ASSESSING THE FEASIBILITY OF MICRO-HYDROPOWER IN HIMACHAL PRADESH

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Assessing the Feasibility of Micro-Hydropower in Himachal Pradesh

An Interactive Qualifying Project Report submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science in cooperation with The Indian Institute of Technology Mandi Submitted on 30 April, 2018

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Abstract

Himachal Pradesh is the largest producer of hydroelectricity in India, and boasts a 99.8% rural electrification rate. However, micro-hydropower is electrical power with off-grid applications that does not cause the negative impacts of large-scale projects. Our team researched the viability of using micro-hydro turbines to power individual households. We conducted interviews with 39 people across eight locations to understand the electrical needs of the community as wells as opinions on micro-hydro projects. We then constructed a micro-turbine prototype and tested it at a local river site. Finally, we made several recommendations for improvements to our prototype as well as continued research on the feasibility of micro-hydro technologies.

Executive Summary

Micro-hydropower is a promising technology that has opportunities for household-level application in agrarian communities like the northwest Indian state of Himachal Pradesh. Although Himachal Pradesh already has an impressive 99.8% rural electrification rate, there are off-grid applications for supplemental energy generation. India harnesses approximately 26% of its hydroelectric potential, and Himachal Pradesh already hosts a number of large-scale hydroelectric plants. However, even if marketed as a "green" technology, hydroelectric dams often negatively impact the surrounding environment. Diversion of water affects water availability, blasting operations scatter debris which destroy grasslands and vegetation, and the cumulative impact of multiple projects may be a source of climate shift in the area. This kind of land manipulation is not required for micro-hydro. Along with providing supplemental off-grid electricity, micro-hydro can also be a source of renewable power with far less environmental impact than large-scale projects.

Approach

The goal of our project was to assess the feasibility of implementing micro-hydropower in the rural communities of Himachal Pradesh. To achieve this we pursued four objectives. Our first objective was to identify communities with an interest in micro-hydropower; villages with a need for supplemental electricity which have perennial streams to power a micro-hydro system. Second, we interviewed 39 residents in nine locations to understand their electric consumption needs as well as features or requirements they would expect a micro-turbine to have. Third, we used this data to design and develop a micro-turbine prototype. Finally, we planned to return to the villages for field testing and feedback on further improvements.

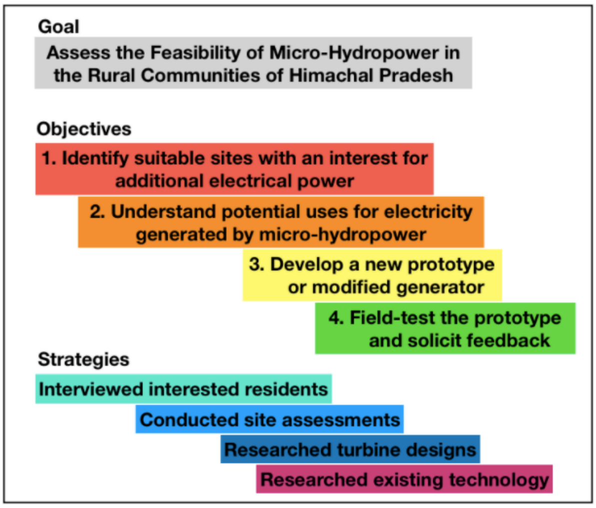

Figure 1: Flowchart of methodology

Results

We discovered that the electrical consumption of most villagers was relatively limited. Villagers mainly use electricity for lights, fans, and televisions. Most villagers' electricity bills are quite low, in part due to government subsidies. Residents expressed interest in using micro-hydro to supplement their electrical consumption. Some respondents were more apprehensive than others, stating that they would need to see a specific design or prototype before deciding if it would be suitable for their lifestyle. While additional electricity is not a pressing need of the community, all residents reported that one of their biggest struggles was dealing with power outages. Routine maintenance or construction work on the power grid requires that it be regularly shut down by the government.There were several major concerns amongst those interviewed on introducing micro-hydro technology. One fear was losing water to the hydro turbine similarly to how water is held by a hydroelectric dam, as they feel there is a water scarcity already. Additional concerns included price-point, difficulty of installation and use, maintenance, and longevity. This information, combined with the highly accessible existing electricity infrastructure, led our team to believe that mitigating loss of electricity during power outages was the most appropriate role micro-hydropower could play in the area.

Figure 2: Interviews in Saghali

Using site visits and interview responses, we designed and constructed a small scale turbine, intended to be low-cost, have minimal ecological impact, and work to mitigate loss of electricity during power outages. Our turbine used a steel exhaust fan as a blade, was housed in an aluminum frame, and was able to produce enough electricity to power four LED lights. Our prototyping process was severely limited by time constraints, available materials, and machining methods. While aluminum was readily available, the shaft, bearings, gears, and dynamo were difficult to acquire. Additionally, we were unable to machine customized turbine blades, as the IIT mechanical lab did not have the capacity to machine curved surfaces. Optimal design of a micro-turbine relies on each part being designed to work together for the most possible electricity generation at a specific site. Our team did not have the resources to achieve this level of precise engineering. In spite of these setbacks, we were able to understand the challenges of designing micro-turbines as well as their potential impact in rural communities throughout the process.

