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A Case Study of the Implementation and Maintenance of a Fee for Service Lighting System for a Rural Village in Sub Saharan Africa

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A CASE STUDY OF THE IMPLEMENTATION AND MAINTENANCE OF A FEE FOR SERVICE LIGHTING SYSTEM FOR A RURAL VILLAGE IN SUB SAHARAN AFRICA

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ABSTRACT

Electricity is a critical need for the rural poor in developing countries. Often this need is met with disposable batteries. This results in high cost and problems with disposal. For example it was recently reported that an isolated rural village in West Africa with a population of 770 uses more than 21,000 disposable batteries per year and that purchase of these batteries accounts for 20-40% of household expense. As a result many organizations are seeking way to meet the need for village energy. This paper presents a case study of one such experience. In this study the efforts to meet the lighting needs of a cluster of eight rural villages with a population of approximately 8,000 people are discussed. A key aspect of this discussion is the challenge of creating a continuing and sustainable village lighting solution. In this case the technology chosen to implement a lighting system was a distributed micro-grid managed locally in each village. The success of this lighting grid has been in large part due to the continuing support of the local micro-grid system both financially and through continued engagement to maintain and upgrade the micro-grid systems.

INTRODUCTION

Rural electrification by grid extension is often a capital-intensive endeavor that requires significant commitment from local governments and utilities. These grid extension projects are often delayed and are uneconomical for the utilities due to the low demand from the new rural subscribers. Because of this there is interest in a number of types of rural power systems that create community-based micro-grids. For example solar home systems in which each home receives a solar panel and battery have been developed. While this technology needs less initial capital, the maintenance of the power system is often neglected as in the case of the Renewable Energy Service Company on the island of Fiji where a number of micro grid systems were poorly maintained and as a result were not operational a majority of the time [1]. Also, rural electrification has shown to have little immediate impact on economic growth but a large immediate improvement in the rural consumers quality of life [2]. Because of this, funding for continuing system operation and maintenance needs to be included in the initial design and planning. All of these difficulties often force the rural consumers to rely on disposable batteries, kerosene, and candles, that are a significant portion of their energy expenditures [3-5]. A different approach is needed that reduces the initial capital investment and thus allows for lower consumption rates while providing acceptable returns, as a part of this, system maintenance can be locally supported. And the significantly improved quality of life for the subscribers can be sustainably realized.

Lighting is a critical link in sustainable and continuing rural development Lighting has shown direct linkage to improved education in the areas where a system has been

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installed. Several researchers have reported that prior to the installation of an electrical lighting system students routinely study by the light of a kerosene wick or candle that provides low quality light and as a result forces students to study almost on top of the light source that increases exposure and inhalation of noxious exhaust products [6-8]. Electrical lighting not only allows students to study later into the night but also attracts more qualified teachers who may offer classes at night if high quality lighting is available [9]. A lighting system also allows for increased socializing and the potential for work opportunities or chores for adults [10-13]. Women may also spend less time collecting fuel and preparing meals because the availability of high quality lighting enables meals to be prepared prior to the meal instead of during the day thus saving fuel spent reheating the meals [14,15]. The human development index, while sometimes contested as an appropriate development metric, has shown improvement after a lighting system has been installed due to these new opportunities available to the consumers [16]. The social benefits that result from lighting systems are far reaching throughout the rural consumers lives. Also, the value of electric ambient lighting has been recognized by rural consumers. For example, in Kenya when a 30% import duty was placed on components for rural electrification, the lighting systems still reached a significant number of households [17].

This case study examines a rural power system implemented in four rural Malian villages. These villages are located approximately ninety km from the capital city of Bamako. A village of about 770 people serves as the administrative seat of a group of eight villages with a total population of 8,000. None of the villages have access to electricity, cellphone, or the Internet, and only half of the 8,000 people have access to clean water in the form of deep wells operated by solar panels during daylight hours. The average income in the villages is approximately $1 USD per adult per day. Family groups in this region are not immediate families, but instead are extended families of 15-50 related adults and their children.

