Investigating Solar Street Lights in Mandi and Kamand

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Abstract

Solar street lights are installed throughout Himachal Pradesh, India to promote small-scale solar, but many are broken. We disassembled lights and conducted interviews with residents and experts to understand the relevant factors, finding that the street light program suffers from inadequate maintenance and that solar is often not the best lighting choice. Finally, we piloted a training program for residents to perform light diagnosis and developed an appropriate technology rubric for selecting evening lighting solutions for Mandi's slums.

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Authorship

Nicolas Adami-Sampson contributed to the writing and editing of each section of the report and took photographs of the interviews, observations, and progress of the project. He conducted data analysis, created the design of the poster, and contributed to the Educational Guide. He assisted in the disassembly of broken solar street lights.

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Deepika Chaudhry conducted and translated interviews and constructed recommendations. She assisted in the disassembly of broken solar street lights and contributed to the Educational Guide.

Kisna Mahajan conducted and translated interviews, documented and analyzed results, and constructed recommendations. He also assisted in the disassembly of broken solar street lights.

Benjamin McMorran contributed to the writing and editing for each section of the report and took photographs of the interviews, observations, and progress of the project. He conducted data analysis, provided input for the design of the poster, and contributed to the Educational Guide. He also assisted in the disassembly of broken solar street lights.

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Project Report

The cloudy state of small-scale solar in Himachal Pradesh

Solar powered street lights have been installed throughout Himachal Pradesh by the Himachal Pradesh Energy Development Agency (HIMURJA). Installations range from small-scale village settings to urbanized centers such as the town of Mandi. These lights are useful since they operate even if the local grid is down, can be installed in remote areas, and promote energy resilience within a community. However, as seen in Figure 1, many solar lights have been in disrepair for years. This may contribute to lowered community appreciation of solar technology. Understanding how they are maintained, why these lights fail, and how residents perceive their usefulness is key for assessing the benefits communities receive from solar street lights and possibly for the future adoption of small-scale solar in the region.

Figure 1. A broken solar street light with a missing battery

The state of Himachal Pradesh wants to increase the use of solar power, but adoption has been slow. While there are a few communities that do not have adequate electricity, 99.7% of villages in Himachal Pradesh are connected to the power grid (Central Electricity Authority, 2015B). Over 75% of this power is derived from hydroelectric sources (Central Electricity Authority, 2015A). While the abundance and renewable nature of hydroelectric power make it an attractive option, infrastructure development has resulted in community displacement, environmental damage, frequent blasting, and geographically consolidated power generation (Times of India, 2013; Thukur, 2015).

Recognizing these vulnerabilities, Himachal Pradesh has developed a solar power policy to diversify its energy supply. Solar panels do not have the geographic restrictions associated with hydroelectric power generation, and can be used anywhere with ample sunlight. Even at a small scale, solar systems can bolster energy resilience within communities and reduce dependence on any one source. Small-scale systems like street lights provide potential for building capacity within the community for maintenance and repair, reducing reliance on external and often unreliable government services. Communities and government both play a role in the development of small-scale solar systems. Our research focused on understanding the social and technical factors necessary to improve and support these systems.

Solar systems in India: history and progress

Solar electric systems can generate power either indirectly with concentrated solar power (CSP) systems, which use the sun to generate heat and drive a turbine, or directly with photovoltaic (PV) systems, which use the physical properties of semiconductors to directly create a voltage (see Figures 2 and 3) (Singh, 2013). The lack of moving parts, rugged design, long effective life, and modular nature of PV give these systems low maintenance costs and high reliability, making solar ideal for off-grid applications. Solar has also found uses on the electric grid. Grid-connected systems are becoming more feasible as the production cost of PV panels drops, but solar power is still typically more expensive than electricity from conventional sources. The energy

Figure 2. Parabolic mirrors focus the sun at a 50 MW CSP installation in Rajasthan, India (Pearson, 2013)

Figure 3. A 4 MW PV installation in Tamil Nadu, India (Vinaykumar8687, 2014) (Wikimedia Commons)

conversion efficiency of solar cells is typically around 14 - 19%, while large hydropower installations like those in Himachal Pradesh can be as efficient as 90% (Razykov et al., 2011; U.S. Department of Interior, 2005). Nonetheless, there is rapid growth of 30 to 40% annually in the global PV industry (Razykov et al., 2011).

For India as a whole, the benefits of solar power outweigh the drawbacks. In 2010, the national government announced the Jawaharlal Nehru National Solar Mission, a plan to grow India's solar power output from nearly non-existent to 20 gigawatts by 2022 through a combination of on and off-grid systems. The mission identifies solar as a secure, scalable, and renewable alternative for India's growing energy needs (Ministry of New and Renewable Energy, 2010). While solar is a good fit for India as a whole, the situation is less clear in the state of Himachal Pradesh due to plentiful cheap hydroelectric power (see Figure 4). However, in its 2014 solar power policy, the state recognized the environmental concerns associated with hydroelectric power, and that solar is important "to reduce the vulnerability of the system" (Government of Himachal Pradesh, 2014, p. 3). This vulnerability extends to individual communities, which should be protected from reliance on a single system.

HIMURJA supports this diversification by promoting and popularizing new and renewable sources of energy in the state. One component of the HIMURJA plan is the distribution of solar PV street light systems. As of 2014, there were 44,338 solar street lights in the state, along with 22,586 solar interior lights and 32,649 solar lanterns (Singh, 2014). Street lights are widely distributed throughout the state, including in villages, along roadways, and in concentrated installations at urban centers. The street

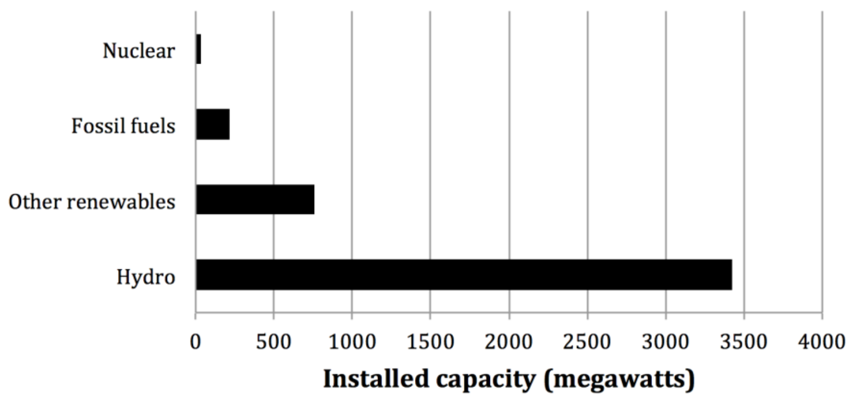

Figure 4. Installed capacity of power utilities in Himachal Pradesh (Central Electricity Authority, 2015A)

light systems can introduce communities to solar power, and are a good fit for regions that are "electrified" but have unreliable or unstable grid connections (Jain et al., 2015).

While solar street lights are widely installed, they are not well maintained. This may be due in part to a lack of planning or perception of benefits among local residents. Recent reports indicate that residents seem to lack knowledge about the full benefits of solar power, but are responsive when informed (Mercom Communications India, 2014). According to one study, the government has also not been informative about the solar subsidies available to individuals (Kumar, 2014). Another report from India found that more than 70% of residential respondents showed some favour towards solar panels with negligible opposition, but also that respondents held many misconceptions about the technology (Mercom Communications India, 2014).

With these issues in mind, community involvement and acceptance is key for successful implementation of renewable technologies. A case study with residents of a community in Germany indicated that participants were more accepting of new technology if they were actively involved in the entire implementation process in collaboration with local authorities (Zoellner, Schweizer - Ries, & Wemheuer, 2008). A lack of communication can result in reduced quality of life for residents by "undesired changes of the landscape, by noise, or by transport issues" (Zoellner et al., 2008, p. 1). While this review evaluated German respondents, many of the concerns that residents face are independent of cultural and socio-economic conditions. Without proper communication between stakeholders, Mandi and Kamand can experience the same disturbances in social norms, infrastructure, and reliability. In addition, stakeholders themselves are often capable of learning how to install and maintain solar systems, but simply lack the training to do so. Barefoot College, a training institute in India, has shown "that both illiterate and semi-literate men and women can fabricate, install, use, repair and maintain sophisticated solar units through basic knowledge share and hands-on practical training" (Barefoot College, 2015). Teaching rural residents to perform maintenance on their own better positions their respective communities for reliable, sustainable small-scale solar.