Figure 3: First iteration of micro-hydro turbine prototype

Project Outcomes

While micro-hydro could be a solution to mitigating electricity loss during grid outages, further research must be done in order to determine how it can be best implemented. The two technical aspects that require the most investigation are how to increase rotation speed of the turbine blades and a better understanding of what kind of dynamos can generate the most power. Three additional social and environmental factors should be further investigated: a) how to increase turbine access to people who do not live directly on flowing water sources, b) how to lower the cost of the turbine, and c) more documentation of water sources that can produce a usable amount of energy. In the meantime, we recommend that residents of Himachal Pradesh who are interested in water turbines coordinate with their local Department of Energy, as there are government procedures and subsidies for building and installing micro-turbines. Additionally, more research could be done on the feasibility of extending solar and wind power to the rural communities of Himachal. Overall, we hope our project contributed to an increased understanding of the role renewable power technologies can play in Himachal Pradesh.

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Contents

List of Figures

List of Tables

1

Micro-hydropower in Himachal Pradesh

Micro-hydropower is a promising technology that has opportunities for household-level application in agrarian communities like the northwest Indian state of Himachal Pradesh. Although Himachal Pradesh already has an impressive 99.8% rural electrification rate (Central Electricity Authority, 2016), there are opportunities for off-grid application of supplemental energy generation. India harnesses approximately 26% of its hydroelectric potential, and Himachal Pradesh already hosts a number of large-scale hydroelectric plants (HPDOE, 2017; India MoP, 2018). Focusing on off-grid or local projects may benefit communities in ways that have a purposeful and direct impact (Agrawal et al., 2015). Micro-hydropower is an adaptable technology that can be altered to suit specific site needs, and can be created from simple materials (Wazad & Ahmed, 2008). There is also the possibility of modifying existing mechanical watermills, which are abundant in the region, to generate electrical power. (Agrawal et al., 2015). Micro-hydropower could help change the adversity to hydropower in Himachal Pradesh by reducing the negative connotations that have notoriously come along with large-scale hydropower plants (Lal, 2003; The Tribune News Service, 2015). Overall, hydroelectricity on a micro scale could be an effective option for utilizing the renewable energy of the water resources in India.

The goal of our project was to assess the feasibility of implementing micro-hydropower in the rural communities of Himachal Pradesh. To achieve this we pursued four objectives. Our first objective was to identify communities with an interest in micro-hydropower; villages with a need for supplemental electricity which have perennial streams to power a micro-hydro system. Second, we traveled to several of these identified locations and interviewed residents to understand their electric consumption needs as well as what kinds of features or requirements they would expect a micro-turbine to have. Third, we used these data to design and develop a micro-turbine prototype. Finally, we planned to return to the villages for field testing and feedback. Our intent was not to produce a market-ready product, but rather a proof of concept that demonstrated the potential of the technology in Himachal Pradesh.

Figure 1.1: Village khul

2
Hydropower: Challenges and Opportunities

In order to best understand the role micro-hydro could hold in Himachal Pradesh, it was important to keep in mind the historical context surrounding hydropower in the area.

2.1. A history of contested development

Himachal Pradesh is a mountainous region densely packed with river networks, making commercial-scale hydroelectric power common to the area. Both the Baes and Uhl rivers run through a large portion of the district. There are currently 145 commissioned hydroelectric plants in the region, yet it is estimated that these only harness about 10,500 MW of the 27,400 MW identified total potential (HPDOE, 2017). While this underutilization has left the government and private sector eager to continue development on the rivers, the inhabitants are not so keen on the idea. Rural residents are dependent on the land for cultivation and the river for drinking and irrigation, so any disruption of the land or river leads to disturbance of their livelihoods (Chand et al., 2016; Kumar & Katoch, 2015).

Figure 2.1: Agricultural land near IIT Mandi

Hydropower, marketed as a “green” technology, often requires heavy construction that negatively impacts the surrounding environment. Diversion of water affects water availability, blasting operations scatter debris which destroy grasslands and vegetation, and the cumulative impact of multiple projects may be a source of climate shift in the area (Kumar & Katoch, 2014). In the specific case of the Kol-dam project (800 MW), 36 - 67% of cultivated land was lost on average amongst 5 local villages (Chand et al., 2016). These are not isolated incidents, as similar occurrences have been reported in Uttarakhand, India and near the Skoto river in China (Chand, Verma, & Kapoor, 2016). Even "small" (2 - 25 MW) hydroelectric projects can inflict considerable damage on the environment, as these systems still require mill streams or diversion channels to produce enough water flow to power the system (Kubeck, Matena, & Hartvich, 1997). Additionally, many residents of Himachal Pradesh have generally been unsatisfied with promises or compensation made by developing parties (Kumar & Katoch, 2015).

2.2. Advantages of micro-hydropower

In light of negative implications from large-scale hydroelectric projects, opportunities exist to research and develop small scale hydropower systems which do not require disruptive construction. A micro-hydropower system is a small scale, potentially privatized and locally based, electrical generation system. The purpose of such systems are to generate electricity through the use of water's kinetic electricity. If properly developed, the electricity generated through hydropower is cleaner in comparison to fossil fuel based energy resources. Micro-hydropower devices could be owned and operated by individual households; powering household appliances and allowing owners to provide for their own electrical needs. These systems can be transportable and deployable at desired locations. Turbines with these qualities are already available on the market (Idenergie 2016; Enomad 2017). Even if micro-hydropower does not completely replace other power sources in a specific region, it can reduce electricity costs by providing a "free" additional source of power. In some places users may be able to sell energy produced by their micro-hydro system back to the grid (Sinclair, 2003). In locations similar to Himachal, data shows canals, tributaries, and small waterfalls that are unsuitable for large-scale development are prime candidates for micro-hydropower systems. For example, in rural Bangladesh, a system was designed by a local resident that used an earthen dam and wooden turbine in a perennial stream to generate power for 40 households (Wazad & Ahmed, 2008). A previous IQP team evaluated the feasibility of a micro-hydro system in Kre Khi, Thailand, and determined that the local stream could provide enough power to run lights and educational tools in a nearby school (Bjork et al, 2002). Clearly micro-hydro has a range of applications and can be adapted to suit specific sites of implementation.