Located in western Africa, Mali is one of the poorest nations in the world with approximately 80% of the population engaged in subsistence-level farming or fishing. Mali ranks 160th out of 169 countries on the Human Development Index, an index that accounts for life expectancy, educational attainment and income [18]. Two-thirds of Mali's 13 million people live in rural areas [19]. Mali has the sixth highest rate of death in the world due to indoor and outdoor air and water pollution [20]. The per capita energy use of 7,500 MJ cap^{-1} yr^{-1} is one-third of the average per capita energy use in Africa. On a national level, the mix of energy sources is biomass (78%), petroleum products (18%), and electricity (4%). Energy use is residential (72%), transport (17%), industrial (3%), and other applications (8%) [21].

Work began on this project in mid 2006. Since the initial trip a relationship has developed that allows for the testing of technologies for the developing world. These technologies have included improved cookstoves, water valves, and grain grinders. Along with these projects, existing technologies within the villages have been maintained such as the solar powered water pumps and the lighting system in the village school. The initial contact with the village was through an NGO that was seeking to build a micro-hydro system to provide electricity for the village and for a medical clinic, A preliminary engineering study found that water flow in the local river was highly dependent on season and would be insufficient to provide power for 4-6 months of the year, also the cost of the micro-hydro system exceeded the cost of solar panels and that there was no maintenance support available for a micro-hydro station. Considering this micro-hydro was not sustainable from either a technical or economic perspective. As a part of the initial review and study, discussions were held with the village to determine village needs, priorities, and constraints. In discussions it was identified that the primary need within the village was for electrical lighting. In addition, a lack of distribution networks, tooling, and funds for continuing system operation and maintenance were identified as significant constraints.

BACKGROUND

The need for electricity in the developing world extends beyond a need for lighting. Electricity can provide reliable water purification, pumping for watering gardens, small-scale refrigeration, fans for cookstoves, radio, and television. The connection between electricity and health, education, and development is so strong that some activists have suggested that there is a "right" to electrical power (suggested at 100 to 200 kWh per person per year) similar to a "right" for clean water, sufficient food, and shelter. Off-grid power generation and distribution is useful in situations where there has been no large initial investment in power generation or in remote, rural villages where connection to a major gird is infeasible due to economic constraints. In 2009, 1.5 billion people did not have access to electricity, and that number is expected to remain roughly constant with approximately 1.4 billion people still lacking access to electricity in 2030 in spite of aggressive grid-based electrification efforts [24]. The majority of these people live in South Asia and Sub-Saharan Africa.

The estimated cost of various lighting solutions amortized over 3 years is given in Table 1. While costs vary widely from region to region, these approximate costs provide a starting place for consideration of various technologies. As shown the combination of a solar panel, NiMH battery, and LED bulb generally provides the lowest cost solution. The simple kerosene wicks and candles in current use are significantly more expensive. Temporary solutions such as flashlights and batteries are very expensive. This provides a significant opportunity for ambient lighting solutions that can overcome a variety of barriers. These barriers include initial cost, distribution of components, and onsite repair of the device.

Lighting Method	Amortized Cost ($/1000 lumen-hr)
Solar-LED: 1W w/ focusing lens (NiMH batt)	$0.19
15W CFL (grid connected)	$0.004
60W incandescent lamp (grid connected)	$0.016
Grid recharged lead-acid battery w/ 15W CFL	$0.25
Solar-LED: 3x 0.1W no optics (NiMH batt.)	$0.38
Pressurized kerosene lamp (mantle)	$0.021
Solar-6W CFL lantern (NiMH batt)	$0.25
Hurricane kerosene lantern (wick)	$0.27
Simple kerosene lantern (wick)	$0.56
6W compact fluorescent lantern (alkaline batt.)	$1.856
Incandescent 0.74W flashlight (alkaline batt.)	$70.52

Table 1. Amortized cost of different lighting technologies (off-grid electrical sources in blue) [22, 23].

