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Community-based Solar Power Revenue Alternative to Improve Sustainability of a Rural Wireless Mesh Network

C. Rey-Moreno, Z. Roro, W. D. Tucker and M. J. Siya

Abstract
Given needs for a clean and easy way to maintain and secure powering rural wireless networks and to generate revenue to guarantee the sustainability of its intended goals, an approach to leverage solar power to address both needs simultaneously is presented herein. Results comprise empowered locals trained to ensure local maintenance and appropriation; local usage and maintenance data; and a costing of the solution and its maintenance after a year of operation. It is shown that the solution presented can be locally maintained and provide additional revenue for a rural wireless network to continue providing intended communication goals.

Categories and subject descriptors
K.4.4 **[Electronic Commerce]:** Payment schemes; K.4.2 **[Social Issues]:** Employment; K.6.2 **[Installation Management]:**
Performance and usage measurement.

General terms
Add General Terms

Keywords: Maintenance, solar, alternative energy.

1 Introduction

Interest is growing in how communication networks can improve the livelihoods of those living in deprived rural areas. Reliable electrical power is a precondition for the smooth operation and satisfactory user experience of communication networks. In rural developing areas, the electrical grid is not always available; and where it is available, it is unaffordable to many and often unreliable, which may cause hardware errors and system software corruption [6, 3, 7]. Therefore, the use of alternative sources of energy has been widely proposed. Many propose a combination of one or more solar panels and batteries, as the main load to be powered for rural networks usually comprises low-cost wireless routers with steady low consumption. However, localized solar solutions are considered expensive. In order to reduce the cost of energy infrastructure, much work with rural communication networks has studied and proposed methods to reduce overall consumption of the network and thereby reduce the cost of the powering the infrastructure [6, 4]. Although the contribution of the aforementioned research outputs cannot be ignored, the increased complexity to implement and maintain such solutions cannot be overlooked either. In rural areas of developing countries, where the technical capacity of local technicians has been reported to be low [6, 3, 7, 1], designing systems in a way that is easily maintainable by local technicians follows good practice that can reduce costs associated with the need of more highly trained people to solve a problem, and also improve the resolution capacity of local staff so they can come to maintain the network independently in the long run and increase the operational sustainability of the network. Even if solar solutions are easy to maintain, several sources have reported theft of solar panels and/or batteries when used to power isolated relay stations and even clients [3, 2].

This paper introduces an approach to power rural communication networks with solar energy with an emphasis to generate local income, ease installation and maintenance, and to secure the solution. The approach is intended for low-income households in rural areas and allows the connection of additional devices to guarantee local appropriation and care of the installation while at the same time contributing to the financial sustainability of the communications network, described in detail in [5]. This paper discusses the installation, use, and maintenance of the solar solution, and shows the costs associated after a year of deployment in the field. During this time, local staff have become capable of maintaining the network and users have shown that revenue can be generated from the solar solution, in addition to any communication services that it can power.

2 Background

The initiative takes place in a rural community in the Eastern Cape province of South Africa. Approximately 580 families, comprising up to five adults and seven children, live in homesteads in 12 villages spread across 30km2. Households, typically spend R500-1400 a month on food, with incomes from government grants and family members who temporarily migrate for work. Local government is formed by a Tribal Authority (TA), which in Mankosi consists of the headman, and sub-headman and messengers from each village [2]. Access to electricity in the community is quite scarce, and the service suffers from frequent and prolonged blackouts. Some houses own gas refrigerators and freezers. Some also have radio and TV powered by lead-acid batteries or generators. Some may own a small solar panel, to charge mobile phones and provide some light, which are taken out every morning and left leaning against a wall, and then taken in at night to prevent theft. The use of a solar regulator to control the battery level is often nonexistent [2], which explains the short lifespan of batteries reported by community members. Nonetheless, in most of the houses, lighting comes from candles and/or paraffin (kerosene) lamps.

According to a survey carried out by the authors, the reported personal ownership of mobile phones by community members 15 or older is 60% and they spend an average of R20 ($2) monthly on airtime. The aim of our project is to study the feasibility and impact of low-cost alternative communications (based on voice over IP) for the community to reduce these expenses and allow some of the money to be used for locally-decided initiatives. To do so, a wireless mesh network consisting of 10 public phones was installed in private homesteads in 2012 [5]. The electrical infrastructure described herein has been operational since then.

