VILLAGE EMPOWERMENT: SUSTAINABLE SOLAR SOLUTIONS

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ABSTRACT

Since 1998 University of Massachusetts Lowell students in service-learning projects have designed and helped install 60 systems, mostly running on renewable energy, in 25 villages and towns in the Andes Mountains of Peru for medical clinics, schools, and town halls. The villages in general have no grid electricity, one pay telephone (or none) per village, no space heating, houses made of adobe, and elevations up to 3500 m (11,400 ft.). The indigenous Quechua, or Inca, people in the villages survive on subsistence agriculture. The systems utilize photovoltaic modules to power transceiver radios, lights, computers, vaccine refrigerators, and other medical equipment in clinics as well as laptop computers and lights in schools. Water supply and purification systems for whole towns have been added as well as microhydro. To help make all these systems sustainable, we return every six months to the same two networks of villages. We are also helping to start microenterprises of aquaculture and of renting solar lanterns and LED headlamps.

1. INTRODUCTION

The purpose of this paper is to discuss the results to date of designing, installing, and monitoring renewable energy systems as part of the Village Empowerment Project: how well they have worked, the impact they have had on the villages and the students and faculty, the lessons we have learned. These lessons learned may be useful to designers and installers of similar systems in remote areas of developing countries. Background of the project is presented first and then results are presented by type of system: transceiver communication, water supply and purification, lighting and personal computers, vaccine refrigeration and other medical equipment, and microenterprise: aquaculture and solar lanterns and headlamps.

The project had its beginning in the summer of 1997 when a group of undergraduates wanted to do international service work and asked the then chaplain Fr. Paul Soper. He and the students visited mountain communities in the Peruvian Andes, in the area of the city of Huarmey. Huarmey is a coastal city, on the Pan-American Highway, about 300 km north of Lima. Two rivers, the Rio Huarmey and the Rio Culebras converge on Huarmey, draining many hundreds of square miles of the Andes. Along these two river valleys are located about fifty villages. Though Huarmey has electricity, telephones, and a hospital staffed by several doctors and nurses, the mountain communities are generally without electricity or communication, and have a clinic staffed by a trained medical technician. The larger villages have schools, some up to grade 12, typically without even books and paper. Some of the villages rely on water from rivers that has to be hand-carried to houses and clinics. The original group of students approached the engineering school for collaboration. The engineering students from the U Mass Lowell solar engineering graduate program and other undergraduate programs started going down in the summer of 1998. A few years later as a result of working with Rotary International, we ventured an hour north of Huarmey to the town of Casma, which has a similar hospital and village network. We now have almost as many villages serviced in the Casma network as that of Huarmey.

The people in these networks of villages are representative of: one-fourth of the world without grid electricity (IEA, 2004), one-sixth with no access to clean water (WHO, 2004), and about one-half making less than $2 a day (World Bank, 2001) (CIA, 2004).

In the seven years of the project (which we now call Village Empowerment), we have installed over 60 systems in 25 villages and towns in two different hospital networks (Huarmey and Casma).
More than 70 students and volunteers, from U Mass Lowell as well as other universities, have participated in this project and made fourteen trips to Peru. All of these systems were designed and installed by undergraduate and graduate students and local people, assisted by faculty and experienced volunteers. Many of these systems formed service-learning projects, in which real community needs are met while academic course objectives are covered in a course (Duffy, 2000). Service-learning is an emerging pedagogy in engineering education.
Most of these systems utilize renewable energy to provide lights, transceiver radio communication, laptop computers, educational experiments/lessons, water supply, drinking water purification, and various medical needs: vaccine refrigeration, nebulizers, and sterilizers. These systems are powered by photovoltaic (PV) modules, solar thermal collectors, and microhydro generators, to provide for continued sustainability (in energy supply, economic costs, and environmental impact).
We have chosen to focus on infrastructure development for a variety of community end uses in a relatively small network of villages in order to help ensure the sustainability of these systems through returning to existing systems to keep maintaining and improving them and through expanding the types of infrastructure needs met in the same networks (health care, education, communication, energy, water, food production, housing). The sustainability of these infrastructure systems is a key goal of our project in keeping with vision of a balance between advance of technology and preservation of the natural/human environment.

2. RESULTS

The system descriptions and results are presented by general category since we have expanded into a number of types of systems. Examples are illustrated in Figures 1 to 4 below.

