 2006.

3.3 Matrix Framework

An evaluation framework based on a matrix approach in which the matrix dimensions are defined by the sustainability factors and project life cycle stages is shown in Table 3.2. The matrix approach allows each sustainability factor to be considered throughout the life of the project. Therefore, each matrix element defines how a certain sustainability factor can be dealt with at each point in the project life. A matrix framework is an effective assessment tool because it allows each element of the matrix to be evaluated separately. An assessment of individual elements can highlight strengths and weaknesses in project approaches, allowing decision makers to identify key areas for improvement. The matrix dimensions are defined by the sustainability factors (socio-cultural respect, community participation, political cohesion, economic sustainability, environmental sustainability) in one direction, and the project life stages (needs assessment, conceptual designs and feasibility, design and action planning, implementation, operation and maintenance) in the other (See Table 3.2).

Life Cycle Stage	**Sustainability Factors**					
	Socio-cultural respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)	20
Conceptual Design and Feasibility	(2,1)	(2,2)	(2,3)	(2,4)	(2,5)	20
Design and Action planning	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)	20
Implementation	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)	20
Operation and Maintenance	(5,1)	(5,2)	(5,3)	(5,4)	(5,5)	20
Total	20	20	20	20	20	**100**

Table 3-2: Sustainability Assessment Matrix. The matrix dimensions show five life cycle stages and five factors of sustainability. Adapted from McConville, 2006.

The following sections provide details and scoring criteria for each element of the matrix. Within each matrix element (for example, element (4,3) = political cohesion of the implementation stage) four recommended tasks and actions (bulleted items) are provided for improving sustainability. To determine the score of a project the evaluator assigns a rating (0-4) to each matrix element, depending on the number of sustainability recommendations completed. If none of the recommendations are met the matrix element is scored 0 (poor evaluation). If all of the recommendations are met the matrix element is scored 4 (excellent evaluation). The potential score for each sustainability factor or life stage is 20, while the total possible score is 100. The guidelines and scoring mechanism serve as self-assessment and educational tools in the process of development project implementation. More detailed descriptions and scoring guidelines are included in Appendix II.

Element (1,1) Needs Assessment: Socio-cultural Respect

- Identify social preferences and traditional beliefs regarding lighting energy supply.
- Is there preferred form of energy (for lighting) over another?
- Determine level of education regarding ability to understand energy.
- Gender roles in energy usage?

Element (1,2) Needs Assessment: Community Participation

- Conduct PACA at local level?
- Identify stakeholders and community leaders.
- Determine the type of political organization and cohesion at the community level.
- Reach a consensus with community members that project intervention is appropriate.

Element (1,3) Needs Assessment: Political Cohesion

- Conduct a situational analysis of regional and national issues, such as political structure and stability, government policies, and foreign aid.
- Ensure that proposed project is consistent with regionally identified development priorities and plans.
- Research the history of NGO and government projects in the area.
- Establish communication lines with existing NGO and/or government institutions in the area.

Element (1,4) Needs Assessment: Economic Sustainability

- Understand the local and national economic situation (poverty level, employment, cost of living, flow of resources).
- Understand how the community economic situation is affected by electrical energy issues.
- Identify sources of monetary and non-monetary resources (materials, labor, and tools) within the community.
- Assess the community willingness-to-pay in both monetary and non-monetary terms for current electrical energy services.

Element (1,5) Needs Assessment: Environmental Sustainability

- Identify local resources for electrical energy.
- Collect data on climate and environmental constraints that will factor into project design.
- Identify potential environmental concerns at the local and regional level.
- Determine community understanding of environmental problems and the willingness to correct them.

Element (2,1) Conceptual Designs and Feasibility Study: Socio-cultural Respect

- Assess how the proposed interventions will affect daily activities and socio-cultural roles within the community.
- Evaluate the willingness and capacity of the community to perform operation, maintenance, and disposal requirements for each design.
- Design recognizes and respects traditional gender roles.
- Recognize why biases exist towards certain technologies by donors and/or locals.

Element (2,2) Conceptual Designs and Feasibility Study: Community Participation

- The project goals are clearly defined and understood by the community and development workers.
- Identify a representative committee that can act as the community liaison throughout the project.
- Present several technically feasible alternatives for community evaluation and feedback.
- Community members formally select a design based on an understanding of the constraints involved in the selection process.

Element (2,3) Conceptual Designs and Feasibility Study: Political Cohesion

- Develop a working relationship with partner organization(s), including at least one that is based in the host country.
- Consult the plans and designs of other organizations on similar projects.
- Explore options to integrate existing technologies or programs into conceptual designs.
- Contact potential partner institutions for project financing.

Element (2,4) Conceptual Designs and Feasibility Study: Economic Sustainability

- Estimate the implementation costs of each conceptual design.
- Estimate operation, maintenance, and disposal costs for each conceptual design.
- Assess the community willingness-to-pay in both monetary and non-monetary terms for each improved system.
- Conduct an economic feasibility assessment to evaluate long-term project viability based on cost estimates, projected operation and maintenance costs, community willingness to pay, the need for outside resources, and the availability of outside funding.

Element (2,5) Conceptual Designs and Feasibility Study: Environmental Sustainability

- Assess the capacity for sustainable electrical energy use in the geographic area.
- Consider how seasonal variation in energy supply, demand, and environmental conditions will affect each conceptual design.
- Consider land needs and availability of suitable land for each alternative.
- Conduct a site impact analysis for each alternative.

Element (3,1) Design and Action Planning: Socio-cultural Respect

- Understand the traditional structure of community projects.
- Consider the seasonality of labor in setting the timeline.
- Explore options for increasing gender equity in project roles and capacity building.
- Confirm that labor and resource contributions are equitably divided.

Element (3,2) Design and Action Planning: Community Participation

- Community input is solicited in refining the selected technical design.
- Final technical design is approved through a process of community consensus.
- Community members are involved in identifying and sequencing tasks that will be incorporated into an action plan.
- The community members and development workers approve of the timeline and responsibilities laid out in the action plan.

Element (3,3) Design and Action Planning: Political Cohesion

- The roles and responsibilities of partner institutions are defined in a detailed action plan.
- Agree on financial commitments.
- A timeline is drafted that meets the requirements of all institutions involved.
- Final project design and action plan are presented to partner institutions and local, regional, and/or national level authorities.

Element (3,4) Design and Action Planning: Economic Sustainability

- Verify the costs and availability of resources.
- Confirm the community contribution for money, materials, equipment, tools, and labor.
- Finalize budget based on local costs, available resources, and community contribution.
- Develop an action plan for resource procurement.

Element (3,5) Design and Action Planning: Environmental Sustainability

- The final project design minimizes ecological disturbance, energy use and waste emissions.
- The project design uses renewable and/or recyclable local resources.
- The action plan considers the seasonality of resources.
- Develop an environmental action plan to mitigate impacts during construction

Element (4,1) Implementation: Socio-cultural Respect

- Set a realistic work schedule, based on available resources and preferred work styles.
- Scheduling includes float time to allow for the unexpected.
- Encourage the involvement of women throughout the construction process.
- Use public gatherings to review benefits of the project, promote education, and discuss operation and maintenance.

Element (4,2) Implementation: Community Participation

- Involve the community in revisions of the action plan, program changes, and problem solving.
- Work with a local foreman or work supervisor in organizing labor.
- Train local laborers in any new techniques and tools that are introduced.
- Finalize the management plan with respect to the “built” system.

Element (4,3) Implementation: Political Cohesion

- Contact institutions in the area for assistance in training and labor requirements.
- Inform partner institutions of the start of construction, project milestones and major changes.
- Invite local government and NGO officials to view the construction site.
- Discuss partner roles in operation and maintenance.

Element (4,4) Implementation: Economic Sustainability

- Community members contribute to project implementation.
- Recheck the quality of materials and equipment during resource procurement.
- Monitor spending and budget restrictions throughout the project implementation phase.
- Draft final report on the budget and share with community members and partner organizations.

Element (4,5) Implementation: Environmental Sustainability

- Recheck physical and environmental constraints used in the project design and make design corrections if necessary.
- Take precautions to avoid negatively affecting existing electrical energy resources and minimize environmental impacts during implementation.
- Involve the community in waste management and environmental education.
- Restore any areas disturbed during construction.

Element (5,1) Operation and Maintenance: Socio-cultural Respect

- Discuss unanticipated constraints to SHS use.
- Discuss unexpected limitations to maintenance schemes.
- Reassess how gender roles affect the proper use and perceived benefits of the SHS.
- Ensure that costs and benefits are equitably distributed within the community.

Element (5,2) Operation and Maintenance: Community Participation

- Community members are actively involved in performing the necessary operation and maintenance.
- Conduct a participatory evaluation to get community feedback and suggestions for improvements.
- A community organization exists with the capacity to make decisions regarding the operations and maintenance of the SHS.
- The SHS is controlled by culturally appropriate and traditionally respected people.

Element (5,3) Operation and Maintenance: Political Cohesion

- Invite officials to the opening ceremony.
- Coordinating institutions sign a formal agreement that defines their roles and expectations in operation and maintenance of the system.
- A locally based institution is involved in project monitoring.
- Share monitoring reports and project evaluations with partner institutions.

Element (5,4) Operation and Maintenance: Economic Sustainability

- Estimate realistic, long-term operation and maintenance costs based on the “built” system.
- Financing exists to cover projected operation and maintenance costs.
- A financial management organization exists to manage operational/maintenance costs and the distribution of benefits.
- Regularly review and adjust the financing system.

Element (5,5) Operation and Maintenance: Environmental Sustainability

- Minimize, treat, and dispose of waste properly.
- Explore alternative plans for reducing the use of consumables.
- Monitor and evaluate environmental impacts.
- Continue environmental and technical education efforts.

Chapter 4: Assessment Case Studies

During the author's twenty seven month Peace Corp service there were many exposures to various installations of solar electrical systems in different institutional settings and many opportunities to speak to and interact with a wide variety of stakeholders. Three case studies were chosen for the assessment methodology as they represent a diverse range of solar electrical system (SHS) application, and project basis in rural Vanuatu (See table 4.1). The data for the three case studies were gathered from both formal and informal interviews with stakeholders during the author's site visits.

