Assessing the Impact of Off-grid Solar Electrification in Rural Peru: Replicability, Sustainability and Socioeconomics

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***Abstract* – In rural communities throughout the developing world, lack of access to electricity can have far-reaching impacts. Students are often unable to study after sunset for want of adequate lighting; access to technology is limited or nonexistent for lack of power to charge devices. For one off-grid community in rural Peru, this was not a satisfactory situation, and they approached Engineers Without Borders-USA (EWB-USA) to work on a solution. Ultimately, after careful assessment and an enlightening false start, the Walla Walla University chapter of EWB-USA (EWB-WWU), in partnership with the community of Japura, designed and implemented standalone solar photovoltaic systems to electrify the community. The outline of this process is discussed in this article. A monitoring trip over a year after implementation allowed insight into the project's health and sustainability and also taught the team lessons about training, communication, socioeconomic impact, and community empowerment. This assessment and the resulting lessons are the focus of this article.**

Index Terms – Sustainability, off-grid photovoltaic, solar home system, Engineers Without Borders, EWB.

INTRODUCTION

Universal access to electricity is widely considered an essential step toward alleviating poverty and achieving the UN's Sustainable Development Goals.ⁱ Unfortunately, the International Energy Agency estimates that 1.1 billion people have no access to electricity.ⁱⁱ In urban environments, traditional grid connections can help reduce that number. However, remote areas must be served by mini-grid and off-grid systems, which are quickly becoming increasingly affordable.ⁱⁱⁱ The

increasing affordability of off-grid solar photovoltaic technology helped the Walla Walla University chapter of EWB-USA (EWB-WWU) work with the remote village of Japura, Peru to bring electricity to every home.

Engineers Without Borders-USA (EWB-USA) is an organization that endeavors to satisfy basic human needs through community-driven engineering projects.^{iv} Volunteers from around the country partner with communities around the world to work on projects ranging from civil works to energy to agriculture.^v EWB-WWU, active since 2007, has worked on multiple projects in Central and South America, and has just finished the last year of a 5-year contract with the municipality of Pitumarca, Peru. This 5-year contract has covered multiple projects: a water project in Pucutuni (2013-14), a gravity-fed water system in Pantiñeque (2014-15), an energy project in Japura (2015-2017), and an energy project in Labramani (2017-18). The Japura project, which was the largest and most complex undertaking of all EWB-WWU's Peru projects, is detailed in this paper.

EWB-WWU began its Japura project after previous experience working in Andean Peru. Two gravity-fed water systems—one in Pucutuni (2013-14) and another in Pantiñeque (2014-15)—established the chapter's relationship with the regional municipality. After the successful completion of these projects, the municipality asked EWB-WWU to help electrify the remote community of Japura.

Using off-grid solar photovoltaic (PV) systems to electrify rural Peru is not an endeavor unique to EWB-WWU—thousands of off-grid systems have been installed in response to various electrification initiatives.^{vi} Other EWB chapters have also undertaken projects using similar technology. For example, an EWB team from the student chapter of University of Nebraska worked in rural Madagascar to pilot a solar lighting system in a primary school classroom. As with EWB-WWU's Japura project, EWB-NU performed an alternatives analysis to determine which technology would best serve their community. Solar power rose to the top, thanks to its “high immediate feasibility, constructability, low operating and maintenance costs, flexibility in design for demand and sustainability.”^{vii} Ultimately, after a data collection trip, design work, stateside prototyping, an implementation trip, and teacher education, “the pilot installation [was] considered successful from the implementation standpoint. Monitoring will confirm the utility and performance of the system” over time.^{viii} The article on this project in Madagascar also notes its representation of “a unique model in the dual promotion of conservation and education through humanitarian efforts,” as students involved in the project learned and practiced valuable skills.^{ix} EWB-WWU's Japura project saw similar dual impacts.

Rebecca Watts from Engineers Without Borders Australia in Melbourne, Australia details another project relying on similar technology: a solar home system (SHS) project in rural Cambodia. Just like rural Peru, rural Cambodia has limited access to grid electricity. Solar home systems were found appealing because of their increasing economic accessibility, reliability, and convenience. The project involved designing and implementing two SHS in Secret Beach to assess the technology's suitability for achieving quality-of-life and economic improvements in the community (similar outcomes to those desired in Japura). Education, monitoring, and evaluation were also critical components in the project process. Ultimately, Watts and her team concluded that SHS are “an appropriate energy solution for rural households” because they provide “affordable, reliable and clean electricity” in remote places lacking existing electricity infrastructure and suffering from “high and volatile” electricity prices.^x The success of home-scale,

off-grid solar systems in environments with circumstances similar to Japura, Peru lends credibility to EWB-WWU's decision to implement such technology in its Japura project.