Figure 2.2: Micro-turbine in Laos (Tuler, 2006)

Integrating existing hydropower technology in the area with new developments can promote self-reliance and usage of local resources. The citizens of Himachal Pradesh are not unfamiliar with water based technology, as they designed the gharat, one of the oldest forms of watermills in the world (Vashisht, 2012). The gharat is a tool utilized in Northern India to grind grains using blades that are propelled by a flowing water source. A research team assessing gharats in 2015 recommended technological upgrades to the existing structures, and stated there was a high level of interest from gharat owners for an attachable generator that could power light bulb (Agrawal et al, 2015). The previously mentioned system developed in Bangladesh encouraged us to consider modification of gharats with an electrical component as a viable option of prototyping. Incorporating a micro-hydro turbine to an already established gharat design could provide a sense of familiarity that promotes interested households to employ the device in their everyday lives.

When designing and implementing technologies, it is important to consider needs of the stakeholders as well as unintended consequences the technology may have. Large scale hydroelectric systems, such as the one illustrated in Figure 2.3, require development of large amounts of land and cause the destruction of many ecosystems when a dam is built. We had to consider environmental factors that influence physically sustainable of hydropower so that we could avoid the shortcomings of large-scale projects.

Figure 2.3: Pandoh Dam in Himachal Pradesh

Neglecting potential effects of development on beneficiaries is an oversight of large scale projects. Talking to household owners allows greater insight to community processes that are effective, as well as aspects that have the potential to benefit from alteration (Human Centered Design, 2011). Understanding local perspectives on farmland and water loss due to large-scale hydropower projects gives us insight to hydraulic energy perceptions in the region, and deeper understanding of important factors in prototype design. In our case, micro-hydropower could allow residents to keep the environmental resources they already possess while fostering innovation by having community members become responsible for their own energy.

3

Methodology: Assessment, Interaction, and Design

In order to assess the feasibility of micro-hydropower in the rural communities of Himachal Pradesh, we focused on understanding the specific needs and requirements of local communities to design a device tailored to meet those interests. Figure 3.1 outlines our objectives and strategies.

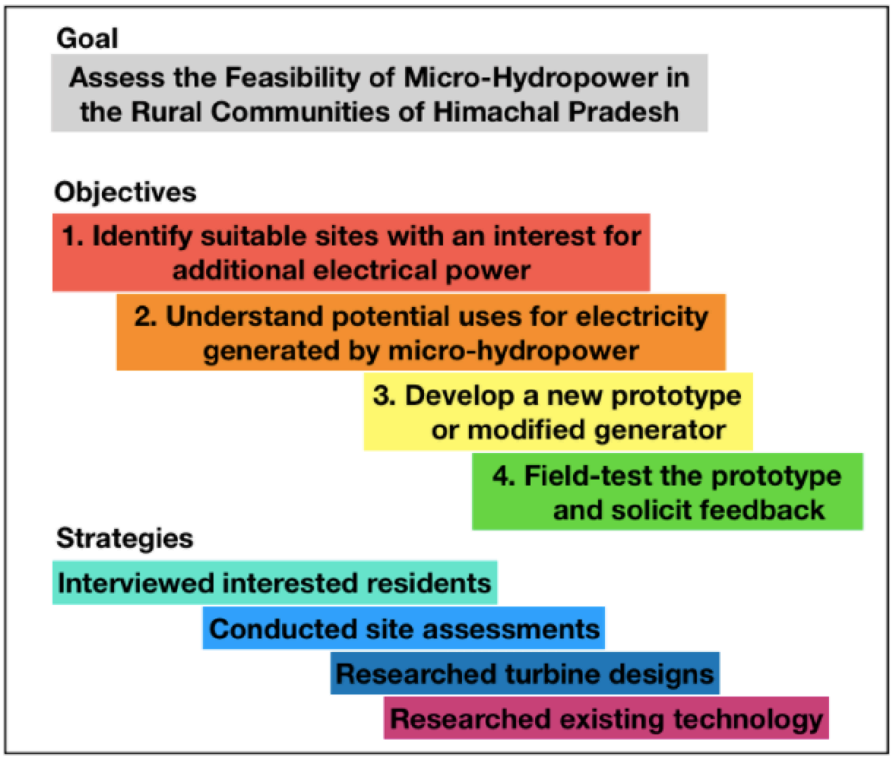

Figure 3.1: Work Flow Chart

3.1. Identify suitable communities

We began by traveling to nearby villages where we anticipated micro-hydro technology would be most applicable. Dr. Rinki Sarkar was very helpful in providing us with detailed information on many of the local villages, as well as giving us preliminary training in conducting interviews. We identified villages near large rivers or perennial streams and interested households using snowball sampling to collect recommendations from area residents. Respondents had a greater knowledge of the area, and steered us towards people who would be most interested in our project. Additionally, we traveled to villages that were not directly adjacent to rivers to see if micro-hydro could also have applications in these areas.