Methodology: technical analysis and interviews

Our goal for this project was to use solar street lights as a model for understanding the social and technical factors that impede continued adoption of small-scale solar technology in

Himachal Pradesh. We broke this goal down into three objectives with accompanying strategies shown in Figure 5.

Isolated solar street light systems are currently installed in many locations throughout the region, including on the Indian Institute of Technology (IIT) Mandi campus, at several temples in Mandi town, and in surrounding villages. We performed a rapid assessment of the reliability of several installations by counting and labeling the non-functional lights at night. We disassembled several non-functional campus lights and measured their technical characteristics. These systems consist of three major components: a solar PV panel, a battery, and a light fixture with enclosed charging circuitry. We measured the open circuit voltage of the panel and battery, as well as the charging voltage from the light fixture. We also checked for continuity in wires connecting circuit elements. These measurements were used to diagnose which component in the light was faulty. Voltages and continuity were measured using multimeters available on campus.

We used semi-structured interviews with residential subjects to learn about the local perception and awareness of solar street lights (see Figure 6). Interviews were conducted in the villages of Nehri, Katindi, Nisu, Dhuki, Dudar, Sandoa, Kataula, the temple at Prashar Lake, and the slums in Mandi Town with travel arranged through the IIT. Samples of convenience were used in all locations along with snowball sampling where applicable. IIT students conducted the interviews and translated the responses. Interview questions captured basic demographic information, awareness and perception of solar street light systems including their history at the site, and level of understanding of photovoltaic technology itself. With permission, smartphones were used to record audio for reference. All records were securely stored and numeric identifiers were used instead of names.

We also conducted a semi-structured interview with an expert at HIMURJA in Mandi Town about the state of solar deployment in the region, its challenges, and suggestions for improvement. This interview was designed to provide more background and context to the problems described by residents in earlier interviews.

Finally, we used the knowledge gained from light disassembly and interviews to develop educational materials suitable for training local residents how to diagnose and repair broken solar street lights on their own. We tested these educational materials in the field by returning to some of the

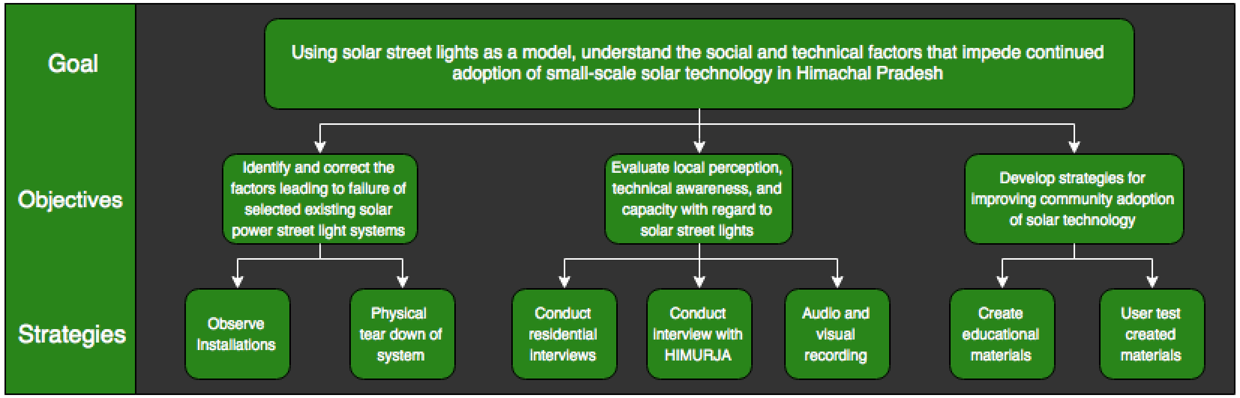

Figure 5. Outline of goal, objectives, and strategies

Figure 6. A site assessment in the village of Dudar

villages and working with local residents to follow the instructions and diagnose their solar light. These tests were video recorded for later analysis.

Results and Discussion

Through interviews, technical analysis, and pilot testing of educational materials we developed a broad understanding of the social and technical factors affecting solar street light adoption in the Mandi and Kamand region. Here we present the results of each objective followed by discussion of these results.

Objective 1: Understanding technical causes of light failure

We disassembled the three failing lights on the IIT Mandi (Kamand) campus to understand the technical reasons why they failed. We observed three distinct issues with the systems. The first system had a failing battery and was not able to hold a charge. Simple checks across the terminals of the battery with a multimeter verified that it could not produce a voltage under load. After replacing this battery with a battery from a working light, we observed that the light was functioning properly after a day of charging in the sun.

The second system had a simpler issue. Initial voltage checks on the panel and the battery were good, meaning the problem likely existed in light fixture circuit itself. After opening the fixture, we observed that the connection between the lightbulb and its socket was not clean. Dirt likely entered the fixture through poorly sealed electrical tape after the fixture was previously opened. The light worked properly after cleaning the connection and realigning the bulb.

We were unable to diagnose the exact issue causing the third system to fail. Battery voltage was good, and while the panel voltage was relatively low, this was acceptable given the light's occluded position and cloudy weather during testing. The electrician who assisted us suspected the light fixture circuit was faulty, but there was no visible damage. With more time we could have fully diagnosed the problem, but limited time and resources prevented a complete investigation. The electrician also noted that if the circuit was the problem, he was unsure how to find a replacement, which could make it difficult to repair.

Objective 2: Local perceptions, technical awareness, and capacity

Most interviews were ultimately conducted in small groups, resulting in collective results rather than individual perceptions. In sum, we conducted 39 site interviews with 61 participants. 27 of the interview sets were conducted in 8 local villages and historical sites that have solar street lights installed, 8 interview sets were conducted in and around the Bhimakali Temple in Mandi Town, and 4 interview sets were conducted in the slums of Mandi Town near Victoria Bridge. See Figure 7 for a summary of results.

All village sites were well electrified. Most reported 24-hour electricity with only 14 out of 39 interview sessions reporting some power loss. 10 of the 14 sessions reported mild semi-regular power cuts lasting for less than two hours a day, with the remaining 4 sessions at Prashar Lake reporting regular power except for outages lasting several days during severe weather. Given this reliability, it was not surprising to learn that most respondents did not depend on solar street lights for regular lighting needs. Only one site, the Mandi Town slum area, had no electricity at all.

When asked about solar power, 39 of 50 interviewees understood the concept and had a general understanding of how it worked. Men were more likely (89%) than women (54%) to understand the basic idea of solar power, but otherwise there were no clear distinctions based on age or level of education. Slum residents had a solid understanding of solar power despite most of them lacking any formal education. Familiarity with solar power appears to have much more in common with previous exposure to solar-based systems than educational background.