Despite the virtues of the technology, a study on the sustainability of such systems in Peru found numerous factors inhibiting healthy development of off-grid photovoltaic electrification, including limited citizen involvement and awareness in environmental decision-making.^{xi} Sudden political changes in the energy sector, and general mistrust of formal institutions and government among Peruvians, were also cited as factors hindering institutional sustainability of electrification efforts and potentially causing “widespread outsourcing” of those efforts.^{xii} Broadly speaking, sustainability of off-grid PV systems has been seen to be affected by a host of other factors, including warranty enforcement, institutional corruption, regulations, scarcity of technical expertise, cost effectiveness, environmental awareness of the society, and other factors.^{xiii} Naturally, EWB-WWU had to consider and surmount many of these challenges when working to sustainably electrify Japura.

Additionally, Andean communities face special challenges distinct from those faced by other rural communities. Besides being more sensitive to the effects of climate variability and climate change, these communities also face marginalization and exclusion from decision-making processes.^{xiv} Unfortunately, “physical remoteness, together with cultural, social, political and economic marginality, often promoted by urban elites, not only results in poor access to information or financial and technical resources; it also leads to limited accessibility to the communities during emergencies caused by natural disasters.”^{xv} In other words, Andean communities are especially vulnerable to destabilization and difficulty due to a variety of factors. This makes them attractive partners for development projects, due to the potential to help counteract some of the special challenges they face.

It is worth noting that despite its widely-regarded importance in meeting development goals, electrification is not necessarily without its pitfalls. In a 2017 paper, Raul Jimenez synthesized 50 different studies evaluating the impact of improved and increased access to electricity. Overall, the synthesis tended to support theoretical assumptions that increased access to electricity leads to statistically-significant welfare gains. However, results were largely heterogeneous, with a large variation in impact across the studies considered.^{xvi} In other words, electrification does not seem to impact all communities and people in the same way. For example, a 2015 paper examines Honduras' electrical expansion from 1992 to 2005 to “estimate the impact of access to electricity on educational attainment.”^{xvii} Interestingly, the paper concludes that “access to electricity decreases educational attainment,” and that its impact “on attendance is heterogeneous across years of schooling.”^{xviii} Jimenez proposes that the heterogeneity of results from electrification may be explained by differences in the “settings and countries under study, the different empirical strategies used, the quality and availability of data, and deficiencies in the electrification programs and policies, among others.”^{xix} Whatever the cause, it is clear that electrification—especially if not implemented properly—can have a range of effects. This range of effects was observed during EWB-WWU's post-implementation survey of Japura, where some potentially negative lifestyle consequences were noted among the positive benefits of the electrification project.

Because of the potentially mixed effects of electrification, and because of EWB's focus on sustainability, EWB-WWU felt it important to do an in-depth evaluation of the project's impact in Japura. This evaluation was performed during a trip to the community in November 2018. Naturally, when reflecting on the broad impact of a project like the one EWB-WWU undertook in Japura, it is critical to consider the project's effects on diverse members of the community. In

particular, the project's impact on women should be considered. A similar solar home system (SHS) project in Rwanda was evaluated using random telephone surveys and purposive in-household surveys. The surveyor found that in in-household surveys, 45 percent of the respondents were female, compared to a mere 16 percent in the random telephone surveys. During the in-household surveys, it was much easier for the researcher to talk with women, "precisely because they are the ones more likely to be at home during the day."^{xx} Across the telephone and in-household surveys, 61 percent of men and 66 percent of women responded that women used the SHS the most.^{xxi} During our team's recent survey of Japura, we were careful to talk with both male and female community members, ensuring that we heard their different perspectives. In many cases, our findings were similar to those of the Rwanda project—women were often the ones at home, actively using the system. Their responses proved very insightful as we worked to evaluate the impact of our project.

INITIAL PROJECT ASSESSMENT

To meet Japura's request for electricity, EWB-WWU initially planned to build a micro-hydropower system. Japura is separated into two sub-communities: Japura-Suyo and Japura-Qelcca. It lies in the municipality of Pitumarca and sits between two small rivers, one to the north and one to the south. When EWB-WWU began working with Japura, the team spoke with Pitumarca's local engineer, who is very interested in hydropower and advocated it as a solution. Because of the two rivers that flow near Japura, the team agreed with the municipality engineer that hydropower was an ideal choice. On our initial assessment trip, then, we proceeded in this direction, conducting civil engineering surveys and building weirs in the local rivers to determine flow rates. After this assessment, we confirmed that the rivers could provide enough power to make a micro-hydropower project feasible. Each of the two rivers was able to serve the sub-community nearest it: the northernmost river could power Suyo and the southernmost could power Qelcca.