2.1 Communication

In these villages there are either no telephones or perhaps one pay phone for up to 500 people. We now have two radio transceiver communication networks encompassing a total of 19 clinics in small villages and two hospitals in coastal towns. We use the ham radio band (2 m wavelength) and generally 5 W handheld units (for low standby loss) with 35W amplifiers. Fifty W photovoltaic modules are used with charge controllers with low voltage disconnects. Flooded lead acid batteries made in Peru have a storage capacity of 120 to 140 Ah; they are fairly heavy duty but not specifically deep discharge. We tend to over design the storage to prevent deep discharging the batteries. Some batteries have been in service for seven years. The systems have been fairly reliable. Mechanical parts on the radios, like microphone on-off switches and posts for 12 V power supply plug, wear out from a significant amount of use. The feedback we get from the villagers and medical staff is that these radios have improved health care delivery and in fact have saved many lives. We are now working on a system with radio modems and PCs for sending files and emails among the clinics and the hospitals.

2.2 Water Supply and Disinfection

To give an idea of the impact that some of the systems have had, consider the situation in the towns of Quian and Huayash. Not only do the people in these villages have no electricity but also they had to hand carry water in buckets to their houses, which in some cases are a half mile away. Students designed and installed two different solar-powered water supply and drinking water purification systems using two different technical approaches. The one in Quian uses a spring and gravity to provide water and a UV light to purify the drinking water (Hart *et al.*, 2003); the other pumps water from a river to an elevated tank and uses sand filters to purify the drinking water. In each case, individual families on their own have connected their houses to our common water supply points. A 74-old man insisted on helping paint the water tanks in Huayash in January 2004 since he said he has water in his house for the first time in his life!

In addition, in the town of Quillapampa we installed a PV-powered pump to draw water from a well in addition to piping and a storage tank on a hill above the town. We encouraged the villagers to use the SODIS method of water purification (EAWAG, 2005), in which ordinary recycled soda bottles filled with relatively low-turbidity water can be disinfected in sunlight in about a half day. We are working on rods with TiO_2 photocatalyst to speed up the disinfection rate (see, e.g., Sunada *et al*., 2003, for background information).

We have designed and built two solar pasteurizers with flat plate collectors for village medical clinics. Getting the folks to use the disinfection systems in general is a struggle. From our own observations and those of the medical personnel, the people are not convinced they really need disinfected water. Based on our testing, none of the water in any of the villages is suitable to drink without treatment. Of the four water disinfection systems we have installed, the UV light system appears to be the most successful. We tested the water in January 2005 with a presence-absence test (Hach part 2610796) for hydrogen sulfide producing bacteria, which are considered good indicator organisms for testing, and found zero bacteria. We believe the 12,000 l bladder storage tank used in the system which prevents air from contacting the stored water is the reason no bacteria reinfect the water. In addition, the doctor at the clinic in Quian told us that he has seen fewer cases of stomach illnesses since our system has been operating. It is a batch system and water is available at key taps in town. We will keep trying to get the people in other villages to use the water purification systems.

2.3 Lighting and Personal Computers

We have installed over 20 lighting systems in clinics, schools, churches, and town halls, with roof top PV modules, and about 25 portable lanterns in clinics, recharged from the PV panels. We have found the Sollatek Lumina compact fluorescent lights the most reliable, although expensive. The sealed lead batteries in the lanterns seem to last about two to three years.

We also have about 10 laptop computers in clinics and 10 in schools along with donated software with lessons, all powered from PV modules and battery storage systems. In all the schools, the teachers are asking for more solar panels and more laptops so the students can use the PCs longer. The schools otherwise have essentially no books and hardly any paper.

2.4 Vaccine Refrigeration and Other Medical Equipment

The designs and prototypes of vaccine refrigerators, both stationary and portable, have been undergoing continuous development and improvement over the whole period of the project. We have been trying to utilize thermionic modules and phase-change material for lower cost (e.g., Trelles and Duffy, 2003). But it is hard to improve on the reliable vapor compression refrigeration approach for in-clinic use, particularly since recently two small fridges have been become available commercially, which we find through continuous field monitoring are twice as efficient as the thermionic module fridges.

We have had data loggers at three different clinics to provide feedback on how well the solar systems are doing and weather data to help design new systems for the area. The average annual horizontal global irradiation is measured by an SPLite pyranometer from Kipp and Zonen every second and averaged and stored every hour. The average daily irradiation measurements are estimated so far as: Malvas 6.0 kWh/m2/day (elev. 3100m, 9.9ºS, 77.7ºW); Raypa 4.9 kWh/m2/day (elev. 1400m, 9.6ºS, 77.9ºW); and Cochapeti 4.1 kWh/m2/day (elev. 3400m, 9.98ºS, 77.6ºW).

A solar autoclave was developed by another group of undergraduates (Fig. 4). It utilizes a locally made parabolic concentrator and a modified pressure cooker. On a sunny day, only one set up needs to be performed on the parabolic dish to direct it towards the sun, and the steam is generated at the proper pressure and temperature for the required half hour to sterilize medical instruments.

