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Extending Electric Service to Rural Nepal

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Extending Electric Service to Rural Nepal

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Foreword

The Lyndon B. Johnson School of Public Affairs has established interdisciplinary research on policy problems as the core of its educational program. A major element of this program is the nine-month policy research project, in the course of which one or more faculty members directs the research of ten to twenty graduate students of diverse disciplines and academic backgrounds on a policy issue of concern to a government or nonprofit agency. This “client orientation” brings the students face-to-face with administrators, legislators, and other officials active in the policy process and demonstrates that research in a policy environment demands special knowledge and skill sets. It exposes students to challenges they will face in relating academic research, and complex data, to those responsible for the development and implementation of policy and how to overcome those challenges.

The curriculum of the LBJ School is intended not only to develop effective public servants, but also to produce research that will enlighten and inform those already engaged in the policy process. The project that resulted in this report has helped to accomplish the first task; it is our hope that the report itself will contribute to the second.

This project evaluated the potential in rural Nepal for using renewable energy for village electrification, including solar, wind, micro-hydro, and biomass/biogas sources. Research took place in 2017-2018. The report discusses how to estimate energy demand and use supply models to evaluate village electrification projects. If capital costs can be paid over time through electricity user fees, it is already feasible for rural communities now distant from Nepal’s electric grid to pay for electricity for home lighting and recharging cell phones. Electrification of rural infrastructure can be feasible if government or nonprofit sources can subsidize capital costs for water pumping, computer use, and refrigeration.

One challenge for Nepal is the choice of technology for each village, as the costs and benefits of solar, wind, micro-hydro, and biomass and biogas sources vary by location. A second issue is how to finance capital and operating costs of village electrification. This report develops recommendations for electrification in two Nepali villages, Kothape and Rakathum, which are now distant from the existing Nepali electric grid.

Neither the LBJ School nor The University of Texas at Austin necessarily endorses the views or findings of this report.

Angela Evans
Dean

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This report was drafted by Samer Atshan, Marshal Atwater, Cody Brasher, William Delgado-Thompson, Katherine Drews, Casey Floren, Ashlee Frandell, Catherine Harris, Caleb Mangohig, Kristy McCarville, Casey Roberts, Dovile Vilkauskaite, and Sara Wadud, with the advice of David Drew, Cristina Mendez, and Drake Hernandez. This report is based on fieldwork by graduate students, staff, and faculty from Nepal, Japan, and the USA; contributors are listed above as project participants. Lauren Jahnke copyedited the report.

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Executive Summary

This project examines the feasibility of expanding electrical service into rural villages not currently serviced by Nepal's electrical grid. One hypothesis is that renewable energy sources can enhance each village's economy and improve rural Nepal so as to produce local wealth and employment. The operational definition of "development" includes enhanced educational attainment, business development, and an improved quality of life and health. A key question is whether village electrification can be sustainable and cost-effective by providing electricity to light homes, schools, small businesses, health clinics, or pump water for drinking and irxviiogation. This project evaluated the technical and economic options to provide electric power based on different demand scenarios.

Any effort to extend electric service to rural villages in Nepal distant from the grid would be based on a choice between grid extension (where that is feasible) versus renewable energy options such as solar, wind, micro-hydro, or biomass. Electric service is feasible only if rural residents can pay through user fees for operating costs as well as capital costs not covered by government subsidies or nongovernmental organization donations or investments. Rural electrification faces challenges beyond cost, such as Nepal's mountainous terrain, available economic resources in each village, demographics, as well as each village's system of local governance.

A group of graduate students supported by staff and faculty from Tribhuvan University, Hiroshima University, and The University of Texas at Austin participated in a research project in 2017-2018 to evaluate prospects for electrification of two villages in rural Nepal. Project participants worked with representatives of Nepali government agencies and nonprofit organizations. Students visited two villages, Rakathum and Kothape, which have yet to be connected to Nepal's electric grid.

After evaluating the potential for grid extensions or renewable energy options for Kothape and Rakathum, students concluded that micro-hydro and wind micro-grids would not be feasible for those villages due to the absence of a sufficient hydraulic head nearby and prevailing wind speed too weak to sustain power generation, respectively. Study participants observed that the villages, although isolated, already had access to electricity via solar panels to charge cell phones and lights in homes, as well as laptops at the schools.

As the villagers in Kothape and Rakathum earn their income primarily from farming, students evaluated the potential benefits from expansion of solar energy projects to supplement irrigation as well as use of biomass/biogas for household purposes. Connection to the existing grid also could be considered, given government initiatives in the area. It is beyond the scope of this project to determine how energy demands in Kothape and Rakathum could best be met, as such decisions will reflect potential subsidies or contributions from the Government of Nepal, non-profit organizations, philanthropic donors, and village residents.

Chapter 1. Nepal and the Study Area

This project investigated the potential for micro-hydro, solar, wind, biomass/biogas, and grid extension plans to provide electricity to rural Nepali villages. Participants in this study began by developing potential energy demand from homes, based on a few demand scenarios. Students evaluated the feasibility of extending and increasing electric service based on demand scenarios for homes, schools, and possible business ventures in the villages of Rakathum and Kothape.

Feasibility was measured by comparing potential costs to benefits, including variables such as villager income, lifestyle and preferences, the surrounding environment, government or nonprofit/donor subsidies, and existing energy projects.

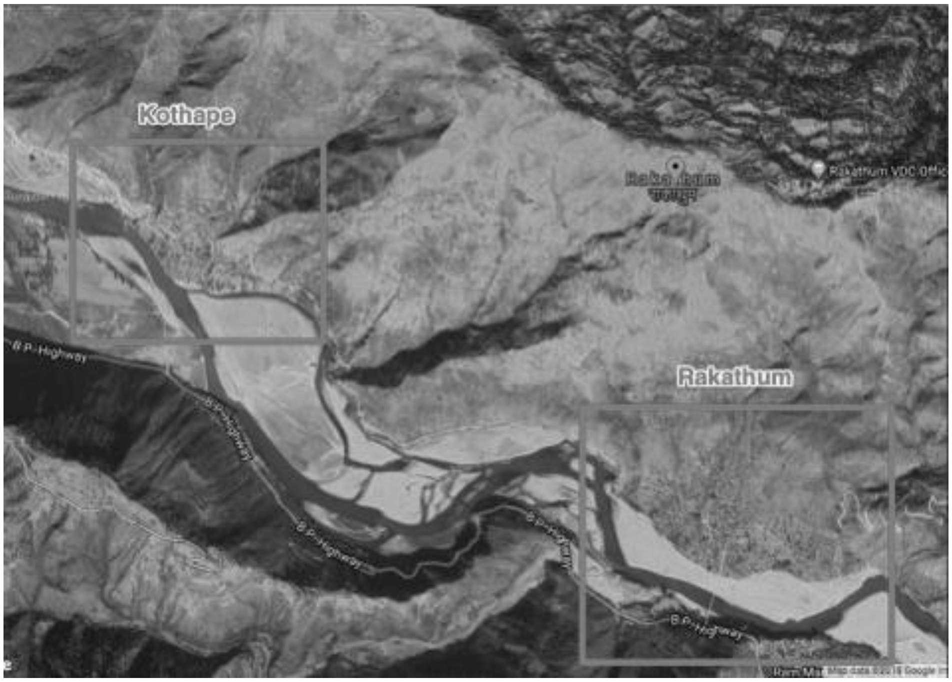
The Federal Democratic Republic of Nepal, a country in Southern Asia located between China and India, has an area of 147,181 square kilometers (km^2). Nepal's climate varies from warm humid summers to cool winters in the central valleys, and subtropical summers and milder winters to the south. The terrain includes the plain adjacent to India, a flat river plain within the Ganges and Brahmaputra river basins, as well as the high peaks of the Himalaya Mountains in the north adjacent to China. The mean elevation of the country is 2,565 meters. In Nepal, 28 percent of the land is used for agriculture and forest covers one-fourth of the country.[1]

According to a July 2017 estimate, the population of Nepal is around 29 million, more than half (52 percent) of whom are under the age of 24. Life expectancy for males is 70 years and for females is 71 years. About 64 percent of individuals over the age of 15 are able to read and write, although 34 percent of children ages 5 to 14 participate in child labor. About 11 percent of citizens are internet users and 53 percent use mobile phones.[2] One-quarter of the population of the country lives below the poverty line, making Nepal one of the least developed countries in the world. Remittances from Nepali citizens living abroad make up around 30 percent of the gross domestic product (GDP). Agriculture provides the livelihood for two-thirds of Nepali citizens but only contributes one-third to its GDP.[3]

Nearly one-fourth of the population, or about 6.6 million people, live without electricity in Nepal. Nepal faces natural and social obstacles developing electricity. For example, Nepal suffered a massive earthquake in 2015 that damaged infrastructure and impeded economic development. Hydropower generates most Nepali power (93.8 percent of total installed capacity), while only 6.2 percent comes from fossil fuels. It is estimated that Nepal has a larger scope for hydropower with 43,000 megawatts (MW) of commercially feasible capacity, though most of that capacity has yet to be developed and foreign investment in the electricity sector remains modest.[4]

To evaluate the potential for the extension of electricity to Nepal's rural communities, this project focuses on two communities in Nepal visited by project staff, Rakathum and Kothape, located in the Khadadevi Rural Municipality, along the Bishweshwar Prasad Koirala Highway (B.P. Highway). Figure 1.1 illustrates the location of Kothape and Rakathum in the Sunkoshi River Valley and along the B.P. Highway. Figure 1.2 is a map of State 3 that shows the location of Khadadevi Rural Municipality, where the study villages Rakathum and Kothape are located.[5]

Figure 1.1. Location of Rakathum and Kothape Villages



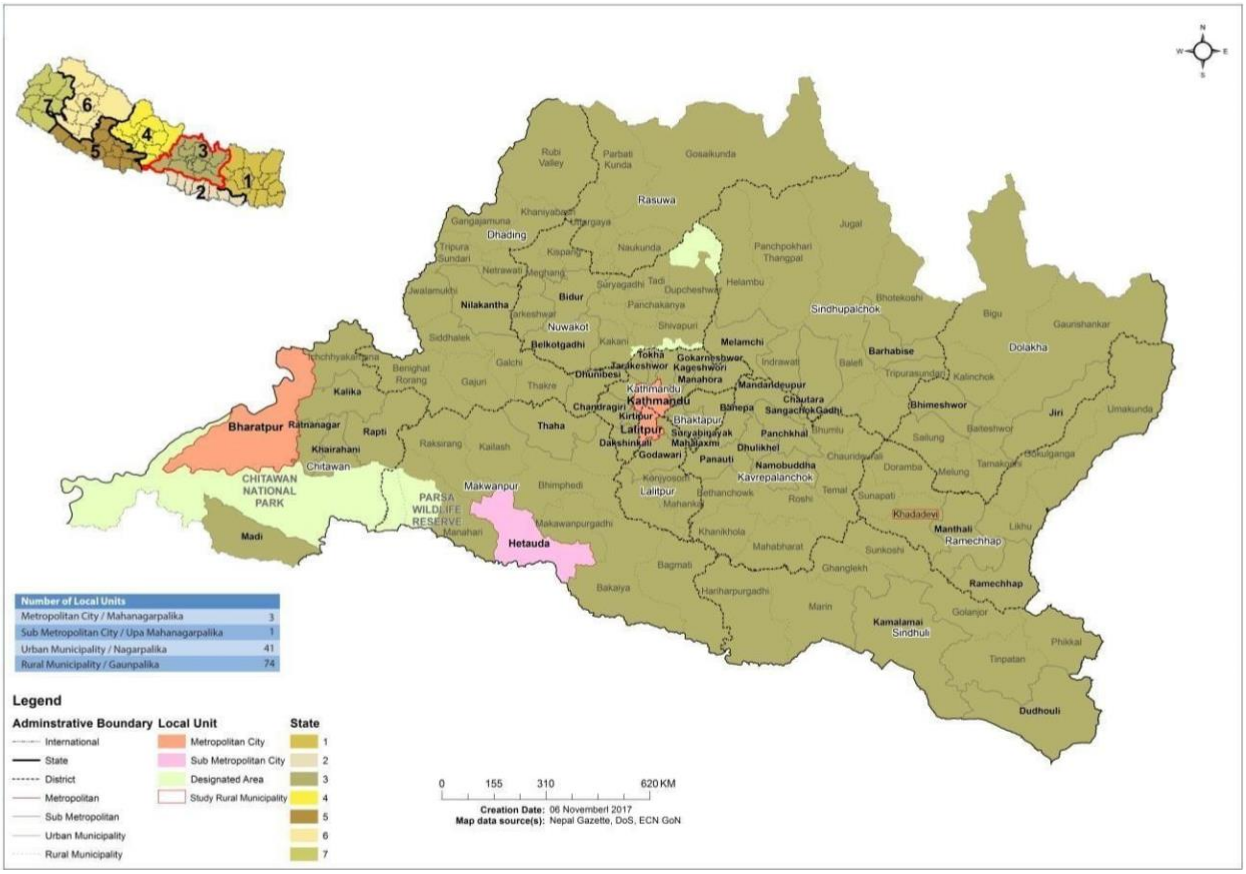
Source: Google Maps, Nepal, https://www.google.com/maps, accessed May 7, 2018.

Rakathum

Rakathum is a three-hour drive from Kathmandu and can be accessed by crossing the Sunkoshi River on a suspension bridge by foot. The main electric grid is on the opposite side of the river, about 500 meters away. The village is home to 407 people whose primary economic activities are agriculture and animal husbandry of chicken, goats, and buffalo.[6] There are one primary school and two small stores in the village. Villagers living in Rakathum must walk for about 30 minutes to access a health center located in a different village.

Rakathum is situated on the banks of the Sunkoshi River, which flows about 10 meters downhill from the village. There is a solar water pumping system that supplies drinking water to a collection tank. The system supplies water to the public for two hours each morning from the collection tank. Villagers can collect what water they need for the next 24 hours from a pipe connected at their house. The solar water system, financed by Nepal’s Alternative Energy Promotion Centre (AEPC), pumps groundwater from a depth of 10 to 12 meters. Each village household currently has a 20-watt solar home system to provide LED lighting and limited cell phone charging. The school has a 50-watt solar system that powers four laptop computers and lighting. Project staff observed that there is no physical infrastructure in Rakathum (such as paved roads) or utilities (such as water or electricity).

Figure 1.2: Map of State 3 Showing Study Rural Municipality



Source: United Nations, Administrative map of Nepal State 3 showing the study rural municipality, http://un.org.np/sites/default/files/Map4_Nepal%20Administrative_State3_A1_06Nov2017_v01.jpg.

Kothape

Kothape, the second village, is accessible by a three-hour drive from Kathmandu after crossing the Sunkoshi River and walking about one hour past Rakathum. The village can be accessed by using local assistance to float across the river on a makeshift raft, as there is no bridge connecting the village to the main road. The distance to the main grid is about 500 meters.

This village has about 52 households, with an average household size of four to five individuals. There is one primary school in the village that serves children up to third grade. The main economic activities of Kothape are subsistence farming (which is viable for six months out of the year) and animal husbandry of poultry, buffalo, cows, pigs, and goats. Villagers also sell livestock and fish caught from the river on the main road. Due to reduced flow in the Sunkoshi River, the supply of fish in the river has recently been dwindling. Villagers must walk about one hour to reach a health center. The Community Development Society (CDS), a non-governmental organization (NGO) with its head office in the district headquarter Manthali, has recently constructed a small clinic building that is yet to be staffed by medical personnel. The CDS funded installation of a solar water system in the village that pumps water into a tank available to villagers for two hours each morning. The CDS is planning to implement a solar water irrigation system in Kothape, as its land has become less arable in the last several years due to increased drought incidence.

Project staff observed that most households in Kothape have home solar photovoltaic (PV) systems that provide enough electricity for LED lighting and charging cell phones.

1 “The World Factbook: Nepal,” Central Intelligence Agency, November 14, 2017, accessed November 22, 2017, https://www.cia.gov/library/publications/the-world-factbook/geos/np.html.

2 “Statistics,” The United Nations International Children’s Emergency Fund (UNICEF), 2017, accessed November 22, 201, https://www.unicef.org/infobycountry/nepal_nepal_statistics.html

3 Ibid.

4 “Nepal,” International Hydropower Association, updated May 2019, accessed April 8, 2018 https://www.hydropower.org/country-profiles/nepal.

5 United Nations, Administrative map of Nepal State 3 showing the study rural municipality, http://un.org.np/sites/default/files/Map4_Nepal%20Administrative_State3_A1_06Nov2017_v01.jpg.

6 Observations by project participants in Nepal, March 2018.

Chapter 2. Energy Options and Field Observations

Extending Nepal's electric grid to isolated villages in mountainous Nepal would be costly and community poverty may not allow rural residents to cover its capital, operation, and maintenance costs. One alternative to grid extension is to install relatively small, inexpensive electrical sources (solar, wind, biomass, or hydro) that are not technically complex within isolated villages. Subsidies from the Government of Nepal or philanthropic donors can pay for some capital costs. Business or financial plans can spread remaining capital costs over time through user fees so as to pay for operation and maintenance costs.

Electricity can be extended through either a stand-alone generator (such as a wind turbine or solar panel) or a generator connected to an energy storage or distribution center. A "micro-grid" is a local energy grid with limited capacity that can operate separately from a central power grid.[1] Micro-grids can be powered by a combination of generators, batteries, and renewable resources. A separate electrical micro-grid can enable isolated communities to be energy independent based on their local supply of resources. A micro-grid energy can be scalable to power a single building or an entire community. Micro-grids can include renewable energy sources to provide a dependable and sustainable electricity that is independent of a national grid. Renewable options include hydro (micro or even pico-hydro), small scale solar, wind, or biomass and biogas, as discussed below. Village electrical utilities can be created to operate renewable energy based on user fees.

This section evaluates energy options for the two villages, Rakathum and Kothape; in both cases small solar photovoltaic systems are cost-effective. Biomass and biogas are widely used as energy sources and biogas is appropriate in these two villages. Grid connection of both villages could be possible in coming years. After considering the options, micro-hydro and wind micro-grids do not appear to be viable solutions for Rakathum and Kothape. Comparable geographical factors will influence the cost-effectiveness of sources for other rural villages in Nepal. This chapter's results illustrate how to evaluate alternate renewable energy options.

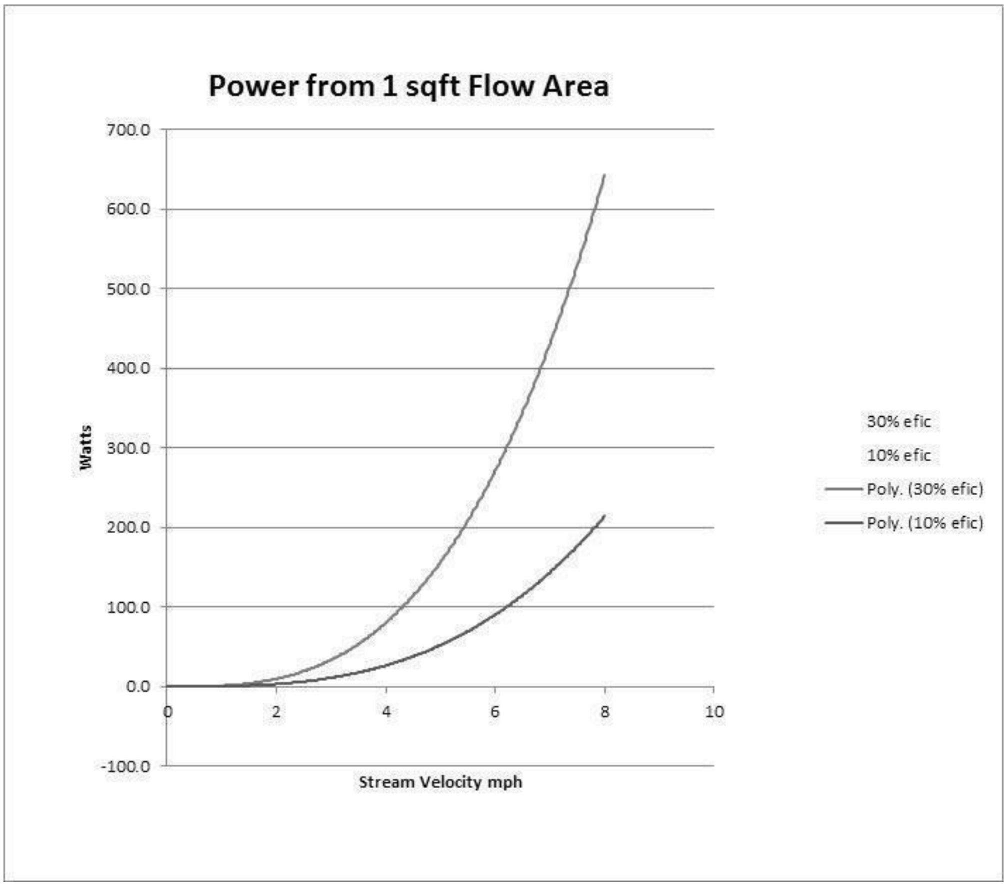
Micro-Hydro Technology

Micro-hydro systems harness falling water to generate electricity. These systems can generate electricity through "run-of-the-river" or even reliable groundwater flows that divert water into a pipeline that leads to a power house containing a turbine which turns a generator and generates electricity.[2] The Alternative Energy Promotion Center, part of the Nepal government, uses "micro-hydro" to refer to a plant that generates more than 10 to 100 kilowatts (kW) of electricity.[3] By contrast, a small conventional dam may generate approximately 10 megawatts (MW) of electricity, one hundred times more electricity than a micro-hydro plant.