The sources of power for lighting systems vary throughout the world, in the case of the affected village in Mali a few sources can be eliminated. A grid connection often has one of the lowest delivered energy costs but the Malian government has no plan to extend the grid to reach the village within the next 20 years [25,26]. Additionally, many grid extension projects falter initially due to the low electrical demand of the new customers due to their limited purchasing power to acquire electrical appliances to increase the load in the system [27,28]. The lack of a potential for grid extension has not been uncommon in the developing world as a result there is large range of distributed energy technologies. Second, due to the remoteness of the village fuel prices for kerosene, petrol, and diesel fuel are prohibitively expensive for purchase on a regular basis. As a result high fuel costs eliminate both kerosene powered lamps and generators powered from fossil fuels to generate the needed electricity for lighting systems. As illustrated in Figure 1 disposable alkaline batteries which currently meet a portion of the villages lighting in the amount of 21,000 batteries per year are extremely expensive to be used on a regular basis to power lighting systems [29]. Also, due to the improper disposal the battery contents are leached into the local environment. Because of this village energy solutions derived from renewable energy options currently provide the most effective solution on both an economic and environmental basis.

LED lighting has made significant strides in performance and costs in recent years resulting in the slow adoption of the technology by consumers in the developed world. The technology is still beyond the financial means for general

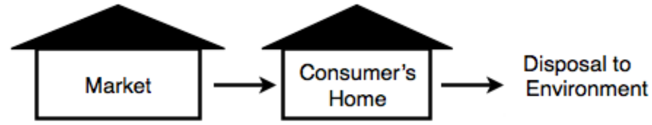

Figure 1. Life Cycle of a Disposable Battery.

lighting but has shown success in task lighting in the developing world. The need though is not task lighting but instead general lighting allowing for an entire room to be lit, because of this solutions that featured LED lighting were not considered. Given these costs, it is not surprising that the most common method for providing off-grid electrical lighting involve the use of a solar panel, a battery, and an LED lamp (sometimes a compact fluorescent lamp). This may be in the form of a flashlight or lantern with a built-in solar cell (e.g. a BoGolight, [30]). While this is the approach taken by many lighting projects in the developing world, it may not be the best solution. As an initial part of this study of a variety of LED lighting devices were tested by consumers in the village. All of these systems were based on the design paradigm of a portable system composed of an LED lamp, small solar panel and NiMH batteries. As conceived the villagers would expose the lamp to sunlight during the day and the use the lamp at night. In only one case out of twenty four did an LED lighting system replace a kerosene wick lantern. In this case a single kerosene light in a small village mosque was replaced with a diffused LED light. This was a stationary system composed of a solar panel on the roof, and a LED lamp and NiMH battery in the mosque. In all other cases the LED light was used to supplement a kerosene wick lantern. In most cases individuals indicated that they would not be willing to pay for the LED devices. Villager comments indicated that more light and diffuse area lighting were needed. In part, simply providing the same amount of light or slightly more than the existing oil lamp did not meet the need. The existing oil lamps did not provide sufficient light and additional LED light were additive rather then replacement sources of light. As additive devices they were not able to inspire the consumer commitment needed for a successful and sustainable village lighting system.

Renewable solutions to power lighting systems have been tested and installed across the developing world. These systems include small scale hydro, wind turbines, photovoltaic solar panels, biogas, and a wide variety of hybrid systems featuring a combination of renewable and non renewable solutions. Considering this a number of different village lighting options were considered and investigated prior to the chosen solution. Each energy option contained its own attributes, the key factors considered were initial investment cost, operational cost, maintenance cost, safety, and the availability of skilled labor to maintain and operate the system. In addition, the overall lighting solution needed to inspire sufficient consumer commitment to ensure the continued sustainable success of the lighting project. These were some of solutions considered and eliminated:

- Biogas provides combustible gasses obtained through the anaerobic consumption of cattle dropping contained in a digester, these gases could then be combusted and used to generate electricity. The option was eliminated form consideration because of the lack of cattle in the village which is a direct effect of the lack of economic means within the village.
- Wind turbines were also considered but the uncertainty of reliable wind speed data along with the lack of qualified maintenance creates an unacceptable large risk both economically and technically to be implemented. Photovoltaic solar are a proven technology that has been implemented in a variety of environments while also meeting different levels of electrical demand.
- The electrical demand of the village was very minimal consisting of compact florescent lights and cell phone battery charging. Due to the low demand systems such as a solar home system (SHS) which consists of solar panels and on a battery bank on a home which is then wired with electrical outlets and switches would have been excessive because of the almost non existent purchasing power of the villagers that nets a slow if any adoption of electrical appliances.