Other medical devices students have developed include an oxygen mask utilizing a recycled soda bottle and plastic bag that uses 80% less oxygen than the commercial masks available in the US. A prosthetic leg for a young girl was developed by undergraduates last year, and this year another team is producing a prosthesis for a young man and is also developing a more generic design utilizing locally available materials and manufacturing processes.

2.5 Microhydro

Students have designed four and installed three microhydro systems. In two cases there was less water available than we had estimated, and we are in the process of moving the systems to other villages. The San Miguel system is working quite well, however, with a Harris turbine-generator at 48 dc and an inverter with an output of 230 V ac 60 Hz (the standard in Peru). Twenty-five 20 W fluorescent street lights are lit by the microhydro every night from about 6 to 9 pm. There were initial problems of voltage spikes zapping the inverter after a couple of months, but a simple redesign of the circuitry solved the problem.

2.6 Microenterprise: Aquaculture and Solar Lanterns and Headlamps

All the systems discussed so far have been for the communities, not individuals. It appears, however, that to make development more sustainable in the villages businesses must also be started. We have been assisting in sustainable business development: aquaculture systems for trout and crayfish in three villages to also improve the diet. Trout are difficult to raise, and the concrete pools expensive to build high up in the mountains. Crayfish, on the other hand, are relatively hardy and require only earth-lined ponds. Two crayfish farms are producing and selling the crayfish to the local restaurant and probably eventually to the city of Huarmey below.

A second business venture involves selling or renting solar lanterns for room lighting and headlamps for reading or working. Twenty lanterns are being built in Lima with as many locally available parts as possible, based on a design by Tavaranan (2005). A PV charging station was installed in Quian as a test site for rentals. A marketing survey indicated a high degree of interest in Quian and other villages in buying or renting the lanterns and LED headlamps with rechargeable batteries, also under development.

3. IMPACTS

The Village Empowerment project has transformed the lives not only of many of the villagers but also of the students and volunteers. Some of the students have changed their life-long professional goals as a result. At the very least, they have some idea of what it is like to be very poor and to understand, and perhaps eventually alter, world events. One said he can't take a drink of water even now without thinking of the villagers. The project has helped university students learn professional skills of sustainable technology development applied to human and environmental needs while becoming citizens of the world. Medical personnel in the clinics have told us repeatedly that the radios have saved many lives. The lights, vaccine refrigerators, laptop computers, and water supply systems have helped increase productivity and have helped deliver better health care and education.

4. SUSTAINABILITY

There are several aspects of sustainability of renewable energy systems in remote areas: user training, investment by the community, maintenance, reliability, cost-effectiveness. We address these issues in the following ways. We have held workshops for the users of our systems (medical personnel, teachers, town leaders). We provide manuals on the principles of operation, use, and maintenance of the systems in Spanish. Unfortunately, there is a high turnover typically of medical personnel in the villages because the government wants to save money by not hiring "permanent" employees. We have to retrain constantly.

We try to get the users to make simple repairs in case of trouble. We also have a radio-email network of sorts over which we can feedback suggestions on how to troubleshoot and fix problems. Sometimes repairs have to wait until we visit on the next trip. But we do keep coming back. At first the villagers could not believe that we kept our word about returning. Apparently not many people do keep their word to them. Spare parts are kept in the parish house in Huarmey. On the next trip we are going to explore moving spare parts to the two base hospitals, but security of the parts is a big concern.

The people in the villages invest in the systems through the labor they provide in installing the systems, i.e., “sweat equity.” Our policy is not to do things **for** the people but **with** them.

We try to utilize reliable components in the systems. Batteries in general have lasted up to seven years, but a few have failed prematurely. Radio parts just wear out from heavy use. Three PV modules have failed, one from water leaks, and two from chemical failure of the coating on flexible polycrystalline modules. One battery charge controller failed. We had one PV array of seven modules fail because of corrosion of wire connections on the roof. We now use antioxidant grease on all our connections.

Finally, **there is a danger in the apparent popularity in students participating in service projects in developing countries involving “one-shot” designs and installations in which there is no sustained involvement for training, maintenance, and replacement.** Such systems typically fail sooner or later and can result in local people concluding that “solar does not work.” Such installations ultimately do no good for the local people nor for the long-term prospects of solar systems being accepted. The importance of continual training of local personnel, of periodic maintenance and adjustment, of learning and redesigning from operating experience cannot be overemphasized.

5. ACKNOWLEDGEMENT

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Fig. 1. PV panels going up in Quillapampa and microhydro installation

Fig. 2. Raising an antenna in Chipre and medical technician with transceiver radio, lights, lanterns.

Fig. 3. Huayash solar-pumped water system sand filters.

Fig. 4. Solar autoclave in Huamba.