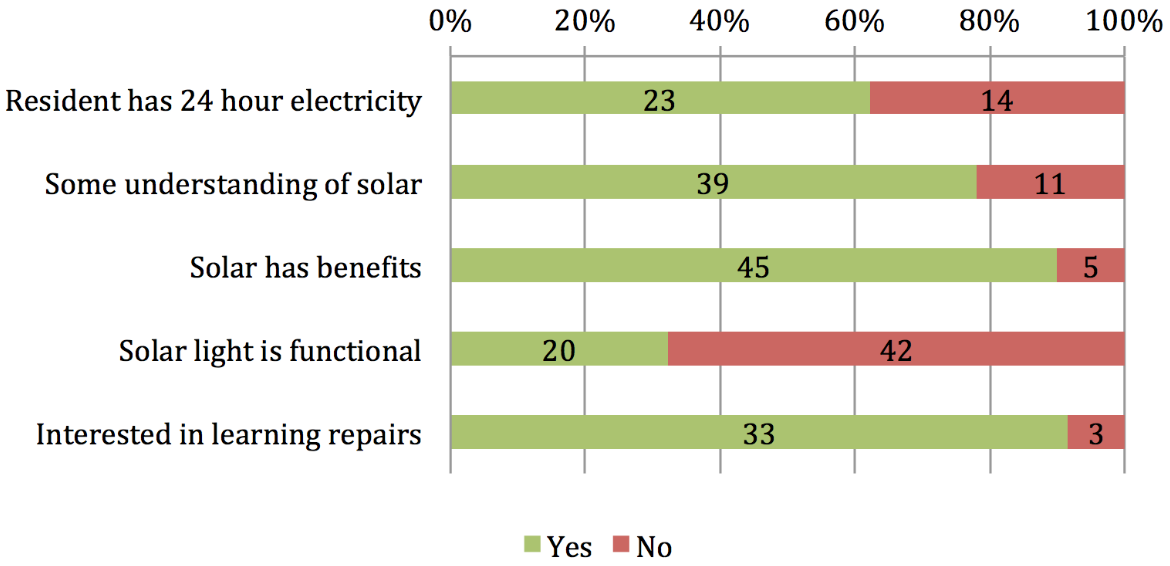

Figure 7. Summary of major findings from residential interviews

When asked about benefits of solar power, 45 out of 50 respondents supported solar power based on its low maintenance, low cost, perceived reliability, and easy installation. Cost was an important factor for many residents. Because it is off-grid, solar lighting is effectively free when compared with home lighting powered through the grid. 5 respondents believed that there were no real benefits of solar power, demonstrating a potential disconnect between the actual benefits of solar and the communities using it. Though in most communities the lights were not strictly needed, stakeholders still found the lights beneficial and wanted them to work. Slum residents in particular described the light as highly beneficial for their school-aged children to study at night. All interviewees supported the idea of more solar street lights, notably to improve safety and productivity, but again cost was a major concern. Several residents supported the idea only if the new lights were free of charge or heavily subsidized.

Despite this positive perception, the lights are not well maintained. Of the 62 solar street lights we encountered, 42 were reported as nonfunctional by respondents. 14 of the 25 lights at the Bhimakali Temple were broken, 12 of the 21 lights in villages and slums were broken, and all of the 16 lights at Prashar Lake were broken and missing batteries (see Figure 8). Most of the village lights were installed 4-6 years ago by HIMURJA, but there were some notable exceptions. Nehri village purchased its one light as a community 10 years ago, and the slum community purchased its light only one year ago. Both of these community purchases were in response to a lack of electrification at the time. The lights became less of a necessity as villages became electrified. The lights that fail are typically reported to have stopped working within 1-2 years after installation. Worse, respondents reported that most of the lights have never been officially maintained. Only the light in the slum community had regular maintenance performed by the municipal government. The lights at Prashar Lake were failing for a year before the deputy commissioner took action by removing the batteries for repair, but the batteries are still missing after six months.

While official support is lacking, there is potential to build capacity for solar street light maintenance within the communities themselves. Of the 36 individuals we asked about interest in learning to diagnose or repair these systems, the vast majority (33) expressed a willingness to learn. Exceptions came mainly from Mandi Town residents who felt they were too busy and would rather have the local government perform maintenance. However, the need for solar street lights is less pressing in these urban areas. We observed one situation in Dudar village in which a resident had connected the lighting fixture of a solar street light to his home's electricity after the light stopped working, and maintained it himself for 5 years. Similarly, the residents of Nehri village bought and assembled a light themselves. These actions demonstrate the latent capacity that exists within these communities.

We also interviewed an expert at HIMURJA in Mandi Town to understand the issues surrounding solar street lights from an institutional perspective. HIMURJA itself does not directly install or maintain lights, or create policy, but

Figure 8. Broken light at Prashar Lake

instead acts in a coordinating capacity to implement renewable power initiatives from higher-level government agencies among local companies. Local government officials provide lists of eligible communities to HIMURJA, which then collects bids from installation companies. New lights cost Rs 15,360 for a light emitting diode (LED) type light or Rs 18,365 for a compact fluorescent light (CFL) type light, but under previously existing subsidies communities pay only 10% or less of the total cost. After installation residents receive basic manual instructions about proper care and procedures for reporting broken lights.

The lights are under warranty for 5 years. During this time, residents can either contact HIMURJA directly by phone or contact their local government to report a broken light. HIMURJA will send a technician out for repair and cover all costs. Battery failure is reportedly the most common reason for repairs, but when other parts fail they often must be ordered from Chandigarh, a city nearly 7 hours away by vehicle. The process for contacting HIMURJA is outlined below in Figure 9.

After the warranty period has expired, HIMURJA is no longer responsible for the lights' maintenance and they often remain in a state of disrepair because villages cannot afford to fix them. HIMURJA believes the maintenance process works well, and supports the idea of building maintenance capacity within communities themselves, especially after the warranty of the light has expired. Building this capacity reduces the burden on HIMURJA and makes the installations more self-sustaining.

Objective 3: Development of strategies to improve adoption of solar

We analyzed data collected from our first two objectives and identified strategies to improve the viability of solar street lights in the communities they serve. The strategies were vetted by experts at the IIT-Mandi and further refined. We also created prototypes for educational materials featuring diagnostic and repair instructions. We piloted the instructions to verify their effectiveness, and to ensure that they are easily understandable and beneficial to local stakeholders. Finally, we conducted additional interviews in the Mandi Town slums to develop an appropriate technology rubric for further development of evening lighting solutions in the community.

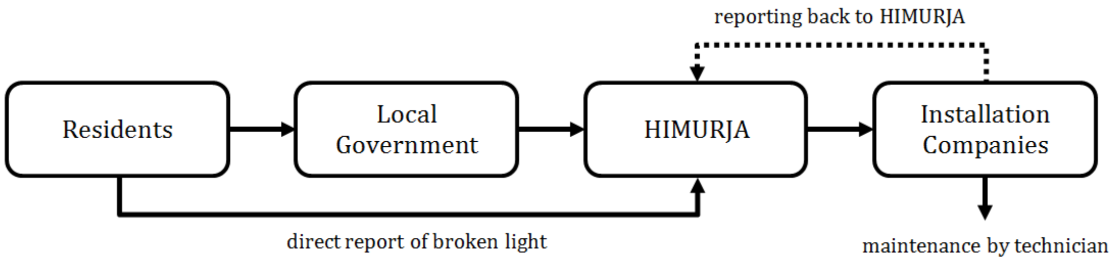

Figure 9. Overview of the process of reporting a broken light to HIMURJA

Discussion

There are several potential reasons why solar street lights have not been maintained in the Mandi and Kamand region. Although residents enjoyed the benefits of solar lighting, they did not always follow through by reporting failures to appropriate authorities. Without adequate maintenance, lights can fail relatively quickly. Regular upkeep is critical in supporting the lighting infrastructure. When residents did make an effort to try to get broken systems repaired, the lights were frequently out of warranty, but residents did not know that this prevented free repairs. After the warranty expires, beneficiaries are required to pay for repairs out of pocket which means that lights are much less likely to be fixed.

Even when communities try to take an active role in maintaining their solar lights, the response is usually weak. Residents of Dudar village and a shopkeeper near Bhimakali Temple complained to their local government, but received little or no assistance. At Prashar Lake, all 16 lights were failing. Outreach by nearby residents to responsible agencies resulted in the batteries being taken for repairs. However, six months later, the batteries are still missing and residents have received no information about when repairs will be completed. These failures are likely due to a lack of communication between beneficiaries, HIMURJA, and companies. Finding where these communication breakdowns occur requires further study.

Residents were sometimes unsure of where to report broken lights even though HIMURJA claimed distribution of contact information. The HIMURJA representative also said that companies educated residents about the systems and proper maintenance techniques after installation. However, few residents knew about this contact information or maintenance procedures. Given that this information is distributed during installation, it is likely that knowledge of the systems does not persist over time due to too few individuals receiving or sharing the training. Both residents and HIMURJA support local maintenance, and clear potential exists in this area for building capacity.