The chosen system in the village was a village charging station based on monthly rental of the lights and charged batteries. This results in some of the lowest initial costs for an ambient lighting system, because of these low capital costs lower monthly fees can be charged on the rural villagers as compared to other lighting systems.

Solar

The primary form of off-grid household power production is based on photovoltaic (solar) panels. Photovoltaic solar panels (PVs) are increasingly available, and their cost is decreasing. Photovoltaic solar panels are an affordable method of electrical power production with an estimated cost of approximately $0.25 per kWh for large-scale systems and $0.40 to $0.60 per kWh for household systems. For household systems the largest barrier is the high initial cost for the equipment. Currently, the installed cost of a 100 W solar panel in Africa is approximately $200. The most common panels are 100 W panels, and this cost is linear for small systems composed of 100 W panels. Based on manufacturer warranties the expected lifetime of the panels is 25 years. A 100 W solar panel more than meets household lighting needs. Most homes in developing countries can be well lit using one to three 15 W fluorescent fixtures. A single fixture will require about 75 Wh each day. A 100 W panel can produce about 640 Wh each day and 200 kWh per year. This is in the range of the minimum electrical needs of 100 to 200 kWh per family in a developing country suggested as a benchmark by some. Amortizing this cost over the 25 y life of the panel provides cost of electricity production at about $0.087 per kWh and $0.24 per kWh with 0% interest and 10% annual interest respectively not including the cost of batteries or lighting devices. Extending this to lighting, the cost of producing electricity for a 15 W fixture using solar would be approximately $2-$5 per year.

Smaller panels are available; for example a 10 W panel currently costs $40 retail in Mali. Including installation framing and other items the cost of 10 W panel would be less than $55 installed. This is sufficient to power a single 15 W fluorescent lighting fixture four to five hours each evening. Another option to be considered is that 5 W, 12 V complete solar battery charging systems can be obtained today for approximately $30 retail in the US.

Lamps

As shown in Table 2 multiple light sources are available for use in the lighting system. The incandescent bulb was eliminated because of its low luminous efficacy. Luminous efficacy was a key performance measure of the lighting sources because of the limited supply of electricity within the system. LED and metal halide sources were impractical due to the hot environment that they would operate in along with the remote location of the system, which creates difficulties in the supply of the already uncommon light sources. The linear fluorescent was chosen over the compact fluorescent light lower cost while also providing a higher luminous efficacy. In addition, the local market has chosen the linear fluorescent bulbs with 12 V DC supply as the solution for urban use. As a result linear fluorescent bulbs are widely available in the developing world.

Light Source	Typical Luminous Efficacy (lm/W)
Incandescent	10-18
Halogen Incandescent	15-20
Compact fluorescent (CFL)	35-60
Linear fluorescent	50-100
Metal halide	50-90
Cool while LED 5000K	45-59
Warm white LED 3300K	22-37

Table 2. Light output as a function of bulb type [31]

BARRIERS IN LIGHTING SYSTEM DESIGN

There are several barriers, in addition to initial cost of the solar panels, that need to be overcome to design and deliver a continuous and sustainable electrical lighting solution. Solar lighting requires an energy storage system when being used for lighting. In nearly all cases this is a bank of lead-acid batteries, that must be replaced frequently at a relatively high cost. Depending on a number of factors including climate, type of battery, and usage patterns; the batteries must be replaced every 2-3 years. The typical battery used in conjunction with a 10-15 W solar panel costs about $100 and can power a 15 W light for 4 hours per day. More batteries are required for systems with more solar panels.