Although hydropower was our favored option, we considered both hydropower and solar power in our analysis of alternatives. However, three major design factors led us away from a solar design. First, we observed that Japura has occasional rainy and cloudy days, and we expected that a solar power system in Japura would need to provide at least four days of energy storage capacity in case of bad weather. Second, creating a large, centralized solar power system for an entire community would require a large array of solar panels, which would be difficult to source. Furthermore, the community was concerned that if their solar power system were centralized, some members would use more than their share of electricity. Thus, we would need smaller, individualized systems, each serving one home or small group of homes. While this would make power transmission and regulation easier, placing that many solar panels throughout the community would also take up a sizable amount of space, and these smaller solar panels could be easy to steal. Finally, we estimated that purchasing this many small systems, each capable of providing at least four days of energy storage capacity, would be prohibitively expensive. Our proposed micro-hydropower system, on the other hand, would have a smaller capacity and require transmission lines, but even including these lines it was expected to have a lower cost. From a design perspective, hydropower seemed like the obvious choice, and this is what we concluded in our official alternatives analysis.

However, our analysis was not as objective as it seemed. The municipality engineer preferred hydropower, and having this level of community and infrastructural support for a design choice gave us a preference for it as well. Although we did research both hydropower and solar power in our analysis, our minds were somewhat made up from the start, and the analysis we did on a solar-powered system merely confirmed our bias. Thus, even though the hydropower system would also be centralized, for example, we still considered it a better option than solar. After performing our alternatives analysis, albeit a somewhat incomplete one, we consulted with the leaders of Japura itself to make the final decision, who also preferred hydroelectric power for its low cost. Together with Japura, then, and at least somewhat influenced by Pitumarca's engineer, we elected micro-hydropower as our first choice for a system and solar power as our second.

With this decision in place, we began creating our detailed design. After some months of work, we conducted another trip to Japura to further discuss the project with the community. However, when we arrived, we discovered that the rivers on which we had based our system could not provide a consistent flow—during dry seasons, they often stopped flowing entirely. Our power source was unusable.

Without a reliable water source, we were forced to adopt a solar power model for our system instead. As we moved forward with a solar design, we were able to mitigate some of the problems we initially had with the technology. Our initial estimate of four days of autonomy was higher than we needed; after consulting with our mentors and creating a load estimate, we determined that two days of autonomy would be sufficient. Although the cost of these individual solar power systems was greater than that of our proposed hydropower system, they still fell within our budget, and building separate systems ensured that each family had an equal share of power.

PROJECT TECHNICAL DESIGN

Having selected solar power as the technology of choice, EWB-WWU developed a system to electrify each home in Japura. Located in the mountains of Peru, Japura receives a minimum of five hours of sun per day and experiences occasional cloudy or rainy days. Community members initially requested a system that could provide ten hours of light per day to each home. To this end, we designed an in-home system that includes a solar panel, charge controller, battery, and three LED lightbulbs (Figure 1). One of these systems was installed at each home in the community: the solar panel was pole-mounted outside the home, an electrical cabinet containing the battery and charge controller sits inside the home, and the lightbulbs were wired to the cabinet and placed where desired. The electrical cabinet also includes breakers and fuses to ensure that safe amounts of power are used at all times. In total, seventy-six of these systems were installed in Japura-Suyo and Japura-Qelcca.

FIGURE 1

TECHNICAL DRAWING OF WWU-DESIGNED SOLAR ELECTRIC SYSTEM

Each system's solar panel points toward the equator at a 13° angle to maximize the amount of sunlight it can receive in a day. Our battery is sized to provide two days of autonomy at a 60% depth of discharge: it can provide enough power for two days between charges, and it is never discharged below 60% of its capacity. This allows us to compensate for the cloudy and rainy days Japura receives while keeping our battery small and maximizing its lifetime.

As we were designing this system, the community also expressed interest in using small appliances such as phone chargers, radios, power tools, and small televisions. Since Japura's initial

request was for lighting alone, EWB-WWU based our load estimates mainly on the amount of energy needed to provide light. However, while our system does not meet all of Japura's desires, it includes enough surplus energy to power some appliances. To make this extra energy accessible, the electrical cabinets were fitted with one DC and one AC outlet. The DC outlet is powered directly from the battery just as the lightbulbs are; the AC outlet is powered from an inverter that also sits inside the cabinet. Since the inverter draws an idle current from the battery, a switch is also installed on the cabinet to turn the inverter off when not in use. With these two outlets, the system is able to power phone chargers, radios, and other small appliances while still providing ten hours of light. However, it does not have enough surplus energy to power heaters, tools, or large televisions. Using power-hungry appliances like that naturally decreases the amount of time light can be used.

