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The Design and Installation of Solar Home Systems in rural Cambodia

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Abstract

Clean and affordable energy development in rural communities in Cambodia plays an important role environmental sustainability and in economic development. Due to the lack of existing infrastructure, prevalence of battery powered appliances, and remoteness of many communities; off-grid energy solutions have large potential. The price of electricity in Cambodia is the highest in the region and with the cost of solar panels decreasing, solar energy is a prime candidate in addressing this. Therefore, standalone solar home systems (SHS) are an appropriate product to supply electricity to rural households in Cambodia. This study was conducted as a pilot project to test the appropriateness of the technology and explore the benefits of SHS for households in rural areas. In cooperation with Engineers Without Borders and an in-country NGO, two solar home systems (SHS) were designed, purchased and installed in the Secret Beach community, a rural community in the south of Cambodia. The technology was accepted by the users and generated economic, social and environmental benefits. The community engaged in an education workshop and were involved in the installation of the systems. This facilitated technical knowledge transfer about the functioning of solar energy and operation and maintenance of SHS. This process empowered the community and has generated the desire to expand the systems and roll out similar systems throughout the entire community.

1. Introduction

In Cambodia only 31% of the population have access to electricity and in rural areas, where 80% of the population live, electricity access is as little as 18.8% (World Bank, 2012). Due to the small size of generation, dependence on high cost imported oil and lack of infrastructure, the electricity price is the highest in the region (UN, 2007). Electricity in rural areas is provided by Regional Electricity Enterprises (REEs) which predominately operate on diesel generators, and the tariff ranges between US$0.50-US$1.00/kWh (MIME, 2013).

With the high cost of electricity and in the absence of infrastructure, approximately 50% of the population access alternates energy sources (MIME, 2013). Many rural households have at least one car battery to power lights and appliances. These batteries are charged at small charging stations that depend on high cost imported fuel and incur a cost to the end user of up to US$4.00/kWh, (MIME, 2013). This comes at a significant expense as 40% of the population live near or below the poverty line (World Bank, 2014). Poverty is overwhelmingly concentrated in the rural areas and the poorest quintile has an average daily consumption of US$0.70/day (Asian Development Bank, 2014). The battery charging stations are also detrimental to the environment, producing 153,337 tons of CO_2 annually and are often plagued with poor conditions, posing health threats to users.

Due to the lack of existing infrastructure and remoteness of many communities, off-grid energy has huge potential. Cambodia has high solar irradiance (NASA 2015) and with the cost of solar panels decreasing, solar energy is a prime candidate in addressing the high cost of electricity. Therefore, standalone solar home systems (SHS) have significant potential to provide a long-term, affordable, clean energy solution. Access to electricity helps reduce poverty, increases the living standard and fosters economic development (UN 2007). This report describes the design and implementation process of two SHS in the Secret Beach community, a rural community in the south of Cambodia.

2. Background Information about the Secret Beach Community

The following information details the energy usage and energy sources for households in the Secret beach community. For lighting, households use a combination of lights powered from disposable batteries (US$0.175 per set), kerosene (US$0.875/L) and/or car batteries. To power appliances and charge mobile phones, most households use car batteries. Figure 1 is an image of a car battery in a household in the Secret Beach Community.

Figure 1. Car Battery in Secret Beach Community, (Rebecca Watts)

The car batteries are charged at battery charging stations. As a representation of the survey, Table 1 details the expenditure on recharging and appliances powered by the batteries. The assumed usage (Whrs/day) and calculated levelised cost of electricity (LCOE) are also tabulated.

Table 1

HH	Cost per charge	Frequency of charging	Capability	Assumed usage	LCOE
1	US$0.75	Every week	TV, phone, lights	84Whrs/day	$2.25/kWh
2	2 batteries, US$0.50 each	Every week	Lights, 3 phones	42Whrs/day	$3.62/kWh
3	US$0.80	Every four days	TV, Video player, lights, 2 phones	118Whrs/day	$2.49/kWh

The information in Table 1 outlines the load profile, thus indicating the size and capability requirements for the design of the SHS. The expenditure in the table indicates the financial capacity of the households and the frequency of recharging highlights difficulties in accessing electricity. The time spent taking the battery to the charging station at least once a week reduces productivity. The SHS addresses this as the battery is charged onsite (in the house). therefore, there is a strong case in support of a solar energy.