Additional barriers that need to be addressed in delivering a solar panel based lighting solution include protection from theft and insuring against weather damage, based on the high cost of the system relative to income. Panels in the range of 50-100 W are viewed in some parts of the developing world as a commodity. If an individual owns one of these and is short for cash, they will rent out the panel to generate cash. This makes them attractive items to steal.

SYSTEM CONSTRAINTS

The analysis of current lighting solutions presents constraints that need to be addressed prior to the implementation of a system. These constraints designate different aspects of the acceptance, use, lifecycle, and sustainment of a lighting system. The options must:

1. Meet the lighting needs of study, work, and social activities in a hut.
2. Must be able to be implemented for \$2-\$5 $month^{-1}$ $family^{-1}$ USD.
3. Have a long-term plan for maintenance.
4. Have a viable plan for safe disposal of batteries.
5. Provide for country sourcing of all materials.

Along with these constraints several other questions need to be considered. These include:

1. If the system is subsidized what are the problems that will result from consumers getting used to below cost pricing?
2. What type of distribution network will be required to make an off-grid lighting system successful?
3. To what extent will consumers use the additional power for things other than lighting?
4. If credit is provided to finance the purchase of capital items, what mechanisms will be used to ensure or enhance repayment?
5. Are the requirements for proper maintenance of micro-grids too rigorous for expertise and skills available in a rural village?
6. Can low cost reliable products be produced in the countries where they are used? What about replacement parts? What about battery care and battery life?
7. What distances are reasonable for grid extension using available transportation methods?

Based on these requirements and constraints a distributed micro-grid was chosen to be implemented in the village. The distributed micro-grid as defined in this research discussion is an energy system consisting of a centrally located charging station from which villagers rent lead acid batteries to power their home. The system bypasses the need to create an infrastructure of power lines common in micro-grids by using the battery as the medium to transmit and store energy at the villager's convenience. Figure 2 shows the cycle of the charging system in which a battery is returned to the charging station once it has been discharged from its use powering a linear fluorescent light.

The distributed micro-grid system designed for use in the villages is composed of common components in a rural power system a solar panel, lead acid battery, and linear fluorescent lights. The system in use in the village distributes power via a lead acid battery, that are charged from a central solar panel charging facility. A centralized battery charging facility was chosen to reduce cost, maintenance, and security needs. The reduction in the number of solar panels needed for a system is the result of the lower power requirements needed to supply lighting.

The purpose of the charging system is to provide light for the affected village and so each villager that rented a battery also received a linear fluorescent lamp. As discussed earlier, the a linear fluorescent lamp was chosen over incandescent and compact fluorescents due to the luminous efficiency of the light and the local availability of linear fluorescent fixtures. The cost of the total light fixture is around $20 USD. The lights are wired using lamp wire with hose clamps that attach to the battery terminal. The lights remain at the user's home while they have their battery recharged.

The distributed micro-grid is based upon a fee for service (FFS) system that charges the users a flat monthly and a per charge fee. The maintenance of this photovoltaic system is paid through these fees and is one of the most important factors to the system's success. The subscribers never own any aspect of the system, which eliminates their economic risk of failure and

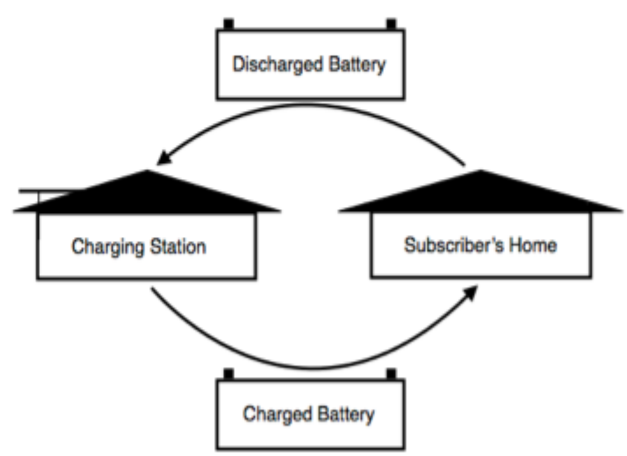

Figure 2. Lifecycle of Distributed Micro-grid.

the their cost to maintain the power system. In many ways this is similar to electrical power distribution in the developing world. Expensive and difficult to maintain power plants provide power to consumers who pay a monthly charge and are protected from unexpected system failures and costs.