Finally, many residents enjoyed solar street lighting due to its low cost when subsidized, as well as its other benefits, including safety and extended evening activities. These features are not restricted to solar street lights, but solar is a good fit in the current regulatory framework because of heavy subsidies. Rural residents tend to care more about the cost of the system than other features such as grid independence and environmental friendliness. From a technical perspective, traditional street lighting may be a better fit for these residents because it is less likely to be plagued by the maintenance issues of solar street lights and be more reliable in the long run. Solar street lighting is a natural fit in areas like Prashar Lake where power loss is common, but in most locations the choice is not as clear. Communities would benefit from alternative evening lighting solutions that are more carefully tailored to their individual needs.

Project Outcomes

Our research led us to a broader understanding of the issues surrounding solar street lights in Himachal Pradesh and a realization that solutions to the true problem of evening lighting may lie outside solar technologies. We developed three key project outcomes:

1. A critical review of the existing solar street light program and suggestions for how its effectiveness could be improved
2. A pilot program for training local stakeholders how to diagnose and potentially repair existing lights that are out of warranty
3. A case study of the evening lighting needs of the Mandi Town slum community, including the development of an appropriate technology rubric and proposal of technological solutions

Solar street lights in Himachal Pradesh: a critical review

HIMURJA's solar street light program has successfully distributed over 40,000 lights throughout Himachal Pradesh, increasing the visibility of small-scale solar technologies in many communities. These lights bring highly desirable benefits, including safety and extended evening activities. As discussed, solar street lights are also a good fit in areas with unreliable grid connections, like Prashar Lake. Unfortunately, in practice these benefits often last only a few years before the lights fall into a state of disrepair.

In theory, the lights should be well maintained during the five year warranty period after installation through HIMURJA's partnership with local companies. During this time, residents are able to report broken lights either directly to HIMURJA or to local government and receive repairs free of charge. In practice, however, the program appears to be mired in bureaucracy and poor accountability. Reporting from maintenance companies back to HIMURJA is poor, local government can fail to take action, and residents are often unaware of how to report a broken light. Additionally, the five-year warranty period is far too short for most communities. If properly maintained, a solar street light could bring benefits to local communities indefinitely, much like traditional street lighting.

Cost of lighting is a major factor in most communities. With large subsidies available, solar street lights initially appear attractive. But given their history of poor maintenance, communities can easily end up losing the benefits they seek. Nearly every community we studied was well electrified by the power grid, with minor power cuts lasting no more than two hours per day. This finding is consistent with state level reporting on village electrification. Given the reliability of the electric grid in most areas, traditional grid-connected street lighting is a technologically superior choice. Because they are connected to the grid, traditional street lights do not need to generate or store energy and therefore have fewer components that could fail, resulting in increased long-term reliability. Traditional lights carry associated monthly bills from the state electric board, but are much more likely to bring long-term benefits to the communities they serve. While solar street lights have the potential to build energy resilience in rural communities when well maintained, the poor implementation of the solar street light program actually results in reduced energy resilience and quality of life.

Solar lighting is a technologically superior choice in a few areas, like Prashar Lake where power is lost for weeks during the snowy season. There should be an increased focus on long-term maintenance and accountability at these sites, but building this capacity is a complex problem that is unlikely to be solved soon. If more solar street lights are installed in Himachal Pradesh, the site selection process should be modified to favor communities that would see the most benefit from solar technology by incorporating factors like community acceptance, the reliability of the existing grid connection, if any, and already installed evening lighting solutions.

Ultimately, the failure of solar street lights to bring lasting benefits to communities in Himachal Pradesh can be viewed as a misalignment of national energy objectives and the needs on the ground in the region. The national government wants to build India's solar capacity in order to reduce dependence on fossil fuel sources and bring electricity to un-electrified villages. Himachal Pradesh, however, already has abundant, cheap, and renewable energy from large hydroelectric power installations, and a well-developed electric grid with near 100% penetration in rural villages. Himachal Pradesh would be better served by developing incentive programs that promote regionally appropriate technologies that better serve community evening lighting needs, but we recognize that such change is difficult within the national framework.

Improving community maintenance capacity through local education

Despite the shortcomings of the solar street light program, many of the failing lights that are currently installed could potentially be diagnosed and repaired by residents. While better official light maintenance is the ideal solution, community maintenance education can create immediate and lasting impact by restoring the benefits of existing lights. HIMURJA identified battery failure as the most common cause of light failure. Fortunately, this case is simple to diagnose and new batteries can be easily sourced from

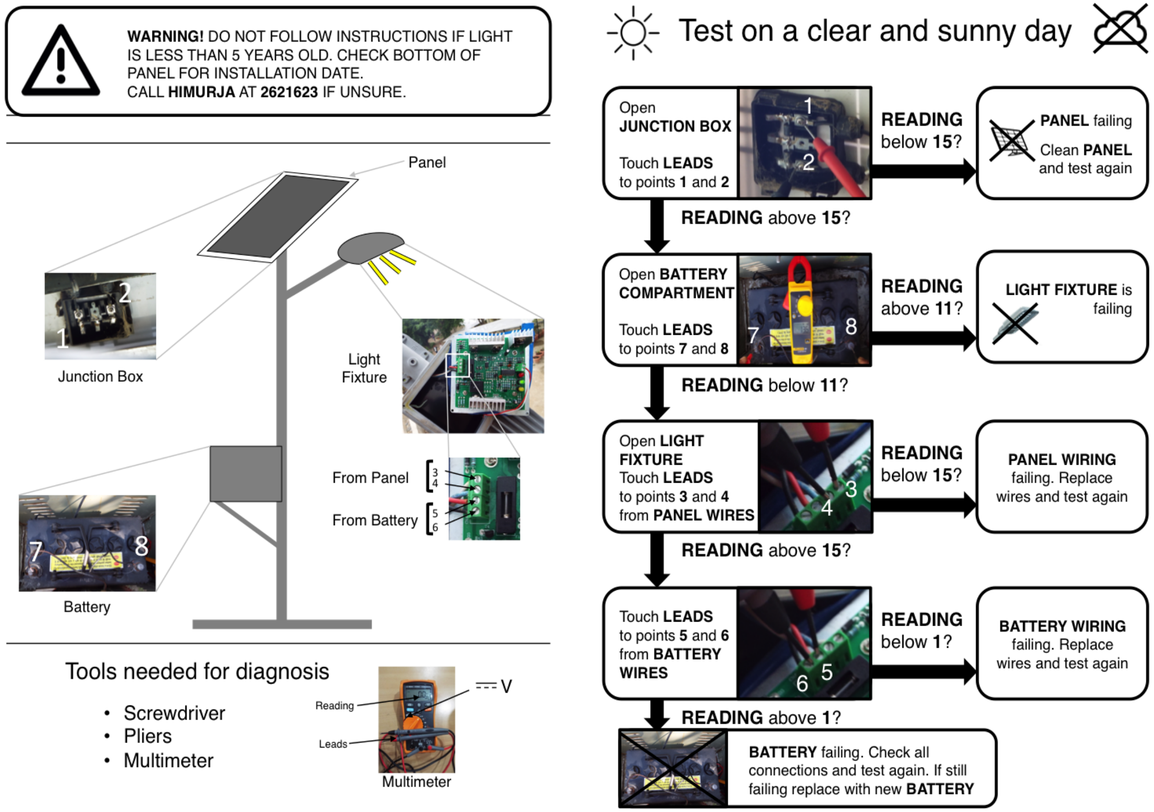

Figure 10. Educational diagnosis guide (English version)

local car parts suppliers. However, our own research revealed that some units suffer from faulty circuits and other more difficult to diagnose failures.

We developed an educational diagnostic guide that can be affixed to the inside of the battery compartment (see Figure 10). This guide was designed to be easy to follow with only basic literacy and a minimal set of tools. The most complex tool required is a multimeter, but in our fieldwork we found that this tool is commonly available in local hardware stores. Using the guide, users can diagnose failure in the solar panel, light fixture, battery, or wiring. Failures of the battery or wiring can be resolved within a community without special orders for expensive parts. Affixing the guide to the inside of the battery compartment protects it from the weather and keeps the information at the point of use, avoiding community knowledge loss over time.

We pilot tested this guide with 5 users in the villages of Dudar and Nisu as well as on campus to assess its usability and effectiveness. Residents were provided with the guide and necessary tools and instructed to attempt to diagnose the solar street light. We were available to answer questions and assist.