The design of this infrastructure is informed by past experiences in the area [2, 9], however, Tucker et al. only powered low-end WiFi routers. Bidwell et al. presented a mobile solar charging station within a study of the practices around charging mobile phones. Its design aimed at ensuring that "people could protect stations from criminal intent and the elements". It consists of a solar system mounted on a wheeled trolley that allows the solar panels to be fitted in different positions, i.e. to fit through a rondavel doorway and to get maximum sun exposure when outside. Two 'solar trolleys' were installed and have been in operation since 2010. More than 700 people have paid R3 to charge a phone, where the cost to do so in other local businesses is R5.

3 Approach

The criteria for the project were to maximize the energy generated; secure against criminal intent; ease maintenance; provide physical safety to users; and extend the lifetime of components. This section discusses each in turn.

To maximize energy generation, exposure to the sun had to be constant. We opted for a fixed unit rather than the mobile trolley for a number of reasons. The trolley system was not always outside to collect from the sun; rain and sun can alternate quite often in the same day. Furthermore, even on sunny days "the panel was often shaded in the afternoon" [2]. A trolley would also expose a wire between cart and router; exposed to children, animals and other irritants that could diminish the life of the wire and its connectors. In addition, high winds, very common in the area, destabilized a trolley and weakened the mounting. To avoid these issues, we installed a solar panel on the roof with the batteries inside. As we could not find a waterproof solution to install the panel on top of a rondavel, we used only flat houses. The solution was shown to the community by a member of a local NGO; it protects against the wind, orients the panel to the north, and provides yearlong optimal inclination.

To secure units, the installation in the roof utilized threaded rods and metal wire hooked to beams inside the house, and covered every hole with tar tape to avoid leaks. Removal is difficult and would take time and make much noise. Furthermore, among the criteria suggested for the selection of the homes some were related to enhance security: fenced premises, surrounded by neighbours, with as many people around as possible to guarantee constant human presence.

To ease maintenance, all stations were meant to be identical [6]. However, a donation of two BB12 Solar Kits means we now have two different power solutions. Eight nodes follow the design presented herein, although all nodes have fixed mounted solar panels. The rest of the system fits in a wooden box designed by a local NGO member, with handle holes to facilitate transport, a breathable battery compartment, space for logbooks and idle phone chargers, and a removable panel. The top side of the panel contains user elements, while the bottom side of the panel contains elements meant to be accessed only by maintenance staff. The user can access an analogue phone, two cigarette lighter sockets and a voltage meter (operated by a doorbell button). The sockets were included as a way to allow users to generate revenue from charging phones based on the experience from [2] to help make the communications network sustainable; and also for connecting lights to help ensure that people benefit additionally and are motivated to take care of the unit. The voltage meter is included to allow a user to easily see how much power remains. When the doorbell is pressed, colour-coded LEDs illuminate to show the amount of energy in the system, and the meter only draws power when the button is pressed. The use of a this simple meter solved the issues of local operators not knowing how to operate multi-meters [2]. A less detailed but similar interface is provided on the regulator itself. However, we wanted to avoid connections on top and left empty space there on purpose to allow people to write and leave a phone while charging to avoid damage to chargers left hanging [2]. The cigarette lighter socket contains a rim that allows, by drilling an adequate hole, a tight fit. They also contain a thread that allows tightening should they come loose as reported in [2]. The last item on top is an adjustable gland in the corner for the cabling to the solar panel and networking device, which helps avoid foreign objects entering the compartment. The bottom side of the panel contains the solar controller, a power over telephone line (POTL) adapter and all the wiring. All connections inside the box are wired independently to allow easy removal of an element, for inspection or substitution. All wires are plugged into a simple strip connector and each can be unplugged as needed.

To provide physical safety, the two 12v plugs are wired to a 10A fuse to prevent fire or even explosion that a sudden withdrawal of power could cause. To protect the entire system, an additional 20A fuse is located in between the batteries and the regulator. This stops any short circuit happening in the wire that is used to power the router, or in the cables to the solar panel. The thickness of the wires has been also chosen to allow specific amperages, while keeping power consumption to a minimum. In addition, holes at different heights were made in the faces of the battery compartment to allow air circulation and reduce the temperature.