DESCRIPTION OF SYSTEM

The distributed micro-grid obtains its energy from a photovoltaic panels conversion of sunlight into electricity. A charge controller regulates the voltage outputted from the panel that ensures that it is acceptable to charge a 12 V lead acid battery. Once the battery is charged the subscriber brings the battery home to power a linear fluorescent light. When the battery becomes depleted of its charge the subscriber returns to the charging station to recharge their battery. The components of the lighting system are condensed and simplified as illustrated in Figure 3.

The solar panels in the system are 80 W to 120 W polycrystalline panels. The panels are mounted on the roof of the charging station with steel supports. To maximize the security of the panels, the charging stations are centrally located in the village. They are fixed angle panels. The angle of the panel is chosen to maximize the average year round sun. There is no manufacturer of solar panels based in Mali, however the panels are locally assembled. Since the beginning of the program the price per watt of solar panels has steadily dropped with locally supplied panels now costing approximately $200 USD.

The system uses automotive lead acid batteries to store and transport the power from the charging station to the consumer's home. The batteries are standard 12 volt car batteries that feature a 100 amp-hour rating and cost approximately $110 USD. The time required to charge the batteries, depends upon the weather and load but generally one day. Each system begins with 15 batteries with the potential to expand the system in the future. Before being put into service the exterior of the battery is painted and numbered so the technician can record the health and lifetime of the batteries. Once the batteries have lost their ability to maintain a charge they are taken to a lead acid battery recycling company in Bamako (the capital city of Mali).

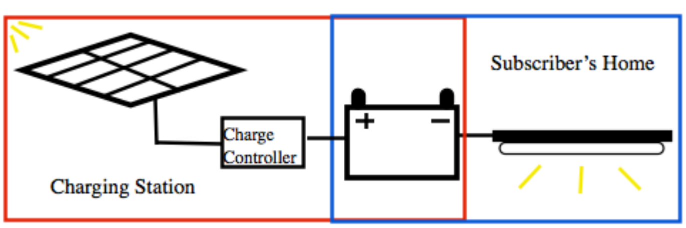

Figure 3: System Components.

A 16-amp charge controller regulates the power output from the solar panels into the batteries. The charge controller is necessary when the panels received maximum midday sun their output ranges from 16-20 volts, well above the lead acid batteries maximum charge of 14.5V. The charge controllers are purchased from a supplier in the capital city, Bamako. At a cost of approximately $100 USD.

In addition to the electrical components there are many locally manufactured components needed to complete the system. The charging station is usually a three-walled structure that with the fourth wall being a part of the operator's home. For safety and security a separate entrance is installed for the charging station. An initial interview with the technician was conducted to determine a location that best suited his family and provided optimal sunlight during the day. Local materials and labor were used to construct the charging station with the construction being overseen by the operator. The total construction cost of each station was negotiated in each village and ranged from $40-60 USD. Once the local artisans completed the physical structure the electronics were installed for the power system.

ECONOMICS OF SYSTEM

The total price of each system is approximately $2600 USD which includes all the hardware and local labor costs while also assuming a discount rate of zero (Table 3). The photovoltaic power systems are designed to be modular and thus expandable. The initial pilot village started with only one solar panel and 15 batteries. As demand grew for the batteries and lights the system was expanded to meet demand. Today the system consists of 4 panels and 60 batteries. The cost of the batteries is the largest portion of the system with 66% of the total cost going toward the purchase of 15 batteries. Based on current experience battery lifetime in the hot and humid environment of the village was estimated to be 2.5 years. Due to this turnover the system needs to generate an annual income of $350 USD to cover the cost of new batteries and lights. Currently the system's price structure covers approximately 70% of the systems costs with the remainder being paid by outside funds.