3. Design and Test

3.1. Aim and Method

To test the operation of the proposed SHS and practice the system set up (to facilitate knowledge transfer when in the community), a model SHS was purchased and tested. This included the following:

Table 2

Component	**Description**
Solar Panel	InstaPower 100W solar panel with monocrystalline cells
Charge controller	10A, 12V regulator
Car battery	50Ah, 12V, lead acid
Light	55W car headlight (high wattage chosen)
Alligator clips and wiring	12mm wires

The system was assembled to mimic the proposed SHS in the Secret Beach community and placed on the roof on the Engineering building at the Australian National University, illustrated in Figure2.

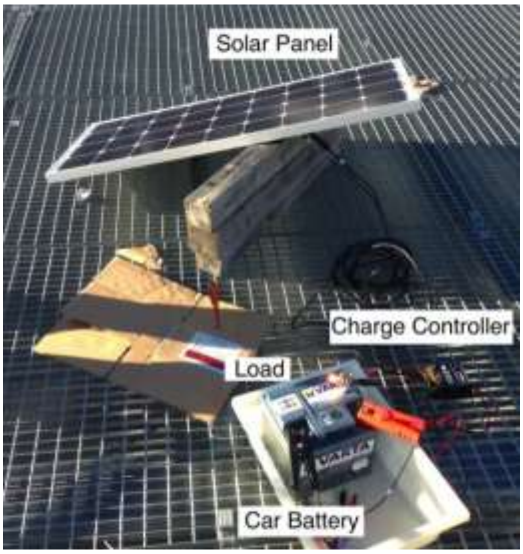

Figure 2. Model System

The tilt angle of the panel was adjusted and the panel was shaded in increments. A load was also added to the system. The sensitivity on output of these variables was tested. The results of the modifications and the implication of this are described in Table 2.

3.2. Results and Discussion

Table 2

Variable	Modification	Result	Implication
Tilt anlge of panel	Panel tilted at different angles.	Optimum tilt approximately 30^o. Deviations from this resulted in lower output. The larger the deviation the larger the drop in output.	Panel must be tilted at optimum angle. This is dependent on by location.
Shading of panel	At varying increments, the cells on the module were shaded.	Shading the panel reduced power output.	Panel must be placed in an unshaded area and need to educate the user about the important of maintenance.
Addition of the Load	Panel Shaded: Adding the light bulb.	Adding the light with the panel shaded drew power from the battery.	At night, appliances are powered from battery.
	Panel Unshaded: Adding and removing the light bulb.	Adding the light to the system diverted some (but not all) of the charge.	During the day, low wattage appliances can be used and the battery can be charged simultaenously.

The optimum tilt angle is dependent on location, specifically the latitude due to the elevation of the sun in the sky. For the Australian National University, the optimum tilt angle is approximately 30^o. In the Secret Beach community, the optimum tilt angle will be close to 10^o due to the proximity to the equator. A lower tilt angle (more horizontal panel) increases the susceptability of the panel collecting dirt. Therefore, there is a trade off between power output and maintenance required. Although not tested, it is important to note the effect of temperature on output. According to the data sheet of the module, the temperature coefficient is -0.47%/^{o}C . The panel should be installed somewhere that has airflow at the back of the panel to prevent overheating and decreases in efficiency.

4. Final Design and Implementation

4.1. Purchased Solar Home System

The following SHS was purchased from a solar energy company in Cambodia.

Table 3

Component	Description
Solar Panel	15W polycrystalline with 8m cable and integrated connector
Battery	7Ah, 12V sealed lead acid
Control unit (excl. battery)	Continuous DC output power: 60W. Battery state of charge display, 2 x USB outputs, 4 x 12V DC outputs
Accessories	2 x 2W LED -128 Lumens USB phone cord with various phone connectors

The SHS has a stored energy of 60Whrs/day, lower than the current usage, (118Whrs/day). The capability is also less as the system powers up to four lights (only two provided) and charges up to two mobile phones. Thus, the SHS is likely to be used in conjunction with the car battery. Thus reducing the use of kerosene and to some extent, the usage of the car battery.

4.2. Workshop with the Secret Beach Community

Prior to the installation of the systems, the community were engaged in workshops about solar energy and the operation and maintenance of the systems, as shown in Figure 3.

Figure 3. Solar Energy Workshops, Cambodia (Rebecca Watts)

4.3. Advantages of Solar Home Systems

The workshop facilitated discussions about the advantages of solar energy. The community members identified current issues in accessing electricity and there was a transfer of knowledge about the features and benefits of the SHS. Through this, the advantages of SHS were acknowledged. This included discussing the increased battery lifetime, reduced reliance on expensive diesel, eradication in use of kerosene, increased productivity as battery is charged in the house, reduction in pollution from diesel generators and reduction in health concerns due to lead acid exposure.