Solar Project Name	JICA Rural Electrification	Rural Community Institutions	Lamap, Malakula Island
Panel Wattage (W_p)	40-100	40-300	20
Ownership	Private/ESCO	Institution	Private
System Cost ($USD)	1600+	1000-6000	500
Funding Source	Self/Fee-For-Service	External Donor	Self
Number of Installations	120+	30+	9

Table 4-1: Case studies project summary. (ESCO=Energy Services Company)

The JICA funded rural electrification project was a pilot project to establish the necessary institutional infrastructure in rural Vanuatu. The rural community institutional solar projects were funded by external donors as part of a school or as necessary power source for medical and/or communication equipment in clinics and police stations. The Lamap SHS project is a grassroots self-initiated and self-funded effort with the goal of improving quality of life.

The project life cycle-sustainability assessment will be discussed in methodological detail for the JICA rural electrification project. Pertinent observations and issues will be summarized for the subsequent case studies and less structural details will be given as they follow the same matrix element scoring guidelines.

4.1 Case study 1: Japan International Cooperation Agency (JICA) funded SHS rural electrification pilot project on Efate Island

Although Vanuatu consists of 65+ inhabited islands, electricity is supplied in only two main towns by a French owned energy services provider using diesel generators, and the rate of the household electrification is under 10 percent (Energy Unit, 2008). As the demand for electricity was on a micro scale and widely dispersed throughout the islands, it was not economically feasible to construct any form of centralized grid infrastructure. In addition, the price of electricity is about 5-15 times the price in developed countries due to imported fossil fuels and geographic isolation. Therefore the government of Vanuatu had been trying to develop a decentralized system of renewable energy to enable rural electrification. (Energy Unit, 2008)

The decentralized system goes much beyond the island level, because each individual village and community on any particular island is usually disconnected from one another in terms of easy accessibility. However, the government of Vanuatu suffered from a chronic deficit, with foreign aid being directed toward public facilities such as schools, water systems, and health clinics and omitting electrification of the households. Under these circumstances, the government of Vanuatu requested the government of Japan to provide assistance in the form of locally appropriate Solar Home System (SHS) for rural-area electrification. In Vanuatu solar electrical systems and solar panels aren't unfamiliar sights since all the local landline telephones on many of the inhabited islands are powered by standalone solar systems. These standalone telecom systems are on a periodic maintenance schedule by a dedicated team of trained technicians from the state owned telecom so majority of them are usually in working condition.

Japan International Cooperation Agency (JICA), headquartered in the capital city in Vanuatu, is a volunteer based agency similar to Peace Corps. The main difference is that JICA employs many short term professional specialists for projects. JICA had prior experience developing SHS based rural electrification projects (Malawi rural electrification, 1998) and partners with the Vanuatu government ministry of lands, geology, mines, energy, environment, and water resources (MLGMEEW) to establish the energy unit within the ministry to administer the rural electrification pilot project.

4.1.1 JICA internal project evaluation

According to JICA, the overall goal of the project is to enable the supply of electricity to non electrified rural areas and to contribute to the improvement of villagers' lives.

In March 2002 at the 2 year 6 month mark since the initial installation JICA conducted a project outcome evaluation with a team of experts and concluded the following:

(1) Outcome of the Project: (from JICA project evaluation summary)

- The energy Unit, as an organization, is established.
- The electricity tariff system and the electricity charge collection system are established.
- The SHS sets are installed in the participating houses in the villages.
- The operation and maintenance system of SHS is established.
- The site villagers understand the mechanism of an electricity utility.

(2) Lessons Learned: (from JICA project evaluation summary)

- In implementing this kind of project, it is necessary to secure local staff that can maintain and manage the technology and instruct management in operation-related matters. It is also necessary for the Government of the implementing country to ensure a budget for sustainable project management.
- In order to address upkeep problems of equipment, it is necessary to introduce equipment with parts that are available on-site. It is also necessary for the

Japanese side to provide counterparts with a contingency plan that addresses expected problems.

- To cope with the basic issues of the rural electrification, it is necessary to carefully consider the business and management aspects of the project, such as settling electric of utility fees, collecting fees, and formulating a plan that fosters the personnel in charge of the maintenance and management.

JICA concluded in 2002 the rural electrification pilot project a success in terms of their objectives.

4.1.2 Assessment application

For this case study site visits and interviews at four of JICA's pilot project villages on Efate island were conducted. All the JICA pilot project villages were under the same general implementation, administration, management framework developed by JICA and the energy unit.

1. Mangaliliu village, Efate island (14 SHS surveyed)
2. Epau village, Efate island (10+ SHS surveyed)
3. Emua village, Efate island(10+ SHS surveyed)
4. Lelepa village, Lelepa Island, part of Efate. (10+ SHS surveyed)

The following table shows the scoring of JICA funded SHS pilot project on Efate Island, using the project life cycle-sustainability assessment matrix. In the sections to follow the matrix elements will be discussed in detail.

Life Cycle Stage	**Sustainability Factors**					
	Socio-cultural respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	3	3	4	4	1	15/20
Conceptual Design and Feasibility	2	1	4	2	2	11/20
Design and Action planning	3	1	4	4	3	15/20
Implementation	2	4	4	4	1	15/20
Operation and Maintenance	0	3	4	2	0	9/20
Total	10/20	12/20	20/20	16/20	7/20	**65/100**

Table 4-2: Assessment score of JICA funded SHS on Efate Island

Needs Assessment: Socio-cultural Respect, Community (individual household) Participation

In terms of needs assessment not much has been done when it comes to SHS in rural Vanuatu. This statement is in the context of the fact that it is irrefutable that everyone wants an improved quality of life in having good lighting at night. In terms of lighting usage there are five choices in the rural Vanuatu area; candles, kerosene fueled hurricane lamps, battery powered torch lights, generators with AC light bulbs, and SHS with DC light bulbs, in the order of increasing initial equipment cost. It is normally observed that in all rural areas without grid electricity small (<5Kw) generator sets are the most common way for people or small businesses (usually village stores or co-ops) to have AC power. For individual houses the purchase of a generator almost always goes with the purchase of a small TV and a DVD player and sometimes stereo with bigger loudspeakers. There are no other electrical appliances in a typical village house. The quality of the lighting provided by the candle or the hurricane lamp is significantly poorer than that provided by electrical light bulb. In terms of quality lighting need there is no debate that people prefer light bulbs over candles or hurricane lamps, when they can afford the means to generate electricity for the light bulbs. JICA and the energy unit offered DC fluorescent light-only SHS for cost effectiveness and simplicity of the system design and configuration. This was done without a user survey of what other AC electrical appliances that people would really want to use with their SHS. To be fair AC electricity is considered a luxury item in the rural area. (Score 3,3)

Needs Assessment: Political Cohesion

JICA together with the energy unit conducted SHS awareness information sessions in the pilot project villages, while working with village leaders and chiefs. In terms of political cohesion at the government and local leaders level there is full cooperation. The information sessions describe what kind of SHS is offered and what it can do. They also explain the fee-for-service structure of the project and the different levels of monthly electricity fee for different SHS configuration. Fee-for-service is not a foreign concept as many of the villages have this model for their piped water system. The participation in the project is strictly voluntary since it requires cash outlay for startup equipment purchase despite heavy subsidies provided by JICA. (Score 4)

Needs Assessment: Economic Sustainability

JICA and the energy unit fully understand the high equipment costs of solar electrical systems. They have designed a lighting-usage-only system for cost effectiveness and with different fee scale depending on the number of lights a participating house chooses. In terms ability to pay most of the pilot project villages have easy access to the main market in the capital city where they can command much higher selling prices for their products compared to outer island rural area markets. The electricity fee-for-service scale was set up with careful consideration to local income levels. (Score 4)

Needs Assessment: Environmental Sustainability

The willingness to cut down trees causing shading of the solar panel is a recurring theme even today. There are also negative social-cultural aspects of cutting down trees. Some of the villager's have trees that were planted by their respected elder generation and it is considered 'taboo' to cut or trim the tree in anyway. Also, proper disposal or recycling of end-of-life batteries are universally almost never addressed in SHS projects worldwide. (Score 1)

Figure 4.1: Examples of shading of solar panel

Conceptual Designs and Feasibility Study: Socio-cultural Respect, Community Participation

The JICA funded SHS design was very conservative. The solar panels used for the SHS range from 40w to 100w. Lights are 8w to 15w DC fluorescent tubes. The battery is either 70Ah or 100Ah deep cycle specified for solar applications. The design goal and sizing of the system is such that it would enable long component lifespan with minimal operational and maintenance costs. The technology appropriateness has a definite link to socio-cultural respect because it is usually challenging to determine during the conceptual design stage whether a technology (Gensets or SHS) might be appropriate for the local culture. In the case that they are not quite appropriate, user education must be carried out with good results to ensure project continuality. The SHS design for the most part was top-down and JICA and the energy unit limited usage of each individual lights to 3 hours per day (warning stickers in local language placed by the battery and charge controller).This strategy of limiting user usage of the system has major drawbacks since the author had experienced on many occasions the lack of concept of time during the two years interaction with the locals. The local culture may have difficulty differentiating time duration between 3 and 5 hours. Communities may have been briefed on the usage limitations but to just tell people and place warning stickers is simply not enough. Usage that is severely beyond the designed specification, even with a conservative design will be detrimental to the component lifespan. (score = 2,1)

Conceptual Designs and Feasibility Study: Political Cohesion

Since this is a high level technology project in the area where the host country does not have technical expertise, a strict top-down design by the JICA technical experts is implemented with full support of the Energy Unit. JICA does have prior SHS project experience in neighboring south Pacific countries. (Score =4)

Conceptual Designs and Feasibility Study: Economic Sustainability

This is a highly subsidized project. Even with a one-time initial cash contribution from the participating households and a monthly fee-for-service of up to usd$15 JICA still ended up paying more than 50% of the total initial equipment cost. The most expensive component in the life cycle of a SHS is the battery. The ability, willingness, and the concept to put aside savings for future component (battery) maintenance and replacement is mentioned but not totally absorbed or understood by the locals. Based on the author's two years of experience living at the local village level this is not a culture that understands the need for replacement parts, or have a strong desire to fix broken things. This statement is not meant to be a degrading remark, it is strictly the author's observation. The local culture only has experienced western goods which are of the 'throw-away' quality. Most consumables owned by the locals cannot be fixed cost effectively. As a result there is no concept of saving for spare parts or a desire to fix broken things which in their experience will break down again very soon. (Score 2)

Conceptual Designs and Feasibility Study: Environmental Sustainability

Most solar system component parts have enviably long operational life span compared to other electricity generating equipment. The only component of the system that needs periodic replacement is the battery. Used battery disposal are almost never addressed in a typical project. Another often overlooked area is the potential shading of the solar panels from over growing trees. (Score 2)