SYSTEM SOURCING AS A MODEL FOR REPLICABILITY

An important aspect of sustainable development is the local sourcing of project materials. However, for off-grid solar electrification in Japura, this meant more than simply purchasing parts made in Peru. All parts for a recently completed water project in Japura had been sourced locally or regionally (within southern Peru). In addition, we provided thorough training in operation and maintenance. Yet, during the year following implementation, the community did not make simple repairs to maintain system functionality. Through conversation with community members, we learned that the community did not feel empowered to find and purchase replacement parts.

Taking the lessons learned from our community water project, we took a much more intentional approach to connecting community leaders with vendors and repair technicians for their off-grid solar electrification project. As the project implementation phase approached, we invited community leaders to travel with us as we visited vendors, met potential installation technicians, and discussed the pros and cons of each product, vendor, and technician. This approach provided a number of benefits. First, it enabled the community to play a real-time role in exploring technology options and vetting project partners. Second, it enabled them to establish personal relationships with suppliers and repair technicians. Third, they developed a first-hand knowledge of store locations, making it much easier for them to return in the future for spare parts.

As we found additional project partners, we realized that all of the necessary technology, assembly personnel, and installation technicians were regionally available. We added value as a project partner simply by helping Japura to establish relationships with all of the necessary project partners. This, in turn, greatly reduced the communities' reliance on us for technical assistance.

Our work in Japura has changed our paradigm about our role as project partners. While we will continue to have engineering domain expertise to offer, our most important contribution may be to establish a supporting network of local partners to assist the community with each phase of a project's life cycle.

PROJECT IMPLEMENTATION

Previous trips to Peru, as well as extensive stateside design and coordination work, left the team with a set of systems ready to be installed in Japura. During an implementation trip in March 2017, members of WWU's team worked with local labor to install the galvanized steel mounting poles

next to each of the 76 homes in Japura (see Figure 2 below). A local contractor took care of installing the rest of the system components after the WWU team left.

FIGURE 2
DRAWING SHOWING APPROPRIATE INSTALLATION OF MOUNTING POLES

The installation of the poles was accompanied by a focus on training and education. Community members were given a manual along with each system, which instructed them about how to operate the systems on a basic level and remain safe. The team didn't have any significant safety concerns about the system or its battery, but the community was trained to avoid connecting any third-party batteries to the panels. They were also taught that the batteries would eventually need replacement as their storage capacity diminished, and they were expected to work with the source company to perform battery replacements when necessary. We did not specifically outline a battery disposal or recycling plan since it was assumed that the source company would take care of this when necessary. In hindsight, we should have been more explicit about enunciating this part of the plan to all parties involved and in ensuring that the source company had appropriate battery disposal procedures in place.

For issues beyond basic operation, both Japura-Suyo and Japura-Qelcca also formed their own electrical committees. These committees were made up of community members specially selected to be responsible for basic system maintenance, further education of the other community members, and long-term life planning for the systems. During the implementation trip, members from WWU's team worked with the members of both electrical committees, teaching them how to do maintenance and solve simple problems that may arise. Members of the electrical committee were also informed about basic safety principles, such as making sure the system was off when performing maintenance and never shorting between battery terminals. Finally, they were told who to contact in case of more complicated problems.

Ultimately, the implementation trip was about helping the community develop self-sufficiency and preparing them to care for their new systems well into the future. This emphasis was in keeping with EWB's focus on sustainability; our team wanted Japura to benefit from the system for years to come, overcoming any issues that may arise with the systems. To ensure that this goal was being met, EWB-WWU visited Japura several more times to assess the project's health.

ASSESSING PROJECT HEALTH TO UNDERSTAND SUSTAINABILITY CHALLENGES

In November of 2018, EWB-WWU took a trip to Peru to follow up with our old projects in the region and implement a new one. During this trip, one of this paper's authors focused on assessing the impact and overall health of the solar electric system in Japura. This assessment included community meetings in the sub-communities of Japura-Suyo and Japura-Qelcca (Figure 3), as well as in-person surveys with members from both sub-communities. The surveys were designed to simultaneously assess the technological and sociological success of the project. Although the survey sample size was small (N=14 participants), it included a diverse population with a wide age range from both genders and various positions within the community. Interestingly, despite the diverse population, the responses were often very similar.