The NGO absorbs all the financial risk involving the initial costs of the lighting system, the risk is mitigated though through each subscriber paying monthly rent and per charge

Hardware	**Quantity**	**Unit Cost (USD)**	**Cost (USD)**
Solar Panel	2	$200	$400
Charge Controller	2	$100	$200
Lead Acid Batteries	15	$110	$1650
Lights	20	$12	$240
Building	1	$40-$60	$40-60
Miscellaneous	1	$50	$50
Total			**$2600**

Table 3. Pricing of Lighting System Components.

fees. The charging fee is accessed every time the battery is brought to the station for a charge, if though the battery needs more than two charges per month, with normal use, the charging fee is waived. The per charge fees are used to pay the operator with the monthly fees is saved in the local bank. The operators from surrounding villages take their collected fees to the bank branch in the village.

Prior to the introduction of the system a family group routinely spent 20-40% of their income on disposable batteries and kerosene. The system's effect on the energy portfolio of the pilot village has reduced kerosene consumption by half [32]. These results confirm those of an early study conducted in a newly electrified village in South Africa which found that as a village gradually became electrified the purchase of disposable batteries and kerosene for light declines [33]. The cost to rent a battery and light from the system is approximately $4.50 USD per month if they user has their battery charged every week. The reduction of income expenditures frees up funds for other purposes.

The popularity of the system can been seen through the waiting lists of more than seventy-five families that have been developed in the villages. In addition the operators are free to utilize their solar power systems however they chose as long and have found additional sources of incomes with their systems charging mobile phones, motorcycle, and logging truck batteries costing $0.50, $1.00, and $2.00 USD respectively. From this operator income is approximately $50 USD a month. The country manager is paid $100 USD per month from outside funds.

IMPROVEMENTS AND LESSONS LEARNED

Three years following implementation, costs are expected with all the initial cost and approximately 30% of the continuing being provided by outside funding. Both fluorescent lights and batteries last on average 31 months. The solar panels and other components have not yet failed. Recently, the type of battery used within the system switched from a vented to a sealed battery. The change in battery type was the result of a higher than average failure rate that was observed over a period of a few years in the villages. The first generation batteries featured vent holes that allowed the batteries to release pressure when the environment temperature increased beyond a certain point, these holes though allowed the acid mixture to leak out of the battery if it were to lie on its side. The results from this not only reduced the battery's lifetime but also posed a safety risk to the users due to their exposure to the acid solution. Another benefit to the new generation of sealed batteries was that they arrived pre-filled with an acid water solution unlike the vented batteries, which arrived dry and needed to be filled with a mixture of acid and distilled water. Also the new sealed batteries eliminate the maintenance of the acid level in the batteries once the first generation of batteries is fully phased out it is hoped that these new batteries will last 4-5 years.

The current system's success in part comes from the failure of technologies that have been implemented in the past. One piece of equipment that was designed, implemented, and discontinued was a low voltage disconnect (LVD). An LVD would extend the lifetime of the battery by cutting off the power outputted when the voltage dropped below a certain level. The device also featured LED lights that would indicate how much charge was left in the battery. The villagers discovered that the removal of the LVD improved the short-term life of the battery and the subsequently removed the devices from the batteries in the system. We are searching for ways to implement the LVD's consistent with consumer behavior.

We are working to implement new technologies that will improve the system. Currently work is being completed on a charge controller that would be half the cost of current commercial models and also record the charge data of the battery. The result from which better data can be captured in order to better understand the variables that effect system performance.

CONCLUSION

A lighting system was developed to meet the need of rural off-grid villages located in Mali. This work is part of a larger 10 year longitudinal study founded on rural village energy use. Preliminary results of the study were used to determine the design constraints and concerns to be used in the design of a lighting system. From the study it could be determined how much energy and income the village put toward lighting solutions. Future work includes understanding the impact of lighting on village life and energy use and developing other energy appliances (e.g., an electric wood cookstove). Currently there is a high demand to expand the system in each village as well as demand for the lighting system to other villages in the area. We hope to address these needs by finding a NGO willing to use our current lighting system design as a pattern for lighting village programs.

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