Our strategy not only allowed us to locate viable sites, but also locate current functioning hydro-based technology in the area. Upon locating sites with gharats in the community, we documented the location of each gharat in relation to the surrounding households and gauged opinions on their modification. Ultimately, this all contributed to determining if the community was suitable for the implementation of micro-hydropower technology.

3.2. Understand potential uses

After we had been guided to interested individuals, we conducted interviews to determine the feasible applications of micro-hydropower for individual needs. We conducted 39 interviews across 7 locations using a semi-standardized interview guide (Figure 3.2, Appendix A). The interviews helped us to learn the citizen's opinions of hydroelectric technology, energy usage, and level of interest around micro-hydro technology. We also interviewed a member of the Himachal Department of Energy and a micro-turbine owner to learn about the perspective of government involvement with these projects.

Figure 3.2: Interviews in Saghali

3.3. Develop a new prototype

Our third objective was to design and develop a micro-hydro turbine prototype that could be installed at a suitable location to meet the needs and preferences of the user-base. The plan was to select designs that suit the desires and expectations of individuals, as determined from our interviews. Throughout the interview process we created an appropriate technology rubric, a practice adapted from previous technical projects (Slater et al. 2016). The technology rubric gauges how practical a new technology could be in any given situation and what requirements it must meet to be considered acceptable by the community. Incorporation of the site assessments, interviews, and the rubric was used to create a design matrix that guided development of our prototype. Machining and construction was completed in the IIT machine shop.

3.4. Field test and solicit feedback

The prototype was tested on the IIT Mandi campus to determine if the design met our identified basic power requirement of 100W, determined by the interviews. Once we constructed an operational prototype, we planned to returned to the villages where we conducted interviews to obtain feedback on our design. While we were ultimately unable to complete this field testing, we expected it to further involve the community in the design process and create informed suggestions for future work.

4

Results: Sites and Energy Uses

Here we summarize our findings from site assessments and interviews which helped us design our prototype.

4.1. Identifying suitable sites

Initially, we sought to locate villages with flowing water sources, as we anticipated these villages would be able to best use micro-hydro technology. Speaking with area residents, we identified three villages containing perennial streams: Magal, Arnehar, and Kataula. Two additional communities, Duki and Saghali, did not contain perennial streams, however both had gharats with water channels that we were able to use for research purposes. We also learned of a site between Mandi and Pandoh where a private business owner had installed his own micro-turbine. Figure 4.1 shows a map of these locations as well as the number of individuals interviewed at each location.

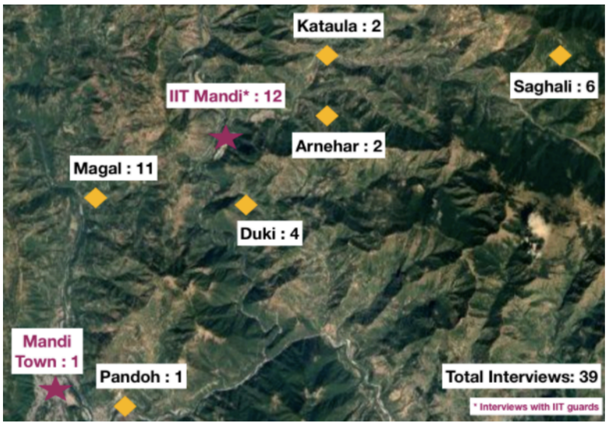

Figure 4.1: Locations of sites visited and number of interviews (Google Maps, 2018)

4.2. Villager energy uses and needs

We discovered that the electrical consumption of most villagers was relatively limited. Villagers mainly use electricity for lights, fans, and televisions. Only 9 of the interviewees had refrigerators or freezers, mainly due to the high costs of the appliances themselves, not the cost of the electricity required to power them. In fact, most villagers' electricity bill is quite low. Figure 4.2 shows the breakdown of electricity costs for the people we interviewed. Additionally, the majority of respondents replied that they were either satisfied with their current amount of electricity or indifferent, i.e. that they were not strongly desirous of additional power. This information is summarized in Figure 4.3.

There were conflicting responses on seasonal variations in energy supply. Around 46% of those interviewed said they had less electricity in the winter while the rest said there was no seasonal variations. These responses conflicted even within individual villages. According to the Himachal Pradesh Department of Energy, neighboring states in India are under agreement to provide electricity to each other

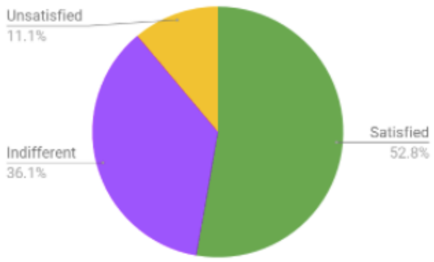

Figure 4.2: Average monthly cost of electricity (Rs.)

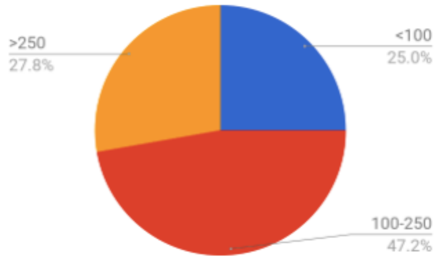

Figure 4.3: Satisfaction with current amount of electricity

during seasonal shortages, so the supply of electricity should be relatively consistent all year long. Those who complained of electric deficiencies in winter mainly wanted to get more use out of their appliances in the winter seasons. There were also conflicting responses on power outages. All residents experience occasional blackouts, but there was no clear consensus on the average duration of these power shortages and whether the villagers were given prior notification.