Hydropower systems range from small hydropower, which produces up to 10 MW, to mini-hydropower, which produces power from 100 kW to 1 MW.[4,5] Smaller systems are labeled micro-hydro if they produce less than 100 kW or pico-hydro if they produce less than 5 kW, or 10 kW in Nepal's case. A micro-hydro or even pico-hydro system can provide adequate electricity for a small village, depending on its diurnal demand.

While a high-efficiency water turbine can operate at around 60 percent efficiency (conversion of energy into motion), energy efficiency values are closer to 35 percent for a conventional modern turbine or 20 percent for a water wheel.[6] Figures 2.1 and 2.2 illustrate the relationship between energy output and flow rate in the form of an energy output curve; more efficient energy conversion can enable higher capacity than less efficient devices. If a lower wattage output is needed and finances are tight, a small pico-water wheel may be sufficient. If a turbine is to power more uses, it makes sense to invest in a more modern, efficient turbine.

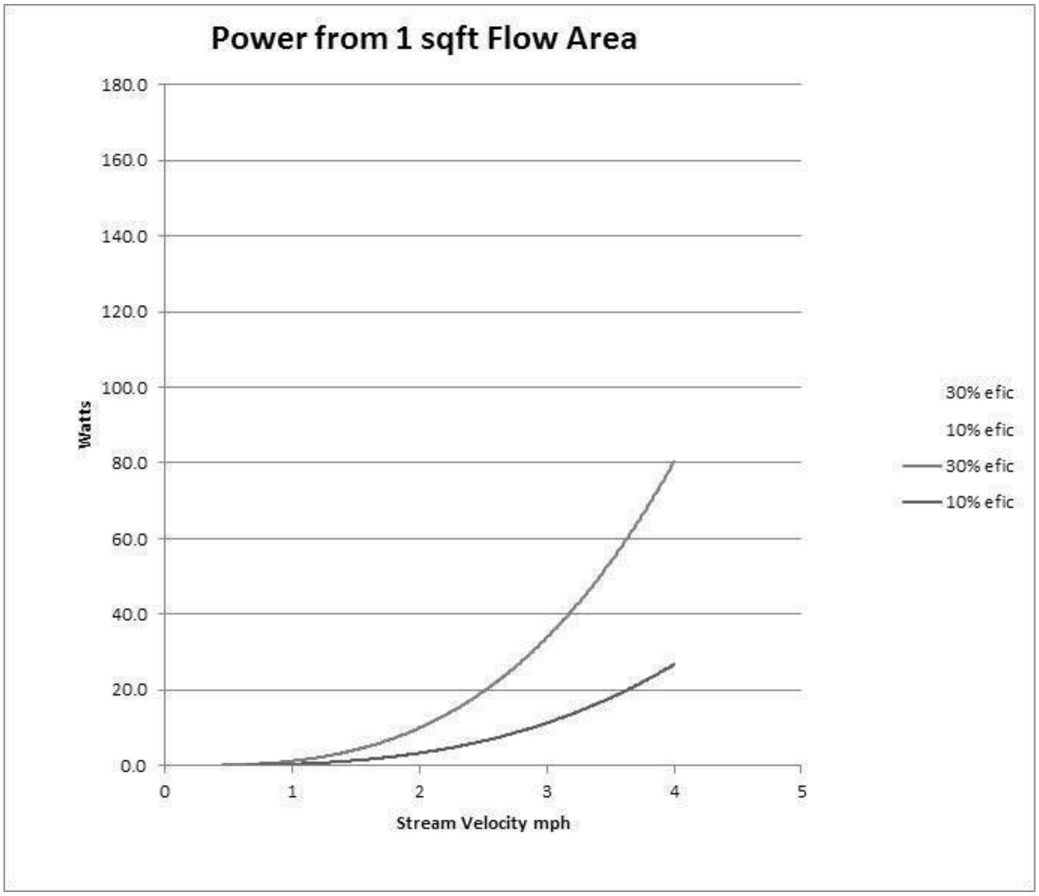
Figure 2.1. Power Potential from a Fast-Flowing River



Source: Build It Solar, "Flow of River Hydro—Using Only Stream Velocity to Drive a Turbine," http://www.builditsolar.com/Projects/Hydro/FlowOfRiver/FlowOfRiver.htm, accessed February 24, 2018.

Run-of-river systems divert water from a river through a channel, pipeline, or pressurized pipeline that delivers or channels water to a power house and eventually discharges the water back to the river.[7] The energy of flowing water is transformed into rotational energy by a turbine, pump, or waterwheel. That rotational energy is then transformed into electricity by an alternator or generator controlled by a regulator. Generated electricity is delivered through a distribution system of wires that lead to homes or businesses. Figure 2.3 illustrates these components, as well as the process by which a run-of-river system functions through the diversion of water from a river or stream, through a weir and settling basin, into a forebay tank, through a penstock, and into a powerhouse, where it runs through the turbine. Compared to larger-scale methods of capturing hydroelectricity, such as a dam, this method has a comparatively lower environmental impact because both the volume of water withdrawn and return flow are modest.

Figure 2.2. Power Potential from a Slow Flowing River

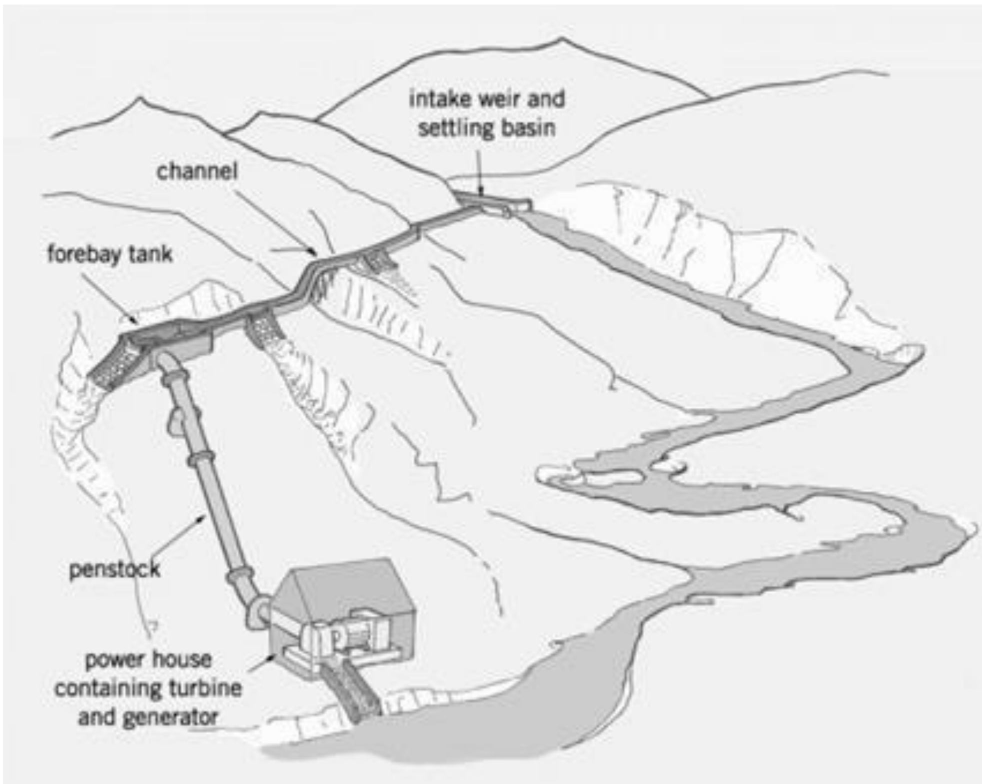


Source: Build It Solar, "Flow of River Hydro—Using Only Stream Velocity to Drive a Turbine," http://www.builditsolar.com/Projects/Hydro/FlowOfRiver/FlowOfRiver.htm, accessed February 24, 2018.

There are diverse types and sizes of micro-hydro systems available, depending on the environment, streamflow rates, and the "head," the altitude differences between hydro intake and discharge. Impulse turbine designs are used in rivers with high head; examples are a Pelton wheel, Turgo impulse wheel, or jack rabbit turbine. The Pelton wheel works by funneling water through a narrow-pressurized pipe so that it sprays into buckets and turns the wheel. The Turgo impulse wheel is similar in concept, though this wheel is smaller and angled so the spray of water will hit three buckets at once instead of one. The jack rabbit turbine is a flexible, drop-in-the-creek system that can generate a maximum of 100 watts at a stream with a depth of just 13 inches. Daily output from this system can average 1.5 to 2.4 kilowatt-hours, depending on the site.[8] Pumps and water wheels can be scaled in size up or down and are relatively inexpensive.

Reaction turbines are efficient hydropower systems used in large-scale projects that depend on water pressure instead of the velocity that comes from a spray of water. It is unlikely that they would be useful in a small village given the need for smaller scale systems. Conventional massproduced pumps can be used in place of a hydraulic turbine, though they are less efficient than other methods. The source of water used to power a turbine at a site should have a constant head and flow to drive a pump effectively.

Figure 2.3. A Large Run-of-River System



Source: The Three Villages, "Hydro Scheme," http://www.threevillages.org.uk/community- development-trust/hydro-scheme, accessed March 1, 2018.

Nepal produces 90 percent of its electricity through hydropower. However, that electricity accounts for just 2 percent of the country's total energy consumption.[9] For comparison, electricity made up approximately 39 percent of the energy consumed in the United States in 2016.[10] Burning biomass accounts for approximately 86 percent of Nepal's energy consumption.[11] The World Bank estimates that the rivers and streams that flow through Nepal are capable of generating to 83,000 MW of electricity.[12] The Nepali government and the World Bank have partnered to harness hydropower capabilities by building more than 1,000 micro-hydro grids in rural communities.[13] Nepal has developed a policy to provide subsidies for micro-hydro systems with a capacity of 3 to 100 kilowatts that meet certain criteria: the project must be a legal entity; the installation area must be in an area not reached by the main grid; the initial investment cannot exceed certain costs that depend on the distance from the nearest road; and the power demand in the area must be above 10 percent.[14] This means that in a given area, the demand for energy must be such that it is not satisfied by other small-scale renewable energy sources, such as biomass.

Micro-hydro plants have advantages over some renewable and fossil fuel systems, including a relatively low maintenance cost. Unlike solar energy, micro-hydro does not necessarily need to be supplemented with a battery, as a running stream is capable of continuously providing energy 24 hours a day. Run-of-the-river systems have the potential to reduce the environmental impact caused by the project at a relatively low cost. The Asian Development Bank estimated that hydropower displaces around 10 million kilograms of carbon dioxide each year of operation.[15] The drop and flow necessary for micro-hydro to function is relatively small; as little as two gallons a minute (7.57 liters/minute) in flow and a drop as small as two feet (60.96 centimeters) should be sufficient to generate some electricity.[16]

Micro-hydropower projects can generate light or power a cooker, substituting for a need to collect biomass. Such projects can empower village women by freeing up their time from collecting and carrying biomass (fuel wood) to their homes or enabling them to mill grain via machine and not by hand. Increase in milling efficiency can improve villagers' economic status.

Based on AEPC and World Bank experience, micro-hydro generators or distribution systems can develop energy reliably off-grid.[17] Some micro-hydro systems have uncertainties related to surrounding conditions that can affect system effectiveness, including the weather, terrain, and the water flow rates. Micro-hydro systems lack scalability, as the scale of micro-hydro is limited by river or tributary volume. Micro-hydro systems generate electricity through a run-of-river turbine rather than a dam, so the amount of produced power depends on river flow. There are few ways to compensate for low water flow should flow rate decrease during dry months.

Case Study: Karamdanda

The small village of Karamdanda is located about 65 km south-east of Kathmandu along the BP Highway. The Roshi Khola stream borders Karamdanda and the village is adjacent to the highway. Karamdanda is not connected to Nepal's national grid. Decisions for the village are made by a committee. Prior to the introduction of micro-hydro to the village, many households relied on solar panels obtained with the help of an AEPC subsidy.[18] In 2010, an elected Karamdanda Committee (the Committee) opted to implement a run-of-river micro-hydro plant.

The Committee authorized a feasibility study to verify that a project could be viable and then hired a consultant to create a design, which was reviewed and endorsed by a technical committee. The village issued a "Request for Proposals" so construction firms could bid on the project. One firm was selected and it built the project, which was commissioned on September 7, 2010.[19] For this micro-hydro project, the headrace canal is 1,446.85 meters (m) in length, the penstock is 23 m, the turbine is a T-15 crossflow, and the generator has an output of 35 kilo-volt-ampere (kVA) and is synchronous. The project also includes approximately 4,630 m of transmission line.[20] The project cost was 4,129,905 Nepali rupees (NPR), or about $55,065 USD.[21] The Committee relied on an AEPC subsidy of 2,125,000 NPR ($20,442 USD) to finance this undertaking, which covered 51.5 percent of the project costs.[22] Other costs associated with the project were financed through a mixture of local efforts within the community (the majority of remaining funding) and a few external sources. No single external source of funding aside from the AEPC subsidy reached 10 percent.[23]

The specifications of the Karamdanda micro-hydro project and the river itself at that location both contributed to the project's overall success. The Roshi Khola is a tributary to the Sunkoshi River, which contributes to the ease at which it may be diverted.[24] The Roshi Khola flows down to the Sunkoshi near the village, so there is sufficient hydraulic "head" to power a turbine.[25] Figure 2.4 shows the view of the Karamdanda water system with the power house and system adjacent to the higher elevation cliffs that the village overlooks (to the immediate west of the highway). Multiple canals enable a steady flow of water even during the dry season.[26] The canals used for the micro-hydro project are on higher ground, as is the water diverted from the stream,[27] which means that there are no complicating factors such as a need to bring the water up to higher elevation—the flowing water's elevated status allows it to run freely with the help of gravity rather than pumping. With a net head of 13.01 m and a flow rate of 216 liters per second (lps) the physical properties of the stream are sufficient for power generation.[28] If the head or flow rate were significantly smaller, this would reduce the feasibility of the project. The Karamdanda micro-hydro project is not labor-intensive, as only one person is needed to oversee operations.[29] The low labor expenses of hydro-power means the system is comparatively less costly than alternative sources of electricity for Karamdanda.

Figure 2.4. Map of Karamdanda

Source: Google Maps, Karamdanda, https://www.google.com/maps, accessed May 7, 2018.

The micro-hydro project has a maximum power output of 17 kW, which is sufficient to provide power to the 179 households in the village along with a number of businesses. The project provides power to a poultry farm, a photo studio, a computer electronic shop, and a telecom tower. There is a possibility of expanding in the future by providing power to an agricultural processing mill and a milk chilling center.[30] On average, each household within the village pays 100 NPR ($0.96 USD) for electricity per month, with businesses paying substantially more due to their used of more electricity.[31] The Karamdanda micro-hydro project's ability to provide power at lower rates for households is subsidized by the rate paid by businesses within the village. Villages wishing to emulate Karamdanda may want to consider alternative uses for electricity beyond those of a household.

The structure of the local government in Karamdanda helped facilitate the project's success. The central Committee that manages all water-related issues enabled the project. Beyond the Committee's role in organizing the project, it also oversees other water use issues, such as drinking, irrigation, and domestic water uses.

Viability of a Micro-Hydro Plant in Kothape and Rakathum

This study seeks to evaluate whether micro-hydro is a viable supply option for the electrification of Kothape and Rakathum. As mentioned previously, the flow rate of water is a factor that determines power generated in a run-of-river system. Based on the nearby Karamdanda hydro plant, flow rate may not be a limiting factor in this environment, as the multiple canals in the village enable a steady flow of water even during dry season (around 216 liters/second). Given the locations of Kothape and Rakathum, it is reasonable to assume a comparable river flow rate. The result of the analysis shows a potential head of 7.4 meters, less than the 13.01-meter head at the Karamdanda micro-hydro plant. With the head difference between Kothape and Rakathum (7.4 m versus 13 m), the 7.4-meter head in Kothape and Rakathum would produce half the power produced in Karamdanda, or 9.5 KW.

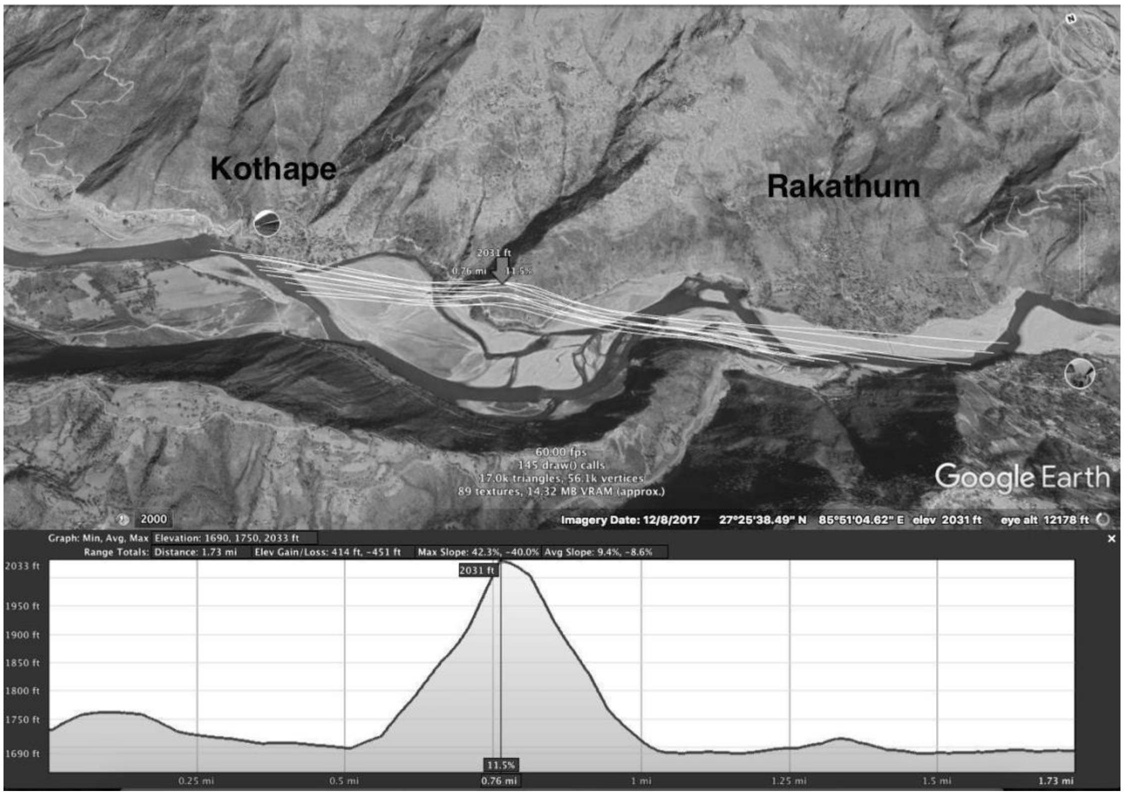
The head of a micro-hydro plant is the pressure created by the difference in water surface elevation. There are several methods to calculate water-surface elevation difference such as using a tape, lasers, or pressure gauges. This report uses Google Earth topographic elevation differences as proxy of the potential head for a micro-hydro plant.

As Kothape is up-stream from Rakathum, one option would be to design a run-of-river system to have an inlet weir from the Sunkoshi River and settling basin somewhere around the river banks of Kothape, while the turbine and powerhouse could be somewhere near Rakathum's Sunkoshi River banks. This would minimize transmission and construction costs, as well as simplify villagers' roles in system maintenance and oversight. Because of this assumption, one way to calculate the head of the run-of-river system is the difference in the water surface elevation near Rakathum and the water surface elevation near Kothape.The elevation of the water surface and river banks near the villages vary significantly. This project took 10 random points near the village of Kothape and drew 10 perpendicular paths to 10 random points near the village of Rakathum. The points were chosen at diverse lengths up and down the stream at the center of the width of the river so as to capture the Thalweg elevation, the lowest point of the river if a cross-section is considered.[32] Figure 2.5 illustrates as lines the 10 random paths taken from Kothape to Rakathum. After the paths are chosen, the elevation in feet of the start and end points for each path can be identified, as illustrated in Table 2.1. The potential head or the difference in water surface elevation should yield roughly the average elevation difference for all 10 paths.