Design and Action Planning: Socio-cultural Respect, Community Participation

This is strictly a top-down design and action planned project. There was very little community participation in this part of the process. One local caretaker in each village was selected and trained thru extensive series of workshops to certify them as technicians. This is consistent in concept with the local water committee technician for troubleshooting and repairs that most rural villages are familiar with. It is also desirable to ensure that local personnel would be able to handle most maintenance and troubleshooting tasks. Villagers were almost universally satisfied with the design and action planning part of this project. (Score 3,1)

Design and Action Planning: Political Cohesion, Economic Sustainability, Environmental Sustainability

JICA and the energy unit had complete control in terms of timeline, budgeting, and action planning. There were no conflicts or issues as far as the author's aware of and JICA is a professional, competent organization with prior experience managing projects in developing countries. There were some unforeseeable procurement issues that cased slight delays, but project delays in Vanuatu have nearly 100% occurrence rate so no one really worries too much about it. (Score 4,4,3)

Implementation: Socio-cultural Respect, community participation, political cohesion, Economic Sustainability, environmental Sustainability

In this strict top-down project, there was very little local input and community participation. However, in the context of a high technology system the implementation was done professionally and very well managed. Villagers were almost universally satisfied with this part of the project. The installation team from energy unit performed all the installation work. A lot of trees were trimmed, but not cut down entirely. This was social-cultural respect and sensitivity to people's needs but in retrospect turned out to be a terrible idea as the tree branches grows fast in the tropical region and soon shaded many panels, severely compromising system performance and battery lifespan. (Score 2,4,4,4,1)

Operation and Maintenance: Socio-cultural Respect, Community Participation

In this culture when people use candles or kerosene lamps or dry cell battery powered flash lights, it is the norm to use the light until it goes out due to candles, kerosene, or dry cell battery being used up. For a typical house that can afford the generator it is also common to use the generator until the gasoline runs out. There are normally no light switches as electrical components are expensive and if any particular electrical part can be avoided in usage it will be. It is very common for all the lights in a typical village house to be wired parallel, directly to an electrical plug, which plugs in to a generator, often without a fuse or a circuit breaker. All the lights will be on when the generator is on. This usage pattern is fuel limited, rather than user self-limited. In a SHS setting, by design, usage of lights are required to be user self-limited. This requires a user behavior change that is often not observed, or achievable because of lack of usage hourly duration awareness. In many observed instances users kept the lights on over night as a night light or a security light. The need to keep wet-cell battery fluid topped up with the correct type of fluid is also not observed. The idea that solar panels needs to be clear from any form of shading or physical obstruction is communicated repeatedly but very seldom followed through with the action of actually cutting and/or removing the obstruction. There is also limited understanding or misunderstanding on the requirement of periodic maintenance of the battery. This is also a culture that is very creative and improvises to make things work. There are some instances of self-installs of additional lights for the system. While the self installed lights might work the installation itself are often of terrible quality with improper wire gauge size, exposed wires and loose connectors. Many enterprising SHS owners even put in their own DC-to AC inverters so they can run any store bought AC electrical appliance with their SHS. Many systems were abused when the owner buys an inverter and hooks it up directly to the battery. This bypasses the low voltage disconnect protection from the charge controller, and often results in deeply discharged batteries, leading to severely shortened battery service life.(Score 0,3)

Operation and Maintenance: Political Cohesion

There seem to have a lot of confusion and disconnect in communicating the responsibilities of the users, the care takers, and the energy unit. People were unsure of who should be paying for replacing the batteries. Some users were expecting repairs that were beyond the level in which the local caretaker was capable of, but no senior technician ever came from the energy unit to look at the problem. There was also a dispute between the energy unit and a powerful chief in one of the village. Basically the chief defended his villagers system from being taken away due to non-payment, claiming many years of payment with sub-par performance of the system should have been enough to entitle the individual houses to own the system outright. The energy unit is could not do much about it so it is ending all ties and support with the village as far as the project is concerned. At the moment the particular village only has a handful of SHS still in working condition. There are also observed instances of users not willing to work with the local caretaker due to a variety of unknown, unconfirmed reasons. Interestingly despite all the above this project scored high in this element using McConville's scoring guidelines. (Score 4)

Operation and Maintenance: Economic Sustainability

The most common complaint of the SHS from the site survey is the monthly fee-for-service cost of roughly usd$15 for a four light system. Some households were not able to keep up with the payment and after the first month of non-payment their lights would be cut out by the local technician. There is now even less of an incentive to pay the high monthly fee because the lights are not working. After a few months of non-payment the Energy unit sends in a crew to remove the system from the house. Approximately close to half of all installed systems were removed from different pilot villages with this scenario (exact number difficult to determine). The second complaint is the cost of battery replacement. The project had high design and component quality standards and deep-cycle solar specific batteries were implemented in the beginning. Once the initial batch of batteries start needing replacement people soon realize they have no financial means to replace them with the high cost solar specific batteries (usd$350+). Even the regular automotive batteries were priced beyond the level in which most users were willing to pay (usd$100+) for. (Score =2)

Operation and Maintenance: Environmental Sustainability

Used, non-functioning batteries were disposed of freely or left at whatever place that was out of the way and convenient for the owner. There were no instructions on end-of-life battery disposal. (Score =0)

4.1.3 JICA project site observed issues

Four care takers of the SHS in each village were interviewed. All of them have very good working and technical knowledge of SHS. Below is a list of the most common problems they have experienced in operations and maintenance areas:

1. Some people were unclear as to who should pay for battery replacement. Lots of batteries lasted only 1-2 years, due to system misuse.
2. 12v DC Fluorescent lights, each about 8w-12w, deteriorated rather quickly in terms of lighting quality. Light tubes darkened on the ends much more quickly than anticipated. (Likely caused by prolonged low voltage operation causing mechanical deterioration)
3. Adding wrong kind of battery refill fluid ruined battery, no one has knowledge on correct battery fluid refill procedure.
4. A lot of users have unrealistic expectations of installing a refrigerator to an inverter hooked up to the battery. Panels are 40w to 100w, not adequately sized for refrigeration loads.
5. Too much rain and cloudy weather negatively affecting system performance.
6. Too many self-installs of wire extension of sub-par quality connection and causing short circuits.
7. Too many DC->AC inverter usage in systems. SHS was never designed to be used with inverter types of loads.
8. Significant tree shading on lots of panels but people will not cut down trees despite repeated communication attempts.

The experiences of the four technicians were literally identical the author's personal observations from site visits. A comparison of this project's assessment with other case studies will be discussed in Chapter 5.

4.2 Case study 2: Various donor funded solar system at local community institutions.

There are many community institutions in rural Vanuatu that have standalone solar systems. The author had visits to the following institutions, and for the older non-working systems was asked to inspect the system to find out what was wrong with them.

- Sangalai school, Maskylene island.
- Ludis Clinic, Maskylene island.
- Lamap police station and hospital, Malakula island.
- Maewo health clinic, Maewo island.
- South Maewo school, Maewo island.
- Loh secondary school, Loh island

These community institution solar electrical systems are included as part of the case studies because in operation they are very similar to SHS. The community systems range in power output from 80w to 400w, with the majority under 300w. They are mainly used to power communication radios and lights in clinics, police stations, and lights and computer(s) at schools. These systems are often donated by foreign donors with the usual caveat of "future operation and maintenance is the responsibility of the recipient" and majority of those systems are often not working after a few years due to lack of replacement parts budget, trained maintenance personnel to carry out any repairs, and system misuse. Most recipients were happy with the solar systems while they worked in the first few years. Many understand that the batteries will eventually need to be replaced but no one knows how. In all cases the underfunded clinics, police stations, schools have no capability to pay for battery replacements.

The following table shows the assessment scoring summary of donor funded community solar project on different Islands. Due to high degree of similarities of community solar projects one assessment is given in Table 4-3, representing the average of the six institutions visited.

Life Cycle Stage	**Sustainability Factors**					
	Socio-cultural respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	2	2	4	1	1	10/20
Conceptual Design and Feasibility	2	1	1	2	1	7/20
Design and Action planning	2	1	2	4	3	12/20
Implementation	2	1	1	2	1	7/20
Operation and Maintenance	0	1	3	0	0	4/20
Total	8/20	6/20	11/20	9/20	6/20	**40/100**

Table 4-3: Assessment score of various community institution solar electrical system

4.2.1 Assessment summary

In terms of the first four stages of the lifecycle; needs assessment, conceptual design/feasibility, design/action planning, and implementation, most donors do an adequate job. What the projects fail completely is in the area of operations and maintenance. The following lists the author's observations and experiences with various community solar systems:

- There were situations where it was not possible for the donors to provide professional installation work. When the donor simply donated equipment and left the installation work for the receiving institution the end results were almost universally bad. See Figure 4.2.

- When the donors does provide professional installation of the system the non-native installation crew does not realize how quickly trees or tree branches can grow in the tropics. Any tiny tree sapling near the solar panel installation location can become a major source of shading in just a few years. See Figure 4.3
- In one case the French government donated a police boat complete with solar system and short wave radio onboard. One of the police officers in charge of the boat saw that there is a small indicator light on the electronic module onboard that is on. The police officer proceeded to flip a 'switch' to turn the indicator light off when the boat is not being used. This seems like common sense for the police officer to do but it turned out to ruin the brand new battery in this case. The small indicator light is on the charge controller indicating that the panels are charging the battery and everything is operational and under normal status. The 'switch' turns out to be the solar panel's circuit breaker. It looks like a switch to any person unfamiliar with electrical circuit breakers. When the circuit breaker is off it disconnects the panel from the circuit, so no charging of the battery can occur, and the indicator light on the charge controller is off. The new battery was left discharged for more than 2 month when the police officer asked the author to diagnose the system. The battery was damaged from being in extended discharged state.
- Lots of system abuse when a DC-AC inverter is included in the system. The inverter supplies AC power and whenever an AC receptacle is present people tend to perceive it as 'free power'. All sorts of personal electronics were observed plugging into an inverter. None of the inverters have adequate battery low voltage protection feature. Frequently, the battery gets deeply discharged resulting in shortened service lifespan to no more than 1-2 years.
- In some cases there would be operation and maintenance manual written in the local language. The instructions seem clearly written and straightforward to follow but no one seemed to bother reading it. Often the manual goes missing. Light and inverter usage allowance are sometimes posted near the battery and charge controller, not sure if anyone actually follows them.
- Whenever there is an issue with the system, there are no local personnel capable of troubleshooting what is wrong.
- It is not financially feasible to get professional service support from the two main town centers in the country. Even when the problematic systems are located within reachable areas of local professional technician, the willingness to pay for system troubleshooting is not there.