4.4. Installation Process

One system was installed in a household (HH1) to demonstrate the household level usage and the other system installed at the local primary school (HH2). Installing a system at the school was to raise awareness of the technology, as it is a central hub for the community. It also results in widespread access as the teachers at the school can use the system. A teacher and his family also live at the school and are able to use the system during the night. Thus, further demonstrating how the technology can be used at the household level.

The community members were involved in the installation of the system. This helped develop local skills and increases the potential for the installation of systems in the future. In addition, local involvement facilitated transfer of technical knowledge. For example, it initiated further discussions about the importance of installing the panel in an unshaded location with correct orientation but also taking into account the trade-off in tilt angle. Through trial and error, the principal of the school (pictured in Figure 5) successfully installed the panel on the roof of a classroom at the school, the correct orientation and with sufficient airflow behind.

Figure 4. SHS at the Local School (Rebecca Watts)

At the household (HH2), through a similar discussion with approximately 20 community members, an appropriate location for the panel was identified. A member of a neighbouring household attached the panel to the roof of the shed using locally sourced plastic cable, hooks and nails.

Figure 5. SHS at a Household (Rebecca Watts)

4.5. Potential Financing for the Installed SHS

As it was a pilot project consisting of two systems, with one providing public usage, the systems were a donation and no repayment arrangement established. Furthermore, it was not viable to employ someone to collect money from only one household. In order to investigate the financial viability, the following economic analysis was undertaken. For insight into potential financing arrangements, three scenarios were investigated:

1) Scenario 1 –user pays all capital costs upfront
2) Scenario 2 – user repays nominal capital cost through periodic instalments, with no subsidy, and
3) Scenario 3 – user repays nominal capital costs of through periodic instalments, with subsidy of a quarter of the system cost (US$32.25).

The value of the repayments was based on cost savings generated by systems, with the O&M cost is deducted.

Table 4

	Scenario 2	**Scenario 3**
System Cost	US$129	US$129

Subsidy	0	US$32.25
Evaluation Period	10 years	10 years
Avoided costs/year – recharge	US$19.50	US$19.50
Avoided costs/year – battery replacement	US$8.33	US$8.33
Repayment amount per year	US$25.33 for years 1-4 and $25.67 for year 5	US$25.33 for years 1-3 and US$19.25 for year 5
Maintenance costs per year	US$2	US$2
Discount rate	12%	12%

Economic analysis generally takes into account the impact of the interest rates. The interest free financing would be a consideration to incentivise users to transition to solar energy. Therefore, this cost of this financing would be born by those providing the product. The low repayment rate (US$25.33) is another incentive and provides an arrangement tailored to the financial capacity of the households. Table 5 details the economic indicators for the three scenarios, with the most favourable for scenario 3. The LCOE for all scenarios lower than the current LCOE, which ranges from US$2.47-US$3.26/kWh. Therefore indicating the systems are more cost effective than current sources.

Table 5

	Scenario 1	**Scenario 2**	**Scenario 3**
Net Present Value	US$29.86	US$45.58	US$64.33
Levelised Cost of Electricity	US$0.93/kWh	US$0.80/kWh	US$0.75/kWh
Simple Payback period	-	4.63	3.75

With the subsidy, the system would be repaid within four years, whereas without the subsidy the system would be repaid within five years. From this time onwards, the households would have access to free electricity. For scenario two and three for the first few years while the systems are being repaid, the households are no worse off as the current expenditure would be redirected to repay the systems. For scenario one, the user would be out of pocket for the first five years and only reap benefits after this. This indicates that the systems are financially viable and have the potential to provide an affordable source of energy.

5. Results From Installation

It is important to monitor the progress of the project, identify the impacts of the SHS and assess whether changes are needed for future SHS. Table 6 gives details the achievements of the project through key performance indicators (KPIs).

Table 6

Stage	**KPI**	**Value for KPI**	**KPI Achieved in Project**
Input	Technical	Land Labour	Negligible Two man hours per system
	Community	Number of awareness programs	One awareness program
	Financial	Funds used	US$258
Outputs	Technical	Number of SHS installed	Two
	Community Participation	Number of people with knowledge about solar energy due to project	22 people directly

	Capacity Building	Number of supporting activities	0
Short-term Outcomes	Access	Percentage of households connected with SHS	2%
	Affordability	LCOE of SHS vs. other sources	Electricity from SHS is free, but the LCOE is US$0.93/kWh for all upfront cost paid
	Usage	Hours of electricity used: From Solar Energy	Household: 2-4 hours/day School: 2-4 hours/day

5.1. *The Product (the SHS)*

The following analysis is drawn from a survey from the household (HH1), the principal and teacher that lives at the school (HH2). This information is presented describing the successes and limitation for the product (the SHS) and the process (the implementation).