Google Earth can be used to measure the length of the 10 paths and estimate the shortest distance between each pair of points. These estimates can be used to understand the challenges of building a channel or canal that connects intake to penstock and powerhouse. The main challenge is that all the paths pass through a hill (see the elevation profile in Figure 2.5).

Although a canal could be built around this hill, these operational details demonstrate a bigger issue in the geography of the land. The banks for the river around both villages are mostly hills and cliffs, which makes it harder to build a canal to transfer the water. The canal must be dug deep enough so as to aid the water in flowing downward.

Figure 2.5. Map Showing Elevation Profile of Path Number 1



Source: Google Earth, https://www.google.com/maps, accessed May 7, 2018.

One reason to assume the shortest paths between inlet and outlet is to minimize head loss. The distance water has to travel in a canal between the two villages causes friction that reduces head. The longer this distance, the more friction created between the water and surfaces of the canal and more lost head. For each path, head loss is computed based on friction due to the length of that path, flow, and the Darcy Friction Factor.[33] Equation 4 in Table 2.2 shows the calculation of head loss due to friction. For the purpose of this analysis, it is reasonable to assume the "canal" to be a circular concrete pipe with a one-meter diameter. After subtracting the head loss of each path from the head, the net head can be computed as the average across 10 paths, or a head of m.

If water would have to be pumped up from the river to each village and the elevation difference for a possible hydro system in the Sunkoshi River is so modest, a micro hydro plant at the site would deliver too small of a net power production to drive a local water supply or irrigation system, let alone a small business power auxiliary. As a result, hydro is not an attractive or cost-effective option as a renewable energy source for Kothape and Rakathum.

Table 2.1. Net Average Head Calculation

Path No.	Inlet Point Coordinates Near Kothape (DMS)	Elevation of Inlet Point (ft)	Outlet Point Coordinates Near Rakathum (DMS)	Elevation of Outlet Point (ft)	Head1 (ft)	Head2 (m)	Perpen-dicular Flow Distance (miles)	Perpen-dicular Flow Distance3 (m)	Head Loss due to pipe length4(m)	Net Head5 (m)
1	(27°25’ 59.25” N) (85°50’ 27.17” E)	1732	(27°25’ 12.12” N) (85°51’ 52.19” E)	1695	37	11.2776	1.73	2871.8	0.61	10.67
2	(27°25’ 59.73” N) (85°50’ 26.96” E)	1734	(27°25’ 14.24” N) (85°51’ 44.57” E)	1706	28	8.5344	1.6	2656	0.56	7.97
3	(27°25’ 52.38” N) (85°50’ 32.96” E)	1714	(27°25’ 13.65” N) (85°51’ 46.65” E)	1704	10	3.048	1.47	2440.2	0.52	2.53
4	(27°25’ 49.45” N) (85°50’ 34.82” E)	1705	(27°25’ 20.35” N) (85°51’ 40.13” E)	1690	15	4.572	1.26	2091.6	0.44	4.13
5	(27°25’ 52.75” N) (85°50’ 41.58” E)	1727	(27°25’ 17.66” N) (85°52’ 40.76” E)	1695	32	9.7536	1.24	2058.4	0.44	9.32
6	(27°25’ 54.63” N) (85°50’ 30.42” E)	1728	(27°25’ 08.76” N) (85°52’ 00.42” E)	1690	38	11.5824	1.83	3037.8	0.64	10.94
7	(27°25’ 55.96” N) (85°50’ 29.46” E)	1730	(27°25’ 07.10” N) (85°52’ 10.58” E)	1715	15	4.572	1.99	3303.4	0.7	3.87
8	(27°25’ 02.49” N) (85°50’ 22.53” E)	1720	(27°25’ 08.96” N) (85°52’ 01.22” E)	1681	39	11.8872	2.09	3469.4	0.74	11.15
9	(27°25’ 56.81” N) (85°50’ 29.16” E)	1737	(27°25’ 13.01” N) (85°51’ 47.98” E)	1704	33	10.0584	1.6	2656	0.56	9.49
10	(27°25’ 50.23” N) (85°50’ 34.29” E)	1703	(27°25’ 07.89” N) (85°52’ 14.06” E)	1688	15	4.572	1.9	3154	0.67	3.9
								Net Average Head 6 (m)		7.4

Source: Created by Samer Atshan (Project Participant).

Solar Energy Technology

Nepal has invested widely in solar power to improve the quality of lives of rural villages. One example is the Nepal Energy for Education Project (NEEP), which since 2013 has operated a rural Nepali micro-grid program[34] to test whether renewable solar energy could improve education in rural schools in the village of Matela. Before the project, villagers in Matela relied mainly on kerosene and wood fuel for lighting and cooking, with batteries to power radios.

Between the stand-alone PV systems and the small solar home systems (SSHS), 10.6kW of solar energy capacity are now available to Matela residents.[35] The Matela project provided electricity to two schools with a 6-kilowatt (kW) solar c (PV) micro-grid system. The Malika Upper Secondary School grid powered both the school and a computer lab. A 0.7 kW system at the Rastriya Secondary School powered two computers and classroom lighting. The solar panels were installed in clusters at the schools, each with a battery to back up supply, to be replaced every seven years.[36] The Matela project also distributed small solar home systems that contained portable lamps with batteries, to provide lighting at home after school to over 700 students’ families. This lighting enables students to study at night, and allows their families to reduce indoor pollution caused by kerosene-burning lamps.

Table 2.2. List of Equations for Average Net Head Calculation

$Head\ (ft) = Elevation\ at\ Inlet\ Point - Elevation\ at\ Outlet\ Point$
$Head\ (m) = Head\ (ft) \times\ 0.3048\ (^{m}/_{ft})$
$Perpendicular\ Flow\ Distance\ (m) = Perpendicular\ Flow\ Distance\ (miles)\ \times\ 1.66\ (^{Km}/_{miles})$
$Head\ Loss\ (m) = F_D\ \times\ \frac{L}{D}\ \times\ \frac{V^2}{2g}$
$F_D\ =$ 0.055
$Darcy\ Friction\ Factor\ of\ the\ duct\ determined\ from\ a\ Moody\ Chart\ with\ roughness\ of\ concrete\ duct$
$L = Variable$
$Perpendicular\ Flow\ Distance\ of\ the\ Duct$
$D = 1\ meter$
$Duct\ Diameter\ is\ the\ diameter\ of\ the\ assumed\ circular\ pipe\ transferring\ the\ water$
$V\ =\ \frac{Q}{A} = \frac{216\ \left(\frac{liter}{s}\right) \times 0.001\ \left(\frac{m^3}{liter}\right)}{\frac{\pi \times D^2}{4}}\ = 0.275\ \frac{m}{s}$
$Flow\ Velocity$
$g = 9.81\ m/s$
Gravitational Acceleration
$Net\ Head\ (ft) = Head\ (m) - Head\ Loss\ (m)$
$Net\ Average\ Head\ (ft) = Net\ Head\ /\ 10$

Source: HOMER Pro 3.11, “Pipe Head Loss,” https://www.homerenergy.com/products/pro/docs/3.11/pipe_head_loss.html.

In this Rakathum and Kothape project, staff wondered whether solar local grid systems could yield such village improvements in the two off-grid villages. Prior to the village visit, project staff had no information as to whether each village had access to any electricity. Class members wondered whether a first step towards electrification could be through small solar home systems in each household to power lighting. On site, project staff observed that most of the homes in each village already had small solar home systems (20 watts of power for lighting and charging cell phones).

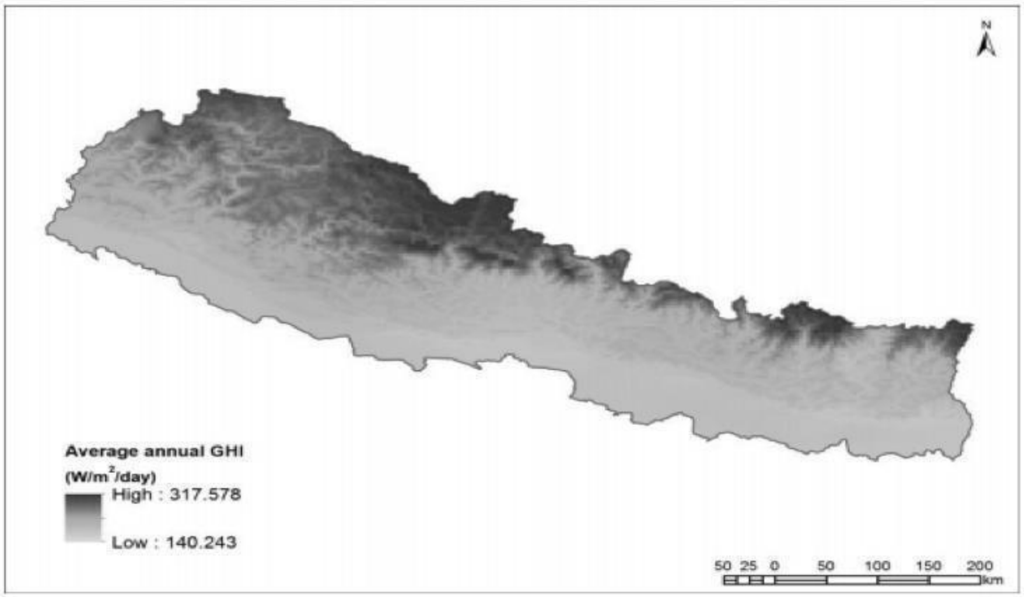
In Rakathum, the primary school had a 50W solar PV system to provide power for lighting and charging four laptop computers and villagers operated a solar water pumping system. Rakathum has a 2kW solar water pumping system, which uses power from solar PV panels to pump water to the top of the village for collection in a tank with the capacity to hold 18,000 liters. This system pumps 10,350 liters per day, allowing about 30-35 liters of water per person per day in the village, a value just above the World Health Organization's (WHO) 20 liters per person per day minimum quantity of water needed to meet the needs of replacing water lost through physical activity and to take care of basic hygiene needs and basic food hygiene (laundry or bathing would require more water).[37] The cushion between the average 10,000 liters for daily use and the capacity of 18,000 liters provides some water security for days when the sun is not shining. Each household in the village pays a 100-rupee tariff each month for access to this water. The operator of the system is paid 2,000 rupees per month. A consumer committee is responsible for setting rules in the village and managing daily operation. The solar water pumping system was made possible through a subsidy provided by AEPC. The total cost of the system was around US$23,000. AEPC provided 44 percent as a grant, the village contributed 14.7 percent in labor (in kind) as well as 0.5 percent cash; the remainder was contributed by outside organizations.[38]

The Kothape solar water pumping system has 2.4 kW solar PV panels. The system pumps 15,350 liters per day, or between 30 to 35 liters per person per day, a volume just above the WHO standard of 20 liters of water per person per day.[39] The system pumps the water into a 27,000-liter tank where 10,000 liters of water are used daily. Each household pays a 100-rupee tariff per month, which is paid quarterly. Kothape has roughly US$200 in savings. A village consumer committee has responsibility for daily operation. Financing for the pump was provided by Community Development Society (CDS), a nonprofit Nepali organization.[40]

These village findings illustrate that solar energy is a viable alternative to fossil fuels in Nepal, specifically for electrification of villages not connected to Nepal's main grid. For remote villages, the cost of fuel and transportation presents an expensive challenge for rural area electrification. Solar energy in Nepal is abundant, as the country is located at 30 degrees north latitude, with over 300 days of sunshine, and an annual average solar insolation of 5 kilowatt-hour per square meter per day.[41] Solar PV systems generate electricity, and solar thermal systems produce heat directly. Solar energy can provide electricity for a variety of needs, including lighting homes, charging cell phones, powering computers, and pumping water. Available solar technology can produce around 33.5 MW per square kilometer (km^2) of land.[42]

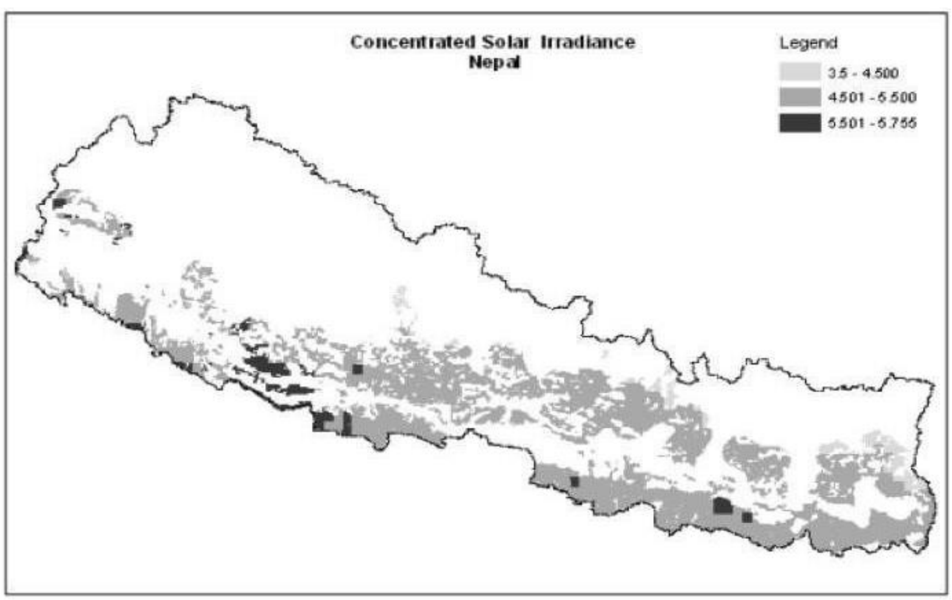
Figures 2.6 to 2.8 are maps of solar irradiance in Nepal.[43] They illustrate which regions have solar power potential and what kind of solar power can be generated there. Figure 2.8 illustrates that the region of Rakathum and other regions throughout Nepal have potential for PV systems. The region of this study (including Rakathum, Kothape, and other rural villages) is highlighted, indicating a good potential for generating solar energy. Small villages, such as Rakathum or Kothape, do not need so much power to justify a centralized electric distribution system or a micro-grid. This study sought to assess whether villages with as few as 20 households could be served on a cost-effective basis by solar home systems.

Figure 2.6. Average Annual Irradiance



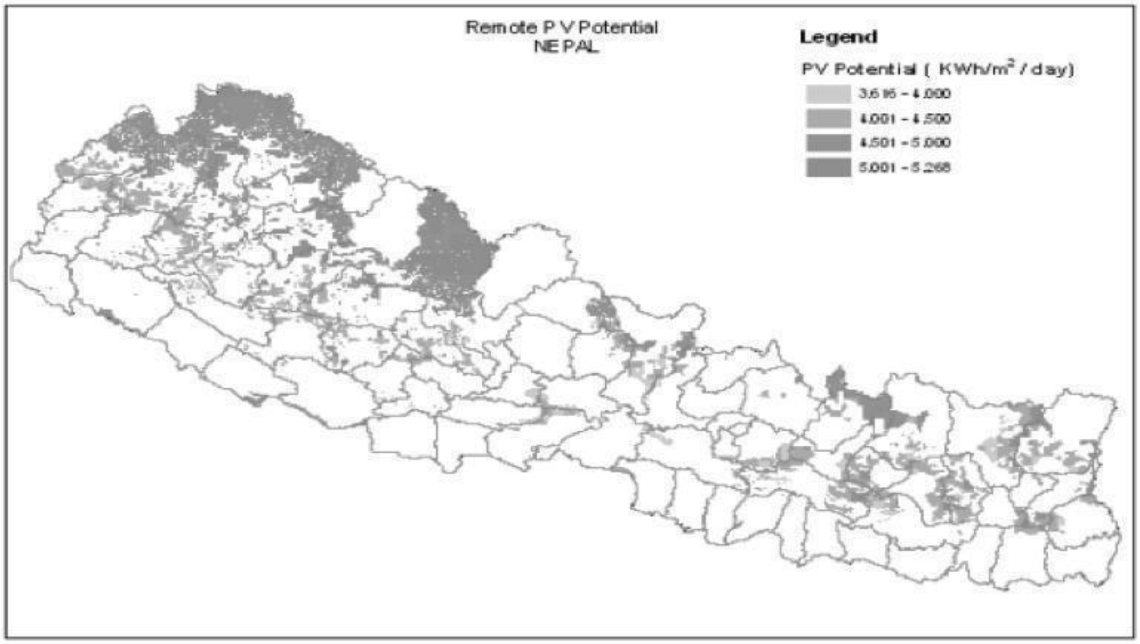
Source: Alternative Energy Promotion Center (AEPC), "Solar PV Technology," https://www.aepc.gov.np/?optain=renewable&page=solarpv&mid=2&sub_id=12&ssid=1&cat=solarPVTechnology, accessed November 22, 2017.

Figure 2.7. Concentrated Solar Power Potential



Source: Gesto Energy Consulting, Governmental report for Nepal Electricity Authority (the consulting group requested their report be kept confidential).

Figure 2.8. Photovoltaic (PV) Potential

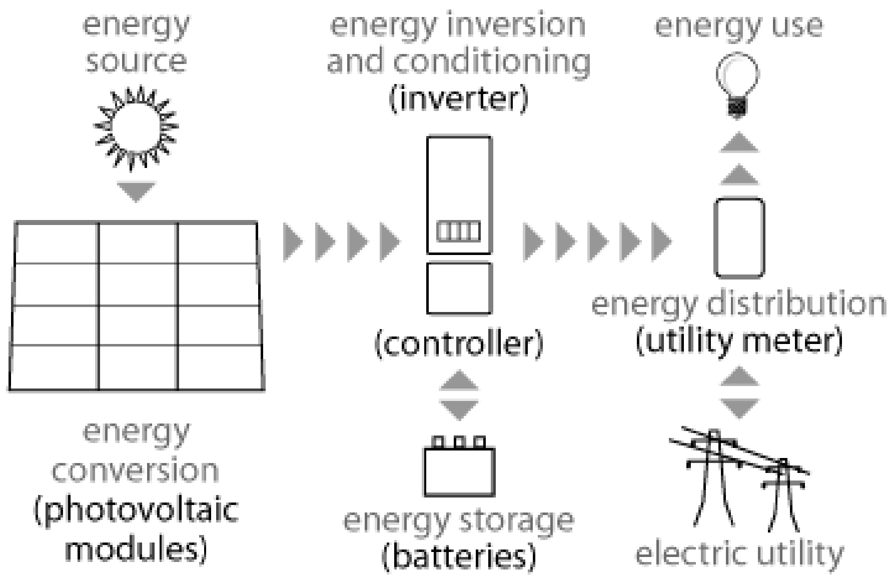


Source: Gesto Energy Consulting, Governmental report for Nepal Electricity Authority (the consulting group requested the report be kept confidential).

Solar PV technology directly converts sunlight into electricity by converting radiant energy in photons to electric energy in electrons. Traditional solar cells are typically made of flat plate silicon. Solar PV technology is widely used in Nepal, with an estimated 16 MW installed.[44] Solar PV systems can include solar charge controllers, solar batteries, solar PV modules, solar inverters, solar pumps, and solar lamps. Solar charge controllers regulate voltage and current from solar PV modules, protecting the battery from overcharging and energy discharge.[45] Solar batteries are storage mediums that contain electrochemical cells for converting chemical energy to electrical energy. Batteries are a necessary component of solar electrification systems because the sun only shines during the day and it does not shine every day; at other times energy stored in the batteries can supplement solar collection.[46] Off-grid solar inverters convert DC from batteries into AC that can be used as electricity.[47] An off-grid solar inverter may be necessary in these villages for use of specific appliances.

Figure 2.9 illustrates the energy flow in a potential solar PV system. Another application of solar PV technology is solar pumps which "are used to convert electrical energy to potential energy. They are widely used to lift water to a higher altitude by direct coupling with solar PV module/array."[48] A solar lamp is another common application of solar PV technology in Nepal; solar lamps typically use light-emitting diode (LED) lights powered by solar panels attached to solar batteries to provide lighting at night.[49] Solar thermal technologies can be useful for direct heating in remote villages even though they produce no electricity directly, just heat. Some potential technologies include solar dryers, solar cookers, and solar water heating technologies. Solar dryers can be used to dry some crops to increase shelf life. Solar dryers are preferable to sun drying certain foods because it prevents spoilage and losses from rain and animal scavenging. Solar dryers can also be used to dry non-food materials, such as timber, rubber, and paint.[50] Solar cookers convert sunlight into heat by concentrating it on a reflective surface such as a mirror in a small area for cooking.[51] Solar water heating can be used for residential or industrial water heating andconsists of three parts: a heat collector, heat storage, and auxiliary heating.[52] All of these technologies have the potential to improve quality of life of remote villages.