Residents expressed interest in using micro-hydro to supplement their electrical consumption. Some respondents were more apprehensive than others, stating that they would need to see a specific design or prototype before deciding if it would be suitable for their lifestyle. A major concern amongst those interviewed was losing water to the hydro turbine, as they feel there is a water scarcity already. These fears stemmed from the development of the large scale dams in the region. Villagers have experienced loss of land and water from large scale hydropower projects. They told us that when a dam is put into a river the flow downstream is almost eradicated, while upstream the river floods and causes them to lose land. In fact, villagers in Saghali were so adamant about not losing water for electricity, they voted against the development of new dams, even after being promised a 90% subsidy on the electricity produced. Additional concerns from respondents included price-point, difficulty of installation and use, maintenance, and longevity.

Interviews with a micro-turbine owner and a Department of Energy official gave us a wider perspective on micro-hydro in the area. We learned that the government is willing to provide subsidies on micro-turbine costs for commercial and private use, however there is a fairly extensive application process for these subsidies. Typically the government will coordinate with a private contractor to design and install an appropriate turbine at a given site.

Figure 4.4: View of micro-turbine site

5

Discussion: Sites and Energy Uses

There were three key observations we made through analyzing our interview and site assessment data that aided in forming our prototype design.

First, interviewees did not express need for more electrical power. Almost all residents we interviewed claimed they had enough electricity to power all of the appliance they owned. There is little barrier to people consuming more electricity if they want to, as access to the power grid is widespread and electricity is quite cheap. The low cost of electricity also has important implications on price point for a micro-turbine. Considering the average monthly electricity bill to be around Rs. 150, most residents would only be willing to pay 10-20 months-worth of their electricity bill (Rs. 1,500 - 3,000) for a micro-turbine if it could completely power their homes. This feedback further encouraged us to consider cost as an important component of our prototype.

Second, interviews with gharat owners led us to quickly discard the idea of modifying gharats. We discovered that many gharats have been abandoned in recent years as people are moving towards more modern methods of grinding grain. We also learned that the land gharats are built on is often given by the government to people living below the poverty line, so it is unlikely that these residents would be able to afford installation of a turbine for private use. As a final contrary point, many of the gharat owners we interviewed were fearful of losing land through the encroachment of turbine installations, whether government or private. All these factors led us to instead focus on developing a separate, individual turbine unit. However, the village water channels and kuhls were still considered as potential test sites.

Figure 5.1: Gharat exterior

Third, we identified two main logistical concerns about the feasibility of a micro-turbine: accessibility and preference for off-grid systems. Even in villages with rivers and perennial streams, most residents do not live directly on the water, but rather at higher elevations in the mountains. This led to some concerns on accessibility. To connect a micro-turbine to the power grid, as we originally planned, would require extensive wiring, which would be costly and complex. Additionally, this would not necessarily solve any problem. While additional electricity is not a pressing need of the community, all residents reported that one of their biggest struggles was dealing with power outages. Routine maintenance or construction work on the power grid requires it be regularly shut down by the government. Therefore a turbine connected to the grid would not be useful during a grid-wide shutdown. Most residents simply deal with these outages as a part of daily life, but many were interested in off-grid ways to mitigate their loss of electricity at these times. We learned that some residents are looking into solar power and battery technologies for this application. This, combined with the highly accessible existing electricity infrastructure, led our team to believe that mitigating loss of electricity during power outages was the most appropriate role micro-hydropower could play in the area.

The feedback from our interviews was combined with feedback from similar past projects (Slater et al, 2016) and summarized in the appropriate technology rubric shown in Table 1.

Table 5.1: Appropriate technology rubric

Technical Requirements	Environmental Requirements	Economic Requirements
• Ideally powers entire home, lights and appliances at least • Can be off-grid • Minimal and easy maintenance • Long lifetime • Resistant to corrosion • Portable and maneuverable by single person • Easily accessible	• Does not consume water • Operational in all seasons • Does not contaminate water source • Constructed from inert materials • Endures variable weather and monsoon floods	• Max cost for individuals: Rs. 3000 • Max cost for multiple households: Rs. 10,000 • Inexpensive maintenance • Implementation leads to cheaper electricity in long term • Monthly payment plan made available

6 Prototyping and Testing

Using site visits and interview responses, we designed a small scale turbine that was to be low-cost, have minimal ecological impact, and work to mitigate loss of electricity during power outages. We also worked to fulfill as many criteria from Table 5.1 as possible.

Due to time and cost constraints, we aimed at developing a proof-of-concept. We elected to build our proof of concept based off of an existing turbine blade given to us by the IIT mechanical lab as it was readily available and we were unable to machine our own turbine blade. We chose aluminum as the frame material for its low cost, ease of machining, and resistance to corrosion. Figure 6.1 illustrates the first iteration of our prototype. All machining and construction was completed in the IIT mechanical lab.

The IIT test site was located near South Campus at a spot in the river with sufficient depth to fully submerge the turbine blades. After testing several dynamos and coupling one with an amplifier, we were able to create a system that could power three LEDs when tested.