Figure 4.2: Example of community institution self-install. Panels are facing the wrong direction and mounting directly on tin roof results in overheating the panels, significantly reducing power output.

Figure 4.3: Tree saplings near solar panel location in the beginning of installation resulting in almost total shading after a few years. Author advised cutting down the offending trees in both photos and neither were cut down.

Figure 4.4: Lights usage guidelines placed near the charge controller and battery.

4.3 Case study 3: Lamap SHS project, Malakula Island

This is a case study that differs from the other two in some significant aspects. First of all, this is true grass roots, self initiated, self funded SHS project. Secondly, this is the community where the author served during his two years of Peace Corp's service. Before the start of the project the author already had knowledge of the lifecycle-sustainability methodology developed by McConville (McConville, 2006) and also comprehensive knowledge from reading other SHS projects in the literature (World Bank, 2001) and seeing and experiencing firsthand how development projects work and fail in Vanuatu. The author was directly involved with every stage of the Lamap project since its inception, and had personal incentives to ensure the project's success in every way. On paper this project is poised for unquestionable success! We shall see how the project turns out from this case study.

Malakula Island is 120km long and roughly 30-40km at its widest point and has a sparse population of 20,000 people. There is just one 4WD dirt road connecting northeast and southeast of the island. Transportation in the southern part of the island is by 4WD trucks, small 8 passenger boats or by foot. The Lamap community is located on the southeast corner of the island and has about 1000 people, 40% of them teenagers and children under 17. The community consists of many small villages spanning about a two hour walking distance. The area has three working trucks and a boat.

This is a rural community that does not have central electricity. Almost every household uses kerosene lamps and flash lights. About 40%-50% of the families run 800w-1500w generators periodically for lights, dvd player, and a small TV. Gasoline price is usd$9-12 a gallon so generators are run sparingly or under special occasions.

As a volunteer with some electrical engineering background and a strong aversion to living without electricity, the author soon acquired a small SHS powering a few LED lights, a fan, a radio, a portable DVD player and a laptop computer. Villagers were frequently inquiring about the SHS and so the author conducted a 2-hr SHS information session/workshop. The interest was immense as there were close to 80 people that turned up and 20+ people requested to sign up to purchase a small, relatively affordable light only system. The author also taught solar system basics class at the community school and got his students involved in the project by making them responsible for installations and possible future maintenance of the SHS project.

The first meeting was held among the potential buyers a month later on how the project was going to proceed. It was decided as a group that the author would be designing the SHS, selecting system components, and making purchasing arrangements with various vendors. All the participating households would give author the funds to purchase their SHS components. The potential buyers also voted to take three months time for every household to save up for the full system cost of roughly usd$500. This was the most inexpensive SHS that the author could conceivably design and acquire in Vanuatu. The per capita GDP for Vanuatu is usd$2442, so the SHS price was a major expense for any rural household.

One of the main sources of income for the people of Lamap is copra (dry coconut meat). During the 3 month period after the first meeting the copra price was at a historic high because of international market demand. Many locals confirmed with the author that this was a special time period where it would not be too difficult for a household to raise usd$500.

Up to this point the project assessment has a perfect score in the first life cycle stage: Needs Assessment (Social-cultural respect =4, Community Participation=4, Political Cohesion=4, Economic Sustainability=4, and Environmental Sustainability=4)

At the end of 3 month time the second meeting was held where the all funds were supposed to pool together to be able to make the component purchases. Out of the 20+ households that had signed up, only 9 could come up with the funds. No reason could be determined as to why more than half of the households couldn't make the seemingly generous deadline decided among themselves. Other locals informed the author that people were simply being financially irresponsible. This was a good example illustrating the difference of the desire to pay and the ability to pay. This meeting also informed the group the finalized system design and component selection. The decrease in the number of participating households resulted in an increased system purchase price because of the loss of volume pricing discount. Fortunately plenty of margin was built into the SHS pricing estimate and resulted in very little additional funds required by each paying household.

Another meeting was held two months later when SHS components had finally arrived in Lamap. In this meeting all the components were distributed to the owners and the functionality of the components were explained again. Special attention was focused on the charge controller as many details were discussed from the user manual making sure everyone understood the different SHS operational scenarios and what the different indicator lights mean. The manual was very well and clearly written in multiple languages (including French, where 97% of the locals can read and speak in) and with diagrams. Another purpose of this meeting was to tell the group to make sure that their chosen location for the installation of the solar panel can not contain any shadow from objects and trees and that the installed panel needs to face true north. A one page write-up of SHS operations guideline in the local language was handed out. It includes a picture (see Figure 4.4) explaining the different sun path depending on the time of the year and also explained why the panel needs to be free from shading and obstructions. Due to the lack of practical SHS installation work experience of the students at the local school, it was agreed by the group that the author will lead the students in installing the 9 SHS systems. This arrangement was invaluable experience for the students and benefitted the group in having free installation. In addition, it opened up the possibility for future troubleshooting. It was also decided that the installation priority will be based on whoever fabricates their solar panel mounting post and clears the area to make sure no shading are on the panel. In a period of about 7 weeks the author and his students did all the installation work.

4.3.1 Lessons in implementation

Many things were learned during this installation period:

- Many of the households did not follow the guideline of proper panel placement despite repeated emphasis by the author. A few trimmed their trees, sometimes at the objection of other family member and elders. Some insist there is no tree shading on their chosen panel placement but in actuality the shading exists.
- There were repeated attempts to involve the owners of the system during the installation. Some simply refuse to participate in the installation process even though the author mentioned that this is a great opportunity to learn the basics of wiring for future self troubleshooting and repair. A simple, 2 color coded sketch detailing one switch, one light (See Figure 4.5) was given to a few owners who expressed interest in trying. None in their first few tries were able to follow the seemingly simple and straightforward wiring diagram and correctly wire a single switch with a light.
- Most of the students have by now been learning wiring basics for close to a year. A few understood the concept real well, but a majority of them still do not understand even the fundamentals. This improved as they gained more experience throughout the installations, but even after 7 weeks of practical work some student still cannot be trusted to do unsupervised electrical work.

Both the community participation and the environmental sustainability area scored lower than expected in the project lifecycle stages up to implementation. Even though social cultural respect scores well, there were signs foreshadowing potential trouble ahead with the willingness but the inability to pay scenario, and not willing to cut down trees that are blocking the solar panels. It was also observed that the actions needed for certain elements were conflicting with other elements, a fact noted by McConville [McConville 2006].

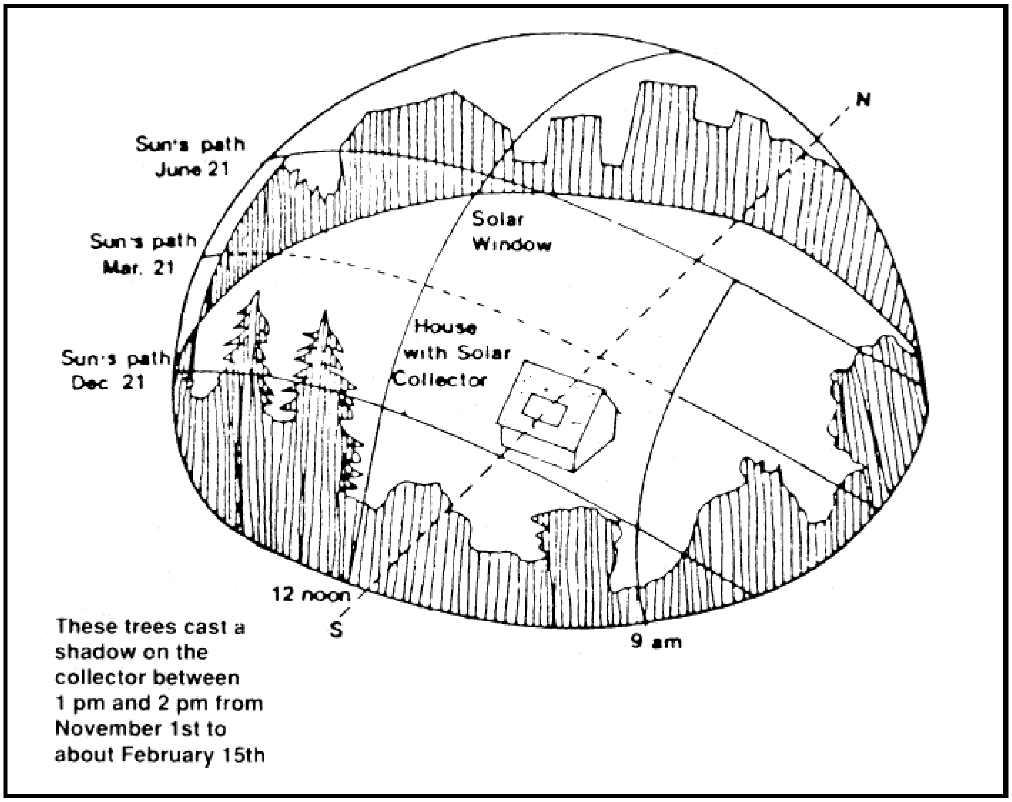


Figure 4.5: Sun path on winter and summer solstice dates and potential solar panel shading

Figure 4.6: Student installation team with 6 girls and 7 boys, ranging in age from 15 to 19. Note the trimmed tree on the left front of the panel but not on the right side areas of the panel.