Figure 2.9. Solar Photovoltaic System Example



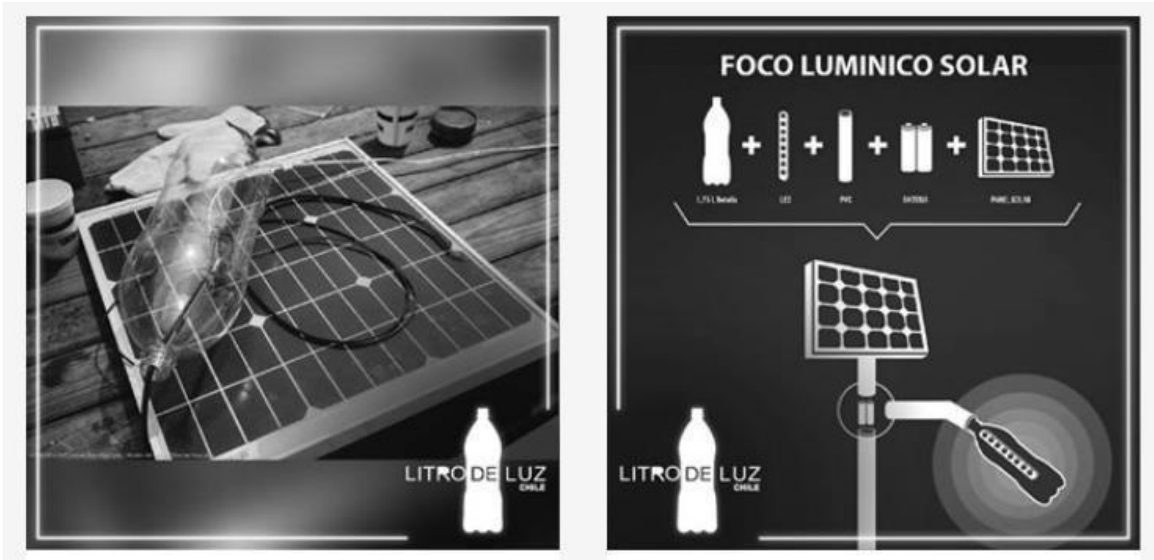
Source: Solar Direct, "Complete Photovoltaic Systems," http://www.solardirect.com/pv/systems/systems.htm.

As part of the research for this project, staff collected information on particular systems in Nepali markets that could be used in villages. The Lights @ Night system is an inexpensive design (see Figure 2.10) that can provide lighting at night. Project staff emailed the grassroots organization that creates this system about the product and about their program but did not receive a response.

A second option for solar technology is a PV 20-watt home solar power system that costs US$18-70 per unit. The components of the system (shown in Figure 2.11) are available for purchase online at alibaba.com; they include two LED lamps of 3 watts each, a USB phone charger, a 4AH 6V battery, and the solar panel. This option is similar to the household systems in both Rakathum and Kothape.[53]

Another potential solar option is a system that could be used for a connected village micro-grid or to power larger projects, such solar water pumping or solar irrigation. One system from Alibaba.com has a capacity of 5 kW and costs between US$2,300-2,600. It includes nine solar panels, an inverter, a controller, and four batteries. Figure 2.12 lists the specifications. Figure 2.13 shows an image of what is included in this system package.[54]

Figure 2.10. Lights Night System



Source: MyShelter Foundation, “Liter of Light USA,” 2018, http://www.literoflightusa.org/.

Figure 2.11. Solar Lighting and Charging System from Alibaba

Source: MyShelter Foundation, “Liter of Light USA,” 2018, http://www.literoflightusa.org/.

Figure 2.12. Solar System Specs from Alibaba

Load Power (W)	5KVA	Solar Power (W)	2250w	Work Time (h)	>8 hours
Solar Panel	Poly250w/30v *9pcs	Battery	200AH/12V*4pcs	Controller	MPPT 60A 48V*1pc
Inverter	480V-220V, 5000VA 50HZ	Full Power	7680W	Efficiency	>90%

Source: David Eaton (Director), *Forestry and Economic Development on the Oki Islands, Japan*, Policy Research Project Report 196, LBJ School of Public Affairs, The University of Texas at Austin, 2018.

Figure 2.13. 5kW Solar System from Alibaba

Source: David Eaton (Director), *Forestry and Economic Development on the Oki Islands, Japan*, Policy Research Project Report 196, LBJ School of Public Affairs, The University of Texas at Austin, 2018.

Both Kothape and Rakathum villages are now considering larger solar power projects: solar water pumping for irrigation. While solar water pumping systems are already being used daily, the solar irrigation systems are still under design and not yet implemented in the villages.

Rakathum plans to build a solar-powered irrigation system with the help of AEPC. A water shortage for the last four years has limited agricultural activities in the village; many other areas of Nepal have experienced a comparable decrease in water flow. Rakathum has approximately 12 hectares of arable land, which lies approximately 50-75 meters above the river. A 4kW solar panel system powering a two-horsepower pump would be capable of discharging 28,000 liters per hour for irrigating five hectares. The estimated cost of this system is about $20,000.[55]

AEPC also investigated the potential solar irrigation in Kothape. Due to the poor condition of the land in Kothape, there is not enough demand for a solar irrigation system to be implemented and funded by the organization. However, the Community Development Society (CDS) is planning to fund and implement a solar powered irrigation system to encourage the villagers to continue to expand their farming. With proper sunlight, a two-horsepower pump with a 4kw solar system can pump 28,000 liters per hour to integrate five hectares of land, which is estimated to cost between US$20,000-25,000. For example, Figures 4.1 and 4.2 in Chapter 4 document progress with the recently completed Kothape Lift Irrigation Project.

Biomass Energy

According to the APEC, more than 70 percent of households suffer from detrimental effects from in-home smoke pollution due to the use of traditional cooking stoves, like those used in Kothape. This indoor air pollution disproportionately affects women, who are more likely to spend longer periods of time in the kitchen. Nepal has attributed more than 22,000 deaths per year to the use traditional cooking stoves.[56] Biomass and biogas represent alternative energy sources for in-home cooking. Biomass refers to the use of fuelwood or agricultural residue as an energy source. Biogas is methane gas produced from animal and human excreta, kitchen waste, and agricultural residue.[57,58]

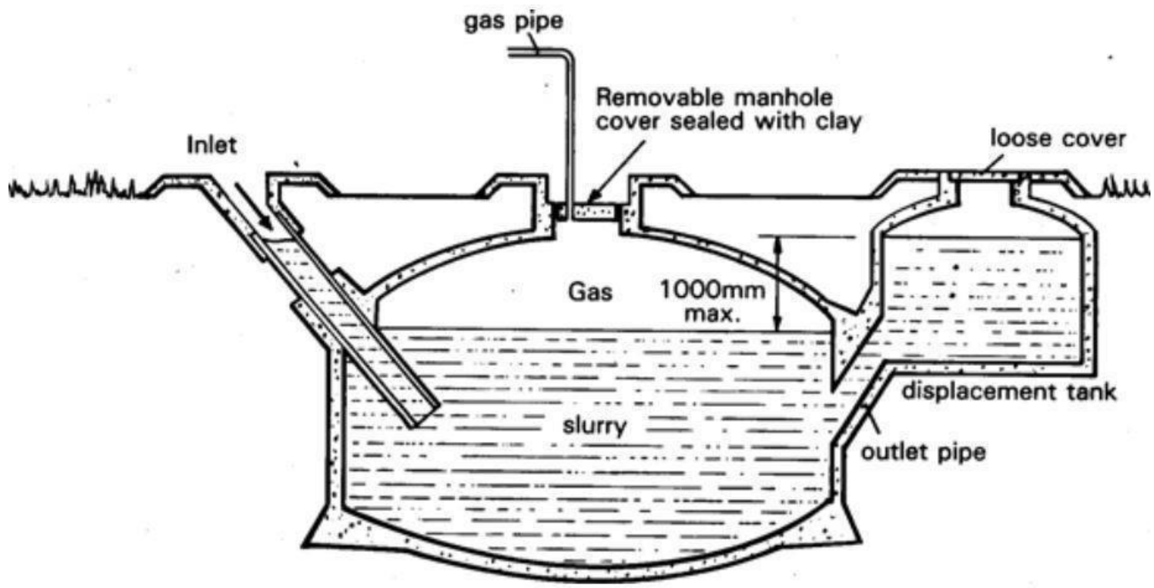
Biomass energy is the use of organic matter such as wood chips, mulch, sewage, or manure to produce a renewable biogas, which can be directly burned to create electricity or heat, or it can be converted into organic fertilizer. Biomass energy, while relatively clean, can be less efficient than traditional fossil fuels and faces many technical and logistical challenges, such as the supply of the biomass materials. Creating an efficient biomass electrical production system requires large amounts of biomass—most often in the form of trees. If not properly managed, the felling of trees to supply a biomass industry could devastate a natural forest.[59] Burning biomass is even more carbon-intensive than oil or gas, as the conversion efficiency of biomass to usable energy is less than concentrated fossil fuel.

An ideal biomass system operates under the concept of "cascading use." Cascading use occurs when value is added to each phase of the biomass' processing before all of the original resource is exhausted. For example, biomass as trees can first be turned into lumber—the most valuable product. Excess wood scraps from the saw mill can then be turned into wood chips. Finally, sawdust produced at the mill can be turned into wood pellets or lignophenol.[60]

The first biogas plant in Nepal was established in 1955 by Father Saubolle at the St. Xavier's School. The Government of Nepal implemented its first national biogas program in 1974 in response to Nepal's oil crisis.[61] Today over 400,000 household (domestic) biogas plants have been installed, with over 1.9 million of Nepal's rural population served by these plants.[62] Biogas plants require relatively low initial operational costs as compared to other renewable energy.

Biogas plants can be built to accommodate a range of capacities, from residential to commercial, and can process various inputs, such as woody biomass, agricultural waste, and human or animal waste. Biomass as fuelwood is the most common energy source for cooking in both Rakathum and Kothape. Biomass energy can be harnessed in the form of biogas through the processing of human and animal waste. The waste is collected in large cement "digester" containers (see Figure 2.14). The waste is first placed in a mixer and churned to "activate" the digestion process. The waste is then channeled into the digestion tank, where it sits and produces methane gas as a byproduct. The methane gas can then be supplied to individual houses via a small pipe from the holding tank. The leftover slurry can then be stored separately and used as high-quality organic fertilizer.[63]

Figure 2.14. Digester Model



Source: Biogas Plant (Anaerobic Digester) Blog. "Biogas Plant Picture," http://bio-gas-plant.blogspot.sk/2011/05/biogasplant-picture.html.

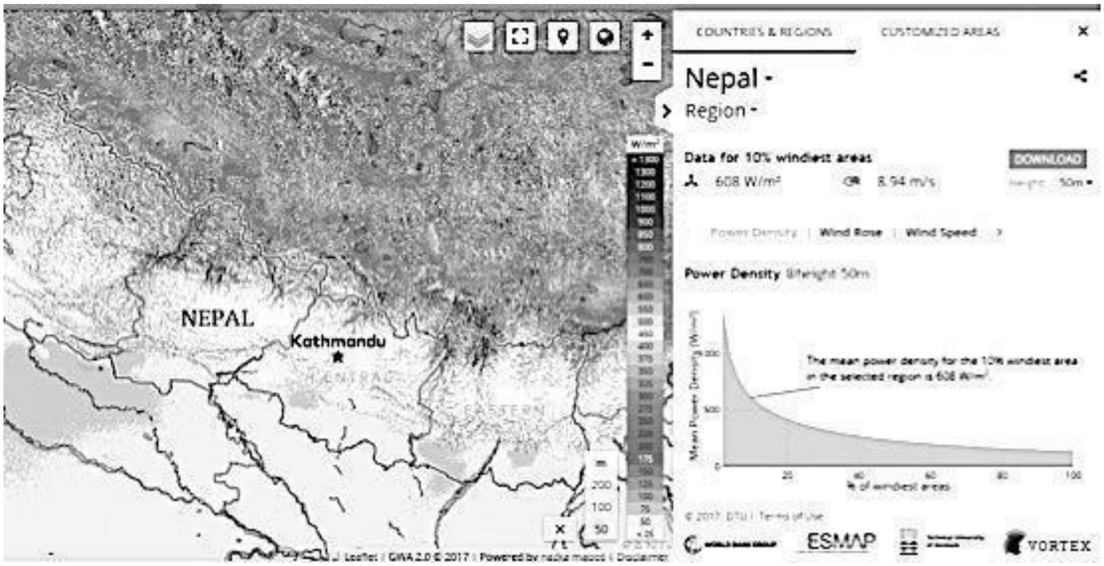
Biogas use is now widespread in Nepal. The Government of Nepal has stated a goal "to install 600,000 domestic biogas plants using cattle dung" by 2030. The Government of Nepal also provides significant subsidies for community and domestic biogas plants, as well as for commercial, institutional, and municipal plants.[64] Livestock roam largely unconfined in both Rakathum and Kothape. The result is that animal wastes are scattered in and around the village, a practice that is unsanitary and poses health risks.[65] Rakathum has six household biogas units in use. Kothape currently uses none of its biogas units due to insufficient maintenance and repair training. Members of the community reported that they lacked resources and knowledge to repair units. Instead, they returned to utilizing liquid petroleum gas and fuelwood.[66]

Wind Power

Wind turbines already generate significant power in some parts of Nepal where the wind blows heavily for much of the year with sufficiently high wind speeds and reliable wind to produce power cost-efficiently.[67] In other parts of Nepal (as in Ramechhap, the focus of this study), the wind speeds may not be high enough to make wind power a viable or cost-effective energy option. Figure 2.15 shows average wind speeds in Nepal at 50 m, with high-wind-potential areas shaded most darkly. Small pockets along Nepal's northern border have wind power potential.

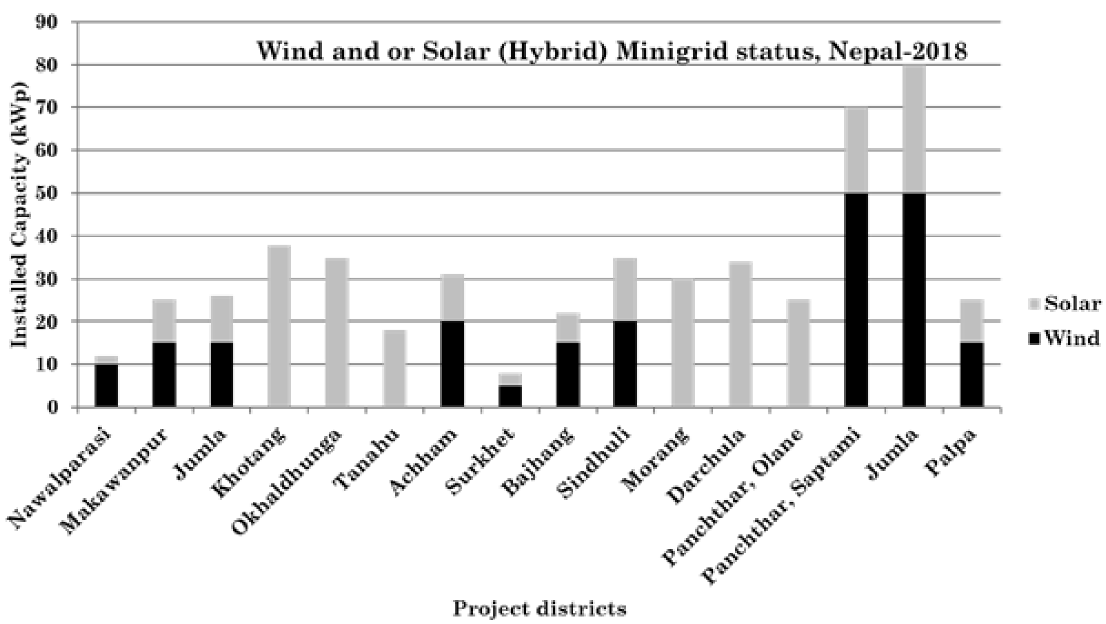
The rest of the country has lower average wind speeds that are insufficient to produce electricity from a turbine at a low cost. AEPC conducted a Solar and Wind Energy Resource Assessment that reported 3,000 MW in total wind energy potential for the entire country.[68] Figure 2.16 illustrates the current status of AEPC projects.

Figure 2.15. Global Wind Atlas Map for Nepal



Source: Global Wind Atlas, "Nepal," https://www.globalwindatlas.info/area/Nepal/.

Figure 2.16. Progress of AEPC Wind-Solar Hybrid Projects



Source: Prakash Aryal, "Experience of AEPC in Implementing Wind (Solar) Hybrid Projects," Presentation, 2018 Nepal PRP trip lectures, Kathmandu, Nepal, March 12, 2018.

Among power systems that utilize wind energy, hybrid wind and solar systems are popular because of the variation in energy production capacity of these renewable sources. AEPC has supported two successful hybrid projects. One, in Dhaubadi, has a wind-solar hybrid mini-grid producing 12 kW that has been in use since 2011; the system provides enough energy to power 45 households and a local police station.[69] Figure 2.17 illustrates a subsequent project in

Bhorteni Village in Makawanpur District, Nepal. The combined mini-grid system produces 25 kW for 131 households, a school, a health post, and a police station from two 5 kW wind turbines and a 15 kW solar PV array.[70]

Figure 2.17. Wind Turbine and Solar Array

Source: Prakash Aryal, "Experience of AEPC in Implementing Wind (Solar) Hybrid Projects," Presentation, 2018 Nepal PRP trip lectures, Kathmandu, Nepal, March 12, 2018.

This project tested the viability of wind power for villages through a software simulation using HOMER88 (Hybrid Optimization Made for Multiple Energy Resources), a microgrid software produced by HOMER energy.[71] The wind turbine used in the HOMER simulation is a 5 kW model manufactured by Qingdao Allrun New Energy Company and available for purchase on Alibaba.[72] The turbine, pictured in Figure 2.18, produces electricity at wind speeds of between 3 and 30 meters per second and has an estimated lifetime of 20 years. The turbine has a rated capacity of 5 kW, with maximum power production at 7 kW. This particular 5 kW system is appropriate for the needs of either of the two Nepali villages, based on an estimate of 4 kW of power needed for an irrigation system. An incremental available kW would allow for future growth and development potential in either village.

The HOMER results did not support cost-effective wind-only systems for electrification of either village. All viable power combinations paired any wind system with an accompanying solar system. However, a solar-only system proved to be less expensive than a wind-solar hybrid system.

As part of this research, project staff evaluated the economic efficiency of using wind power for energy production in Kothape and Rakathum. One measure of the economic efficiency of power generation is the Levelized Cost of Energy (LCOE). The LCOE is an assessment of the average total cost to build and operate a power-generating asset over its lifetime, divided by the total energy output of the asset over that lifetime. The simplified LCOE given here provides an estimate of the per-unit cost of wind energy (in U.S. dollars per kilowatt-hour). This cost can be compared to the cost of other energy sources, such as solar and hydropower, to determine the most economical option. The LCOE for wind generation in our study villages was calculated using the generation capacity of the selected 5 kW turbine and wind data from the NASA

Surface Meteorology and Solar Energy Dataset. As illustrated in Table 2.3, the LCOE for Kothape and Rakathum is $2.71 per kilowatt-hour (kWh).

Figure 2.18. 5kW Turbine

Source: Alibaba, "New 20Kw to 50Kw Farm Wind Generator," https://allrun.en.alibaba.com/product/1940376280-803050843/New_20Kw_TO_50KW_farm_wind_generator.html.