Figure 6.1: First iteration of micro-hydro turbine prototype

6.1. Limitations

The prototyping process was severely limited by time constraints, available materials, and machining methods. While aluminum was readily available, the shaft, bearings and gears were difficult to acquire. Additionally, we were unable to machine customized turbine blades, as the IIT mechanical lab did not have the capacity to machine curved surfaces. Optimal design of a micro-turbine relies on each part being designed to work together for the most possible electricity generation at a specific site. The greatest difficulty for our project was in finding an effective dynamo. It came to a process of finding whatever pre-built dynamos were available and testing them with known rotation spend to see if they could produce a useful amount of electricity. Even the best dynamo we found still required an amplifier to create an effective system. In spite of these challenges, we were able to construct a functional prototype and understand the challenges of designing micro-turbines as well as their potential impact in rural communities throughout the process (Figure 6.2). While the prototype we created is far from market-ready, the information compiled in Table 5.1 for system requirements will be very valuable to future work on micro-hydro in Himachal Pradesh.

Figure 6.2: Results of prototype testing

7 Project Outcomes and Conclusions

The results of our prototyping and research lead to two recommendations for future designs and implementation of micro-hydropower and other renewable energy technologies in Himachal Pradesh

7.1. Technical recommendations for micro-turbine designs

While micro-hydro *could* be a solution to mitigating electricity loss during grid outages, further research must be done in order to determine how it can be best implemented. The two technical aspects that require the most investigation are how to increase rotation speed of the turbine blades and a better understanding of what kind of dynamos can generate the most power. Three additional social and environmental factors should be further investigated: a) how to increase turbine access to people who do not live directly on flowing water sources, b) how to lower the cost of the turbine, and c) more documentation of water sources that can produce a usable amount of energy. In the meantime, we recommend that residents of Himachal Pradesh who are interested in water turbines coordinate with their local Department of Energy, as there are government procedures and subsidies for building and installing micro-turbines.

7.2. Alternative solutions

Other opportunities and options for supplemental energy from renewable sources should be explored. Micro-hydropower is only one of several viable options of providing renewable and off-grid electricity to rural residents. There are subsidies for wind and solar power, and several residents have already looked into purchasing these technologies. Solar power appears to be particularly promising. Solar panel design is relatively site independent as compared with wind and hydro, the industry is growing quickly in India (Chandrasekaran, 2017), and solar can be developed for the same uses we aimed our micro-hydro prototype at addressing (Prasad, 2016). Many villagers are also looking into battery technologies for storing power to use during outages. We recommend researching the feasibility of expanding other renewable energy sources in addition to continuing research on micro-hydropower.

7.3. Conclusions

It is difficult to say with confidence whether or not micro-hydropower is a feasible technology for Himachal Pradesh. Our research indicates that the residents do not lack electricity, but lack a consistent energy source due to power outages and perceived seasonal variations in access. Therefore, we believe the best application of micro-hydropower technology is to mitigate loss of electricity during extended power outages. While our prototype did not meet the expected level of performance, it was far from an optimal system, with many components that could be improved upon with additional time and resources. Since we were not able to test our prototype in village communities due to time constraints, factors such as long term use and maintenance could not be recorded or commented on. Further research will need to be completed to fully understand how feasible micro-hydropower is in Himachal Pradesh and if there is a micro-hydro turbine design that is more suitable for the area. Additionally, more research could be done on the feasibility of extending solar and wind power to the rural communities of Himachal. Overall, we hope our project contributed to an increased understanding of the role renewable power technologies can play in Himachal Pradesh.

8
References

Agrawal, A., Garg, A. Leiro, A., Lentz, M., & Paredes, D. (2015). Assessing Gharats in the Kamand Valley (Undergraduate Interactive Qualifying Project). Retrieved from Worcester Polytechnic Institute Electronic Projects Collection: https://web.wpi.edu/Pubs/E-project/Available/E-project-050115-024528/unrestricted/Assessing_Gharats_of_the_Kamand_Valley-_IQP_India.pdf

Bhakra Beas Management Board. Dehar Power House. (2017, November 17) Retrieved from http://bbmb.gov.in/dehar.html

Chand, H., Verma, K. S., & Kapoor, T. (2016). Environmental impact assessment of Kol-Dam hydropower project – A case study from Himachal Pradesh, India. *Current World Environment, 11*(1), 167-177. doi:10.12944/CWE.11.1.21

Chandrasekaran, K. (2017). India's solar energy capacity expanded by record 5,525 MW. *The Economic Times,* 06 April 2017, retrieved at https://economictimes.indiatimes.com/industry/energy/power/indias-solar-energy-capacity-expanded-by-record-5525-mw/articleshow/58037873.cms

Government of India, Ministry of Power. (2018). *FAQ's on Hydropower.* New Delhi, India: Author http://powermin.nic.in/en/content/faqs-hydropower

Harrelson, Cheryl C; Rawlins, C. L; & Potyondy John P. (1994, April). Stream Channel

Human Centered Design (2011). (2nd ed). s.l.: IDEO. Reference Sites. Retrieved on February 27, 2018, from https://www.fs.fed.us/rm/pubs_rm/rm_gtr245.pdf

Himachal Pradesh Directorate of Energy (HPDOE) (2017, October 31), *Status of Hydro Potential in Himachal Pradesh, HPDOE.*

Hudson, P., Hudson, R (2012), History, *Settle,* accessed at http://www.settle.org.uk/history/

Frequently asked questions. *Idenergie,* Retrieved from http://idenergie.ca/en/frequently-asked-questions/

Jagnoor, J., Suraweera, W., Keay, L., Ivers, R. Q., Thakur, J., & Jha, P. (2012). Unintentional injury mortality in India, 2005: Nationally representative mortality survey of 1.1 million homes. *BMC Public Health, 12*(1), 487. doi:10.1186/1471-2458-12-487

Kubecka, J., Matena, J., & Hartvich, P. (1997). Adverse ecological effects of small hydropower stations in the Czech Republic: 1. Bypass plants. *Regulated rivers: research & management, 13*(2), 101-113.