To maximize the life of components, we use treated pine beams for the solar frame; galvanized metal parts when possible, and when not, protecting them with steel primer; and UV-protected CAT5. In addition, the boxes inside homes are varnished to protect them against humidity. Apart from using the regulator for controlling the correct charge/discharge regime, the storage system was over-dimensioned to increase batteries' lifespan. Following standard practice, and considering a total load of 14.9 Ah/day, and 4 days of autonomy, two 102Ah batteries and one 140W solar panel were installed. The BB12 referred to above generates less power from the sun and has less storage capacity. With the TA's agreement, they were enclosed in a customized wooden box that only allows powering a wireless router (and also a connected analogue phone). Power above 12V and current enough for load requirements during the worst (weather) month was required, too. Although a smaller panel could have been chosen, we choose one providing 140W, with a V^{max} value of 18V, to leverage every moment of sun appearing during cloudy periods.

4 Results and experiences

We draw on data generated using Ethnographic Action Research [8] through participant observation during training and on-going in-depth interviews carried out with the maintenance team and members of the households where the stations are installed. We also draw on data from household logbooks to register the number of phones charged. Due to local politics, phone charging revenue has only been regularly collected and registered in the last month and a half.

4.1 Capacity building and local participation

The TA agreed on the approach and appointed community members to the support team, who were provided with transportation and food. A team of 5-6 people was waiting to be picked up every morning at 7:00am (Mon-Fri) for one month, although the number varied each day depending on responsibilities, as reported in [1], too. We first built a sample solar panel frame and mounted it on the initial homestead's roof. We assumed no prior knowledge about electricity and started by providing theoretical background. It soon became apparent that some members of the team had experience with electricity via solar energy, although they lacked some crucial knowledge. For example, none of their homemade solar systems used regulators, and if a fuse blew they would simply reconnect the two sides with wire. After discussing the structure and components of the proposed solar system, we moved on to the hands-on part of the training. This part included building the boxes to hold the batteries, designing the solar panel frame for rooftop mounting, and wiring the top panel of the box. Only one sample of each of these tasks was done by a trainer, thoroughly explaining every step. Then trainees used the sample as a model to build and adapt the rest. By using this approach, we hoped to pass on the necessary skills to the local support team and encourage them to take credit for fixing the system, and be able to build one from scratch if needed without an outsider's help. The support team are the trainers of the users, who gain confidence in the support team; and the team members also learn by teaching others. The training provides in-depth details about how the system works, to troubleshoot, to change fuses and to take good care of the system. The trainers explained the concepts regarding daily usage of battery power, security and emphasized that the solar system belongs to the community. With this approach, we hoped to build the capacity of a wider cadre of users, so they can troubleshoot and fix basic problems themselves, reducing their dependency on the support team.

4.2 Local usage

Table 1 presents the results from using the electrical infrastructure[1]. Considering that R3 are paid by each, R972 was collected. It is worth noting that the TA only recently called a meeting to let people know about charging money for charging phones to guarantee the sustainability of the project. We are still in the process of relaying that message via more meetings. Previously, some charged neighbors for charging phones and claimed they used that money to buy mobile phone car chargers, although some neighbors declined to pay since they consider the system (including the chargers) an outsider intervention such that locals have no right to charge money for it. We hope that a wider, and more local, understanding will prevail. Note that phones charged by household members are not included as it was agreed they could charge their phones for free as compensation for the work and responsibility involved.

Table 1: Phones charged per household.

Household Number	1	2	3	4	5	6	7	8	9	10
Phones charged	95	16	54	19	25	33		46	36	

From interviews conducted over an entire year, households 8 and 9 reported people bringing more phones when it rains, since, although some people have their own solar for charging the phones, they are not dimensioned for so many rainy days in a row. So when that happens, they have no other option. Households 2 and 3 are in an area with more access to the grid, so logically they report a higher number of phones being charged when the grid is not functioning.