4 of the 5 test users were able to successfully diagnose the light. The light in Nisu suffered from a broken light fixture and the light in Dudar had a broken panel (see Figure 11). In general, users found the instructions easy to follow and understand as measured by a five point Likert scale. Measuring the voltage from the panel and battery was straightforward, but measuring the voltages inside the light fixture proved more challenging for some users. They initially struggled to identify the proper terminals to connect the multimeter to, but the numbering of connection points and close-up photos of multimeter connections usually resolved the ambiguity. This problem is compounded by the fact that a wide variety of solar street light designs exist in the field, and our small team did not have the resources to design an educational guide for every design. This forces users diagnosing a different model to have a higher level of technical literacy. Ideally a separate set of instructions would be developed for each model.

Figure 11. Instruction usability testing in Nisu

Despite their successes, users were not always confident in their ability to diagnose a light in the future. One user said that he would need to follow the instructions at least 3 more times in order to feel confident. Building confidence with a purely paper-based educational solution is difficult, and a manual walkthrough of light diagnosis would clearly be better. Coupling instructions affixed to the inside of the battery compartment with the manual training already present during installation could bring both the confidence benefits of manual training and the persistent knowledge benefits of permanent instructions to local communities.

None of the test users already owned a multimeter, and most were concerned about their ability to obtain one. However, this may have more to do with a lack of familiarity with the tool than a true lack of availability. We found multimeters for sale during our fieldwork, and residents would likely be able to obtain one if needed. Users were confident in their ability to obtain other tools and repair materials like wire and car batteries.

All users agreed that the instructions should be included with solar street lights and that doing so would improve the maintenance of the lights. However, users also highlighted some of the larger issues surrounding the solar street light program. One user explained that because the community doesn't really need the lights, he would only try to repair a light if he knew there were government funds available for repair costs, but these funds are unlikely to ever be available. Given these concerns, the instructions will prove most useful for communities with a strong dependence on their solar street lights due to intermittent or no grid power.

Evening lighting needs in the Mandi Town slums

Many of the failures of the existing solar street light program stem from a failure to understand the needs of the communities the lights are being installed in. Residents appreciate the low cost, safety, and productivity benefits that solar street lights bring, but these benefits are not unique to solar street lights. A top-down approach that dictates technological choices fails to consider the evening lighting needs of individual communities. To better understand these needs and develop more appropriate technologies, we conducted a case study in slums of Mandi Town. This community is particularly interesting to study because it is not currently electrified, has expressed desire for increased evening lighting, and has strong constraints on the cost of a potential solution.

Relevant Need	Economic limitations	Cultural compatibility
• Need light primarily for children to study at night • Need light for other activities like cooking and games	• Rs 500 per Month but low or no recurring cost preferred • Rs 500 – 1000 one time purchase • Rs 2000 group purchase	• Light can be purchased locally • Light is simple to operate for all social groups • Light can function as a drop-in replacement for candles • Light is legal by Indian law
Technical literacy	**Environmental responsibility**	**Usability**
• Includes maintenance instructions in Hindi • Light last at least 1 year without maintenance • Minimal tools required for maintenance • Minimal technical understanding for maintenance	• Works in extreme wind or rain • Works in extreme temperatures • Does not produce harmful waste products indoors • Minimal technical understanding required for maintenance	• Does not require grid connection • Produces white light • Bright enough to light a small work area for reading and writing • Lasts 3-4 hours per night • Performance of light is consistent over time • Can be hung/attached to ceiling or moved • Can charge mobile phones

Figure 12. Appropriate technology rubric for Mandi slum lighting

We conducted semi-structured interviews with 9 residents of the Mandi Town slums to understand current evening lighting practices and requirements for new lighting technology including cost, usage, technical literacy of users, maintenance requirements, environmental suitability, and usability. Using the interview responses and our background understanding of the problem, we developed an appropriate technology rubric suitable for selecting and developing improved evening lighting solutions for the slum community (see Figure 12).

We found that residents currently spend around Rs 500 per household per month on candle lighting, but are not satisfied. They buy candles at the local market daily or weekly, use 3-5 candles each night and get light for 3-4 hours. Residents were unhappy with the light output of the candles and the color of the light. Weather is also a major factor, as candles in the open slum dwellings can easily blow out in wind or rain. Providing light for children to study at night is the most common use of lighting, but the light is also used for other activities like cooking and games. Residents felt comfortable with basic maintenance of an improved lighting solution, but did not feel confident diagnosing electronics. Some residents were also interested in having mobile phone charging as part of the lighting solution.

Based on our rubric, we developed a prototype solution for improved evening lighting. We selected solar lanterns as a good fit for the community due to their reliability, low recurring costs, robustness in bad weather, higher light output, and light color. Solar lanterns have been used elsewhere in Indian slums for replacing kerosene lanterns (The Indian Express, 2015) and quality standards concerning reliability and light output exist for the technology, avoiding some of the pitfalls observed with solar street lights (Lighting Global, 2016). They are also a relatively low cost technology, especially over time.

We found solar lanterns for sale in Mandi Town for Rs 1,835 each. These lanterns provide 10 times the light output of 3 candles, provide mobile charging, and last for up to 15 hours each night. While the cost is prohibitive for individual purchase, several households would be able to buy one of these solar lanterns as a group. Individual purchase would also be feasible if payment plan options were available. This business model has been used in other Indian slum lighting projects (The Indian Express, 2015). Overall, the lantern scored 21 out of 24 on our rubric.

We provided two of these lanterns to the community for evaluation and testing. Community members strongly preferred the lanterns to candle lighting. When we returned to the slum two days later to evaluate the residents' opinions of the lanterns, we found that the community had started constructing a new school building to hang the lights in (see Figure 13). This kind of building was not present previously. Latent capacity existed, and providing evening lighting was the push needed to unlock it. When we told the residents how much the lights cost, they expressed a willingness to purchase more lights as a group at that price point in the future. There is clear potential for continued growth, and it appears that a simple lack of knowledge about alternative lighting solutions and their availability was holding the community back.

Cheaper solar lanterns are also available commercially, running as low as Rs 500, but we were unable to find these products for sale locally. These lights typically have reduced light output, sometimes not much more than several candles. However, they can still

Figure 13. School under construction

be useful by focusing the light better than candles, creating adequate task lighting in a small area the size of a few sheets of paper. Maintenance is also less of a concern with prices this low, as it would be feasible for community members to simply buy a new lantern if their current lantern fails. These lanterns may be more applicable for individual homes. Purchasing these cheaper lights would likely require the community to place an order as a group with a local store.

While our prototype solution is not perfect, the design together with our appropriate technology rubric provides the first step for improving evening lighting in the Mandi Town slums and throughout the region.

Conclusion

Solar street lights are valued by local communities because of the safety and productivity benefits they provide, especially in areas with intermittent or no access to the electric grid, but our study revealed a pattern of poor maintenance and failing lights due to poor program implementation and a failure to consider the appropriateness of the technology. Educating residents about simple procedures that can be used to diagnose and potentially fix common causes of failure in existing lights enables these communities to restore lost benefits and build internal capacity for small-scale solar technologies. Looking forward, new evening lighting initiatives should carefully consider the needs of local communities and develop solutions that will enable these communities to benefit from evening lighting for more than just a few years. With proper consideration of appropriate technologies, evening lighting can be a reliable way to create a brighter future for the most vulnerable communities in Himachal Pradesh.

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Supplemental Materials

Interview Questions for Residents

Metadata: Date/time, Location, Anonymous subject ID,Number of interviewees per interview, Gender of interviewees, Research team members present

CONSENT STATEMENT

We are a group of students from IIT. We are investigating community perception of solar power for a school project, and are interesting in learning from your opinions. We have a brief survey of questions that should only take 5 minutes of your time. Your responses are anonymous and confidential. Would you like to participate? Are you comfortable having this interview audio recorded?

General Questions

1. Do you know what solar electric power is and how to the technology works?
2. How many solar panels are you aware of in your community?
3. Where does/do you know where your electricity come from?
4. How often do you lose power? Do you know why this happens?
5. What do you think the benefits of solar are?
6. Are you aware of any government programs to support solar power? Do you think the government should do more?