Kumar, D., & Katoch, S. (2015). Sustainability suspense of small hydropower projects: A study from western Himalayan region of India. *Renewable Energy,* 76, 220-233. 10.1016/j.renene.2014.11.025

Lal, K. (2003, January 12). Beas-Sutlej Link Project bane of Balh Valley. *The Tribune India.* Retrieved from http://www.tribuneindia.com/2003/20030112/himachal.htm#3

Lune, H., & Berg, B. L. (2017). *Qualitative research methods for the social sciences* (8th ed.). Harlow, England: Pearson.

Prasad, R. (2016) Now, solar energy can power air conditioner, refrigerator. *The Hindu,* 21 March 2016, Retrieved from http://www.thehindu.com/todays-paper/tp-features/tp-educationplus/now-solar-energy-c article8378355.ece

Pujol, T., Vashisht, A., Ricart, J., Culubret, D., & Velayos, J. (2015). Hydraulic efficiency of horizontal waterwheels: Laboratory data and CFD study for upgrading a western Himalayan watermill. *Renewable Energy: An International Journal*, 83576-586. doi:10.1016/j.renene.2015.04.060

Richter, B. D., Baumgartner, J. V., Powell, J. and Braun, D. P. (1996), A Method for Assessing Hydrologic Alteration within Ecosystems. *Conservation Biology*, 10: 1163–1174. doi:10.1046/j.1523-1739.1996.10041163.x

Sharma, R. C., Sharma, R., Bisht, Y., & Singh, D. (2008). Gharats (watermills): Indigenous device for sustainable development of renewable hydro-energy in Uttrakhand Himalayas. *Renewable Energy, 33*(10), 2199-2206. doi:10.1016/j.renene.2007.12.023

Sinclair, A. J. (2003). Assessing the impacts of micro-hydro development in the Kullu District, Himachal Pradesh, India. *Mountain Research and Development, 23*(1), 11-13.

The Tribune News Service (2005, March 10). CM ups the ante on reviving Mandi's ecology. *The Tribune India.* Retrieved from http://www.tribuneindia.com/2005/20050311/himachal.htm#1

The Tribune News Service (2015, December 18). Central Team inspects Shanan Power house. *The Tribune India.* Retrieved from http://www.tribuneindia.com/news/himachal/central-team-inspects-shanan-pow 172136.html

Vashisht, A. K. (2012). Current status of the traditional watermills of the Himalayan region and the need of technical improvements for increasing their energy efficiency. *Applied Energy*, 98, 307-315. doi:10.1016/j.apenergy.2012.03.042

Wazad, M. A. & Ahmed, S. (2008), Micro Hydro Energy Resources in Bangladesh, *Australian Journal of Basic and Applied Sciences 2*(4) pp 1209-1222

Wölz, J., Engwall et. al. (2008). Changes in toxicity and ah receptor agonist activity of suspended particulate matter during flood events at the rivers neckar and rhine — a mass balance approach using in vitro methods and chemical analysis. *Environmental Science and Pollution Research, 15*(7), 536-553. doi:10.1007/s11356-008-0056-6

A

Appendix A: Interview Guide

Begin by explaining we are from IIT, looking into developing small-scale water turbines for personal household use, looking to get opinions on the project

Preliminary questions:

- Would you be interested in this project and willing to be interviewed?
- Is there any specific person or household in your village that would be interested?
- Do you know of other villages nearby that may be interested?
- Are there mechanical hydropower (like gharats) systems or water wheels that are used in this area? What are they used for?

Recorded questions:
For people who have an interest and would like to be further interviewed, try to get an understanding of what their needs are and how they would use this technology.

- What do you mainly use your electricity for
- Are you satisfied with the amount of electrical power you currently have?
- How much money do you pay for electricity per month and per unit?
- Is the government subsidizing any of this cost?
- If you had more electrical power what would you use it for?
- Are there currently unpowered areas on your property that you would like access to electricity at?
- What are the seasonal variations in your electricity?
- Do you lose power? If so, for how long?
- What is most necessary to be powered when you lose electricity?
- Do you have any ideas on how to obtain additional electricity?
- Do you think a portable water turbine would be a good way to supplement your electricity? What are your opinions on the project idea?
- Do you have any design ideas for a water turbine?
- What new problems or complications, if any, would you expect micro turbines to introduce?
- What is the limit on what you would be willing to pay for a water turbine?

Additional questions for gharat owners and operators:

- How long have you owned and/or operated this gharat?
- Are there times of the year when you are unable to use your gharat?
- Do you believe access to electricity at this site would help in your work process at all?
- What are some uses the gharat or gharat storehouse could get from electrical power? Would a light bulb for night time lighting interest you?
- What are the regulations on modifying this gharat? Is this gharat still in service?

Question for turbine owners producing electricity:

- What type of dynamo is used to produce electricity? (Is the design of the system open sourced?)
- How is power supplied to the villages?
- How many people utilize the power from a single generator?
- How much power is provided on average?
- What is/was the generator powering?
- Who maintains the generator?
- How is excess energy utilized?
- Is the generator still functional? If not, why?
- Who was the main contact for the generator?
- Who installed the generator?