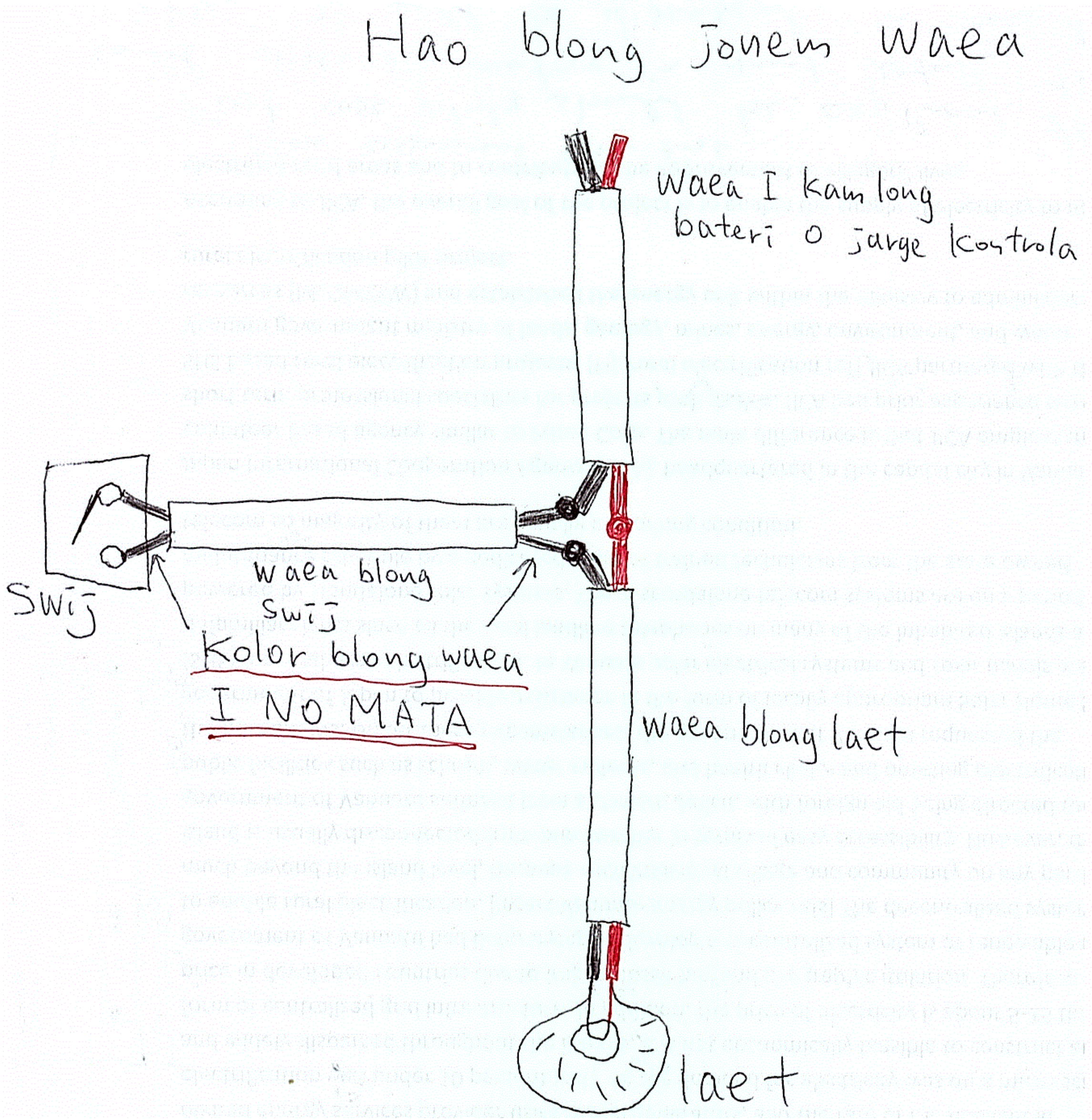


Figure 4.7: Sketch of one switch, one light wiring diagram given to students and owners.

Immediately following the completion of the installations, everyone was provided an operation and maintenance guideline and component vendors contact info for future parts replacement. Included in the guideline is a graph of battery voltage vs. battery SOC % (State Of Charge) where all the owners had been explained to in multiple occasions that the life of the battery is directly proportional to the average SOC% of the battery. This project was a good opportunity to have real measured data on the batteries in the field. Every SHS owner was instructed and shown how to take daily measurements of their battery SOC with a digital voltmeter that was included as part of their component purchase. The battery measurements are to be done at 6pm every day. This specific measurement time is chosen to give a rough indication of the health of the battery and to also determine charge/discharge pattern. This is the time when the sun has gone down for about an hour (surface charge on the battery mostly dissipated to ensure accuracy of measurement) and no lights (or other electrical loads) has been switched on yet. Ideally, the voltage measurement of the battery will read 12.65v or more, meaning that the battery has 100% SOC. If there are consecutive sunny days and the sizing of the system was properly matched to the expected daily loads, the battery will have 100% SOC every day before the lights are first used. On the first rainy day the battery will read below 100% SOC. If there are 3 consecutive rainy/cloudy days and the daily load usage are about the same, the battery should be close to 50% SOC or 12.2v based on system design

Measured battery voltage data were intended to be collected and analyzed at the end of the first 6 month period since initial install. This data will serve as valuable indicator on the overall adequacy of the design and will also reveal insights on individual household energy usage pattern. During the first two month each SHS household were re-visited multiple times to make sure that the data is being taken correctly and to check for proper system operation. Many confessed that sometimes they were unable to take the data consistently every single day, but at least five or six days out of the week they were able to. Both woman and children were involved in the data gathering procedure. Browsing through the battery voltage data at each household, the voltage ranges from a low of 12.03v to over 13v, nothing too terrible. By the 5 month mark, a few of the digital voltmeters had ran out of battery and ceased to function. The volt meters use consumer 9v rectangular batteries which were not always available in the rural area village stores. The author was able to locate a few selling for usd$5 each, and informed all the SHS owners where to buy them. Only one replaced the battery of the voltmeter, the rest did not and stopped taking measurements. It was likely perceived that the SHS was working fine and there is no need to buy an expensive battery just to keep taking measurements.

At the 8 month mark since the initial installation of the SHS in Lamap community, all systems and lights were still functioning and everyone is happy with their SHS providing lights and charging mobile phones. The author was finishing his Peace Corp service and visited each SHS household to get one last update on system operation and other possible issues and user comments. The measured battery voltage data was also to be collected. But it turns out that out of 9 households, only one was able to provide data. The rest have all misplaced their note books or the paper containing the data. This was a disappointment for academic purposes, but itself gave insights on how any paper work cannot be counted on to stay put in a rural village house with 12+ people and kids.

4.3.2 Main observations from operations and maintenance stage

Bullets below list the main observations for the operations and maintenance part of the project lifecycle.

- Measuring the battery voltage everyday gave people the confidence that they can operate an electronic device they have never had exposure to and also perform part of the troubleshooting on their own. And seeing the exact battery voltage themselves everyday helps to create the awareness of the importance of battery health.

- It is empowering for the woman and children when they are in charge of the measurement process and this also lowers the new technology intimidation factor; fear for touching and breaking a solar system.
- Some have started using their SHS for an income generating activity; offering mobile charging service for other villagers. This is good utilization of SHS for economic benefits but does put additional loading demand on the system.
- Because of the relative large number of people in any one household, most will have all the lights (5-8) on at the same time since every lighted room will be occupied. This common usage pattern is not noted in SHS literature and has important impacts on battery sizing design.
- The habit of turning off the light if there are no occupants in a room is not observed. Most have never lived with a wall mounted light switch and are used to candles and hurricane lamps. This is consistent with the cultural behavior pattern.
- In 8 month time there are already trimmed tree branches that have grown back enough to cause slight shadowing of the panels.
- In one household the panel has been moved to a location of lower roof height. Significant blockage of sunlight occurs at this new location. Severe system performance impacts communicated to the owner, not sure if it will be moved back to a proper location.
- Some have purchased small portable dvd players that can be plugged directly into the 12v DC circuit. This also presents additional un-designed loading to the system.
- Many households like to leave a light on overnight as a security light. This is done under the understanding that no light is supposed to be on for more than 5 hours every night. The lighting usage limit was emphasized repeatedly throughout the project lifecycle.
- 80% of the SHS have had the low battery indicator warning light on at least once. Some have had multiple instances of low battery warning. This should not have happened according to system design. A combination of over-design-limit system load and partially shaded panels are the causes.
- Some wire connections were loose and not solidly joined together. This can be attributed to the vulnerability of exposed wires where unintentional tampering or pulling will occur over time.
- Some SHS owners did not understand what the indicator lights on the charge controller meant even though the various functionality of the charge controller was discussed in detail at least two times. Some misplaced their operation manuals and guidelines and some lost their charge controller manuals.
- One particular kind of LED light supplied with the system is showing signs of decreasing brightness. This can happen with extended operation under low voltage conditions. The author uses the same kind of LED in his personal SHS and has not experienced the decreased brightness.

In general the assessment from the operations and maintenance part of the lifecycle for this project is somewhat discouraging. Based on the first 8 month observations, some of the SHS battery's lifespan might not reach the system design predictions. The project's future success does not seem to depend on how well planned and thought out everything at the start were. It seems to depend entirely on each individual's proper operational understanding and desire and ability to carry out maintenance requirement. Comparisons of the Lamap case study and others will be discussed in Chapter 5.

Life Cycle Stage	**Sustainability Factors**					
	Socio-cultural respect	Community Participation	Political Cohesion	Economic Sustainability	Environmental Sustainability	Total
Needs Assessment	4	4	4	4	4	20/20
Conceptual Design and Feasibility	3	1	2	3	2	11/20
Design and Action planning	2	2	3	4	3	14/20
Implementation	3	3	2	3	1	12/20
Operation and Maintenance	1	2	0	1	1	5/20
Total	13/20	12/20	11/20	15/20	11/20	**62**

Table 4-4: Assessment score of Lamap SHS project

Chapter 5: Conclusions and Recommendations

A project assessment methodology based on a lifecycle sustainability framework is applied to three solar home system projects in rural Vanuatu. A lifecycle matrix tool is used to score and compare the case studies to gain insight on the potential factors contributing to the failure or the success of a SHS project. The life cycle matrix provides a tool for development workers to approach a project in a different way, looking at the sustainability of each life cycle stage. Each matrix element contains relevant tasks to determine appropriate score for that particular element. In the Japan International Cooperation Agency SHS and various community institutional solar projects the scoring was done long after completion of the project. In the Lamap SHS case it was applied right from the beginning and throughout the duration of the project.