FIGURE 3

AN EWB-WWU TEAM MEMBER TAKES NOTES DURING A COMMUNITY MEETING IN JAPURA

Technical Status of Systems

Without exception, all of the solar electric systems seen or heard about by the November survey team were still functioning. In general, it seemed that the panels had been kept clean by rain, and no additional maintenance had been required. These findings were in stark contrast to the findings on a previous trip in March of 2018. During the March trip, 19 out of 76 systems were found not working, with issues ranging from simple and trivial (like a broken light module or blown fuse) to more complex and significant (like faulty relays, charging issues, and rapid discharging). The community was not doing maintenance, and they had not been in touch with anyone from the source company for help (despite contact information for the relevant person emblazoned on a sticker on each system and written into the informational manuals left for the community at implementation time). After learning about the problems with the 19 systems, the EWB-WWU team got word to a technician from the source company, who fixed the issues before the one-year warranties expired. The fact that the technician was not contacted until the EWB team's visit means that the initial post-implementation education did not stick with the community. It is worth noting that this was not for want of quality educational materials. The original education plan included locally, professionally-developed reference manuals (Figure 4), which were written in Spanish (and were heavily pictorial) and reviewed by one of the solar installation technicians who helped

install the systems. The manuals were carefully adapted for the local culture and left with the community during system implementation. Extensive training was performed by members of the EWB-WWU team, and by one of the solar technicians. Even with all of the attention paid to quality education, the broken systems discovered on the March 2018 trip demonstrated that repetitive, follow-up training is required for lessons to stick.

FIGURE 4
SYSTEM MANUAL AND LAMINATED QUICK REFERENCE GUIDE

Community-Identified Issues

The most common complaint encountered in conversations with the community during the November 2018 trip was that the system batteries were depleting too quickly. Of the 14 people surveyed, 6 were having some problems related to the battery being too small for their use. As best the survey team could determine, these issues were not due to premature battery failure. Instead, it seemed that many community members were forgetting to turn off their AC inverters (which constantly drain power when running), and also stressing the system by using TVs or portable

DVD players. A couple of respondents specifically linked their troubles to cloudy weather. When encountering these issues, the team took care to educate the system users on the importance of turning off the inverter when not using it, and the importance of spending less time using high-load appliances. These issues were also addressed by Percy, a local installation technician, during the community meetings the team hosted in both sub-communities (Suyo and Qelcca).

It is important to note that the battery capacity issue is not due to a design failure. Prior to the electrical project in Japura, Dr. Julian Melgosa performed a sociological study of the community, which included gathering information in semi-structured interviews with community members. One of the topics covered was the community's anticipated use for electricity. By a wide margin, responses indicated lighting as a top priority. A fair number of respondents also highlighted potential entertainment uses (such as radio and TV), but Melgosa ultimately concluded that the community's likely electricity use would be "moderate." One respondent in Melgosa's interview mentioned that their needs might be different if they had the money for a radio or TV, but in their current situation, electricity for lighting was all they needed. As Melgosa put it, "questions regarding the intended use of electricity as well as the positive/negative aspects of power in the community showed a consistent message of frugality."^{xxii} EWB-WWU designed the systems with the knowledge that the introduction of a new technology or service would fuel increased demand for that service, above the community's initial expectations. Both the batteries and the solar panels were chosen to provide more than enough power for home lighting, even under adverse weather conditions. However, the design team intentionally avoided designing the system to fully support television use, since TV use was not identified as a priority by the community, and since the team feared that widespread TV use may introduce an unwelcome influence.

Despite the team's perception that the battery depletion issues were due to overuse (especially during cloudy-weather periods), some community members felt that the batteries' efficiencies had decreased, or that the batteries were not charging completely. This was not a concern that the EWB team was able to test or verify, but if problems persist even as power use behavior changes, follow-up testing may be in order.

System Maintenance and Management

During surveys and community meetings, it became apparent that very little (if any) maintenance had been performed on the solar electric systems. Given that the March trip revealed 19 broken systems, it was surprising to find everything working correctly despite the lack of maintenance. Perhaps the education performed in March helped people know how to take better care of their systems, even if they were not explicitly performing maintenance. Or perhaps the initial system failures were just natural outcomes of the commissioning process as faulty units surfaced. Either way, a couple of concerning sentiments surfaced as the team worked to determine whether community members would be capable of fixing the systems should something need repair. One woman explained that she did not want to try cleaning her system's panel, for fear of messing something up. The president of Japura-Suyo explained that people had forgotten what they were taught in the info sessions. (At this point, the community had been trained at the project's implementation, and again during a follow-up visit roughly 9 months later in March of 2018. This meeting was their third information/training session.)