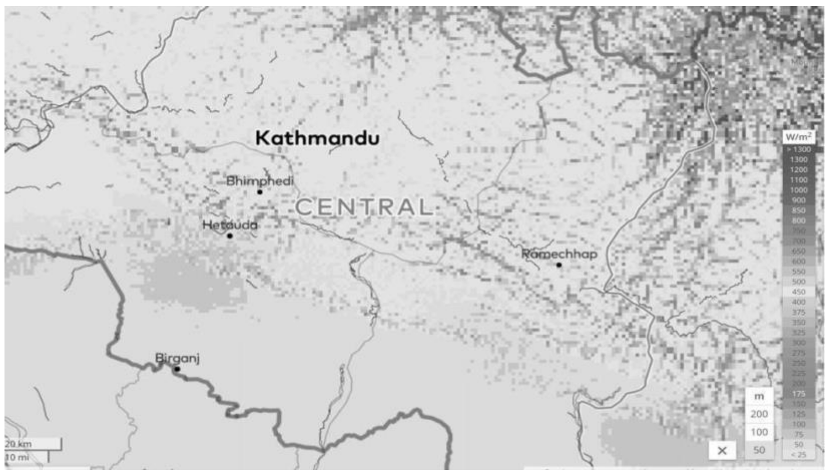
Table 2.3. Assessment of Wind Energy

month	x	speed	power	hours in month	kwh/month
jan	0.00025926	3.52	0.01130741957	744	8.412720157
feb	0.00025926	3.8	0.01422611472	696	9.901375845
mar	0.00025926	3.97	0.01622209861	744	12.06924136
apr	0.00025926	3.96	0.016099822	720	11.59187184
may	0.00025926	3.63	0.01240096243	744	9.226316049
jun	0.00025926	3.03	0.007212127606	720	5.192731876
jul	0.00025926	2.4	0.00358401024	744	2.666503619
aug	0.00025926	2.36	0.003407779811	744	2.535388179
sep	0.00025926	2.41	0.003628997294	720	2.612878052
oct	0.00025926	2.98	0.006860950862	744	5.104547441
nov	0.00025926	3.24	0.008818009194	720	6.34896662
dec	0.00025926	3.36	0.009834524099	744	7.316885929
				energy/year	82.97942697
		total cost	$4,500		
		life span	20		
		cost per year	$225		
		lcoe($/kwh)	$2.71		

Source: Created by Amit Subedi and Marshal Atwater (Project Participants).

At $2.71 per kWh, the LCOE for a 5 kW wind power system is higher than that of other potential power sources. For example, the cost of energy from the national grid is approximately 7.30 Nepali rupees ($.073) per kWh. The cost of solar energy is approximately 25 Nepali rupees ($0.25) per kWh. The main reason for the relative economic inefficiency of wind power in Rakathum and Kothape is that average wind speeds, which range between 2.36 and 3.97 m per second throughout the year, are insufficient for the wind turbine to produce electricity at high capacity at low cost. Figure 2.19 illustrates the wind potential of Ramechhap district, where the two study villages are located.

Figure 2.19. Wind Potential in Ramechhap



Source: Global Wind Atlas, "Nepal," https://www.globalwindatlas.info/area/Nepal/.

The LCOE of $2.71 per kWh is computed on an over-simplified basis, as it only includes turbine and generator costs but does not include other applicable costs, such as installation, hardware, transformers transmission lines, and maintenance. A simplified LCOE was used because other costs are uncertain and would vary by location and the level/demand for electricity. In any case, the real-world LCOE for wind power would exceed considerably the $2.71/kWh calculated cost.

Grid Connection

Kothape and Rakathum villages are not connected to Nepal's national grid because they are 0.5 km distant from the nearest grid node. Residents of each village draw electric power via solar panels on their own roofs, obtained through the help of a government subsidy. Each village relies on a larger solar panel to pump community drinking water. Given the relative proximity of the villages to the grid, a connection could occur sooner or later, although there are no near future plans to extend the grid to these two villages, or any plan for creating new dams nearby on the Sunkoshi River.[73]

The Sunkoshi River is a barrier to grid connection, as it separates each village from the nearest connection. It is not easy to bring power lines across the river due to its variability/fluctuation in size, as the river swells during monsoon. The wide fluctuations in river width add a strong element of uncertainty when it comes to grid extension, as any designer must be aware of the dangers posed by collapsing lines.

Compounding the issue is the fact that these villages are relatively small in terms of population; each is far below 100 households.[74] In comparison, the nearby village of Khaniyapani, which is connected to the grid, has over 600 households and is home to over 4,000 people.[75]

One factor that could allow grid connection is the constant roadwork near the village of Khaniyapani, which is about 4 km away from Kothape and about 6 km from Rakathum.[76] The Dolalghat Kavre Road is expanding and is expected to reach both villages within five years.[77] The road's expansion is important because of the difficult terrain between both villages and Khaniyapani. If there were to be a paved road to the villages clearing much of the difficult terrain, grid expansion could become more attractive, even if it is over a greater distance.

Electricity Demand Scenarios for Rural Nepal

To determine the best option for electrification in rural Nepal, it is useful to estimate realistic seasonal and daily patterns of electricity demand. Before visiting the villages, project staff assumed that electricity use in the village was nonexistent. In reality, households in both villages have small solar home systems which provide enough electricity to power LED light bulbs or charge a cell phone. Onsite observations of electricity demand in the villages of Rakathum and Kothape changed the initial demand models. Table 2.4 lists summary statistics of estimated costs for electricity. To estimate future electricity demand in Rakathum and Kothape villages, staff created several scenarios that reflect current demand and potential future demand for electricity.

Table 2.4. Summary of Energy Costs

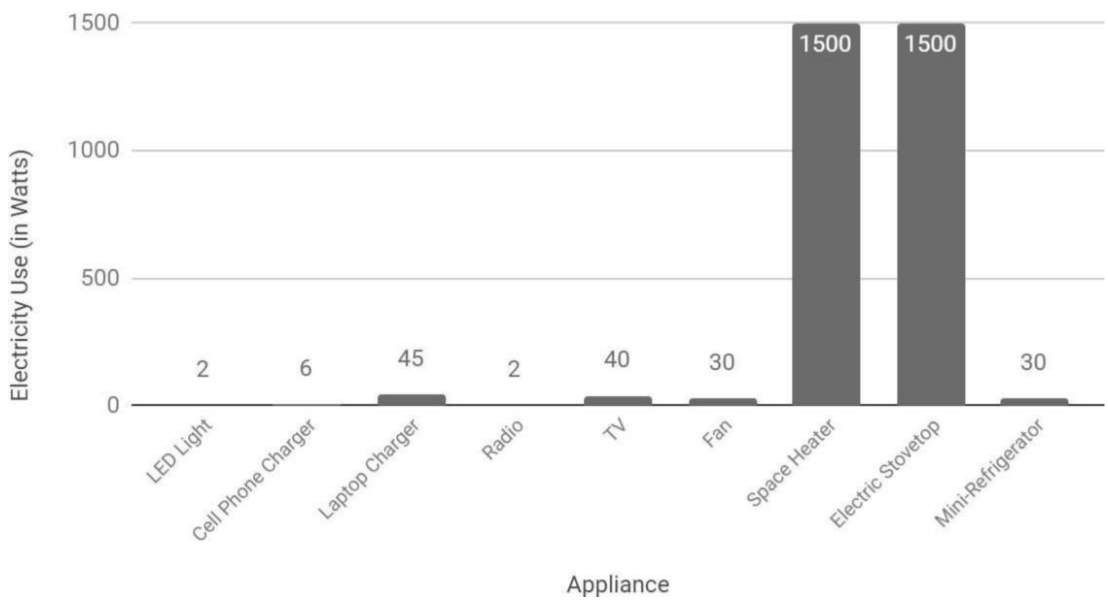
Scenario 1 Rakathum	$0.934/kilowatt-hour
Scenario 1 Kothape	$0.935/ kilowatt-hour
Scenario 2 Rakathum	$1.31/ kilowatt-hour
Scenario 2 Kothape	$1.28/ kilowatt-hour
Scenario 3 Rakathum	$0.874/ kilowatt-hour
Scenario 3 Kothape	$0.877/ kilowatt-hour

Source: Created by William Delgado-Thompson and Katherine Drews (Project Participants).

The HOMER software uses U.S.-market cost values in lieu of Nepal market costs.[78] Estimated costs do not include realistic total system costs, such as system engineering and construction expense. Each demand scenario assumed use of different electrical appliances at different times of day and different times of year. Demand scenarios are based on the power requirements of devices such as light bulbs, cell phone chargers, laptop chargers, televisions, radios, fans, space heaters, electric stove tops, and refrigerators. These electrical devices are included in the demand scenarios because each has a role in village safety, communication, health, or comfort.

Currently the majority of households in the villages use traditional wood-fired stoves with a minority using stoves that burn methane acquired from biomass. An electric top-burner stove would decrease indoor air pollution in households, improving village health, particularly among women and young children. A mini-refrigerator is included in one demand scenario because a mini-fridge has the potential to allow villagers to refrigerate fish caught in the river, extending its shelf life and giving fishermen increased economic bargaining power in transactions. Refrigeration also has the potential to improve family health by chilling food for personal consumption. Another potential use for a refrigerator in the villages is to chill and prolong the life of vaccines for village use. An electric space heater is included in a scenario because the villages can become cold at night during the winter months. Portable electric fans are included in scenarios because the villages can become hot during the afternoon in the summer months. Figure 2.20 illustrates the energy usage of these devices; Appendix A includes further information.

Figure 2.20. Electricity Use of Appliances in Demand Scenarios



Source: Created by William Delgado-Thompson and Katherine Drews using http://www.energyusecalculator.com, http://www.uml.edu, and http://www.siliconvalleypower.com.

Based on discussions with villagers and Nepali government officials, staff created three different electricity demand scenarios that reflect potential future changes in the villages' economic conditions. The first scenario reflects the current electricity use in the villages of Rakathum and Kothape to power light bulbs and charge cell phones. This scenario also describes a first electrification step of villages that currently do not use any electricity. Lighting and cell phone charging are primary concerns for unelectrified villages. Enhanced economic activity could enable villagers to purchase electrical appliances, which would increase load. A second scenario reflects a potential increase in electricity for the villages for communication, entertainment, and climate control. The third scenario reflects another potential increase in electricity use for heating and cooling for cooking and preserving food.

In Scenario 1 (Table 2.5), the electrical supply seeks to provide lighting via three light bulbs and cell phone charging for one cell phone for village homes. One assumption is that lightbulbs will be turned "on" in the early morning and evening for each household in both villages, and that the cell phone will be charged for one hour in the evening for all households. Though these assumptions may be unrealistic at the household level, at the aggregate village level they may represent a reasonable estimate of electricity demand for villages with limited electricity. Based on these assumptions it is possible to estimate the hourly electricity demand for Rakathum and Kothape (see Table 2.5 and Figure 2.20). Electricity usage in this scenario takes place during the early morning hours and early evening hours. Appendix A provides supplemental information on Scenario 1.

Table 2.5. Scenario 1 Hourly Demand Profile

Scenario 1	Rakathum Yearly (watts)	Kothape Yearly (watts)
12am-1am	0	0
1am-2am	0	0
2am-3am	0	0
3am-4am	0	0
4am-5am	210	318
5am-6am	210	318
6am-7am	0	0
7am-8am	0	0
8am-9am	0	0
9am-10am	0	0
10am-11am	0	0
11am-12pm	0	0
12pm-1pm	0	0
1pm-2pm	0	0
2pm-3pm	0	0
3pm-4pm	0	0
4pm-5pm	0	0
5pm-6pm	0	0
6pm-7pm	420	636
7pm-8pm	210	318
8pm-9pm	210	318
9pm-10pm	0	0
10pm-11pm	0	0
11pm-12am	0	0

Source: Created by William Delgado-Thompson and Katherine Drews (Project Participants).

Scenario 2 provides lighting and cell phone charging (identical to Scenario 1), and additional increases in household electricity demand by adding electricity demand for televisions, radios, and fans. Fans are assumed to be used during the afternoon in the summer months from May to August.[79] Televisions are assumed to be on in the evenings, and radios are assumed to be on in the mornings. Table 2.6 illustrates the village hourly demand for Scenario 2, including seasonal change. In the winter, electricity usage occurs in the early morning hours and early evening hours. Electricity usage in the summer months occurs in the early morning, afternoon, and early evening. The afternoon electricity usage in the summer reflects the use of fans. Appendix A provides supplemental information on Scenario 2.

Table 2.6. Scenario 2 Hourly Demand Profile

Scenario 2	Rakathum Sep-Apr (watts)	Kothape Sep-Apr (watts)	Rakathum May-Aug (watts)	Kothape May-Aug (watts)
12am-1am	0	0	0	0
1am-2am	0	0	0	0
2am-3am	0	0	0	0
3am-4am	0	0	0	0
4am-5am	210	318	210	318
5am-6am	280	424	280	424
6am-7am	70	106	70	106
7am-8am	0	0	0	0
8am-9am	0	0	0	0
9am-10am	0	0	0	0
10am-11am	0	0	0	0
11am-12pm	0	0	0	0
12pm-1pm	0	0	1050	1590
1pm-2pm	0	0	1050	1590
2pm-3pm	0	0	1050	1590
3pm-4pm	0	0	1050	1590
4pm-5pm	0	0	1050	1590
5pm-6pm	0	0	0	0
6pm-7pm	420	636	420	636
7pm-8pm	1610	2438	1610	2438
8pm-9pm	1610	2438	1610	2438
9pm-10pm	0	0	0	0
10pm-11pm	0	0	0	0
11pm-12am	0	0	0	0

Source: Created by William Delgado-Thompson and Katherine Drews (Project Participants).

Scenario 3 includes all Scenario 2 amenities and adds to the load an electric stovetop, a mini refrigerator, and space heater. This demand scenario reflects a potential increase in demand for the villages based on some future economic development. Under current economic conditions in the villages this load is unrealistic, as few if any villagers could afford the cost. This scenario is seasonal due to the use of electric fans during the summer months and electric space heaters during the winter months. One assumption is that a mini-fridge would run constantly so there is a load at all hours of the day, unlike previous scenarios. Table 2.7 lists hourly village demand profiles for Rakathum and Kothape. See Appendix A for further information about Scenario 3.

Project staff used the HOMER Micro-grid Modelling Software to determine the most cost-effective way of building a micro-grid in rural villages in Nepal.[80] HOMER models different energy sources and configurations to find the most cost effective combination of energy sources given an estimated electricity demand. The software can incorporate energy sources such as solar, wind, micro-hydro, biomass, diesel generators, and the grid.[81] The user can perform sensitivity analyses for different parameters to ascertain how changes in assumptions can influence the most economical energy configuration. HOMER can also download solar and wind data directly for any location on earth from the U.S. National Aeronautics and Space Administration (NASA) satellite databases.[82] Based on the HOMER analysis, staff determined that solar had the most potential for the locations of the villages, and performed the analysis using solar data downloaded from NASA.

Table 2.7. Scenario 3 Hourly Demand Profile

Scenario 3	Rakathum Mar-Apr, Sep-Nov (watts)	Kothape Mar-Apr, Sep-Nov (watts)	Rakathum May-Aug (watts)	Kothape May-Aug (watts)	Rakathum Dec-Feb (watts)	Kothape Dec-Feb (watts)
12am-1am	1050	1590	1050	1590	1050	1590
1am-2am	1050	1590	1050	1590	1050	1590
2am-3am	1050	1590	1050	1590	1050	1590
3am-4am	1050	1590	1050	1590	1050	1590
4am-5am	1260	1908	1260	1908	53760	81408
5am-6am	1330	2014	1330	2014	53830	81514
6am-7am	53620	81196	53620	81196	53620	81196
7am-8am	1050	1590	1050	1590	1050	1590
8am-9am	1050	1590	1050	1590	1050	1590
9am-10am	1050	1590	1050	1590	1050	1590
10am-11am	1050	1590	1050	1590	1050	1590
11am-12pm	1050	1590	1050	1590	1050	1590
12pm-1pm	1050	1590	2100	3180	1050	1590
1pm-2pm	1050	1590	2100	3180	1050	1590
2pm-3pm	1050	1590	2100	3180	1050	1590
3pm-4pm	1050	1590	2100	3180	1050	1590
4pm-5pm	1050	1590	2100	3180	1050	1590
5pm-6pm	1050	1590	1050	1590	1050	1590
6pm-7pm	53970	81726	53970	81726	53970	81726
7pm-8pm	2660	4028	2660	4028	2660	4028
8pm-9pm	2660	4028	2660	4028	2660	4028
9pm-10pm	1050	1590	1050	1590	1050	1590
10pm-11pm	1050	1590	1050	1590	1050	1590
11pm-12am	1050	1590	1050	1590	1050	1590

Source: Created by William Delgado-Thompson and Katherine Drews (Project Participants).

Project staff input the demand scenarios into HOMER at the coordinates of the villages to determine the most efficient way of providing electricity to Kothape and Rakathum via a village micro-grid. This resulted in six HOMER analyses, one for each village for each scenario. Appendix B presents the HOMER optimization results. The HOMER analysis of Scenario 1 for Rakathum estimated that a 0.965 kW solar PV system with 10 lead acid batteries could store 1 kWh of electricity each and a 0.842 kW converter. The HOMER software operates with U.S. dollars and it is not easy to convert dollars to Nepali rupees because technology differs between U.S. and Nepali markets. As expressed in U.S. dollars, the levelized cost of electricity (the cost of electricity per kWh spread over the equipment's initial capital costs, maintenance costs, and replacement costs) is $0.934 per kWh.[83]

The net present cost of the system, which combines the initial capital costs and the maintenance costs over the lifetime of the project, is $8,542 (2018 U.S. dollars). The estimated operating cost of the system is $199.48 per year. The initial capital required to build this system is $5,963. This system would be a connected village micro-grid system that would power all homes in the village of Rakathum, as opposed to the current unconnected small solar home systems in use.

The HOMER analysis of Scenario 1 for Kothape resulted in a 1.04 kW solar PV system with 10 lead acid batteries capable of storing 1 kWh of electricity each and a 0.856 kW converter. The levelized cost of electricity is $0.935 per kWh. The net present cost of this system is $8,422 and the operating cost is $130.37 per year. The initial capital required to build this system is $5,961. The cost of this system would be similar to the cost of the system for Rakathum, despite the larger number of households in Kothape.

The HOMER analysis of Scenario 2 for Rakathum resulted in a 5.52 kW solar PV system and requires 36 lead acid batteries capable of storing 1 kWh of electricity each as well as a 6.14 kW converter. This is a much larger system compared to the system for Scenario 1. The levelized cost of electricity is $1.31/kWh while the net present cost of this system is $36,981 (2018 U.S. dollars). The operating cost of this system is $727.12 per year and the initial capital required to build it is $27,582.

The HOMER analysis of Scenario 2 for Kothape resulted in an 8.26 kW solar PV system requiring 55 lead acid batteries capable of storing 1 kWh each. This system is significantly larger than the Rakathum system because the model assumes that each household in each village follows the same demand pattern, and Kothape has a higher population than Rakathum. This system requires a 4.76 kW converter. The levelized cost of electricity is $1.28/kWh. The net present cost is $54,752 while the operating cost is $1,071 per year. The initial capital required to build this system is estimated at $40,912. Because the cost to build this system for either village is high due to the larger number of solar panels and lead acid batteries required, it might be more cost effective to develop village practices that use electricity during the day to decrease the number of batteries required.

The HOMER analysis of Scenario 3 for Rakathum resulted in a 79.8 kW solar PV system that requires 821 lead acid batteries that can store 1 kWh of electricity and a 75.5 kW converter. The levelized cost of electricity for this configuration is $0.874/kWh, while its net present cost is $667,700. The system's operating cost is $15,145 per year and its initial capital is $471,908. This number of batteries for a village with only 35 households is unrealistic and unsustainable because batteries have to be replaced periodically. The topography of the area increases the difficulty of finding places to situate batteries and solar panels. Consequently, the system's high cost makes it difficult to justify building this micro-grid rather than connecting the village to the main electric grid.

The HOMER analysis of Scenario 3 for Kothape resulted in a 128 kW solar PV system that requires 1,194 lead acid batteries that can store 1 kWh of electricity and a 117 kW converter. The levelized cost of electricity for this configuration is $0.877/kWh, while its net present cost is $1.01M. The system's operating cost is $22,326 per year and its initial capital is $725,738. The number of batteries and solar panels required in this scenario is not realistic due to situating concerns related to topography. Though this scenario has the most potential to increase economic output in the villages due to the increase in available electricity, the economic output generated would probably not justify the expense of the system. Instead, grid expansion is a more realistic option for this load size as the main grid is only half a kilometer away.

This analysis of electricity demand and the cost of meeting demand illustrates that a village micro-grid based entirely on solar PV power has potential to provide electricity to the villagers at lower levels of electricity use. As electricity demand increases, the cost of providing that electricity with just solar panels and batteries alone increases to the point that connection to the main electric grid in Nepal becomes a lower-cost option.

The cost of this micro-grid would decrease if electricity demand occurred primarily in the daytime because the electricity produced from solar panels could be used immediately rather than stored in batteries. Batteries increase the cost of solar PV systems because they must be replaced every five years on average and have a high initial cost. Inverters are another important factor in the capital costs of solar PV systems. Though connected solar PV micro-grids are cost-effective ways of generating electricity for smaller electricity loads, such as powering light bulbs and charging cell phones, they are not cost effective for larger loads. This analysis demonstrates that connected solar micro-grids are an option for rural villages that have not yet electrified in rural Nepal or whose location is far from the main grid, providing renewable sustainable energy at a reasonable cost.