Streetlight questions

7. Are you aware of the street lights near your home?
8. Do you know who owns these lights?
9. ~~How are these lights powered?~~
10. How long have the lights been installed?
11. How many of these lights do not work?
12. Have the lights been repaired in the past?
13. Do you think the maintenance of the lights is adequate? What would you do if you wanted a light to be fixed?
14. Do you find the lights beneficial?
15. How do the solar street lights compare to traditional street lights? (reliability)
16. Do you think more solar street lights should be installed?

Basic information

17. How old are you?
18. How much schooling did you complete?
19. Have you lived here your whole life?
20. What is your occupation?
21. Would you be interested in learning how to diagnose or repair a solar street light?

Residential Interview Response Sheet

Interview # __ Date/Time__________ Location_____________ # Interviewed__ Gender____

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10. ____
11. ____
12. ____
13. ____
14. ____
15. ____
16. ____
17. ____
18. ____
19. ____
20. ____
21. ____

Interview Questions for HIMURJA

- What is the purpose of installing solar street lights?
  - Lighting communities, acceptance of solar
- What other small scale solar programs does HIMURJA support?
  - Are they accessible at low cost for residents?
- How many lights are installed in the State?
  - When and where were they installed?

- How are communities chosen for installation?
- How much does it cost you to install a light?
- What is the cost of each component?
- How easily can these components be acquired in HP?
- Does it cost the community anything to install a light?
- How are communities involved in the installation process?
- Are communities educated about the light/solar after installation?
  - Maintenance
  - Contact info
  - How solar works
- Who owns lights after installation?

- How are the lights maintained?
- Who is supposed to maintain them?
- How many are people available for light maintenance?
- Do you think the lights are being maintained well?
- What is the whole lifecycle of the repair process?
  - From a community member -> Fixed light
- How many lights have been repaired?
- When was the last repair?
- How long do you expect these lights to last?
  - Do you expect to maintain them?

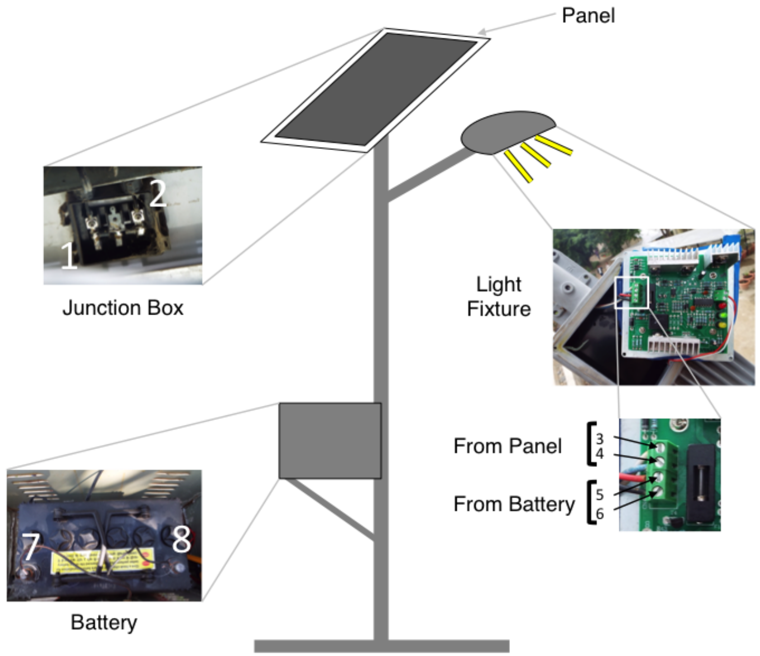
- How often do the installed lights failed?
- What are the most common reasons that lights fail?
- In which of these cases is a cost effective to fix the light?
- What equipment is needed to repair a light and how much does this equipment cost?
- Does HIMURJA have enough personnel for maintenance?

- Do you have a service number or other communication channel that people can reach out to?
- With basic training, would local residents be capable of basic diagnostics and repairs?
- Would you support local residents diagnostic and repairs?

Logistical Questions:
If we want to disassemble a broken light, can we and who should we contact?

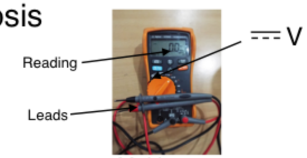
Educational Guide for Light Diagnosis (English)

WARNING! DO NOT FOLLOW INSTRUCTIONS IF LIGHT IS LESS THAN 5 YEARS OLD. CHECK BOTTOM OF PANEL FOR INSTALLATION DATE.
CALL **HIMURJA** AT **2621623** IF UNSURE.