5.1.1. *Successes*

The project was successful in initiating the use of solar energy. The systems have been used to charge mobile phones during the day but predominately used at night to power lights (for 2-4 hours generally between 6:30pm-9pm). This indicates the load profile versus the power generation profile and indicates user acceptance.

Both HH1 and HH2 have identified a desire to increase the size and capacity of the systems (a fan for HH1 and two computers for the school, HH2). It is important to understand the demands of the user and design solar energy solutions accordingly. This will ensure community development is enabled by by solar energy.

The most significant change in behaviour for HH1 has been a reduction in recharging of the car battery and the ability to charge mobile phones in their house rather than at neighbours house. This indicates not only an acceptance of the technology but a preference of the SHS over the the diesel charged battery. This change in behaviour generates the following impacts:

Economic: cost saving due to less frequent recharging (due to less usage) and replacing of the battery (due to less cycles per year). Increased productivity as the time previously spent taking the battery and phone to external sources can be spent on income creating activities.

Environmental: reduces the diesel-generators usage, thus lowering emissions.

Health/social: reduction in exposure to toxic gases and the toxic effects of lead absorption from recharging and recycling battery.

HH2 identified two significant changes in behaviour; Firstly, teachers at the school are able to charge their mobile phones at the school. Which has the following impacts:

Economic: teachers generate cost saving from previous charging source (i.e. if previously charged at a café) or from charge from their car battery at home. Furthermore, increased connectivity (through mobile phones) increases productivity.

Social: widespread awareness as all the teachers at the school now have access to solar energy. Increased access to information (due to increased access to mobile phones) also leads to empowerment.

Secondly, the teacher and family that live at the school have access to light during the night, thus eliminating the use of kerosene. This has the following impacts:

Economic: extended working hours due to high illumination of lighting at night and cost savings from the elimination of kerosene use.

Environmental: reduction in the use of kerosene reduces indoor pollution.

Health/social: reduction in the chance of burns and indoor fires, increased safety due to more lighting at night and increased education as the children of the family are able to study at night.

5.1.2. *Limitations*

The system in HH1 has been used in conjunction with the car battery as is not of sufficient size or capability to entirely replace the car battery. This limits the economic, social and environmental benefits and fails to entirely demonstrate the potential for solar energy at the household level.

5.2. *The Process (the Implementation)*

5.2.1. *Successes*

The installation process and workshops were successful as there was a transfer of technical knowledge and two-way sharing of information. The feedback from the attendees of the workshops were positive, with a member from HH1 commenting:

"You explained [to] us very clearly about how to use and maintain this system."

Sambath, 2015, (Watts, 2015).

There was successful knowledge transfer about how solar energy works as HH1 was able to explain the functioning of the system, commenting

"The solar battery store power, even on the cloudy day we still can use light and charge phone."

Sambath, 2015, (Watts, 2015)

The workshops were successful in transferring knowledge about the operation and maintenance, as the systems have remained functional and have been maintained. This has ensured households can use the systems independently and reap the associated economic, social and environmental benefits.

5.2.2. *Limitations*

Due to limited time and resources, only one education workshop was held and there was no training of a technician. Also, as only one SHS was installed in a household, no financing arrangement was established and the financial viability of the systems can only be predicted.

5.3. *Conclusion*

Due to the high cost of electricity and lack of existing infrastructure in Cambodia, especially in rural areas, standalone solar home systems (SHS) have significant potential in providing a long-term, affordable and clean energy solution.

In conjunction with an educational workshop, two SHS were installed in the Secret Beach community, a rural community in Cambodia. This project was in initiating solar energy in the community, as it is the preferred energy source. For the users, SHS has reduced the recharging and replacing of the car battery and the eradicated the use of kerosene. This has generated cost savings due to reduced fuel costs, increased productivity due to timesaving and extended work hours. This has also reduced emissions from diesel generators and thus reduces the potential for severe diseases caused by the absorption of toxic gases and toxic effects of lead absorption.

The systems have also increased access to lighting, which has increased safety and permitted children to study at night. The reduction in kerosene also reduces the risks posed by inhalation of pollutants and unintentional ingestion.

The workshop successfully transferred knowledge about the functioning of solar energy and the operation and maintenance of SHS. By sharing knowledge, the community identified the advantages of solar energy over current energy sources.

The project has successfully initiated the use of solar energy in the community. SHS have proved to provide economic, environmental and social benefits to households in rural communities. Further installations of SHS has the potential to provide a clean energy solution and translate the outcomes (of this project) into long-term and widespread reductions in poverty, increased quality of life, economic development and environmental sustainability.