Clearly, repetition and restatement are critical components of a successful education plan, which reinforces EWB's model of long-term commitments to communities. Without external

follow-up, it is likely that important lessons about maintenance would never have been learned. Similarly, many community members expressed that they were unaware that they needed to be saving to replace their systems' batteries, despite having been told during previous training. After being reminded, they promised they would begin to save now that they knew they had to. Once again, it was apparent that restatement and reminders are critical to project success. In general, it seemed that the project was serving the community well largely because nothing new had broken yet; it did not seem that they were prepared (financially or technically) to solve new problems should they occur. However, many people did seem to have a pretty good idea about who they should talk to in the event that something went wrong. The people who did not (despite contact information for the relevant contact person being printed in the system maintenance guides) were reminded about who to contact, so hopefully any future problems will find their way to people who can solve them.

ASSESSING PROJECT IMPACT ON SOCIOECONOMIC FACTORS

Educational Impact of the Project

When Japura initially requested electric lighting in their community, one of the primary stated reasons was to allow their children to study after dark (which was difficult, expensive and often unfeasible by candlelight or kerosene-lamp-light). Given that increased studying was a desired outcome of the project from its inception, our survey interviews included questions focused on determining whether students were studying more after dark than before, and whether our electric lighting had enabled this development.

In both communities, most respondents with children of the appropriate age indicated that their children now studied after sunset, for between 30 minutes and 3 hours. Interestingly, we learned that it is fairly common for children to spend the week living and studying in the larger city of Pitumarca, only returning to Japura for the weekend. In at least one of these cases, the lighting was still helpful for academic purposes, because it allowed the children to study on weekend evenings. It also seemed that the lighting was helpful even for families without children. One elderly woman surveyed explained that children from the neighborhood (it was unclear whether they were grandchildren or just neighbors) would come over to her home to study for a couple of hours in the evening.

Our survey did not determine whether students were actually studying more than before, or whether they had just shifted their studies later into the evening. However, every person asked said that the evening studying had improved their children's academic performance.

Economic Impact of the Project

Another key goal of the project was to bolster the community's economic well-being. Rainbow Mountain was becoming an increasingly-popular tourist destination as the electric project was being designed, and at that time, the road to Rainbow Mountain ran right through Japura. Community members were hoping to capitalize on the higher traffic to sell their handicrafts and offer guide services. Someone even opened a restaurant to serve tourists on their way to hike the famous mountain. Our team and the community at large were both hoping that the electricity

project would help Japura respond to the influx of tourists by giving them the ability to make more wares to sell and to run appliances at the restaurant.

On the November 2018 trip to the community, our team learned that a new road has been constructed that bypasses Japura and offers a shorter route from Cusco to Rainbow Mountain. Now there is very minimal tourism traffic through the community. Unfortunately, this means that any economic growth expectations at the implementation of the project have been tempered by changing circumstances outside of the community's control. The electric lighting does still allow for more evening work, however. And without the need to continually buy candles, kerosene and batteries, the community is saving some money there (although this is probably offset by the need to save for system maintenance).

When asked directly about whether having lighting has improved their economic situation, survey respondents shared a variety of positive and neutral perspectives. Several explained that they are able to produce more weaving or other handicraft goods in the evening now that they have lighting. Whereas many would previously cease work at sunset, having a reliable and usable lighting source has expanded the timeframe in which they can work. It has also allowed more people to get involved in the process. One woman mentioned that she used to use a flashlight to make her handicrafts. With the introduction of the solar electric system, her whole family can help her make crafts now that the whole house is well-lit. The president of Japura-Suyo mentioned that the enhanced lighting helps them control dust from the weaving, since they can now see the dust better. Other respondents mentioned the savings from not having to buy candles. Still other respondents said that little to nothing had changed in their economic situation.

Lifestyle Impact of the Project

In certain cases, the lifestyle impact of the project is closely related to its economic impact. As community members take advantage of the lighting to work during the evening, they are now staying up later than before, and getting less sleep. The majority of people asked sleep less than they used to, often waking up early like they always have but going to bed 2 or 3 hours later. Sometimes respondents answered in a way that seemed to refer just to their personal sleep schedules; other times they addressed the sleep schedule of their whole family. From the latter cases, it appears that whole families are often sleeping less than before.