Only two households have reported plugging in anything but phone chargers, lights and a music system, respectively. The rest agree that they prefer to not plug in anything as they do not have the knowledge to do it safely. In this sense, two meetings have been held to agree on a common strategy to provide lights for each interested household. It was decided that each household pay for the materials and the labour of local people trained to do so. This installation will happen soon and be used to provide extra training to interested people, thus empowering more people.

4.3 Local maintenance

The maintenance team leader fixed stations for [2] and has been funded externally during the period under study. During training, he had already demonstrated good technical understanding, although he recognized that this project is more advanced in terms of maintenance. He has developed his own methods for troubleshooting, both remotely (using the network's phones when possible) or on site. The method consists of asking users, when a problem happens: what is working and what is not? If the router's lights are on, and the user can obtain a good voltage reading when pressing

[1] Households 7 and 10 are the ones not having the functionality to charge phones as described above

the doorbell, then the problem is quickly located in the 10A fuse. If both are off, he visits the site and first checks the 20A fuse. If it is fine, and the meter gives a reading, then he hard reboots the router. If the problem is not related to the network, people call to the phone in his house to report a problem that his sister reports to him when he arrives home in the evening. Table 2 shows the problems reported and solved thus far.

Table 2: Problems reported in the system.

Household Number	1	2	3	4	5	6	7	8	9	10
a) Water inside router		1		1						
b)"Salty" cables	1	1		1				1		
c) 10A fuse blown	3	6	2	8				3	1	
d) 20A fuse blown	1	3		3				1		
e) Router down	2	5		3			n	1		n
f) Problem in socket	1									
g) Loose cable								1		

Problems (c, d, f, g) were solved by renewing the item. For (a), the router and RJ22 were substituted (it causes c and d). For (b), new joints were protected with insulation tape (it causes c and d). When (e) is not due to (d), the problem was solved by hard rebooting the router. This requires further research, although its occurrence is rare compared to other projects, e.g. [7]. For nodes 7 and 10, where the router is powered using a BB12, this problem is very common since the BB12 turns off after two days without direct sun. It is worth noting that the router in Household 7 has been off for three months due to replacement of the roof.

Response time varies on how busy he is with another job, the size of the problem and the availability of the NGO's vehicle to travel. When the problem is small, e.g. changing a fuse, and he is "answering emails or writing reports" he goes the next day. When the problem is bigger, or he has "meetings or teaching" the next day, he can take 2 days to visit. One exceptional response time for (a) was 2 months due to unavailability of stock and issues with the postal service.

4.4 Cost

The cost for the box, frame and the electrical infrastructure per household averages to R5000. The cost of replacing the items damaged during the first year of operation adds up to only R1413. This includes R1100 for the replacement of two routers damaged by not using the right materials when substituting the antennae [5]. Since the problem was fixed, and prevented in other nodes, it is not expected to occur again. Furthermore, not a single item of the infrastructure has been stolen. According to local people, it is believed that having worked through the TA may have provided a higher degree of security. That a household is perceived to be never alone has also been mentioned as a reason. The cost of tools has not been included since they have been reused from previous projects. Transport and staff costs have been also been excluded because they are context specific.

5 Conclusion

The work presented in this paper describes an approach that integrates social, economic and technical considerations in order to power a rural wireless network that has proven to be easy and cheap to maintain after a year of operation. Powering a rural network is often taken for granted and/or addressed separately, and we have shown that network power can be a component of financial sustainability, in addition to being secure and technically supportive of rural wireless infrastructure. It is particularly challenging to weave all of these concerns into a cohesive package that locals can appropriate and come to own and support internally. Lack of external intervention is a strong indicator of local appropriation. People demanding to charge phones for free is an example of this. Although this sentiment may appear to compromise future sustainability, we believe that a sustainable solution will emerge through local appropriation and understanding. We have shown that revenue from a service other than making calls can contribute to the financial sustainability of a wireless network, since the revenues from charging phones collected regularly during the past few months are close to the cost of replacing the materials damaged during an entire year of operation. Extrapolating these results for subsequent years, providing revenue collection increases, leaves ample room for paying maintenance staff and for local transport. Further work requires moving toward internal provision of additional infrastructure. We aim to show that phone charging revenue based on solar energy can augment revenue from voice calls, local and breakout, and access to the Internet. We shall explore this combination in the future to continue to lessen the need for external intervention.

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