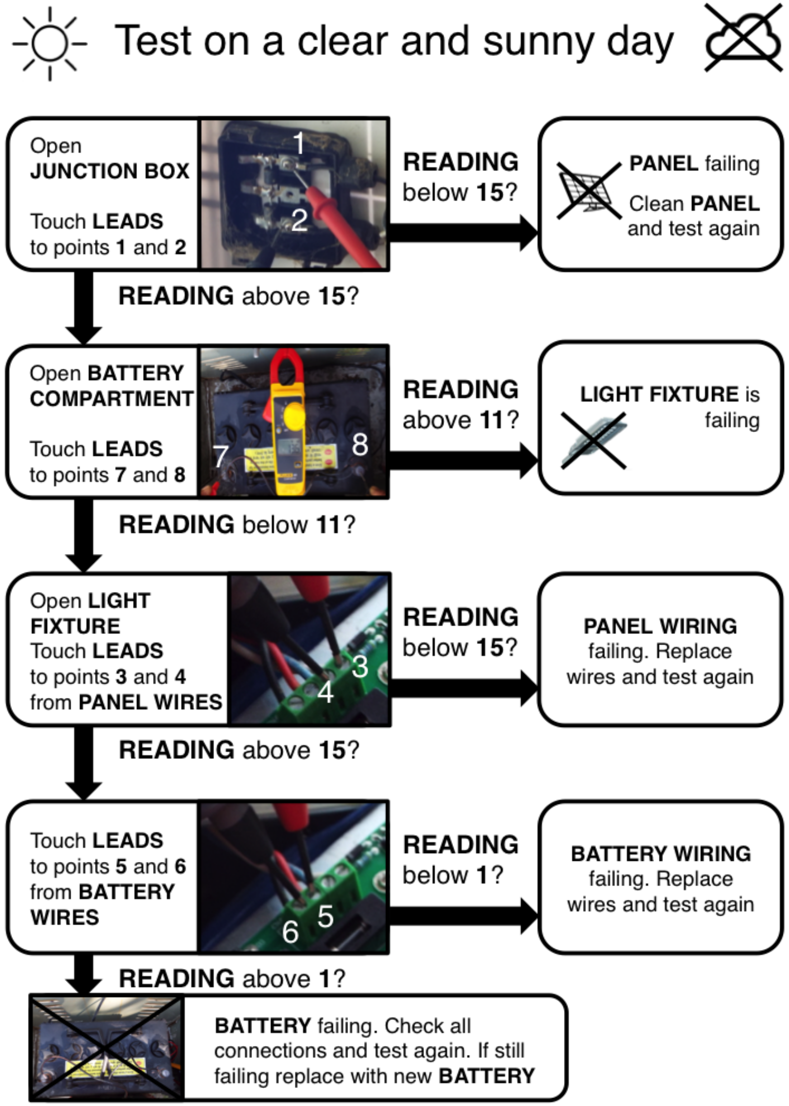


Tools needed for diagnosis

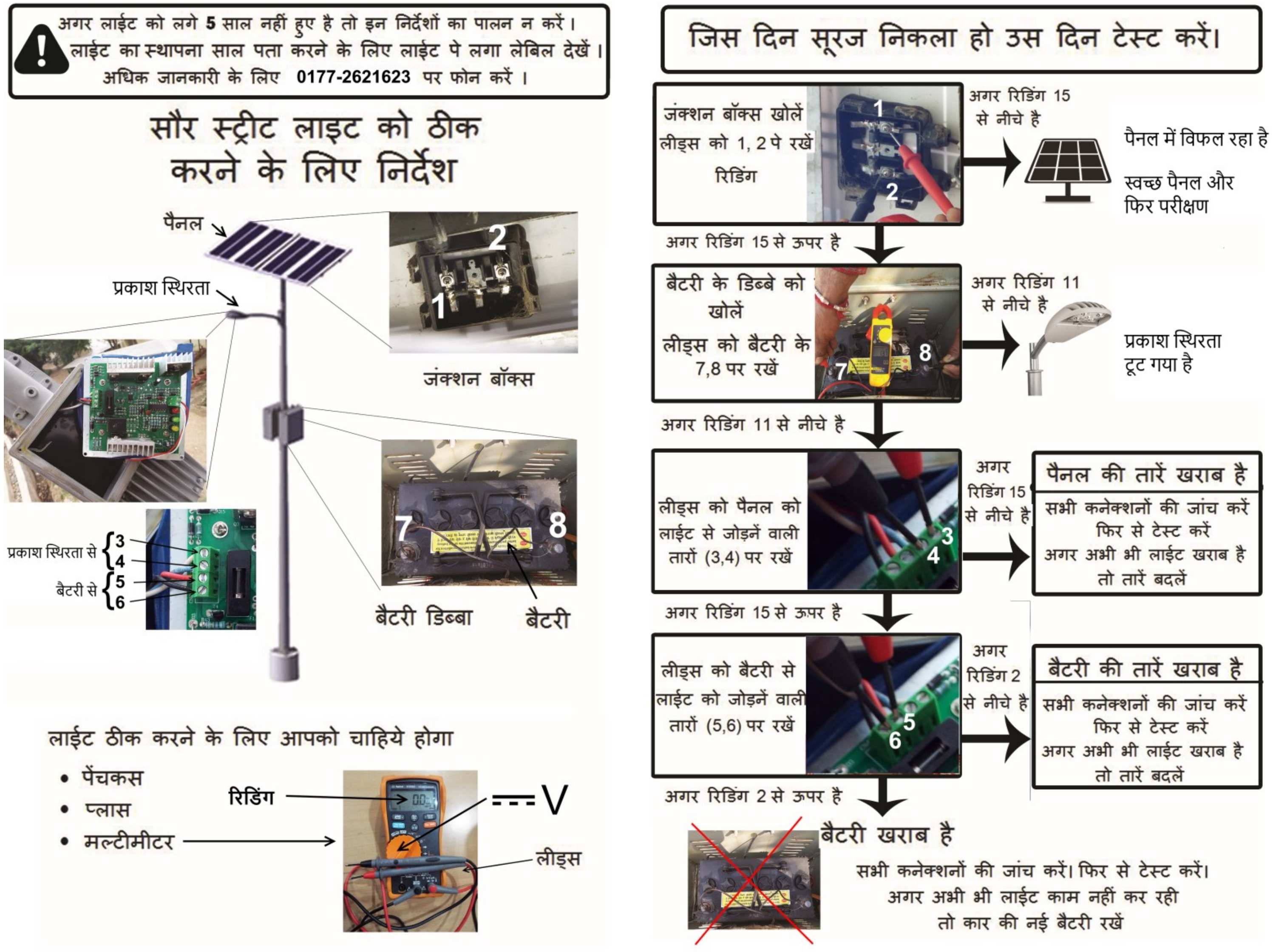
- Screwdriver
- Pliers
- Multimeter



Multimeter



Educational Guide for Light Diagnosis (Hindi)



Educational Guide Usability Questionnaire

Please rate your agreement with the following questions:

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The instructions were easy to use.	1	2	3	4	5
The layout of the instructions was easy to follow.	1	2	3	4	5
I understand how to follow each step in the instructions.	1	2	3	4	5
My solar street light matched the steps in the instructions.	1	2	3	4	5
I successfully diagnosed a solar street light.	1	2	3	4	5
I would feel comfortable following the instructions on my own.	1	2	3	4	5
The pictures helped me understand the instructions.	1	2	3	4	5
The numbering of the wires helped me understand the instructions.	1	2	3	4	5
The written directions helped me understand the instructions.	1	2	3	4	5
I know how to read the multimeter.	1	2	3	4	5
I know how to where to connect the multimeter to the light.	1	2	3	4	5
I understand when the lights are under warranty.	1	2	3	4	5
I understand how the weather should be to follow the instructions.	1	2	3	4	5
I would be able to obtain the tools required to use the instructions.	1	2	3	4	5
I already have the tools required to use the instructions.	1	2	3	4	5
I would find the instructions useful in the future.	1	2	3	4	5
The instructions should be included with solar street lights.	1	2	3	4	5
By including the instructions with lights, the lights would be better maintained.	1	2	3	4	5
Other people in my community would be able to follow the instructions.	1	2	3	4	5
I would be able to obtain a wire to repair a light.	1	2	3	4	5
I would be able to obtain a car battery to repair a light.	1	2	3	4	5

What worked well when you were following the instructions?

What would you change? What was difficult to understand?

FOR INTERVIEWER USE ONLY

The subject successfully diagnosed the light. Yes No

Time taken to diagnose the light:

Errors or questions during diagnosis:

Interview Questions for Slum Technology Assessment

Questions should target the following areas:
Relevant need: Targets a true and non predefined need.
Economic limitations: Ensures costs match local economic capabilities.
Cultural compatibility: Honors existing regional customs, traditions, and institutions.
Technical literacy: Operates within current technical abilities for easy use and maintenance.
Environmental responsibility: Considers local terrain, regional weather patterns, and wildlife.
Usability: Fits within user capabilities and limitations.

Do you need additional lighting in the evening?

How do you currently get light in the evening?
Do you think this lighting is adequate? Why or why not?
What do you dislike about your current lighting?

How much does this lighting cost? (Per item? Per month?)
Do you spend this much individually or as a group?
Where do you obtain materials/fuel for this lighting?
How much time do you spend obtaining these materials?
How much light does your current solution produce?
    How much area does it light? How bright is it?
How long do you have light for each night? Is this long enough?
Do you need light every night?
Are you happy with the color of the light?
What do you use this lighting for? Cooking? Studying? Games? Work?
Which area is the most important to have light in?
Which activity is the most important to have light for?
Do you move the lights? Is this important?

Have you used other light sources in the past? Which ones?
Were these sources better or worse than your current solution? Why?
Is there a light source that you are aware of that you would like to have? Why is this source better?
Would more light be beneficial? Why or why not?

How much would you be willing to spend on evening lighting…
    one time individually?
    one time as a group?
    every month?
How long do you want a light to work without repairs?
Do you know where you could buy batteries locally?

What kinds of weather conditions would the lighting need to endure?
    How hot? How cold? Would it be exposed to rain?

What tools do you have access to for maintaining a light? (Screwdrivers? Pliers? Electronics equipment?)
Do you know where you could obtain these tools?
How comfortable do you feel fixing electronics?