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Appendix

Scenario 1 – All capital cost paid

Net Present Value	4
Levelised cost of electricity	0

	Use per day (hrs)	Energy Output (kWh/yr)	PV of Energy Output (kWh/yr)	Avoided Costs (recharge)	Avoided Costs (battery replace)	Total Benefit	System cost	O&M cost	End cost to user	Total Cost	Net End-User Benefit	PV of end cost Net Benefit to User	T B
2016	4	22	19.64	19.5	8.33	27.83	129	2	129	131	116.96	-103.17	
2017	4	22	17.54	19.5	8.33	27.83		2			1.59	25.83	
2018	4	22	15.66	19.5	8.33	27.83		2			1.42	25.83	
2019	4	22	13.98	19.5	8.33	27.83		2			1.27	25.83	
2020	4	22	12.48	19.5	8.33	27.83		2			1.13	25.83	
2021	4	22	11.15	19.5	8.33	27.83		2			1.01	25.83	
2022	4	22	9.95	19.5	8.33	27.83		2			0.90	25.83	
2023	4	22	8.89	19.5	8.33	27.83		2			0.81	25.83	
2024	4	22	7.93	19.5	8.33	27.83		2			0.72	25.83	
2025	4	22	7.08	19.5	8.33	27.83		2			0.64	25.83	
2026	4	22	6.32	19.5	8.33	27.83		2			0.57	25.83	
Total			**130.63**								**127.05**		

Scenario 2 - Without Subsidy and interest free financing

Net Present Value	4
Levelised cost of electricity	0

	Use per day (hrs)	Energy Output (kWh/yr)	PV of Energy Output (kWh/yr)	Avoided Costs (recharge)	Avoided Costs (battery replace)	Total Benefit	System cost paid by end user	O&M cost	Total End cost to user	PV of end cost	Net End-User Benefit	PV of Net End-User Benefit	S (S
2016	4	22	19.64	19.5	8.33	27.83	25.83	2	27.83	24.85	0	0	
2017	4	22	17.54	19.5	8.33	27.83	25.83	2	27.83	22.19	0	0	
2018	4	22	15.66	19.5	8.33	27.83	25.83	2	27.83	19.81	0	0	
2019	4	22	13.98	19.5	8.33	27.83	25.83	2	27.83	17.69	0	0	
2020	4	22	12.48	19.5	8.33	27.83	25.67	2	27.67	15.70	0.17	0.08	
2021	4	22	11.15	19.5	8.33	27.83		2	2	1.01	25.83	11.69	
2022	4	22	9.95	19.5	8.33	27.83		2	2	0.90	25.83	10.43	
2023	4	22	8.89	19.5	8.33	27.83		2	2	0.81	25.83	9.32	
2024	4	22	7.93	19.5	8.33	27.83		2	2	0.72	25.83		
2025	4	22	7.08	19.5	8.33	27.83		2	2	0.64	25.83	7.43	
2026	4	22	6.32	19.5	8.33	27.83		2	2	0.57	25.83	6.63	
Total			**130.63**							**104.90**		**45.58**	

Scenario 3 - With Subsidy and interest free financing

Net Present Value	
Levelised cost to end user	

Year	Use per day (hrs)	Energy Output (kWh/yr)	PV of Energy Output (kWh/yr)	Avoided Costs (recharge)	Avoided Costs (battery replace)	Total Benefit	Subsidy	System cost to end user	O&M cost	End cost to customer	PV of end cost	Net End-User Benefit
2016	4	22	19.64	19.5	8.33	27.83	32.25	25.83	2	27.83	24.85	0
2017	4	22	17.54	19.5	8.33	27.83		25.83	2	27.83	22.19	0
2018	4	22	15.66	19.5	8.33	27.83		25.83	2	27.83	22.19	0
2019	4	22	13.98	19.5	8.33	27.83		19.25	2	21.25	16.94	6.58
2020	4	22	12.48	19.5	8.33	27.83			2	2.00	1.59	25.83
2021	4	22	11.15	19.5	8.33	27.83			2	2.00	1.59	25.83
2022	4	22	9.95	19.5	8.33	27.83			2	2.00	1.59	25.83
2023	4	22	8.89	19.5	8.33	27.83			2	2.00	1.59	25.83
2024	4	22	7.93	19.5	8.33	27.83			2	2.00	1.59	25.83
2025	4	22	7.08	19.5	8.33	27.83			2	2.00	1.59	25.83

2026	4	22	6.32	19.5	8.33	27.83			2	2.00	1.59	25.83
Total			**130.63**								**97.33**	