It is difficult to say whether the responses to the survey team's question about sleep were reflections of reality or were reflections of what the community thought the team wanted to hear (although this is true about the responses to any of the survey questions). Perhaps the community thought longer work hours and increased productivity would be welcome results to the surveyors. Alternatively, although this seems unlikely, perhaps the community truly did need less sleep. A more focused, in-depth survey would be required to determine the short- and long-term effects of this reduced sleep, but it is unlikely to be beneficial to the community. Whatever the case, the influx of a new technology does present the community with the need to exercise self-discipline in a new area.

Electricity has affected lifestyles within Japura in ways beyond merely providing light to work or study: the presence of electricity has allowed for the influx of televisions and portable DVD players. This has changed the way that recreational time is spent and has increased power demand on the solar electric systems. The changing use of recreational time has also changed family relations.

12 out of the 14 people surveyed had either a TV, a portable DVD player, or laptop on which they watched movies and/or other programming. When asked about how this has changed family relations, respondents were quick to identify positive impacts, but some negative impacts were teased out indirectly. On the positive side, people said they appreciated being able to learn cultural and spiritual things from the programming they watched. One family mentioned that kids having the opportunity to watch Spanish-language programming has helped them learn Spanish (in a region where Quechua is the primary language). Multiple respondents said that the technology has brought their family together, provided a communal activity to share, and/or improved communication. There were also a couple of people who mentioned the significance of having a visual form of entertainment, but what they specifically appreciated about it was difficult to understand across language and cultural boundaries.

Although Japura's residents had plenty of good to say about the presence of visual media in their lives, some downsides also became apparent. One person from the community mentioned that their system's battery was sometimes drained in the evening, because children would come home from school and watch television in the afternoon. Naturally, this defeats the purpose of the system in a significant way: not only are those children not studying or working in the afternoon, they are also depleting the battery and making it more difficult to have lighting to study or work after dark. Although no one specifically mentioned that their children were studying less thanks to television, battery depletion was a widespread problem.

During the early stages of the Japura project, one of the desired benefits of electrification was community retention. Apparently, it is common for younger people to leave Japura to study or work in a larger city. Community members hoped that having electricity would encourage young people to stay (or stay longer) in Japura, and perhaps even entice some who had left for the city to return. Assessing whether electricity has had any effect on community retention is difficult, but the survey team did ask members of Qelcca and Suyo whether people had returned to the community since electrification, or stayed when they might have otherwise left. In Qelcca, the general consensus was that the community's size had remained the same; no one had come or left since the implementation of the system (although one respondent defied the trend by proposing that power in the community was keeping children around longer). In Suyo, the consensus was more in line with some people having returned since electrification. One prominent community member estimated that 4 or 5 youth had returned to the community thanks to the presence of electricity. Whether the return of these youth was tied to electrification or merely coincidental is impossible to say without further study. There are other factors that could affect young people's interest in residing in Japura, such as the changing flow of tourists through the valley. But while it is not feasible to prove that the implementation of solar home systems is directly responsible for a change in resident population, it is fair to say that the electricity is contributing to making Japura a more inviting place to stay, with better opportunities and infrastructure.

CONCLUSIONS

Bringing power to Japura in the form of off-grid solar home systems was an undertaking larger than EWB-WWU had ever tackled before. Successfully implementing the project required innovations to the traditional EWB supply chain model, careful strategic partnerships, and repeated education endeavors. Hard lessons were learned about the importance of communication and

honest assessment when the initial plan for a micro-hydro system was proven infeasible. Important insights into constructability and maintenance were gleaned as the solar systems were installed and began to suffer problems. Overall, the lessons learned can be summarized into a few key categories.

Training and Education

In keeping with EWB's focus on sustainability, EWB-WWU undertook the Japura project with the understanding that training and education would be pivotal to the long-term success of the project. As detailed earlier in this paper, care was taken to create high-quality user's manuals for the systems, and to accompany those manuals with in-person instruction. However, as the team learned on subsequent visits, one round of training accompanied with high-quality manuals is not enough. Repetition is a major part of learning, and so is experience. During the first training session, people had not yet had a chance to use their systems, so there were no experiential hooks for them to hang the lessons on. They did not have the necessary background to fully appreciate the training. And even if they had, it is likely that one session would still not have been enough. Particularly in a community where written and visual materials are less widely used than in many North American communities, leaving behind manuals and quick reference guides was not effective in reminding residents what they needed to know.

The takeaway from the team's experience with training and education is not that carefully-crafted manuals or thorough in-person instruction is not helpful or worthwhile; rather, the takeaway is that it is not enough. Our experience showed that even with careful planning and execution, follow-up and repetition is critical.