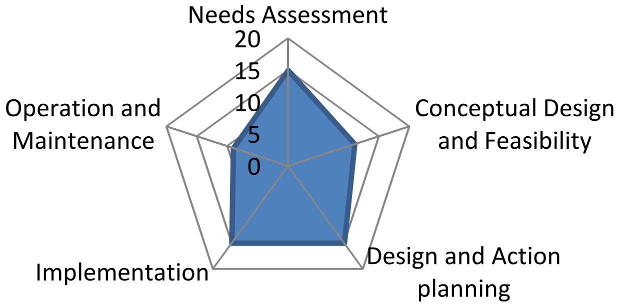
5.1 Case study assessment comparisons

There are some major differences on the basis for each of the projects in the case study. The JICA funded rural electrification project was a pilot project to establish the needed infrastructure in Vanuatu and to test out some of the things that worked well in other SHS projects around the world. The various community solar projects were funded by external donors as part of a school or as necessary power source for clinical and/or communication equipment. The community projects were borne out of necessity to meet minimum public institution service standards. Both projects were heavily top-down managed and implemented, with significant outsider involvement and very little community level local input at least up until the implementation stages of the project lifecycle. In contrast, the Lamap SHS project is entirely self-initiated and self-funded. This simplifies the political cohesiveness and financing arrangements but an outsider still has to make many critical decisions in the beginning stages that may or may not fit in with the cultural habits and expectations.

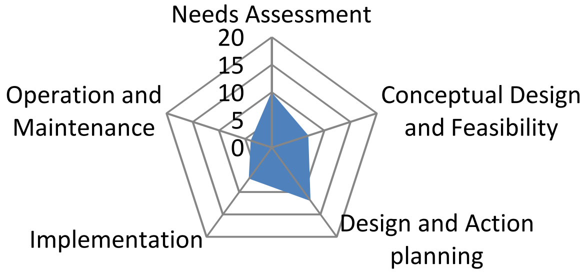
Figures 5.1 and 5.2 show radar plots of the lifecycle stage score and sustainability factor score, respectively, for the three case studies. The five lifecycle stages make up the five corners of the pentagon in Figure 5.1, and the five sustainability factors for Figure 5.2. The scores are represented by the line from the center to the corner of the pentagons. The size of the shaded area represents the overall score; the larger shading, the higher the score.

There is one common trend among all three projects in the assessment case studies. For the operations and maintenance life stage, all three projects scored very low. This is in spite of the JICA project having a local qualified technician in each of the pilot villages, and the Lamap project with a resident expert for over a year that constantly encourages and educates the proper usage of SHS. The community solar projects scored low in the operations and maintenance stage, as expected with the none-existent technical knowledge transfer from the donors. The JICA project scored the highest overall, but the project has failed considering the ratio of non-working to functioning systems, without even taking into account the systems that have been removed due to non-payment.

JICA SHS Life Cycle Scores, Total = 65



Community Solar Life Cycle Scores Total = 40



Lamap SHS Life Cycle Scores Total = 62

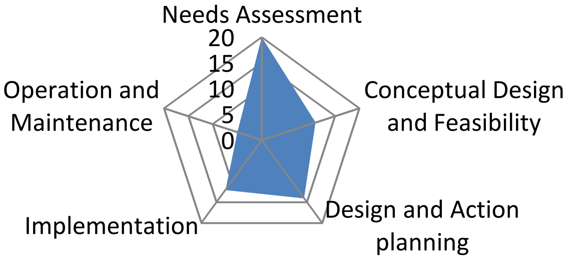
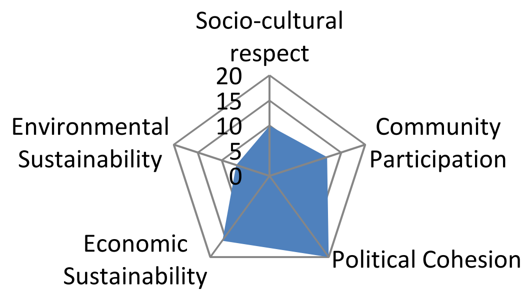
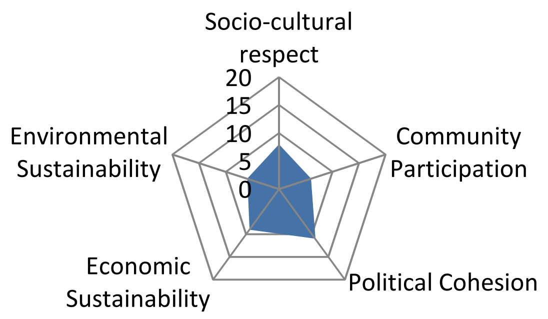


Figure 5.1: Life cycle stage scoring breakdown for three case studies.

JICA SHS Sustainability Scores



Community Solar Sustainability Scores



Lamap SHS Sustainability Scores

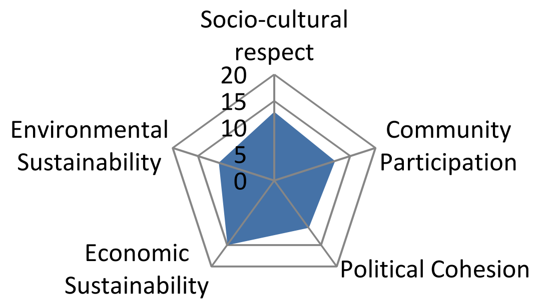


Figure 5.2: Sustainability scoring breakdown for three case studies.

The various community institutional solar projects, despite having a lowest total score, seemed to have fared no worse than the JICA project. The Lamap SHS project, despite having the benefit of prior knowledge of project lifecycle-sustainability concept, could not obtain a higher score. Based on the low operations and maintenance life stage scoring trend and many locally observed SHS operational patterns, the long term project success outlook for Lamap SHS is not optimistic. Looking at sustainability factor scores, there were not a whole lot of differences between the JICA and Lamap SHS projects. Most of the differences in the score come from political cohesion area, where many scoring guidelines in the tool simply did not apply to a self funded and administered project. Political cohesion is important for a self-run project but different scoring guidelines will have to be established (to be discussed in the next section). Another common trend that can be spotted from Figure 5.2 is the low environmental sustainability score for all three projects. End-of-life battery disposal/recycling and solar panel shading issues dominate this factor. The relatively high economic sustainability scores by both the JICA and Lamap SHS project does not accurately predict the real-life lack of financial ability to carry out necessary maintenance and battery replacement.

Some of the major problems identified from the case studies and corresponding recommended actions are:

1. Poor quality installation. This includes improper panel siting location with excessive or potential shading in the future, mounting on thatch roof tops with no tie downs, or mounting on any roof surface without regard to proper orientation.

Recommendation: Do not allow unqualified self installs of solar panel by establishing and enforcing installation standards. Since a person living in the community will be unlikely to enforce installation standards it will be preferable to employ qualified outsider for this work to minimize social cultural conflict. This is an area where technical requirement supersede cultural respect or preference. Equipment vendors will only sell the SHS as a package that includes installation. This will undoubtedly increase upfront system cost but will ensure every system is installed in the optimal manner.

2. System load usage exceeds the design. There are observations and evidence from various site visits pointing to the increased load usage throughout the lifetime of an installed SHS. This increased electrical load usage is also noted in SHS literature (Gustavsson M. , 2007).

Recommendation: In the preliminary system design load demand needs to have significant headroom for future addition of loads. Development workers must communicate strongly during the needs assessment that additional solar panels will have to be added to existing system if additional loads beyond design headroom are to be added in the future.

3. Establish a community battery replacement fund pool.

Recommendation: There are some reported cases in the literature where a community "battery replacement" fund is organized. It encourages the monthly contributions from each participating household so when one needs to replace the battery they can borrow from the fund and pay back slowly minus the amount they have been contributing. This minimizes the financial impact, assuming full participation plus proper fund administrative and management mechanism is in place.

4. Lights being installed outside the house, without using outdoor rated bulbs and proper wire connection weather proofing. This can cause destroyed lights and short circuiting.

Recommendation: In the needs assessment stage it is important to note that people like outdoor lighting. It is recommended to purchase some all weather light bulbs and weather proof outdoor wiring parts even if the users did not explicitly say they will use outdoor lighting. Emphasize importance of wiring safety issues in exposed environment.

6. Older style DC 12v fluorescent tubes have many technical shortcomings such as decreased lighting performance and shortened lifespan under low voltage operational conditions. The newer CFL bulbs solve some technical problems but are still not as robust as the latest LED lights.

Recommendation: Install newly available 12v low wattage LED lights.

7. In many installation locations partial shading of the solar panels will become unavoidable under a variety of circumstances as time goes on.

Recommendation: Using solar panels with better partial shading performance, such as thin-film types.

8. Resuscitation of existing failed projects.

Recommendation: There are a continuously increasing number of SHS or community institutional solar systems in non-working condition. Most have working solar panels, intact wiring, and some still have working charge controllers. Many of these systems will only need new batteries, modern LED lights, and switches to work again. To make the most cost effective SHS project, donors should look into resuscitating existing installations. With the advance of low wattage LED lighting which dramatically lowers electricity load demand and improved battery technology, the costs benefits of old system revival are immense.

5.2 Assessment matrix element weighting emphasis and modifications for SHS projects

This is a project assessment tool developed originally under the context of water and sanitation projects. It has been recommended and suggested by the originating author of this methodology (McConville, 2006) and others (Ocwieja, 2010, Castro, 2009) that the tool can be applied and tailored to other development projects with potentially different lifecycle and sustainability perspective. There were many lessons learned during the process of applying this assessment tool to a SHS project. One of the concerns encountered during the application of the assessment was that some of the matrix element recommended actions and tasks were not always relevant in the context of a SHS project. In addition, different weighting can be given to tasks or actions that are of particular importance when tabulating the score for a particular matrix element or sustainability factor. Listed below are some of the recommendations to emphasize and/or modify certain elements of the tool to make it more suitable for SHS projects.

1. Some SHS projects are private and not necessarily community owned. The Lamap project involves the community only up until the design and action planning stage. After that it is all private. In those cases political cohesion and community participation scores are not always relevant. In the community owned SHS projects attention in those areas will still be important. The low scores in the community participation element for both the JICA and Lamap projects and the low political cohesion for Lamap illustrate this point. In both cases the community is about as involved as it can be, and when interviewed about their involvement of the project, the response was very positive.
2. Economic sustainability in the context of a SHS project has two separate but equally important parts. The first part is the outright ability to pay for the initial equipment, and the second part is the ability to pay for the ongoing maintenance. The need to realistically assess the willingness and ability to pay at every stage of the project lifecycle needs to be weighted heavily in the scoring of that matrix element.
3. In the needs assessment, collecting local data on climate and environmental constraints that will factor into project design needs to weigh more than the other actions within the element. Overestimating the solar insolation and underestimating the panel shading potential is observed to be a common mistake.
4. In the conceptual design stage, involving the community by “Present several technically feasible alternatives for community evaluation and feedback”, and asking “Community members formally select a design based on an understanding of the constraints involved in the selection process” may be counter-productive because of the technical nature of SHS projects. A high degree of technical understanding is required to make informed and sound decisions on evaluating technical matters, and technical comprehension cannot be educated under the typical SHS project time constraints.
5. In the conceptual design stage, strong emphasis needs to be made on considering how seasonal variation in energy supply, demand, and environmental conditions will affect each conceptual design. In engineering terms, realistic worst case scenario needs to be investigated.
6. In the operations and maintenance stage, strong emphasis needs to be on discussing unanticipated constraints to system use. If the low battery warning light comes on, the users must stop using the load until the next sunny day. This is tied to the social-cultural practice and a needed behavior change from the user.