Conclusion

Project staff used the HOMER software to simulate electricity demand in the villages of Rakathum and Kothape. The results of the HOMER analysis indicate that a solar micro-grid is feasible for their small loads. For larger loads, extending Nepal's electrical grid may be a more cost-effective option for future economic expansion. The next chapter discusses financing options for village electrification.

1 "How Microgrids Work," Energy.gov, June 14, 2014, accessed November 22, 2017, https://energy.gov/articles/how-microgrids-work.

2 "Micro-hydro power," Practical Action, accessed November 22, 2017, https://practicalaction.org/micro-hydro-power?gclid=Cj0KEQjwmpW6
BRCf5sXp59_U_ssBEiQAGCV9Gjae8M- payn3uUZzzofRgeCKoNxu08g_CQbFPN-fbcgaAnIR8P8HAQ.

3 "Micro Hydro," Alternative Energy Promotion Centre (AEPC), Ministry of Energy, Water Resources and Irrigation, Government of Nepal, accessed February 28, 2020, https://www.aepc.gov.np/micro-hydro.

4 Ibid.

5 "Mini Hydro," AEPC, accessed February 28, 2020, https://www.aepc.gov.np/mini-hydro.

6 "Flow of River Hydro—Using Only Stream Velocity to Drive a Turbine," November 15, 2011, Build It Solar, accessed February 24, 2018 http://www.builditsolar.com/Projects/Hydro/FlowOfRiver/FlowOfRiver.htm.

7 "Microhydropower Systems," Energy.gov, accessed February 24, 2018, https://energy.gov/energysaver/buying-and-making-electricity/microhydropower-systems.

8 "Off-Grid or Stand-Alone Renewable Energy Systems," Energy.gov, February 24, 2018, https://energy.gov/energysaver/grid-or-stand-alone-renewable-energy-systems, accessed.

9 Amy Yee, "Microhydro Drives Change in Nepal," *The New York Times*, June 20, 2012, accessed February 28, 2020, http://www.nytimes.com/2012/06/21/business/global/microhydro-drives-change-in-rural-nepal.html.

10 "U.S. Energy Facts Explained," U.S. Energy Information Administration, updated August 18, 2019, accessed April 22, 2018, https://www.eia.gov/energyexplained/?page=us_energy_home.

11 Ibid.

12 Ibid.

13 Amy Yee, "Microhydro Drives Change in Nepal," *The New York Times*, June 20, 2012, accessed February 28, 2020, http://www.nytimes.com/2012/06/21/business/global/microhydro-drives-change-in-rural-nepal.html.

14 "Hydro Power," Energy Himalaya, accessed November 22, 2017, http://www.energyhimalaya.com/sources/micro-hydro.html.

15 "Micro Hydro Power – Pros and Cons," *AENews*, accessed February 24, 2018, http://www.alternative-energy-news.info/micro-hydro-power-pros-and-cons/.

16 Ibid.

17 Information provided to project participants in Nepal, March 2018.

18 Observations made by project participants in Nepal, March 2018.

19 Information provided to project participants in Nepal, March 2018.

20 Ibid.

21 Unpublished handout to project staff, "Synopsis of Karamdanda Micro Hydro Project," Alternative Energy Promotion Centre, Nepal, n.d.

22 Ibid.

23 Ibid.

24 Information provided to project participants in Nepal, March 2018.

25 Observations made by project participants in Nepal, March 2018.

26 Ibid.

27 Ibid.

28 Unpublished handout to project staff, "Synopsis of Karamdanda Micro Hydro Project," Alternative Energy Promotion Centre, Nepal, n.d.

29 Information provided to project participants in Nepal, March 2018.

30 Unpublished handout to project staff, "Synopsis of Karamdanda Micro Hydro Project," Alternative Energy Promotion Centre, Nepal, n.d.

31 Information provided to project participants in Nepal, March 2018.

32 "Thalweg," Merriam-Webster, accessed December 6, 2018, https://www.merriam-webster.com/dictionary/thalweg.

33 "Darcy Friction Factor," Corvallis Forestry Research Community, accessed December 10, 2018, http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Darcy_Friction_Factor.htm.

34 "Nepal Energy for Education Solar Project," Global Sustainable Electricity Partnership, accessed February 28, 2020, https://www.globalelectricity.org/projects/solar-nepal/.

35 "Nepal Energy for Education Solar Project," Global Sustainable Electricity Partnership, accessed February 28, 2020, https://www.globalelectricity.org/projects/solar-nepal/.

36 "The Nepal Energy For Education Project," Globalelectricity.org, 2013, http://www.globalelectricity.org/upload/File/the_nepal_energy_for_education_project_publication.pdf.

37 "Water & Sanitation," UN-HABITAT, , accessed July 22, 2018, http://mirror.unhabitat.org/content.asp?cid=2231&catid=270&typeid=24.

38 Ranjit Gautam, AEPC speaker, March 14, 2018.

39 World Health Organization, "What is the minimum quantity of water needed," https://www.Who.int/watersanitation_health/emergencies/qa/emergencies-qa5/en, accessed on February 1, 2019.

40 Ranjit Gautam, AEPC speaker, March 14, 2018.

41 "Solar Energy," AEPC, accessed November 22, 2017, https://www.aepc.gov.np/solar-pv-technology.

42 Gesto Energy Consulting, Governmental report for Nepal Electricity Authority (the consulting group requested the report be kept confidential).

43 "Nepal Energy for Education Solar Project," Global Sustainable Electricity Partnership, accessed February 28, 2020, https://www.globalelectricity.org/projects/solar-nepal/.

44 AEPC, “Solar PV Technology,” https://www.aepc.gov.np/?optain=renewable&page=solarpv&mid=2&sub_id=12&ssid=1&cat=solarPVTechnology, accessed November 22, 2017.

45 AEPC, “Solar Charge Controller,” http://www.aepc.gov.np/?option=renewable&page=solarpv&mid=2&sub_id=12&ssid=1&cat=Solar Charge Controller, accessed November 22, 2017.

46 S. Bhatia, *Introduction to Advanced Renewable Energy Systems*. Cambridge: Woodhead Publishing, 2014.

47 “Solar Battery,” AEPC, accessed November 22, 2017, http://www.aepc.gov.np/?option=renewable&page=solarpv&mid=2&sub_id=12&ssid=1&cat=Solar Battery.

48 “Solar Pumps,” AEPC, accessed November 22, 2017, http://www.aepc.gov.np/?option=renewable&page=solarpv&mid=2&sub_id=12&ssid=1&cat=Solar Pumps.

49 Ibid.

50 “Solar Dryers,” 50 AEPC, accessed November 22, 2017, http://www.aepc.gov.np/?option=renewable&page=solarthermal&mid=2&sub_id=12&ssid=2&cat=Solar Dryers.

51 “Solar Cookers,” AEPC, accessed November 22, 2017, http://www.aepc.gov.np/?option=renewable&page=solarthermal&mid=2&sub_id=12&ssid=2&cat=Solar Cookers.

52 “Solar Water Heating System,” AEPC, accessed November 22, 2017, http://www.aepc.gov.np/?option=renewable&page=solarthermal&mid=2&sub_id=12&ssid=2&cat=Solar Water Heating System.

53 “20W Mini Home Solar Generators Prices Electricity Solar Generation System for Rural Areas, School,” Alibaba, accessed February 28, 2020, https://www.alibaba.com/product-detail/20W-mini-home-solar-generators-prices_573813809.html?spm=a2700.7724838.2017115.216.20eb655cqHwnzN.

54 “Off Grid 5KW 48V Solar Energy Solar Home System, Solar Panel Roof Top System.” Alibaba, accessed February 28, 2020, https://www.alibaba.com/product-detail/Off-grid-5KW-48V-solar-energy_60257134745.html.

55 Observations made by project participants in Nepal, March 2018.

56 Prajwal Raj Shakya, “Biomass Energy Technology Dissemination Experience in Rural Nepal,” Presentation, 2018 Nepal PRP trip lectures, Kathmandu, Nepal, March 12, 2018.

57 “Biomass Densification,” AEPC, accessed February 28, 2020, https://www.aepc.gov.np/biomass-densification.

58 “Household Biogas,” AEPC, accessed February 28, 2020, https://www.aepc.gov.np/household-biogas.

59 David Eaton (Director), *Forestry and Economic Development on the Oki Islands, Japan*, Policy Research Project Report 196, LBJ School of Public Affairs, The University of Texas at Austin, 2018.

60 Ibid.

61 Prakash Aryal, “Organic Waste to Energy through Anaerobic Digestion,” Presentation, 2018 Nepal PRP trip lectures, Kathmandu, Nepal, March 12, 2018.

62 Prajwal Raj Shakya, “Biomass Energy Technology Dissemination Experience in Rural Nepal,” Presentation, 2018 Nepal PRP trip lectures, Kathmandu, Nepal, March 12, 2018.

63 Prakash Aryal, “Organic Waste to Energy through Anaerobic Digestion,” Presentation, 2018 Nepal PRP trip lectures, Kathmandu, Nepal, March 12, 2018.

64 Ibid.

65 Observations made by project participants in Nepal, March 2018.

66 Ibid.

67 Gesto Energy Consulting, Governmental report for Nepal Electricity Authority (the consulting group requested the report be kept confidential).

68 Prakash Aryal, “Experience of AEPC in Implementing Wind (Solar) Hybrid Projects,” Presentation, 2018 Nepal PRP trip lectures, Kathmandu, Nepal, March 12, 2018.

69 Ibid.

70 Ibid.

71 “Efficient, Informed Decisions About Distributed Generation and Distributed Energy Resources,” HOMER Energy, accessed December 6, 2018, https://www.homerenergy.com/.

72 “HOMER Pro,” HOMER Energy, accessed February 28, 2020, https://www.homerenergy.com/products/pro/index.html.

73 Observations made by project participants in Nepal, March 2018.

74 Ibid.

75 “National Population and Housing Census 2011,” Government of Nepal, , accessed April 5, 2018, https://unstats.un.org/unsd/demographic-social/census/documents/Nepal/Nepal-Census- 2011-Vol1.pdf.

76 Observations made by project participants in Nepal, March 2018.

77 Information provided to project participants in Nepal, March 2018.

78 “POWER Project Data Sets,” NASA Prediction of Worldwide Energy Resources, accessed February 28, 2020, https://power.larc.nasa.gov.

79 M. Mathisen, T. Strand, B. Sharma, R. Chandyo, P. Valentiner-Branth, S. Basnet, R. Adhikari, D. Hvidsten, P. Shrestha, and H. Sommerfelt, “RNA viruses in community-acquired childhood pneumonia in semi-urban Nepal; a cross-sectional study,” *BMC Medicine* no. 35 (July 1, 2009), https://bmcmedicine.biomedcentral.com/articles/10.1186/1741-7015-7-35.

80 “The HOMER Pro® Microgrid Software by HOMER Energy,” HOMER Energy, accessed April 19, 2018, https://www.homerenergy.com/products/pro/index/html.

81 Ibid.

82 Ibid.

83 Computed by project students using HOMER software.

Chapter 3. Financing Village Electrification

While Chapter 2 discusses the engineering feasibility and relative costs for delivering electricity to Rakathum and Kothape, a separate but no less central issue for project viability is to understand how such a project would be financed: who pays to build, repair, and maintain a system. Staff researched Nepali government subsidies and policies, potential bilateral and multilateral philanthropic donors, and methods of funding and credit. This assessment assumed the current economic conditions of the two villages based upon in-village interviews. Villages such as Rakathum and Kothape are poor. Economic conditions improve slowly. Major investments will likely rely on financial sources outside the villages, such as Nepali government subsidies and philanthropic donations from aid agencies or non-governmental organizations.

Different financing options are likely to be vital to potential project success. In each of the case study villages, an intra-village microloan system operates from funds raised by cottage-level industry savings.[1] From savings money collected, the cooperative credit-union-type banks already extend loans to individuals. With continued injections from both endogenous and exogenous Nepali funding sources, these villages could in principle afford additional electricity that could power economic growth.

For example, the Alternative Energy Promotion Centre (AEPC) and the Government of Nepal provide energy system subsidies to assist electrification of rural villages not expected to be connected within five years.[2] The Nepali government established a policy in the mid-1990s to bring rural villages without access to grid-generated electricity an opportunity to expand their economic capacities and quality of life through increased access to power through different alternative energy sources.[3] As the Nepali grid has continued to grow outside of major population centers, subsidy distribution has begun to decrease due to the grid's impending connection to more and more remote areas. Nepali villages may find themselves between subsidy requirements and near-future grid connection, and thus remain without electricity for several years.[4]

The Nepal government does not have sufficient resources to supply all of its citizens with access to electricity.[5] Donor countries, binational aid organizations, and not-for-profit foundations/philanthropies already assist rural electrification.[6] Donor organizations help to close the gap between any government subsidy and the realistic economic burden that unelectrified villages can sustain. It is common in Nepal for village-level projects to be funded by a governmental agency along with organizations outside of Nepal's government.[7] For example, the Karamdanda micro-hydro plant was established by a joint venture between the Danish government and Nepali subsidy. Rural electrification would not reach the distant villages as quickly or as feasibly without charitable donor participation.[8]

Microfinance (sometimes referred to as microcredit) involves the provision of small loans to low-income individuals in developing countries to support a small income-generating activity, with an expectation that the loan will facilitate an income sufficient for the borrower to exit from poverty.[9] Muhammad Yunus, Ph.D., a pioneer of modern microfinance, is often credited with giving small loans to poor women in Bangladesh when he founded the Grameen Bank in 1983.[10]

Since the 1970s, different microfinance organizations have implemented microcredit through a diverse range of institutional formats, including individual money-lenders, village banks, credit unions, financial cooperatives, state-owned banks for small and medium-sized enterprises (SMEs), and social venture capital funds. During the 1980s development solutions promoted microfinance to support the emergence of informal microenterprises and self-employment as a solution to poverty and underdevelopment in fragile countries.[11] By the 1990s, by some measures microfinance was the international development community's highest-profile and most generously funded poverty reduction scheme.[12]

Microfinance

Microfinance clients are often just below or above the poverty line, commonly defined as earnings below US$1.25 a day; in practice, women constitute a majority of borrowers.[13] Over the past decades, financial institutions have been developing a range of products to meet the diverse needs of this broad and underserved market. Traditional operators include formal microfinance institutions, as listed above. New mobile operators are using technology to develop innovative delivery methods to bring these services to the poor, sometimes in partnership with existing financial institutions. Mobile banking refers to financial transactions conducted over a mobile electronic device. Mobile banking has the potential to reach more people at a lower cost with increased convenience.

Those who secure micro-loans may perceive the program differently from the promoters of microcredit. Microfinance banks believe loans can help people build assets through savings or financing income-generating activities and can make it easier for them to manage shocks, such as medical emergencies, death, theft, or natural disasters. One reality of living in poverty is that income can be irregular and unreliable. People living in poverty may benefit from diverse financial products or services tailored to their circumstances. Low-income people may pay high costs and sometimes rely on unsecure, unpredictable, and unscrupulous options to access basic financial products and services. This difference in perspective of the lenders versus borrowers has led to a so-called "financial inclusion" movement, striving to encourage delivery of a full range of financial products at fair prices and without the risks poor people face today.[14]

The microcredit movement has been encouraged by success stories in Bangladesh, India, South America, and Africa. These experiences have helped establish microcredit programs as a promising development strategy in the eyes of policymakers. Pre-existing data from well-established institutions (such as the UN, UNICEF, and The World Bank) may not identify challenges faced by microfinance programs in Nepal. Extreme poverty, gender differences, and an unfavorable business climate are some of the challenges that Nepalis face with microcredit. Nepal is an extremely poor country, and the majority of the population in the hilly areas of Nepal rely on agriculture for subsistence. Due to lack of funds to finance new technologies, Nepalis use traditional farming methods. As a result, productivity is low and savings are moderate at best.

Many unemployed people, especially of the younger generation, could use funds in the form of microcredit to start new ventures, which would allow them to become self-employed and independent. Microcredit would help them support a family without borrowing money from landlords or working as agricultural laborers. Although microfinance programs have existed in

Nepal for several years, accessibility by the poor is a challenge. The availability of microfinance programs in the hilly regions has been restricted to urban centers that are inaccessible to the extremely poor, largely due to either lack of access or high cost.[15]

Women in Nepal constitute approximately 52 percent of the total population[16] and suffer from discrimination woven into the nation's cultural and social framework. In most villages, women fetch water, care for children, and collect firewood. Women do not have easy access to microcredit. Women often can do only what their husbands permit them to.[17] Nepal's Parliament passed a bill to end existing discrimination against women by giving women equal right as men on their parental properties before marriage.[18] Nepal has legalized abortion, giving women more freedom to make reproductive decisions.[19] However, the female literacy rate is low: more than two-thirds of women in Nepal are illiterate.[20] One consequence of the gender gap for microcredit programs is the limited participation by women.

Another barrier to microcredit is the lack of climate for entrepreneurship due to political instability and prolonged political transition of nearly two decades. Consequently, there is significant outflow of youth from rural Nepal to overseas migration for work. Nepal receives significant remittances from migrant workers that can contribute to household consumption and loan repayment.[21]

Village Finance and Banking

Kothape and Rakathum are remote villages located in unsecure environments with little to no access to formal financial institutions. Even though formal banks are far from both villages, residents report negative effects of microfinance institutions. Farmers in both Kothape and Rakathum stated the interest rates of local microfinance organizations were too high, at 18 percent. High-interest rates stimulated the need for alternative banking methods, such as village savings and loan associations. A village savings and loan association (VSLA) is made up of a group of people who save together and take small loans to increase individual business stock, cover medical needs, school fees, and other personal needs.[22] The VSLA allows the village members to take small loans at 12 percent interest while increasing its reserve.

A VSLA can combine group members' savings and provide small loans to community members who do not have easy access to formal financial services.[23] The association's reserves are maintained through interest rates in loans. Loan periods vary depending on the amount borrowed, often ranging from three months to one year. Borrowers pay back the loans at 12 percent interest with flexible monthly installments. The VSLAs typically do not lend the same amount to each individual and rely on internal social knowledge about community members and the loan usage to determine the qualified loan amount.[24]

Kothape and Rakathum communities are currently in the beginning stages of VSLA and growth has been slow. While economic growth in each village is currently weak, each association's reserve can increase over time. Once a VSLA has seen growth it could develop a social fund that provides basic insurance for emergency situations. Safety nets can benefit the entire community during unexpected situations, including group members and non-group members.

VSLA group presidents are elected annually and are managed by volunteers. The roles and responsibilities of the management committee are defined and decentralized. VSLA rules encourage participation of all members in the operation of the group and to protect the group from being dominated by a single individual. It should be noted that as of March 2018 female presidents were in charge of financial banking in both villages. Both women stated that elections are held at the end of each term, but they reported that no one wants to fill these positions because they are unpaid and require individuals to cut personal time on household chores or income-generating activities.

Rural community banks are designed to offer low-cost loans for small amounts of money to meet the financing needs of rural citizens. At the same time rural community banks such as VSLAs are exposed to high levels of risk, as most of their borrowers are rural households and small businesses that have inadequate collateral.[25] To meet the demands of villages for larger loans, alternative methods of creditworthiness, such as Tala, as discussed below, can provide mobile loans within minutes.

Mobile Banks

Rural banks in areas with limited infrastructure are difficult and costly to manage. As a result, the formal banks are centralized in and around cities, leaving the majority of Nepalis without easy access to financial institutions. In recent years, USAID's NEAT project and eSewa are both examples of established apps for mobile banks in Nepal.[26] Mobile bank apps allow users to send and receive payments, make deposits and withdrawals, and take small loans through a single mobile bank app.

The rapid technological advances in mobile-based technologies have created opportunities for new and innovative mobile banking services. Mobile banking represents a promising technology even though it has yet to be fully implemented in Nepal. Many commercial banks in Nepal have tried to introduce mobile banking systems to improve their operations and reduce costs. Several commercial banks in Nepal actively promote the use of mobile banking. Bank branches alone are no longer adequate to provide banking services to respond to customers' needs. Therefore, the provision of banking services through mobile banking has provided an alternative means to acquire banking services, and it can be convenient for bank customers. Despite all the efforts aimed at developing better mobile banking, this system remains underutilized.

Many areas in Nepal have poor infrastructure, including Kothape and Rakathum. Nepal's villages located in the mountainous or hilly regions lack access to financial services as villagers must walk hours to formal banks to withdraw and deposit money. As a result, over 70 percent of Nepali remain disconnected from the formal financial sector.[27] On the other hand, 18.9 million people in Nepal have access to a mobile phone but have no access to a bank account.[28] USAID, the UN, and local banks have introduced mobile banking to fill this gap for rural villagers in Nepal.