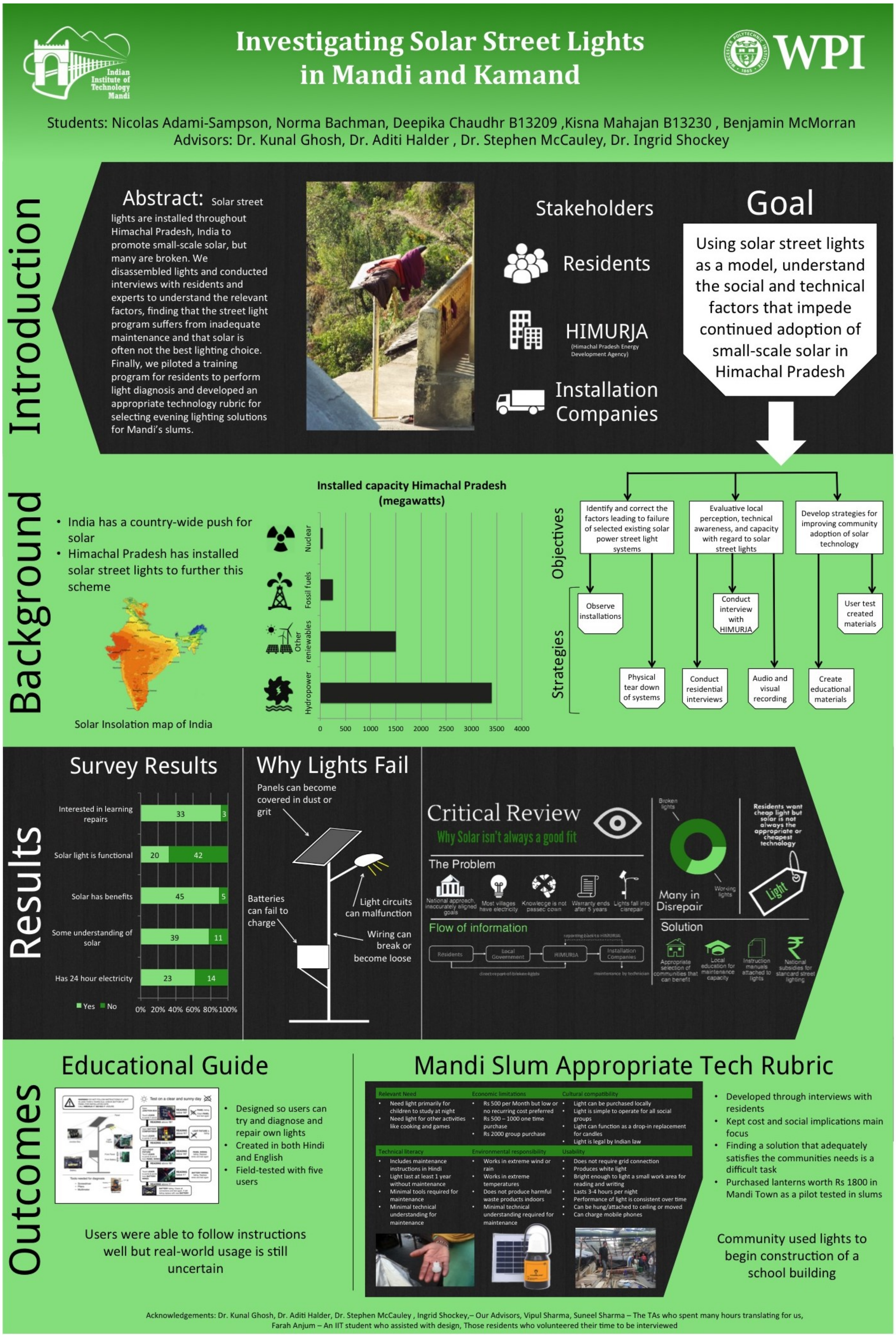
How comfortable do you feel reading written instructions? In what language?
Is it important that you understand how your lighting technology works?

Are there any other factors that would affect your choice of evening lighting technology?

Slum Lighting Appropriate Technology Rubric

Relevant need	Economic limitations	Cultural compatibility	Technical literacy	Environmental responsibility	Usability
Need light primarily for children to study at night Need light for other activities like cooking and games	Rs 500 / month, but low or no recurring costs is preferred Rs 500 - 1000 one time purchase Rs 2000 group purchase	Light can be purchased locally Light is simple to operate for all social groups Light can function as a drop-in replacement for candles Light is legal by Indian law	Includes maintenance instructions in Hindi Light lasts at least 1 year without maintenance Minimal tools required for maintenance Minimal technical understanding required for maintenance	Works in extreme wind or rain Works in extreme temperatures Does not produce harmful waste products indoors Does not create a fire risk indoors	Does not require grid connection Produces white light Bright enough to light a small work area for reading and writing Lasts 3-4 hours / night Performance of light is consistent over time Can be hung/attached to ceiling or moved Can charge mobile phones

Poster


Indian Institute of Technology Mandi
Investigating Solar Street Lights in Mandi and Kamand
WPI
Students: Nicolas Adami-Sampson, Norma Bachman, Deepika Chaudhr B13209 ,Kisna Mahajan B13230 , Benjamin McMorran
Advisors: Dr. Kunal Ghosh, Dr. Aditi Halder , Dr. Stephen McCauley, Dr. Ingrid Shockey
Introduction
Abstract: Solar street lights are installed throughout Himachal Pradesh, India to promote small-scale solar, but many are broken. We disassembled lights and conducted interviews with residents and experts to understand the relevant factors, finding that the street light program suffers from inadequate maintenance and that solar is often not the best lighting choice. Finally, we piloted a training program for residents to perform light diagnosis and developed an appropriate technology rubric for selecting evening lighting solutions for Mandi's slums.
Stakeholders
Residents
HIMURJA
(Himachal Pradesh Energy Development Agency)
Installation Companies
Goal
Using solar street lights as a model, understand the social and technical factors that impede continued adoption of small-scale solar in Himachal Pradesh
Background
India has a country-wide push for solar
Himachal Pradesh has installed solar street lights to further this scheme
Solar Insolation map of India
Installed capacity Himachal Pradesh (megawatts)
Nuclear
Fossil fuels
Other renewables
Hydropower
0 500 1000 1500 2000 2500 3000 3500 4000
Objectives
Identify and correct the factors leading to failure of selected existing solar power street light systems
Evaluative local perception, technical awareness, and capacity with regard to solar street lights
Develop strategies for improving community adoption of solar technology
Strategies
Observe installations
Conduct interview with HIMURJA
User test created materials
Physical tear down of systems
Conduct residential interviews
Audio and visual recording
Create educational materials
Results
Survey Results
Interested in learning repairs 33 3
Solar light is functional 20 42
Solar has benefits 45 5
Some understanding of solar 39 11
Has 24 hour electricity 23 14
Yes No
0% 20% 40% 60% 80% 100%
Why Lights Fail
Panels can become covered in dust or grit
Batteries can fail to charge
Light circuits can malfunction
Wiring can break or become loose
Critical Review
Why Solar isn't always a good fit
The Problem
National approach, inaccurately aligned goals
Most villages have electricity
Knowledge is not passed down
Warranty ends after 5 years
Lights fall into disrepair
Flow of information
Residents
Local Government
HIMURJA
Installation Companies
Broken lights
Working lights
Many in Disrepair
Residents want cheap light but solar is not always the appropriate or cheapest technology
Light
Solution
Appropriate selection of communities that can benefit
Local education for maintenance capacity
Instruction manuals attached to lights
National subsidies for standard street lighting
Outcomes
Educational Guide
Designed so users can try and diagnose and repair own lights
Created in both Hindi and English
Field-tested with five users
Users were able to follow instructions well but real-world usage is still uncertain
Mandi Slum Appropriate Tech Rubric
Relevant Need
Need light primarily for children to study at night
Need light for other activities like cooking and games
Economic limitations
Rs 500 per Month but low or no recurring cost preferred
Rs 500 – 1000 one time purchase
Rs 2000 group purchase
Cultural compatibility
Light can be purchased locally
Light is simple to operate for all social groups
Light can function as a drop-in replacement for candles
Light is legal by Indian law
Technical literacy
Includes maintenance instructions in Hindi
Light last at least 1 year without maintenance
Minimal tools required for maintenance
Minimal technical understanding for maintenance
Environmental responsibility
Works in extreme wind or rain
Works in extreme temperatures
Does not produce harmful waste products indoors
Minimal technical understanding required for maintenance
Usability
Does not require grid connection
Produces white light
Bright enough to light a small work area for reading and writing
Lasts 3-4 hours per night
Performance of light is consistent over time
Can be hung/attached to ceiling or moved
Can charge mobile phones
Developed through interviews with residents
Kept cost and social implications main focus
Finding a solution that adequately satisfies the communities needs is a difficult task
Purchased lanterns worth Rs 1800 in Mandi Town as a pilot tested in slums
Community used lights to begin construction of a school building
Acknowledgements: Dr. Kunal Ghosh, Dr. Aditi Halder, Dr. Stephen McCauley , Ingrid Shockey,– Our Advisors, Vipul Sharma, Suneel Sharma – The TAs who spent many hours translating for us, Farah Anjum – An IIT student who assisted with design, Those residents who volunteered their time to be interviewed

Fieldwork Photos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