Communication

It is impossible to adequately stress the importance of clear, prompt, and thorough communication. Initially, EWB-WWU planned to address Japura's energy needs using a micro-hydropower system. However, it was not until late in the project's design that the team learned Japura's rivers were an unreliable source of power. This forced the team to scrap months of work and regroup to create a solar power system instead. While redesigning the system, the team also took time to reflect on the mistakes made in communicating with Japura. From this, EWB-WWU learned that it is crucial to begin building rapport and fostering dialogue as soon as a partnership is created, and it is equally crucial to maintain this line of communication throughout the project. Each party must have space to ask as many questions as needed, and each must take time to fully understand the other's point of view; designing without a complete understanding of a community's setting and goals creates a risk of redesigning later in the project. By the end of the year, the team had collected these lessons into a document to be passed down to future generations of the chapter. Although EWB-WWU's attempt at a micro-hydropower project was not a success, the conversations that took place during its course provided the team with a more solid relational foundation and a broader array of knowledge to carry into the new solar project.

Especially when working with large teams or across international barriers, it can be difficult to ensure that all stakeholders are in agreement about what a project should accomplish. Based on the stated needs of the community, and because of the potentially unwelcome influence that the team feared may accompany too much electrification, EWB-WWU carefully designed the solar power systems in Japura to provide enough energy for lighting and small appliances but not for extended use of TVs or DVD players. However, as the project progressed, Japura expressed more

of a desire to power larger appliances. Since the systems have been implemented, they have often been used to play movies and television, leaving less energy to provide light. This experience illustrated to our team the importance of defining scope and managing expectations, another lesson included in the team's end-of-year reflection. Once all parties thoroughly understand the community's needs, it is important to decide what capabilities are essential for the system to provide and to communicate this clearly between everyone involved. Once the system is implemented, it can also be helpful to reiterate what it can and cannot do during training sessions. This can help ensure that no one expects something from the system that it cannot provide.

Even with the best communication practices, however, it can still take time to reach a full understanding. Clear communication can most easily—and perhaps only—be achieved between partners that have established a channel of rapport and trust with each other, and such a channel cannot be built instantaneously. It is possible that, even under the most ideal circumstances, EWB-WWU and Japura would still have encountered the same misunderstandings before coming to a solution. Such misunderstandings, then, are not always mistakes; rather, they can be necessary steps toward creating a working partnership. With this in mind, EWB-WWU has learned that, above all, it is important to be flexible when making plans. Clarifications and redesigns may in fact be an integral part of the process of collaboration, and a well-prepared team will plan its timelines accordingly.

Impact of Electrification

Assessing the long-term health and efficacy of any project's physical systems is a valuable and critically important technical task. But when the goal is helping and empowering a community, it is not enough to know if technical systems are working as designed—it is also vital to understand the impact that the systems (and the technology they deliver) have had on socioeconomic factors within a community. This is why EWB-WWU took special care to assess the socioeconomic impacts of electrification in Japura, as detailed in the “Assessing Project Impact on Socioeconomic Factors” section of this paper. Assessment (and background research as outlined in this paper's introduction) demonstrate that electrification is a powerful tool that is not without its pitfalls. While Japura seems to have largely benefitted from the electricity they desired, EWB-WWU was able to learn about some potentially negative side effects and reflect on how these side effects may be mitigated in future projects.

Empowering the Local Community

In the world of international development, there is lots of talk about the importance of local sourcing. And while it is important to source goods locally to avoid disrupting or injuring the local economy and local businesses, that is only part of the picture. EWB-WWU's goal is not to merely bankroll a one-time purchase of equipment from a local craftsman; nor is it to simply provide skilled oversight for construction projects, or solid engineering work for system design. Ultimately, the ideal is empowering communities with the necessary logistical framework, connections, knowledge and confidence to maintain, expand and replicate any projects we work on together. This empowerment inherently improves the sustainability of the project, while leaving the community better off on multiple fronts.

Achieving this ideal of multifaceted empowerment is no easy task, and it would be unrealistic to claim that EWB-WWU was completely successful in doing so with its work in Japura. However, in adopting a somewhat unusual approach to system and labor sourcing (as detailed in the “System

Sourcing as a Model for Replicability” section), the team was able to develop an understanding of practices that can aid in community empowerment. These practices focus on connecting community leaders with vendors and technicians and educating them on the design and maintenance considerations involved in the project’s systems. By continuing to refine and apply these community-centric empowerment practices, EWB-WWU hopes to make even broader, healthier and more sustainable impacts on future projects.

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