Alternative Methods for Creditworthiness

Tala, formerly known as InVenture, is an Android smartphone app that uses alternative data collection to deliver instant credit and help customers build a financial identity.[29] Unlike traditional credit scoring, Tala has proprietary underwriting models that draw on 10,000 data points.[30] Tala collects data on social connectedness, geographic patterns, and financial transactions to score customers in real time.[31] Persons do not need prior credit history to obtain a loan. The app builds a customized credit score based on an individual's habits and offers loans to those who qualify. The entire process, from app download to approval, takes about five minutes. Interest rates for approved persons fluctuate between 11 and 23 percent.

Tala currently operates in Eastern Africa, India, and South Africa, where 2.5 billion people have no credit score.[32] Tala allows people without credit scores in emerging markets to both obtain a credit score and secure a small loan of between $10 and $500.[33] Tala could help rural villages in Nepal once mobile banking becomes more widely used and introduced into the market. The interest rates for Tala are in line with the current village bank and microfinance banks in Nepal. Tala has an opportunity for larger loans than the current ability of village banks. Larger loans could help villagers to develop and maintain ongoing projects in Kothape and Rakathum or start new enterprises. The Tala app represents an option that could change how village electrification can be financed in Nepal.

Remittances

Nepali citizens receive one of the highest per capita rates of remittances in the world, as measured as a percentage of GDP.[34] Nepal's economy was damaged by the Maoist uprising, prolonged political instability, slow growth rates, and large group employment moving overseas. Overseas employment has resulted in remittance inflows of unprecedented levels. Remittances received by poor households in Nepal accounted for between one-third and one-half of the overall reduction in absolute poverty between 1995-96 and 2003-04.[35]

Remittances are an important source of income for households in developing countries.[36] In Nepal a remittance is money sent by a Nepali citizen (working in foreign countries or who has migrated to bigger cities in Nepal) to friends and family residing in the worker's community of origin. Remittances have been identified as a third pillar of development, as their volume in many years can be second to foreign direct investment and higher than overseas development assistance. Nepalis have been leaving their rural villages and moving to larger cities like Kathmandu or outside of the country for job security. Remittances often incur high transaction fees if transferred through Western Union, formal banks, or MoneyGram.

Cash remittances can be sent through an agent. The sender pays a transfer fee and there are often no real-time fund transfers.[37] The costs of a remittance transaction include a fee charged by the sending agent, typically paid by the sender, and a currency-conversion fee for delivery of local currency to the beneficiary in another country.[38] Some smaller money transfer operators require the beneficiary to pay a fee to collect remittances, presumably to account for unexpected exchange-rate movements.

In the last few years Wave (a mobile money transfer application) has been used to send money to selected countries in Africa (Ghana, Kenya, Uganda, and Tanzania).[39] Unlike other money transfer programs, Wave allows a user to send money from anywhere in the world directly from a personal phone with zero transfer fees. Wave generates income based on the currency exchange alone.[40] There are a few restrictions that apply such as the sender must have a bank account in the United States, United Kingdom, or Canada. Wave is currently working to expand its mobile money transfer app to more countries.[41]

Funding Implications

Chapter 2 discussed how electricity is issued in Kothape and Rakathum in homes for light and for charging devices that could enable economic growth. Based on research specific to the two villages, electricity alone would not be enough to stimulate economic activity independently. One common premise for electrification is that an ability to charge a cell phone could lead to a domino effect of economic prosperity. Both case-study villages now have a capacity for lighting inside homes and cell phone charging via solar powered units, even though almost all community residents are farmers who live off the land. Electrification so far has not added revenue or "created" new industries or significant employment. Both villages use a solar-powered water pump that enables residents to have more time for other activities in the village rather than using available man-hours for manual water transportation.

In each village, a grass-roots management group handles the financial mechanics associated with the use of the pump. The collected funds from the local villagers using the pump and the village management group were able to set up a small micro-financing fund. The village bank charges around 11 percent interest. According to villagers consulted, both villages report a loan repayment rate of around 90 percent.[42] Micro-financing per se may enable villagers to begin income-generating activities, such as enhanced animal husbandry.

Even with the ability to borrow money and save time, villagers still face issues of limited markets and insufficient water for economic activity, as so much of the pumped water is still required for domestic drinking water. Both sets of villagers supported the idea of a solar-powered water pump strictly for irrigation, a solar-powered refrigeration device, and a new market for trade closer to the villages.[43]

While individual village-level projects may be small in scope, they may be relatively safe investments that offer a steady repayment rate that few other opportunities may match. The solar water pumping for irrigation relies on pre-existing government subsidies, individual village-level investment, outside financial resources, and labor-in-kind. In these two villages, the return on investment appears to be real and increasing. As of now, the best opportunities for investment in places like Rakathum and Kothape lie in focusing financing resources towards farm-related investment and enhancing human capital. Electrification can kick-start short-term village economic growth and catalyze long-term economic opportunities through irrigating cottage-level cash crops or enabling animal husbandry investments using local water resources and local farming knowledge.

1 Based on personal interviews with a Nepali village elder in Kothape, Nepal, March 2018.

2 "Alternative Energy Promotion Centre," Alternative Energy Promotion Centre (AEPC), accessed March 2018, https://www.aepc.gov.np.

3 Unpublished information provided by Ram Prasad Dhital, Executive Director, Alternative Energy Promotion Centre, Nepal, March 2018.

4 Based on personal interviews with Alternative Energy Promotion Centre representative, Rakathum, Nepal, March 2018.

5 Based on personal interviews with Nepal Electricity Authority representative, Kathmandu, Nepal, March 2018.

6 Unpublished information provided by Ram Prasad Dhital, Executive Director, Alternative Energy Promotion Center, Nepal, in March 2018.

7 Based on personal interviews with the Micro-Hydro Project official, Kavre, Nepal, March 2018.

8 Ibid.

9 Milford Bateman and Ha-Joon Chan, "Microfinance and the Illusion of Development: From Hubris to Nemesis in Thirty Years," *World Economic Review*, 1, no 1, (2012), http://wer.worldeconomicsassociation.org/files/WER-Vol1-No1-Article2-Bateman-and-Chang-v2.pdf.

10 Muhammad Yunus, *Creating a World Without Poverty: Social Business and the Future of Capitalism*, Public Affairs: New York, (2009).

11 Milford Bateman and Ha-Joon Chan, "Microfinance and the Illusion of Development: From Hubris to Nemesis in Thirty Years," *World Economic Review*, 1 ,no. 1 (2012), http://wer.worldeconomicsassociation.org/files/WER-Vol1-No1-Article2-Bateman-and-Chang-v2.pdf.

12 Ibid.

13 "Microfinance FAQs," FinDev Gateway, accessed April 23, 2018, https://www.microfinancegateway.org/what-is-microfinance.

14 Benjiman Opolo Antwi, "The Failure of Microfinance in Ghana: A Case Study of Noble Dream Microfinance Limited," accessed February 28, 2020, http://ir.knust.edu.gh/bitstream/123456789/8552/1/BENJAMIN%20OPOKU%20ANTWI.pdf.

15 Based on unpublished personal interviews with individuals in Nepal during March 2018.

16 Gambhir Bhatta, "'Small Is Indeed Beautiful but…' The Context of Microcredit Strategies in Nepal," *Policy Studies Journal* 29, no. 2 (July 2005): 283-295.

17 Based on a presentation by an AEPC representative, Kathmandu, Nepal, March 2018.

18 Jal Singh, "Feature: Empowering Women." Peace Women: Women's International League for Peace and Freedom (WILPF), 2002, accessed February 28, 2020, http://www.peacewomen.org/news/Nepal/newsarchive02/empowering.html.

19 Khagendra Dahal, "Legal abortion in Nepal and women in Prison," *The Lancet* 363 no. 9424 (June 5, 2004), p. 1905, https://doi.org/10.1016/S0140-6736(04)16364-2.

20 Jal, Singh, "Feature: Empowering Women." Peace Women: Women's International League for Peace and Freedom (WILPF), 2002, accessed February 28, 2020, http://www.peacewomen.org/news/Nepal/newsarchive02/empowering.html.

21 Luni Piya and Niraj Prakash Joshi, "Migration and Remittance in Nepal: A Review of the Push-Pull Factors and Socioeconomic Issues," *Journal of Contemporary India Studies: Space and Society*, Hiroshima University, March 2016, accessed February 28, 2020, http://ir.lib.hiroshima-u.ac.jp/files/public/3/39712/20160413145207426l2/J-ConIndiaStud-SpaceSoc- HU_6_41.pdf.

22 "Village Savings and Loan Association," VSL Associates, accessed April 23, 2018, http://www.vsla.net/aboutus/vslmodel.

23 Ibid.

24 Ibid.

[25] Han Yi and Han Wei, “Village Banks Thrive, but Risk Concerns Mount,” Caixin, March 31, 2017, accessed April 24, 2018, https://www.caixinglobal.com/2017-03- 31/101073147.html.

[26] “Strengthening the Foundations for Inclusive Economic Growth,” USAID, accessed April 23, 2018, https://www.chemonics.com/wp- content/uploads/2017/10/Nepal-NEAT-Final-Report.pdf.

[27] Ibid.

[28] Ibid.

[29] “Building the Future of Finance,” Tala, accessed April 23,2018, https://tala.co/.

[30] Ibid.

[31] Ibid.

[32] Ibid.

[33] Clare O’Connor, “Woman-Led Tala Raises $30 Million Series B For Micro-Loans Via Smartphone,” accessed April 24, 2018, https://www.forbes.com/sites/clareoconnor/2017/02/22/woman-led-tala-raises-30-million-series-b-for-micro-loans-via-smartphone/#112e3e4259bb.

[34] Chandan Sapkota, “Remittances in Nepal: Boon or Bane?” *The Journal of Development Studies* 49, no. 0 (2013): 1316-1331, DOI: 10.1080/00220388.2013.812196.

[35] Ibid.

[36] Therese Nilsson, “Remittances and Poverty in El Salvador,” Master’s Thesis, School of Economics and Management, Lund University, November 2005, accessed April 23, 2018, http://lup.lub.lu.se/luur/download?func=downloadFile&record OId=1857842&fileOId=1857843.

[37] “Remittances: Funds for the Folks Back Home,” International Monetary Fund, updated February 24, 2020 , accessed April 23, 2018, http://www.imf.org/external/pubs/ft/fandd/basics/remitt.htm.

[38] Ibid.

[39] “Send money with love,” Wave, accessed April 23, 2018, https://www.wave.com/.

[40] Ibid.

[41] “E-Sewa,” E-Sewa, accessed April 23, 2018, https://esewa.com.np.

[42] Unpublished information provided to project participants from Rakathum and Kothape, Nepal, March 2018.

[43] Ibid.

Chapter 4. Electrification and Economic Development Outcomes

Previous chapters report on different methods of extending electricity to Kothape and Rakathum and how those systems could be financed. This chapter lists steps for encouraging village economic development by supporting rural entrepreneurship in the villages and installing solar systems to electrify irrigation. This chapter also discusses the potential for biomass systems to contribute to economic development. Both systems represent small short-term steps towards village economic development.

One definition of entrepreneurship is when a person embraces risk and uses ideas to create economic growth. Entrepreneurship is not easy and several supporting facets are needed to stimulate economic growth. For example, in isolated rural Nepali villages loans from banks or other investors can enable investment in electricity and reliable infrastructure.

The Government of Nepal and several organizations have recognized these challenges and have begun to address entrepreneurship.[1] The Government of Nepal and NGOs encourage rural village entrepreneurship through projects such as solar energy and biomass systems to stimulate economic growth. Solar energy systems can pump drinking water to villages or deliver water to fields for irrigation. Biomass systems can produce methane for cooking. Each system enables villagers to have more free time to devote to growing their personal and local village economy, as well as open up opportunities for villagers to build businesses. In the two target villages, Kothape and Rakathum, electricity service has improved the economy and quality of life. The installation of a solar water pump enabled the growth of small businesses such as animal husbandry. The installation of a biogas for cooking enabled the villagers to spend time planting crops instead of gathering firewood, as discussed below.[2]

Solar-Powered Irrigation

Chapters 2 and 3 discussed the viability and applications of solar energy in Kothape and Rakathum. Based on existing practice, solar electrification is cost-effective for home lighting, recharging phones, and operating pumps for drinking water and irrigation. The installation of these solar energy systems can encourage sustainable economic growth and development, improving economic prospects for villagers. This chapter further evaluates the potential impact of solar irrigation system installation on the economic prospects of the villages, based on observed economic costs and benefits.

Solar energy has natural limitations due to the intensity and reliability of solar radiation, based on atmospheric conditions that affect how solar power can be used for electrification in situations of constant demand.[3] However these natural limitations are less severe in uses such as the pumping of irrigation and drinking water, which do not require constant energy supply.

Changing climate conditions may make traditional water sources, such as rainfall or stream flow, less reliable. Since 1997, the Government of Nepal has promoted programs to encourage water and land management in agricultural areas of Nepal through local control and management of irrigation systems, including promoting the installation of solar energy systems. In cases where irrigation systems work well, farmers are able to irrigate crops year-round, increasing net incomes.[4]

In recent years, farmers living in many of Nepal's numerous river basins have experienced what some analysts believe are negative effects of climate change, including more frequent droughts and water shortages.[5] Irregular rainfall caused by a recorded temperature increase of approximately 1.8 degrees Celsius over the last 32 years has affected rural residents, many of whom rely on subsistence farming or cash crop production for their livelihoods.[6] As much as 80 percent of annual rainfall occurs during the monsoon season, meaning that erratic weather patterns can make year-round agriculture difficult. Climate change may have affected the stability of the Himalayan glaciers that feed many of Nepal's rivers. Some projections have suggested that glacier runoff to Nepali rivers could decrease by as much as 14 percent, reducing dependable river flow, which affects both hydroelectric project yield as well as the availability of irrigation water.[7]

Photovoltaic-powered water pumping systems can be cost effective in remote areas where grid connectivity and the use of diesel or other fossil fuels have disadvantages.[8] Alternative grid connections can take years, as projects can be delayed. The installation of solar energy panels for use in pumping drinking water or irrigation may be less expensive than connecting to the national grid, which requires that farmers (who may lack stable incomes) be able to pay a tariff for use of electricity needed to run irrigation pumps. Subsidized solar panels can enable farmers to increase their agricultural productivity with a known and stable increase in income. The use of PV drip irrigation systems increases water efficiency.[9] For example, 90 percent of farmers in the areas surrounding Dhulikhel rely on rainfall and have no access to irrigation, meaning the potential impact of irrigation systems in these areas could be substantial.[10]

Sustainable energy resources have the effect of improving rural residents' capacity to adapt to changing conditions, providing a sustainable path towards development and wealth generation, without further contributing to carbon dioxide emissions that drive climate change.[11] As the national grid in Nepal slowly spreads to rural areas, villages equipped with sustainable energy sources could sell excess energy back to the national grid, thereby offsetting carbon emissions from urban centers.[12] Sustainable and consistent sources of water for irrigation can enable villagers to provide year-round food and income, and contribute to the economic development of Nepal as a whole.

Table 4.1 contains the specifications of the solar-powered drinking systems in Kothape and Rakathum, as discussed in Chapter 3. The total cost of the installation in Rakathum was US$23,000, of which approximately 44 percent was contributed by AEPC, 14.7 percent was contributed by in-kind labor from villagers, 0.5 percent was small cash donations, and the remainder from outside organizations.[13] The solar-powered water pump installation in Rakathum had a significant effect on the economic prospects and daily quality of life for villagers. Prior to the installation of the water pump, villagers had to travel down to the river bed and carry water back to their residences in buckets, a laborious task that drained time that could be used for other activities. The water pump provided a stable and clean source of drinking water that may potentially reduce instances of water-borne disease and improve the health of the villagers.

Table 4.1. Solar-Powered Drinking Water Systems in Villages of Rakathum and Kothape

	Rakathum	Kothape
Number of Households	35	52
Water Demand per Person	30-35 liters	30-35 liters
Amount of Tariff	100 rupees	100 rupees
Size of Cistern	18,000 liters	27,000 liters
Daily Use	10,000 liters	15,350 liters
Pump Size	2 horsepower	2 horsepower
Water Head	136 m	300 m
Size of Solar Panel	2 kW	2.4 kW
Primary Activity	Agriculture	Animal Husbandry
Installation Cost	US$23,000	US$20-25,000

Source: Information provided to project participants in March 2018.

Other tasks such as watering animals, bathing, and washing clothes became easier after the introduction of the solar-power water pump. Villagers in Rakathum were able to take advantage of additional economic opportunities created through the efficiencies introduced by the provision of drinking water. For instance, a woman running a poultry farm was reported to have considered expanding her business as additional water sources became available.[14] Other villagers reported that they could expand livestock holdings as a result of the relative ease with which they were able to provide water for additional livestock. As an added economic benefit, the citizens' council that managed the operation of the solar panel and drinking water cistern was able to save US$2,000 collected through tariffs and saved from unused funds provided for system installation. This money was lent to villagers as a form of community credit, allowing for the opportunity to make investments in expanding livestock holdings and other economic activities. In summary, the solar drinking water system improved health and sanitation and enabled economic benefits.

As a result, the villagers in Rakathum expressed enthusiasm for the planned installation of a larger solar irrigation system. Residents of Rakathum in the past had been able to produce crops year-round. Eight years of reduced rainfall created a difficult situation for agricultural activity in the village. The villagers are limited by the water shortage to farming for six months out of the year, a situation that had caused them significant economic hardship. Rakathum was well positioned to expand its agricultural base, provided it obtained a new source of water for irrigation. The village contains approximately 12 hectares of arable land located approximately 50 to 75 meters above the river bank. Based on the estimates provided to the research team by representatives from AEPC (the organization that would be responsible for the installation of the system), a 4-kw solar panel (one slightly larger than the existing system) would cost between US$20,000 to $25,000 and could power a 2 horsepower pump that could deliver 28,000 liters of water per hour to irrigate five hectares.

Despite the good prospects for a PV water irrigation system in Rakathum, the nearby village of Kothape faces similar but more complicated economic challenges related to irrigation. Facing a smaller endowment of land and relatively less arable land, Kothape had not been selected by AEPC as having enough demand for a solar irrigation pump, despite the fact that it is a larger village of 52 households. Most of Kothape's residents live in relatively more difficult circumstances than the villagers of Rakathum, and perhaps could have reaped even more benefits from additional income provided by a solar irrigation system.

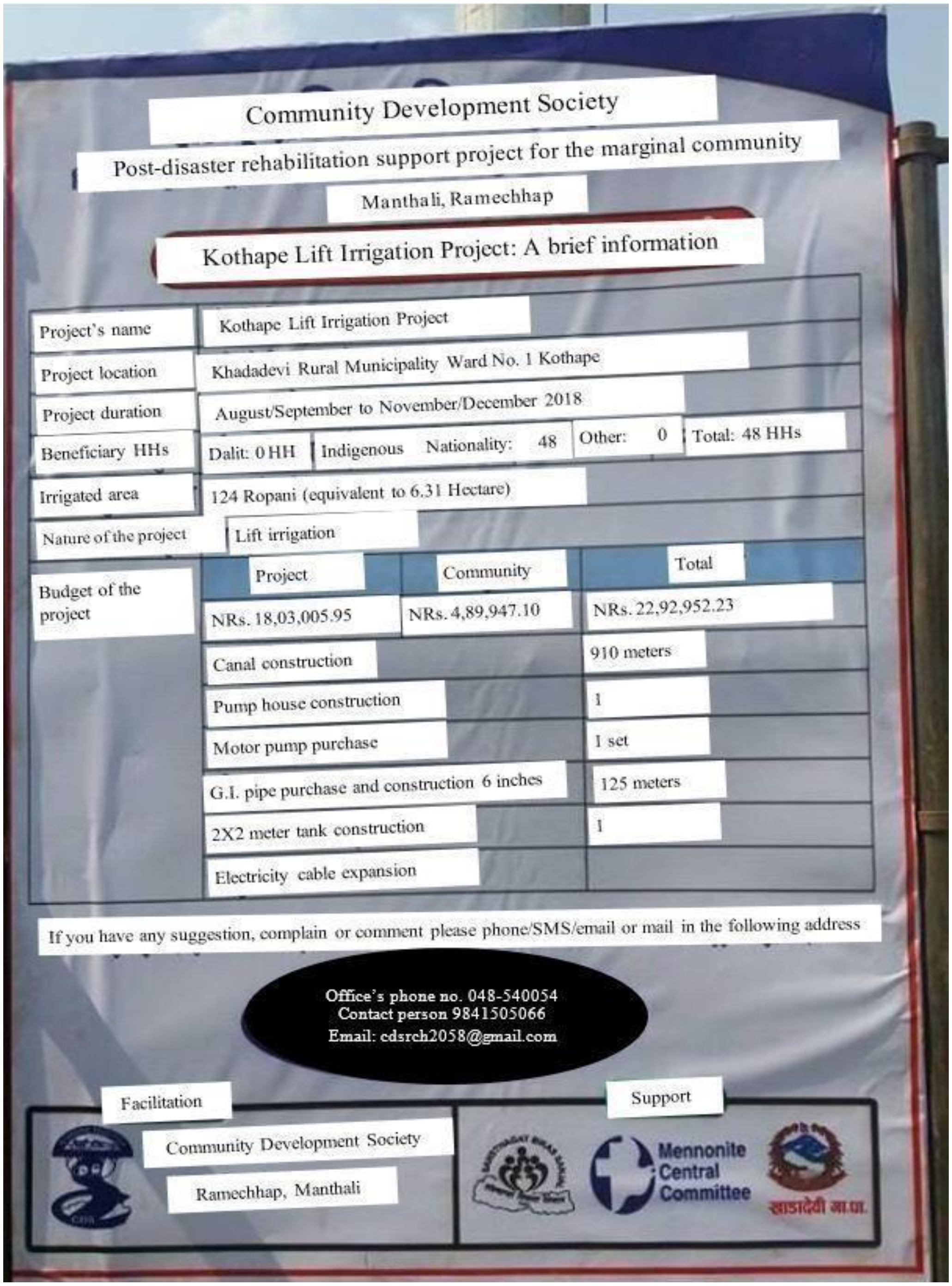
Based on AEPC rules for evaluating potential investments, Kothape would not receive a government-subsidized solar system. However, according to AEPC, the CDS-Nepal may be able to finance plans to install a 4-kw solar-powered, two-horsepower pump at an estimated cost of US$20-$25,000 to pump 28,000 liters per hour to irrigate five hectares of land.[15] CDS recently initiated such a project (see Figures 4.1 and 4.2).

