Elvin Shoolbraid, V01029195
Kate Skipsey, ENGR 110 A05
October 19th, 2023

A Comparative Analysis of Two Renewable Power Generation Approaches for the Village of Gokyo, Nepal

For centuries, Nepalese tradition has involved burning dried yak dung for heating and cooking. In 2017, biomass still accounted for 89% of household energy consumption in rural Nepal [1]. Gokyo, a growing Sherpa village in the Everest region of the Himalayas with ten local-run trekker lodges, continues this tradition [2]. Lacking an electrical grid connection, the village relies completely on yak dung, however this energy source has downsides [2]. Harvesting and burning yak dung require substantial effort, causing pollution and requiring year-round labour-intensive harvesting that depletes soil fertility [2]. Additionally, it harms human lung health by releasing black carbon and particulate matter into living spaces [3]. Transitioning to renewable energy for heating and cooking would address these challenges, with numerous feasible technologies to choose from. Solar energy stands as a common choice, applicable wherever the sun shines, easily scalable, modular, and consistently decreasing in price. However, hydro power surpasses solar power for Gokyo Village across multiple dimensions of analysis; It offers energy with greater consistency, eliminating the need for energy storage [4]. Hydro power not only has significantly lower cost than solar power [4], but also has established government and community support, and has characteristics better suited to the local physical environment surrounding Gokyo.

Firstly, solar power's inherent inconsistency requires complex systems to ensure continuous energy supply. S. Makhidoomi and A. Askarzadeh assert that "due to the intermittent nature of solar energy, it is necessary to integrate PV [solar] systems with an energy storage system" [5]. Lead acid batteries, the mature form of energy storage usually used in small scale systems, only have a lifespan of 3-10 years and require regular maintenance [6]. This would cause logistical challenges for a remote village like Gokyo because outside experts would need to travel in to perform these tasks, increasing operational costs and complexity. On-demand power sources, like diesel generators, offer an alternative to energy storage systems when solar power isn't available. In simulations, B. Robertson *et al*. found that a 225-kW hydro-diesel system would achieve a 66% fuel use reduction compared to an all-diesel system, while a 200-kW solar-diesel system would only achieve a 20% reduction [7]. We can attribute this disparity, at least in part, to the increased seasonal and hourly variability of solar compared to hydro [7]. As an aside, diesel isn't a viable long-term solution for Gokyo due to its polluting nature, high energy cost of 0.92-1.30USD/kWh [4], and the logistical challenges of large-scale diesel transportation; We primarily include it in the service of the comparison between the variability of solar and hydro. In summary, diesel backups and battery storage both increase complexity and cost compared to solutions without the need for backup power sources or energy storage.

Hydro power generation would have far more consistent output than solar power, only fluctuating with Gokyo River's flow throughout the seasons. If the typical minimum flow rate of Gokyo river provides sufficient power, the system won't require energy storage; E. I. Come Zebra *et al.* conclude in their comparison of renewable energy technologies that "where hydro resources are available, it can be used efficiently without combining with other resources, ensuring a continuous supply of energy" [4]. This results in lower complexity, maintenance requirements, and costs compared to solar-based systems, all important factors for any design applicable to the remote and low-income village of Gokyo.

Hydro power has a significantly lower overall cost than other renewables, a critical consideration for the village of Gokyo due to the average rural Nepalese household income standing at around 280 CAD/yr [12]. Solar and most other renewables have much higher overall costs than hydro, as compared by Zebra *et al*. LCOE, which stands for Levelized Cost of Energy, accounts for the lifetime costs and total energy generation of a power source [4, p.8], providing a realistic cost per unit of electricity for different sources. LCOE useful to compare the relative costs of different solutions, as it considers all life cycle costs, including construction. In the analysis by E. I. Come Zebra *et al*. [Fig. 1] the LCOE of solar ranged from 0.4-0.61USD/kWh, around double that of a small (<100kW) hydro power plant in the same analysis (0.22USD/kWh) [4, p.18]. The researchers also compared other options, concluding that "hydro is the most cost-effective solution compared to other sources due to lower generation costs" [1, p.10]. This shows that hydro power has the most economically viable long-term prospects for Gokyo.