7. In the operations and maintenance stage, even stronger emphasis needs to be on discussing potential financing mechanisms to cover projected operation and maintenance costs, specifically battery replacement.

In all, obtaining a high score from the assessment tool is not absolutely imperative, but the overall awareness and understanding of the sustainability factors within each life cycle stage. The scoring guidelines and tasks can be used to serve as an educational or self-assessment tool in both post-project evaluation and in pre-project planning. The project success depends heavily on individuals, local circumstances, and the flexibility to adapt sustainability concepts in a locally appropriate context.

5.3 Developing country rural area specific SHS component selection, design, and economic considerations

Through observations, site visits, informal conversations with solar equipment vendors, NGO's and donor organizations, it became apparent that a different type of approach is needed in solar home system design in the rural areas of a developing country. Because of the remoteness, the lack of reliable and inexpensive transportation infrastructure, limited after sales support, and out-of-reach cost for some SHS components, the absolute foremost design priority becomes system robustness and longevity. Quality of system components is paramount to longevity, but there is a price/quality trade off that will need to be carefully weighted.

One of the most significant SHS component technology advances in recent years is the availability of low wattage 12v LED lights. Traditionally SHS projects use fluorescent tubes and CFL bulbs over incandescent bulbs for efficiency. However the fluorescence lighting mechanism requires a built-in ballast/transformer for high voltage conversion operation that demands a minimum input voltage. In a typical SHS operational scenario this minimum input voltage is not always met and leads to overheating the ballast and reduced lighting performance. LED lights improve on the CFL technology by simplicity of the lighting mechanism, further advancing the efficiency in terms of power consumption per lumen output, and significantly increasing the LED light bulb lifespan. LED lights are also available in extreme low wattage varieties of 0.3 watts per light. This enables the installation of a far smaller and thus affordable SHS or many more available lights given the same solar panel wattage Special attention is needed to note that some LED light designs also use an internal transformer to enable dual AC/DC voltage operation. Under the frequent low voltage operational conditions in SHS, the internal transformer will heat up the LEDs leading to decreased lighting performance similar to CFL's case. Using LED lights without built-in transformers and other complexities is recommended in SHS lighting applications.

Many solar panels are subject to rough handling during shipping and transporting and also vandalism after the installation. It is better to use solar panels that do not have a fragile/breakable surface. Many installation locales also suffer from frequent cloud cover from tropical rainy season. Thin film type of solar panel is thus recommended since they are known for better performance under partial shading and cloudy conditions, and many manufacturer offers thin film panels without a glass or a breakable shield.

There are a variety of charge controllers in many different price range offering different functionality and features. The most important things to look for are battery monitoring indicator lights, Low Voltage Disconnect (LVD), and tropicalized circuit board treatment. High degree of user fool-proofing and less complexity is also ideal. Highly recommended are some manufacturers such as Morningstar, Steca and others that offers charge controller specifically designed for SHS projects in developing countries that meet special technical and tough environmental standards developed by World Bank or other international technical standards (Hans-Peter, Real, & Ruth, 2003).

It has been observed frequently that in a SHS household at night time all the installed lights will be on simultaneously, in addition to other potential loads such as charging mobile phones, portable dvd players, small radios, etc. This presents a peak load to the battery that may exceed the C/20 discharge current that most batteries' capacity is rated under. Special attention is needed in the conceptual design and feasibility life stage to ensure battery sizing will be adequate for future needs. User electrical load usage behavior should be advised. Any load demand other than lighting should be strongly encouraged to be used only during the day time when there is sunlight on the panel. This relives unnecessary current loading on the battery and will help prolong its lifespan.

Due to the immense cost difference (magnitude of 4-5) of solar specific deep cycle batteries and common car batteries in some locales, the former cannot always be implemented in SHS projects even though the technical design calls for it. There are also field evidences (Gustavsson & Mtonga, 2005) showing deep cycle batteries not reaching designed lifespan in SHS applications and that car battery lifespan is not necessarily much shorter.

When the time comes to replace batteries, very few households can afford new batteries, or in the cases they do, it represents a major expense relative to their income. At the present there are some viable battery reconditioning/rejuvenating methods that can in theory revive a sulfated battery. There are chemical treatments on the battery that can be carried out onsite. It may or may not completely revive an end-of-life battery depending on the severity of the battery's condition. However, this procedure has an attractive cost/benefit ratio and is well worth the small upfront investment. This is recommended to be purchased at the beginning along with every other SHS component.

5.4 Future SHS research areas

There are many areas in SHS projects with potential to improve. Below is a list that the author feels is being overlooked at the moment while implementing SHS projects. The list is by no means exhaustive; they are simply a reflection of the author's personal experience in SHS projects.

Developing testing methodology for various battery performance metrics and lifespan in SHS setting: Current battery testing and rating procedures doe not accurate simulate SHS operational environment. It is important for any battery testing and rating procedure to take into account the shallow cycling, deep cycling, deficit-charge cycling, low charge and discharge rates, and limited recharge or finish-charge as found in typical SHS operations.

Investigating various battery recycling options: Since the battery represent a significant part of the SHS total component life cycle cost, there is strong financial benefits in researching the feasibility of a local or regional end-of-life battery recycling, reconditioning, remanufacturing, and disposal facility. The research areas can cover developing low cost, locally appropriate technologies and techniques for SHS battery lifespan enhancement, local remanufacturing, transport logistics, battery recycling deposits, etc.

Charge controller load control algorithm for improving battery lifespan: The existing load control algorithm on nearly all SHS charge controllers does not adequately protect the battery in the case of load over usage. The algorithm simply cuts off the load at a certain fixed low voltage and reconnects the load once the battery reaches a certain fixed reconnect voltage. When this user forced pattern is repeated the battery gradually loses capacity and will eventually lead to shortened lifespan. Development of a novel charge control algorithm that does not depend on user load usage pattern while maintaining the lifespan of the battery will be highly beneficial.

Estimation of local solar insolation that does not require complex equipment: The uncertainties in local solar insolation data frequently leads to under sizing of the solar panels due to cost constraints. There exists measurement instruments but none are likely to be available for SHS projects. It would be beneficial to develop a novel approach using simple meteorological data available in local weather stations or other locally measurable data to estimate solar insolation.

References

Akella, A., Saini, R., & Sharma, M. (2009). Social, economical and environmental impacts of renewable energy systems. *Renewable Energy 34* , 390-396.

Castro, Y. (2009). *Life Cycle Assessment of a Small Garden Drip Irrigation System in Bénin.* Masters Report, Michigan Technological University: http://cee.eng.usf.edu/peacecorps/Resources.htm.

Deep Cycle Battery FAQ. (2009). Retrieved 1 29, 2009, from Battery FAQ: http://www.batteryfaq.org/

Electricity consumption per capita. (2008). Retrieved 3 10, 2010, from Thematic World Maps: http://www.sitesatlas.com/Thematic-Maps/Electricity-consumption-per-capita.html

Energy Unit. (2008). *Vanuatu National Energy Policy Framework .* Port Vila: Vanuatu ministry of geology, mines, water resources, energy unit.

Estes, R. (1993). Towards Sustainable Development: From Theory to Practice. *Social Development Issues 15* , 1-29.

FDJ Nieuwenhout, A. V. (2002). Experience with Solar Home Systems inDeveloping Countries: A Review. *Progress in Photovoltaics: Research and Applications* , 392.

GTZ. (1992). *Basic Electrification for Rural Households.* Eschborn: Deutsche Gesellschaft Technische Zusammenarbeit.

Gustavsson, M. (2007). With time comes increased loads—An analysis of solar home system use in Lundazi, Zambia. *Renewable Energy, Volume 32, Issue 5* , 796-813.

Gustavsson, M., & Mtonga, D. (2005). Lead-acid battery capacity in solar home systems—Field tests and experiences in Lundazi, Zambia. *Solar Energy* , 551-558.

Hans-Peter, B., Real, M., & Ruth, S. (2003). Large scale implementation of Solar Home Systems. *Clean Technology Envirnomental Policy* , 18-25.

Huacuz, J., & Flores, R. (1995). Field performance of lead-acid batteries in PV rural electrification kits. *Solar Energy* , 287-299.

Hund, T. (1999). *Capacity Loss In PV Batteries And Recovery.* Sandia National Laboratories.

Hund, T., & Stevens, J. (2000). PV hybrid VRLA battery test results from a telecommunications site. *IEEE Photovoltaic Specialists Conference*, (pp. 1-4). Anchorage.

Jacobson, A. (2007). Connective Power: Solar Electrification and Social Change in Kenya. *World Development Vol. 35, No. 1* , 144-162.

Jorhe, J. (1998). Beyond the grid: Photovoitaic electrification in rural Mexico. *Progress in photovoitaics: Research and Application* , 379-395.

Kirti Mala, A. S. (2009). Better or worse? The role of solar photovoltaic (PV) systems in sustainable development: Case studies of remote atoll communities in Kiribati. *Renewable Energy 34* , 358-361.

Li, D. (2008). Relationship between the total solar radiation on tilted surfaces and the sunshine hours in Hong Kong. *Solar Energy* , doi:10.1016.

Malawi rural electrification. (1998). Retrieved 3 1, 2010, from JICA project index: www.jica.go.jp/project/malawi/5245038E0/english/01/index.html

Martinot, E., & Cabraal, A. (2001). World Bank/GEF Solar Home Systems Projects: Experience and Lessons Learned 1993–2000. *Renew. Sustain. Energy Rev. 5* , 39-57.

McConville, J. (2006). *Applying Life Cycle Thinking to International Water and Sanitation Development Projects: An Assessment Tool for Project Managers in Sustainable Development Work.* Masters Report, Michigan Technological University: http://cee.eng.usf.edu/peacecorps/Resources.htm.

McConville, J., & Mihelcic, J. (2007). Adapting Life Cycle Thinking Tools to Evaluate Project Sustainability in International Water and Sanitation Development Work. *Environmental Engineering Science* , 937-948.