Previous studies have demonstrated that low-cost drip (LCD) solar irrigation systems in farms can increase incomes of farmers by more efficiently irrigating crops and improving yields by replacing more labor-intensive irrigation practices, such as hand-watering. Table 4.2 contains an evaluation of costs and income for cauliflower production, comparing three different irrigation methods: low-cost drip irrigation, conventional drip irrigation, and hand watering. Compared to conventional drip or hand watering, low-cost drip irrigation produces the highest profit margins for Nepali farmers.

Figure 4.1. Public Audit of Lift Irrigation Project in Kothape (in Nepali)

Source: Figure provided by Professor Niraj Prakash Joshi of Hiroshima University, December 2018.

Figure 4.2. Public Audit of Lift Irrigation Project in Kothape (in English)



Source: Figure provided by Professor Niraj Prakash Joshi of Hiroshima University, December 2018.

Although the capital cost of installing a conventional irrigation system may surpass the ability of farmers to pay from their savings, a low-cost irrigation system can give farmer access to irrigation while incurring a much smaller capital cost, producing substantial benefits quickly. A solar irrigation system in Kothape could enable year-round production, which means that farmers are no longer constrained by unpredictable weather patterns.

Table 4.2. Benefits of Implementing Low-Cost Irrigation to Cultivate Cauliflower

Costs (NRp)	Irrigation method		
	LCDI	CDI	Hand-watered
Capital costs			
Drip irrigation system	900	14300	–
100 l drum	440	440	–
Bucket and scoop	–	–	300
Variable costs			
Fertilizer and pesticides	265	265	265
Seedlings	320	320	320
Labour costs: fetching water	975	975	975
Labour costs: other activities	225	100	563
Total costs (Season 1, Crop 1)	3125	16400	2423
Gross income			
Cauliflower sales (15 Rp/kg)	3840	3840	3840
Net income after one crop (labour costs included)	715	−12560	1417
Net income earned after second crop (labour costs included)	2055	−10380	1717

Notes: All figures in U.S. dollars; LCDI = low-cost drip irrigation; CDI = conventional drip irrigation.

Source: Stefanie von Westarp, Sietan Chieng, and Hans Schreir, "A comparison between low-cost drip irrigation, conventional drip irrigation and hand watering in Nepal," *Agricultural Water Management* 64, no. 2 (2004): 143-160.

The use of solar energy for efficient irrigation has the potential to offset carbon emissions produced by urban energy consumers, if villagers can sell excess energy produced by the solar panel back to the national grid, once grid connectivity is established. Greater productivity in the agricultural sector can increase demand for local inputs such as seeds or fertilizer, which can produce further growth in the agricultural sector when implemented on a national scale.

In the two villages studied, the subsidies (between US$14,000 and $25,000 depending on the size offered by the national government) could pay for installing solar irrigation water pumps. Villagers could contribute in-kind labor. Government subsidies could cover about 40 percent of the total project costs. Given that villagers lack savings, government subsidies remain a key factor for the installation of such projects, which creates difficulties for the cash-strapped central government. Table 4.3 lists barriers and benefits from solar irrigation projects.

Table 4.3. Benefits and Barriers of Solar Irrigation Projects

Benefits	Barriers
Increased income for farmers	Capital investment of solar system
More efficient use of water resources	Lack of local operational knowledge
Excess solar energy offsets carbon emissions	Inefficiency of management
Increased domestic demand for agricultural inputs	Insufficiency of subsidy amounts
Quicker and cheaper access to irrigation than grid or diesel	Villager skills for maintenance

Source: Observations made by project participants in Nepal, March 2018.

Recommendations

Table 4.4 lists four recommendations from this project's fieldwork. Two items refer to improved use of water resources, one to economic planning, and one to enhanced biomass use.

Solar PV water pumping systems confer significant economic benefits for villages by reducing the cost of irrigating crops and reducing risks from irregular weather patterns. Although rural electrification has often focused on providing electricity for running small appliances or providing lighting to villages, successful implementation of solar energy projects is most feasible when tied to income-generating activities, particularly agriculture. The relative success of the solar energy project in Rakathum compared to Kothape was due to a difference of effective local governance structure prepared to take advantage of the opportunities and applications of a PV water pumping system.

Differences in economic endowments (arable land, savings, etc.) affect the feasibility of different renewable energy projects. The relative success of a given project and its impact on the quality of village life is connected to the conditions and natural endowments within a village. Local initiatives and government structure also affect financing and implementation, as well as educating villagers on entrepreneurial opportunities from village electrification.

Pursuing a strategy of solar irrigation in rural areas has the potential to generate economic benefits for Nepal's farmers (see Table 4.4).[16] About 65 percent of Nepali are dependent on agriculture as a source of income; of these, roughly 75 percent are engaged in subsistence agriculture.[17] Year-round irrigation coverage is no more than 38 percent, according to an analysis by the Nepal National Committee on Irrigation and Drainage.[18] Rakathum and other cases document the tangible benefits of increasing access to irrigation through the installation of PV low-cost irrigation systems. This case confirms the viability of demonstrated local enthusiasm and efficiency in local management. There are potential benefits of offsetting climate change and increasing efficiency of water management in Nepal.

Table 4.4. Recommendations

1. Encourage regional economic development of isolated villages
2. Expand water lifting to agriculture and other sectors to promote local economic development
3. Provide resources for villagers to understand how to manage solar irrigation systems to yield economic benefits
4. Utilize biomass/bioenergy as a low-cost and reliable fuel source for food preparation

Source: Observations made by project participants in Nepal, March 2018.

By using subsidized PV panels to operate low-cost drip irrigation systems, the Government of Nepal can encourage growth in the agricultural sector and better economic prospects for villages while offsetting the potential effects of climate change and reducing strain on water resources. Villagers, though generally competent and interested in managing their own systems, may lack skills or equipment to repair different energy systems or employ them efficiently. Given that technical issues often arise, serious attention should be paid in the early stages of project implementation to ensure that villagers have the knowledge required to maintain solar irrigation systems and use them efficiently.

Access to water has the potential to create opportunities for additional economic activities such as animal husbandry, alcohol production, poultry farming, etc. Villages are often constrained by the difficulty and inefficiency of walking down to the river to fetch water. Creative implementation of lifting projects can complement economic activities beyond agriculture. The government should not deny resources to villages based on a limited interpretation of potential applications.

In both villages, barriers existed that created difficulties for farmers interested in using solar irrigation to generate cash crops, such as lack of access to markets and the lack of local availability of agricultural inputs. Rather than simply implement projects on a case-by-case basis, the government could develop a regional strategy with the goal of increasing market access, connecting farmers to cheaper inputs, and resolving infrastructure problems that constrain the potential efficient use of solar irrigation projects.

Biogas

Biogas remains an underutilized resource in the villages, given the amount of potential energy. Biogas in Kothape and Rakathum is used by some residents as a fuel for cooking, although biomass in the form of fuelwood is the primary energy source for cooking. Some well-to-do families in Kothape may recently have reverted back to the use of liquid petroleum gas instead of biogas due to the challenges for proper maintenance and repair of biogas systems.[19] Biogas-powered irrigation is an option that could be considered. In Rakathum, agriculture has been limited by insufficient rainfall and no alternative irrigation system.[20] Relatively small amounts of biogas can be combined with a small amount of diesel fuel (for ignition) to efficiently run an electrical generator large enough to pump water for irrigation. Biogas-powered generators could also generate heating and electricity.

Conclusions

Project staff analyzed electricity demand scenarios for two rural villages, Kothape and Rakathum, to enhance economic development. Renewable energy options could benefit rural Nepali villagers by replacing the burning of kerosene and other fuels while generating sustainable electricity. Researchers found that the villages already had some form of electricity at home through solar panels, as well as a limited supply at each school and for a water pump. The demand for electricity was mainly based in the agricultural industry of the area. Hydro or wind systems were more costly. Solar or biomass could have the most cost-effective impact in villages, especially if used for certain agricultural purposes such as irrigation. Further analysis should be done to test whether a solar-powered or biomass irrigation system could be effective in the village of Rakathum.

These study conclusions are limited by one significant complication in Nepal: an absence of appropriate labor. In Nepal young, able-bodied workers often migrate to its cities or overseas. Remittances make up a relatively large portion of the country's GDP. A potential limitation of focusing on building industry in a rural location is this "brain drain" as well a an overall decrease in rural population due to urbanization.

[1] Suman Shrestha, "Entrepreneurship in Nepal: Challenges and Opportunities," 2018, accessed April 7, 2018, http://sumansth.com/entrepreneurship-nepal-challenges-opportunities/.

[2] Based on interviews with villagers in Nepal, March 2018.

[3] J.T. Pytilinski "Solar Energy Installations for Pumping Irrigation Water," *Solar Energy* 21, no. 4 (1978): 255–62, https://doi.org/10.1016/0038-092X(78)90001-4.

[4] Based on an interview with a village head in Nepal, March 2018,

[5] I. Palazzoli, S. Maskey, S. Uhlenbrook, E. Nana, and D. Bocchiola, "Impact of Prospective Climate Change on Water Resources and Crop Yields in the Indrawati Basin, Nepal," *Agricultural Systems* 133 (Feb. 2015): 143–157.

[6] Ibid.

[7] Shardul Agrawala, Vivian Raksakulthai, Peter Larsen, Joel Smith, and John Reynolds, "Development and Climate Change in Nepal: Focus on Water Resources and Hydropower," OECD, 2003, p. 64, http://www.oecd.org/environment/cc/19742202.pdf.

[8] Ibid.

[9] Ramazan Senol, "An Analysis of Solar Energy and Irrigation Systems in Turkey," *Energy Policy* 47 (August 1, 2012): 478–86, https://doi.org/10.1016/j.enpol.2012.05.049.

[10] Bibek Dhital, "Economy of Production and Labor Requirement in Major Field Crops of Kavre, Nepal," *International Journal of Environment, Agriculture and Biotechnology* 2, no. 1 (Jan-Feb. 2017): 350–53, https://doi.org/10.22161/ijeab/2.1.43.

[11] Annabel Yadoo and Heather Cruickshank, "The Role for Low Carbon Electrification Technologies in Poverty Reduction and Climate Change Strategies: *A Focus on Renewable Energy Mini-Grids with Case Studies in Nepal, Peru and Kenya,"* Energy Policy 42 (March 2012): 591–602, https://doi.org/10.1016/j.enpol.2011.12.029.

[12] Ibid.

[13] Based on interviews conducted with villagers in Rakathum, March 16, 2018.

[14] Based on interviews conducted with villagers in Rakathum, March 16, 2018.

[15] Information provided to project participants in March 2018.

[16] Ibid.

[17] Kathmandu Singhdurbar, "Agriculture Development Strategy (ADS) 2015 to 2035," Government of Nepal, Ministry of Agricultural Development (MoAD), accessed February 28, 2020, http://www.dls.gov.np/uploads/files/ADS%20Final.pdf.

[18] Information provided to project participants in March 2018.

[19] Kathmandu Singhdurbar, "Agriculture Development Strategy (ADS) 2015 to 2035," Government of Nepal, Ministry of Agricultural Development (MoAD), accessed February 28, 2020, http://www.dls.gov.np/uploads/files/ADS%20Final.pdf.

[20] Information provided to project participants in March 2018.

Appendix A.
Demand Scenario Supplemental Information

Electricity Estimates

Project staff used average electricity usage for each device in each scenario, even though actual appliances in the village could draw more or less energy. For example, a LED light bulbs uses 2 watts per bulb when illuminated. Cell phone chargers use 2-6 watts when charging; the demand scenario assumed 6 watts. The power consumption of a television is variable depending on technology and screen size. The scenarios assumed that a 24-inch television with an LCD screen display and LCD backlighting would draw 40 watts of power. Radios can use between one to five watts of power depending on model; the simulation assumed a standard alarm clock radio, which uses 2 watts.

An electric stove top burner uses 1,000 to 3,000 watts. The simulation assumed an average of 1,500 watts in scenarios. A 1.7 cubic foot mini-refrigerator uses 30 watts, so that number is used in the scenarios. A portable electric-convection space heater typically uses around 1,500 watts when turned on; this number is used in scenarios. A typical portable fan uses 30 watts; again that number is deployed in analysis.

Scenario 1 Assumptions

Scenario 1 assumes that 3 LED light bulbs use 2 W while on. Assuming the lightbulb will be on 5 hours a day, 7 days a week, individual household demand will equal approximately 30 Wh per day for a light bulb. Assuming a cell phone is charged for one hour per day, 7 days a week, and uses 6 Wh, individual household demand for a cell phone for one day will equal 6 Wh. We assume that all of the load will occur between the hours of 4 and 6 am and 6 and 9 pm. We assume that the lightbulb will be on constantly from 4 to 6 am and 6 to 9 pm and that the cell phone will be charging from 6 to 7 pm.

There are 35 households in Rakathum. Assuming every household in the village follows this pattern, hourly village demand in Rakathum will be 210 W from 4-5 and 5-6 am, 420 W from 6-7 pm, and 210 W from 7-8 and 8-9 pm. We assume this load is constant over the course of the year and that there is no other load for the rest of the hours of the day. There are 52 households in Kothape. Assuming every household in the village follows this pattern, hourly village demand in Kothape will be 318 W from 4-5 and 5-6 am, 636 W from 6-7 pm, and 318 W from 7-8 and 8-9pm. We assume this load is constant over the course of the year and that there is no other load for the rest of the hours of the day.

Scenario 2 Assumptions

Scenario 2 assumes a radio operating for two hours in the morning from 4-6 am, and that the television will be on in the evening from 7-9 pm. Electricity demand in Rakathum is lower than electricity demand in Kothape because we assumed equity across households in each village and Kothape has a greater number of households than Rakathum. Under this scenario, hourly village electricity demand in Rakathum from September through April is 210 W between 4-5 am, 280 W between 5-6 am, and 70 W between 6-7 am. Rakathum's hourly electricity demand between 6-7 pm is 420 W and 1610 W hourly from 7-9 pm.

Under this scenario, hourly village electricity demand in Kothape from March through April and September through November is 318 W between 4-5 am, 424 W from 5-6 am, 106 W from 6-7 am, 636 W from 6-7 pm, and 2438 W hourly from 7-9 pm. Outside these hours we assume the load to be 0 W.

During the summer months from May to August, hourly electricity demand for the village of Rakathum will be 210 W from 4-5 am, 280 W from 5-6 am, 70 W from 6-7 am, 1050 W hourly from 12-5 pm, 420 W from 6-7 pm, and 1610 W hourly from 7-9 pm. In Kothape during the summer months, hourly electricity demand for the village will be 318 W from 4-5 am, 424 W from 5-6 am, 106 W from 6-7 am, 1590 W hourly from 12-5 pm, 636 W from 6-7 pm, and 2438 W hourly from 7-9 pm. Outside these hours we assume the load to be 0 W.

Scenario 3 Assumptions

Under Scenario 3, the electricity load for Rakathum from March through April and September through November is 1050 W hourly between 12 am and 4 am. We assume that a mini-fridge is used 24 hours a day while an electric stove top is used between 6-7 am and 6-7 pm. The load rises to 1260 W from 4-5 am and 1330 W from 5-6 am. Between 6 and 7 am, the load rises further to 53,620 W. However, the hourly load falls to 1050 W between 7 am and 6 pm. From 6 to 7 pm the load soars to 53,970 W and then drops to 2660 W hourly between 7 and 9 pm.

Between 9 pm and 12 am, the load reverts to 1050 W when only the mini-fridge is running. Under this scenario the electricity load for Kothape from March through April and September through November is 1590 W hourly between 12 and 4 am. The load rises to 1908 W from 4-5 am and 2014 W from 5-6 am. Between 6 and 7 am, the load rises further to 81,196 W. The hourly load falls to 1590 W between 7 am and 6 pm. From 6 to 7 pm the load soars to 81,726 W and then drops to 4028 W hourly between 7 and 9 pm. Between 9 pm and 12 am, the load reverts to 1590 W, as only the mini-fridge is running.

During the summer months from May through August, hourly electricity demand for Rakathum is 1050 W hourly from midnight to 4 am, 1260 W from 4-5 am, 1330 W from 5-6 am, 53,620 W from 6-7 am, 1050 W hourly from 7 am-12 pm, 2100 W hourly from 12-5 pm, 1050 W from 5-6 pm, 53,970 W from 6-7 pm, 2660 W hourly from 7-9 pm, and 1050 W hourly from 9 pm-12 am.

Kothape hourly electricity demand during the summer months under this scenario would be 1590 W hourly from 12-4 am, 1908 W from 4-5 am, 2014 W from 5-6 am, 81,196 W from 6-7 am, 1590 W hourly from 7 am-12 pm, 3180 W hourly from 12-5 pm, 1590 W from 5-6 pm, 81,726 W from 6-7 pm, 4028 W hourly from 7-9 pm, and 1590 W hourly from 9 pm- 12 am. During the winter months from December through February, hourly electricity demand for Rakathum is 1050 W hourly from midnight to 4 am, 53,760 W from 4-5 am, 53,830 W from 5- 6 am, 53,620 W from 6-7 am, 1050 W hourly from 7 am-6 pm, 53,970 W from 6-7 pm, 2660 W hourly from 7-9 pm, and 1050 W hourly from 9 pm-12 am. Kothape hourly electricity demand during the winter months under this scenario would be 1590 W hourly from 12-4 am, 81,408 W from 4-5 am, 81,514 W from 5-6 am, 81,196 W from 6-7 am, 1590 W hourly from 7 am-6 pm, 81,726 W from 6-7 pm, 4028 W hourly from 7-9 pm, and 1590 W hourly from 9 pm-12 am.

Appendix B.
HOMER Output Supplemental Information

Rakathum Scenario 1 HOMER Output

Architecture							Cost				System		PV	
			PV (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
			0.965	11	0.842	CC	$0.934	$8,542	$199.48	$5,963	100	0	3,087	1,770

Kothape Scenario 1 HOMER Output

Architecture							Cost				System		PV	
			PV (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
			1.04	10	0.856	CC	$0.935	$8,422	$190.37	$5,961	100	0	3,333	1,911

Rakathum Scenario 2 HOMER Output

Architecture							Cost				System		PV	
			PV (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
			5.52	36	6.14	CC	$1.31	$36,981	$727.12	$27,582	100	0	17,661	10,125

Kothape Scenario 2 HOMER Output

Architecture							Cost				System		PV	
			PV (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
			8.26	55	4.76	CC	$1.28	$54,752	$1,071	$40,912	100	0	26,447	15,163

Rakathum Scenario 3 HOMER Output

Architecture							Cost				System		PV	
			PV (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
			79.8	821	75.5	CC	$0.874	$667,700	$15,145	$471,908	100	0	255,330	146,387

Kothape Scenario 3 HOMER Output

Architecture							Cost				System		PV	
			PV (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)
			128	1,194	117	CC	$0.877	$1.01M	$22,326	$725,738	100	0	409,629	234,851

Source: Katherine Drews and William Delgado-Thompson produced all HOMER analyses.

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