B

Appendix B: Open House Poster

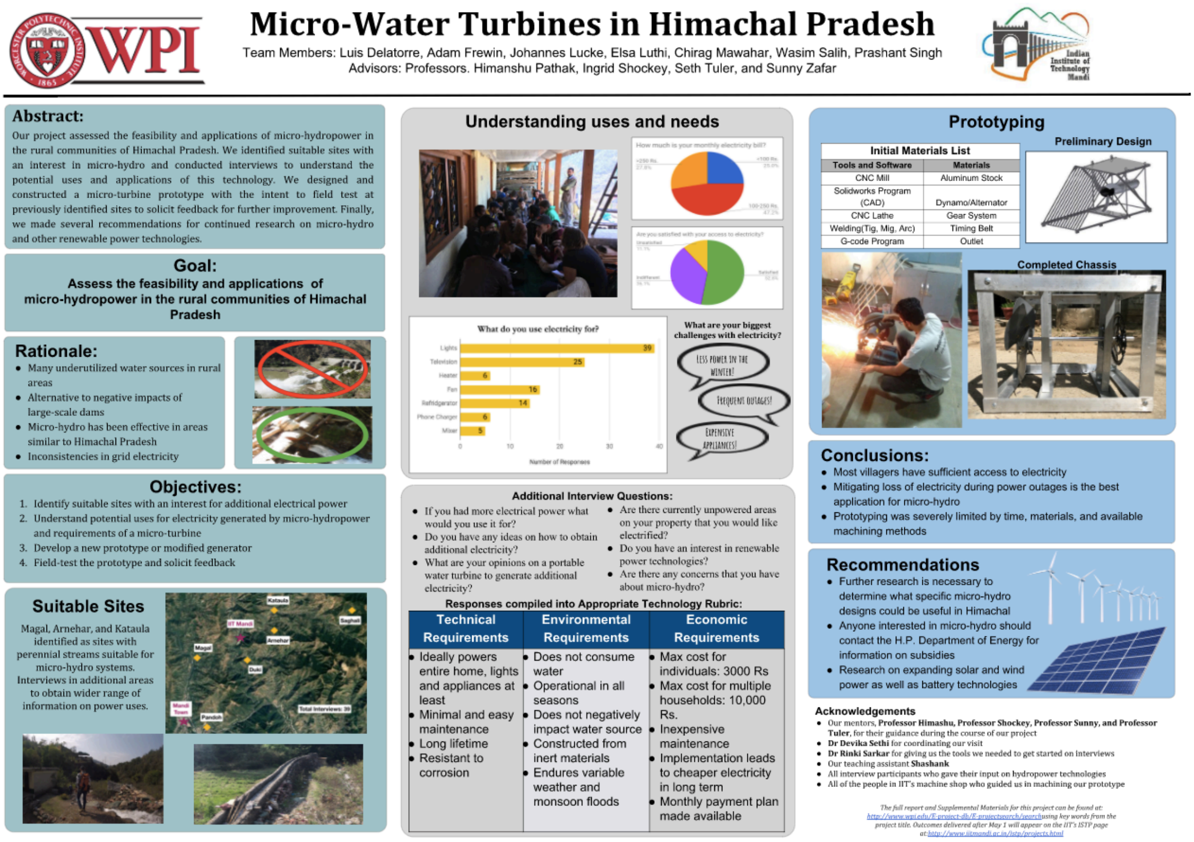

Figure B.1: Open house poster

C

Appendix C: Materials list and original design schematic

Table C.1: Materials list

Tools and Software	Materials
CNC Mill	Aluminum Stock
Solidworks Program (CAD)	Dynamo/Alternator
CNC Lathe	Gear System
Welding(Tig, Mig, Arc)	Timing Belt
G-code Program	Outlet

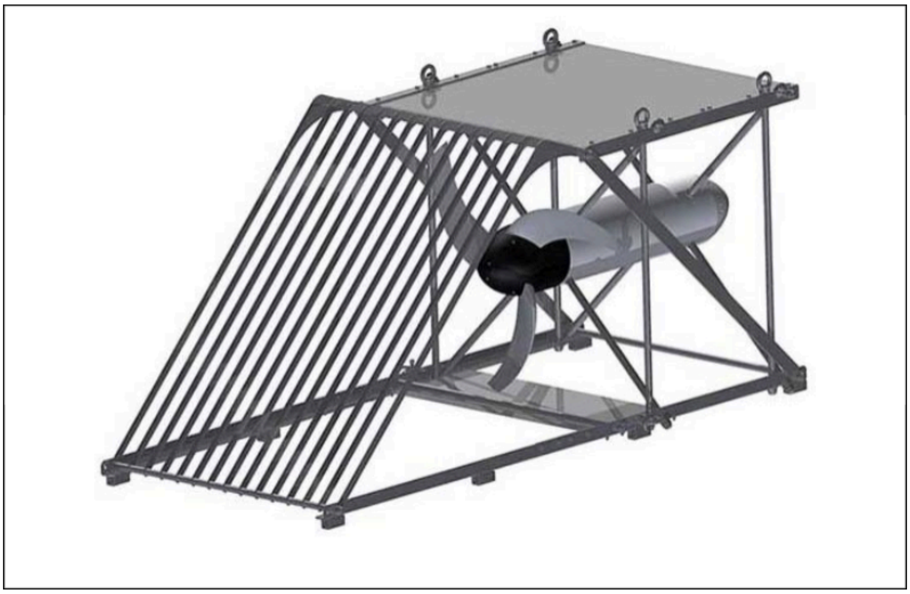

Figure C.1: Original design schematic