Meier, P. (2003). *Economic Analysis of Solar Home Systems: A case study for the Philippines.* World Bank.

MNES. (1999). *Ministry of Non-Conventional Energy Sources MNES Annual Report.* New Delhi: Ministry of Non-Conventional Energy Sources MNES .

Nieuwenhout, F., & Borg, N. (2006). Estimating insolation based on PV-module currents in a cluster of stand-alone solar systems. *Solar Energy* , 1220–1222.

Ocweija, S. M. (2010). *Life Cycle Thinking Assessment Applied to Three Biogas Projects in Central Uganda.* Masters Report, Michigan Technological University: http://cee.eng.usf.edu/peacecorps/Resources.htm.

Raja, P., Ramaseshan, B., & Nayar, C. (2002). Conceptual model for marketing solar based technology to developing countries. *Renewable Energy 25* , 511-524.

Sandia National Labs. (1995). *Stand alone photovoltaic systems handbook.* Sandia National Labs.

Schoon, E. (1998). *Feasibility study of SHS in rural Namibia: which way to go.* Netherlands Energy Research Foundation.

Shepperd, L., & Richards, E. (1993). *Solar photovoltaics for development applications.* Sandia National Labs.

Sunderasan, S. (2005). Solar home systems: Offering credit and ensuring recovery. *Refocus, Volume 6, Issue 1* , 38-41.

Surya, P. R. (1992). *Rural electrification by PV solar home systems, Sukatani, West Java, Indonesia 1988-1992.* Jakarta.

Torcheux, L., & Lailler, P. (2001). A new electrolyt eformulation for low cost cycling lead acid batteries. *Journal of Power Sources* , 248-254.

Urmee, T., & Harries, D. (2009). A survey of solar PV program implementers in Asia and the Pacific regions. *Energy for Sustainable Development* , 24-32.

Urmee, T., Harries, D., & Schlapfer, A. (2009). Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific. *Renewable Energy* , 354-357.

Vleuten, F., Stam, N., & van der Plas, R. (2007). Putting solar home system programmes into perspective:What lessons are relevant? *Energy Policy* , 1439-1452.

Wamukonya, N. (2007). Solar home system electrification as a viable technology option for Africa's development. *Energy Policy, Volume 35, Issue 1* , 6-14.

World Bank. (2000). *Zimbabwe: Rural Electrification Study.* World Bank.

Zahnd, A. (2009). Benefits from a renewable energy village electrification system. *Renewable Energy 34* , 362-368.

Appendix I: SHS Design worksheet

Step 1: Enter the independent variables under the orange row: Quantity of appliance, number of hours an appliance will be on each day/night, measured current, voltage, and wattage. (NOTE: If no measured data available use the wattage specifications from the appliance.)

Step 2: Look at the battery group cells. Blue number shows the required battery capacity in Ah for the storage days desired. Recommended depth of discharge is 50% (green row)

Step 3: Enter panel max power current (panel specific) on the left second block.

Step 4: Look at the C/L ratio generated as a function of daily peak sun hours. Need to have >1.3.

Step 5: Pay attention to the calculated peak load discharge rate as a function of battery capacity. If the number is less than C/20, the available battery capacity will be smaller than rated capacity.

Appendix II: Assessment matrix element SHS specific questions and guidelines for scoring

The following is a list of sample questions to help with the scoring of the lifecycle sustainability assessment matrix elements. The examples and questions are certainly not exhaustive nor will they all be relevant for every SHS project basis. They are meant to be used as a guide to stimulate discussion on a sustainable project process. Not all of the questions following a sustainability recommendation need to be answered in order to obtain a positive score. Instead, the questions and statements are meant to provide the project manager or the assessor a sense of the depth and scope that each guideline encompasses. If the assessor feels that the general essence of the guideline has been addressed in project planning then a positive score can be given. To determine the score of a project, assign a rating (0-4) to each matrix element, depending on the number of sustainability recommendations (four main bullets) that are completed. The questions under each main bullet help to determine the score. If none of the recommendations are met the matrix element is scored 0 (poor evaluation). If all of the recommendations are met the matrix element is scored 4 (excellent evaluation). The potential score for each sustainability factor or life stage is 20, while the total possible score is 100.

The operations and maintenance stage of the Lamap SHS project will be scored here for illustration purposes. (Answer in CAPS)
A full set of the assessment questions used to develop the matrix can be found in Jennifer McConville's report (McConville, 2006)

<u>Element (5,1) Operation and Maintenance: Socio-cultural Respect</u>

- Discuss unanticipated constraints to SHS use. (SCORE = 0)
  - Is the SHS used for intended purposes? (YES/NO) Is it being over used? (YES) Did people receive proper instruction on how to use the system? (YES)
- Discuss unexpected limitations to maintenance schemes. (SCORE = 0)
  - Did people trained in system maintenance leave the community? (NO)
  - Is performing maintenance seen as shameful or dirty work? (NO)
  - Are maintenance guidelines misplaced? (YES)
  - Are maintenance guidelines not followed? (YES)
- Reassess how gender roles affect the proper use and perceived benefits of the SHS. (SCORE = 0)
  - Are both men and women aware of proper operating rules? (NO)
  - Who maintains the system? (MEN) Children involved? (YES)
  - How can differences (if any) be addressed? (sometimes there are new technology intimidating factors and sometimes there are gender roles)
- Ensure that costs and benefits are equitably distributed within the community? (For a privately owned system equitably distributed among all family members?) (SCORE = 1)

  - Are equitable user fees and operating rules agreed on within the community? (YES)
  - Do community members have equal access or opportunity to receive services? (YES)

For this element the total score from the recommended tasks = 1.

Element (5,2) Operation and Maintenance: Community Participation

- Community members are actively involved in performing the necessary operation and maintenance. (For private systems are the owners performing proper O&M?)(SCORE=0)
  - Are the operation/maintenance tasks handles locally? (YES) Maintenance personnel been trained? (YES)
  - Are maintenance documents/manuals available? (YES/NO) Continuing training in place? (NO)
  - Are operations/maintenance responsibilities clear? NO
- Conduct a participatory evaluation to get community feedback and suggestions for improvements. (SCORE = 0)
  - Are a variety of community members involved in the evaluation? (NA for private projects)
  - Was the project perceived as a success? Why? Why not? (YES, provide quality lighting and no more need to buy expensive kerosene/gasoline)
  - How can system functioning be improved? (TO BE ABLE TO USE A FRIDGE)
- A community organization exists with the capacity to make decisions regarding the operations and maintenance of the SHS. (NO) (SCORE=0)
  - How will the community contribute to system maintenance? (NO contribution)
  - Who will take care of preventive maintenance, and repairs? (NO one)
  - Who will collect fees and keep records? (NA)
  - Can the organization contact other agencies for help if needed? (NA)
- The SHS is controlled by culturally appropriate and traditionally respected people. (NA)
  - How are operation and maintenance managers selected? (NA)
  - Are they selected for their dedication and dependency? Or political reasons?(NA)

For this element the total score is from the recommended tasks = 0.

Element (5,3) Operation and Maintenance: Political Cohesion

- Invite officials to the opening ceremony. (NA for private project)
  - Are all participants from planning and implementing stages included?
  - Are appropriate local and regional officials included?
  - Is credit and thanks given to all who helped?

- Coordinating institutions sign a formal agreement that defines their roles and expectations in operation and maintenance of the system. (NA)
    - What roles will government and donor agencies play in operation and maintenance of the system?
    - Monitoring and evaluation reports
    - Promotional activities
    - Financial support
    - Providing training and/or payment for maintenance personnel
    - Equipment or support services
- A locally based institution is involved in project monitoring. (NA)
    - Do they double-check/monitor technical aspects?
    - Can they help in refining management structures?
    - Do they reach out to regional peers to share knowledge and resources?
- Share monitoring reports and project evaluations with partner institutions. (NA)
    - Are periodic reports on operations and maintenance shared?
    - Are financial report shared, if appropriate?

For this element the total score is from the recommended tasks = 0. Although most aspects do not apply to a private project, so this shouldn't have too much weighting on the importance.

Element (5,4) Operation and Maintenance: Economic Sustainability

- Estimate realistic, long-term operation and maintenance costs based on the "built" system. (SCORE = 1)
    - Are costs for materials, replacement parts, and skilled personnel included? (NO)
    - How often will materials and parts need replacement? (battery every few years)
    - Where will replacement materials and parts be purchased?(vendor in capital city)
    - What about transport costs? (HIGH)
- Financing exists to cover projected operation and maintenance costs. (Score = 0)
    - Are there monetary needs to keep the system running? (YES) Technical labor needs? (NO)
    - How will these needs be met?(NO)
    - What is an appropriate fee for use? What are people willing to pay? Who collects the fees? (NA)
    - Is outside aid provided? Are there option for cost recovery? (NO)
- A financial management organization exists to manage operational/maintenance costs and the distribution of benefits. (NA for a private system)
    - Does this organization have the capacity to collect and account for monetary contributions? Labor contributions?
    - Is this organization controlled by the community?

  - Is the role of this organization recognized and respected at all levels of governance?
- Regularly review and adjust the financing system. (NA for private system)
  - Is the financing system reviewed on a regular basis?
  - Can it adjust for changing demands and perceptions of the project benefits?
  - Can it adjust for social constraints (non-payment of fees, under/over utilization)?

For this element the total score is from the recommended tasks = 1.

Element (5,5) Operation and Maintenance: Environmental Sustainability

- Minimize, treat, and dispose of waste properly. (SCORE = 0)
  - Is there waste resulting from the use of the project? (mainly battery)
  - Is waste properly treated (NO)
  - Are monitoring reports and treatment procedures checked by a managing organization?(NO)
- Explore alternative plans for reducing the use of consumables. (SCORE=1)
  - What consumables are used during operation/maintenance of the project? (Battery)
  - Are there ways to reduce the amount of material consumed? (YES)
  - How does usage of consumable parts and energy compare with similar projects? (SAME)
  - Are potential alternatives tested? (YES)
- Monitor and evaluate environmental impacts. (NA for small scale SHS project)
  - Is a methodology in place for impact assessments? (NA)
- Continue environmental and technical education efforts. (SCORE=0)
  - Are supporting behavioral changes reinforced? (NO)
  - Do people understand the benefits of improved systems? (YES)
  - Are community member aware of improvements since the system became operational? Or deterioration? (NA)

For this element the total score is from the recommended tasks = 1.