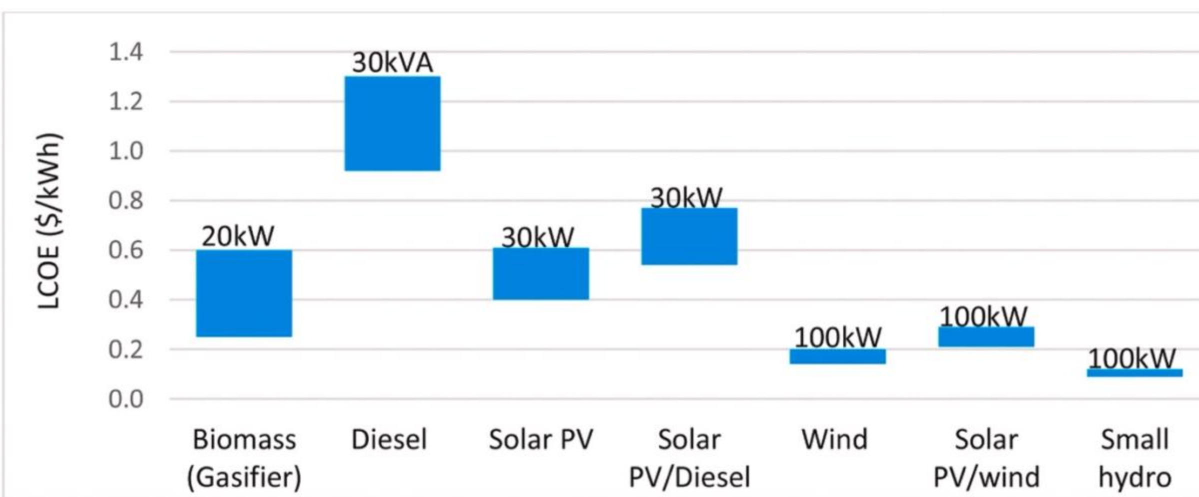

Fig. 1: "LCOE (USD/kWh) of mini-grid and hybrid mini-grid options at different scales" [4].

Solar, along with all other renewable options in [4], has a significantly higher LCOE than that of hydro. However, the researchers cited low generation costs as the reason for this, reflecting the fact that solar typically has a lower initial investment cost. They further state that "[hydro solutions] entail a high capital cost that includes planning, licensing, plant construction, and other social and environmental costs, although O&M costs are low". Solar at least has this advantage over hydro, which possibly explains why Gokyo has not yet built a hydro plant.

Regarding the compatibility of Gokyo's local environment with hydro, Gokyo River has ideal characteristics to support a run-of-the-river style hydro power plant. Run-of-the-river plants have no large reservoir; Instead, a pipe connects an intake from a high part of the river to the generator(s) housed lower down, which then releases the water back into the river [11]. The generators turn gravitational potential energy into electrical energy, dependent on the height differential between intake and generators, and the rate that water flows through, known as flow rate [11]. Gokyo river likely has adequate flow to run the plant year-round, supplying electricity to the entire village. In D. Solomin’s documentary, engineer Peter Sunnucks measures the river for what he states as "probably the lowest flow rate because the lakes are frozen" [1]. The river has significant flow even at this lowest flow rate, as visible from the video [4:35]. While this doesn't form definitive evidence that the river will consistently provide enough energy for the community, Zebra *et al.* corroborate the idea of consistent hydro power in the statement that “where the resource is available, hydro can provide continuous energy” [4]. We can also find a rough estimation of the flow rate through Gokyo lake through a comparison with other watersheds nearby. Fig. 2, 3, and 4 depict screen captures of Google Earth, in which the polygon tool was utilised to estimate the area of the watershed flowing into Gokyo lake, and another watershed of similar elevation, Thulo Pokhari:

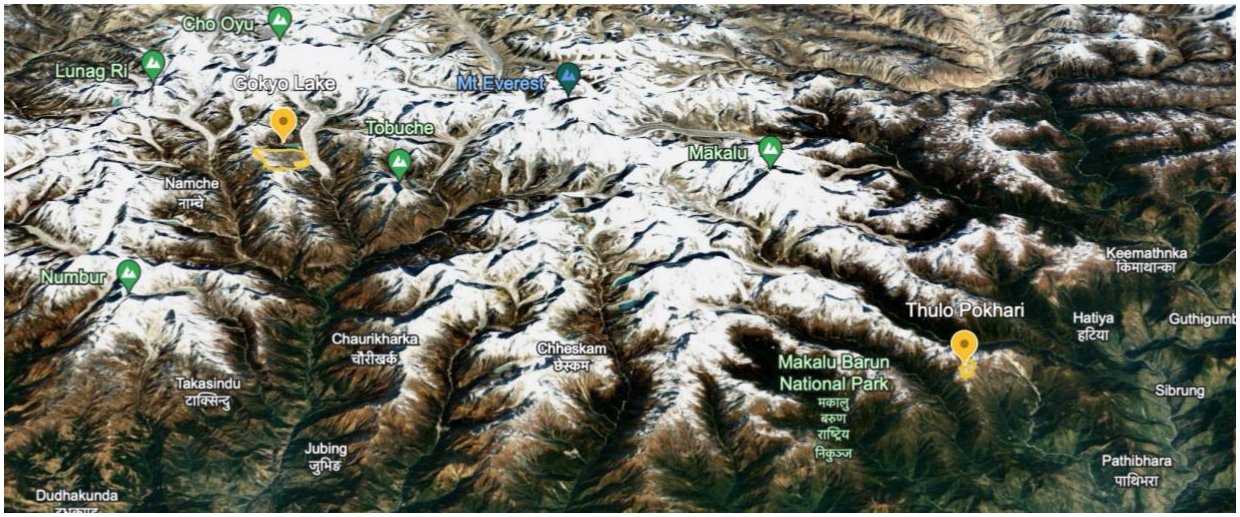

Fig. 2: Relative positions of Gokyo Lake and Thulo Pokhari watershed in the Himalayas [8].

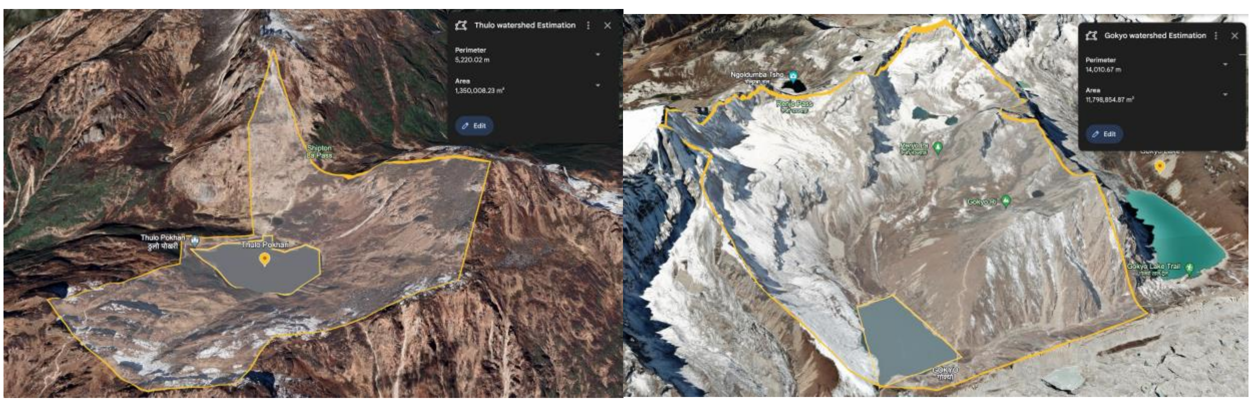

Fig. 3, 4: Area estimation for Thulo watershed (1.35km2) and Gokyo watershed (11.8km2) [8].

A fact sheet by the World Wildlife Foundation states the flow rate of Thulo Pokhari as 0.355 m3/s [9]. Gokyo River likely has at least a similar flow rate, because of the similar elevation, and Thulo Pokhari's visibly much smaller area. This flow rate can power a 100-kW power generator [10] and likely power the village year-round without energy storage, reducing costs and complexity. Decreasing these barriers to implementation drastically increases the chances for project success. Financial and societal support make up precursors to success as well, thus the local government's support for hydro power inspires confidence. Nepal has established the

Alternative Energy Promotion Center, installing and financing over 2000 hydro power mini grids from 1996 to 2015 [4]. This enthusiasm for hydro power extends down to the local level, as revealed by Tshering Tashi, a local lodge owner from Gokyo, stating in Solomin's documentary: "It's a big dream for us to build a hydro power in Gokyo" [2]. Long term success depends on community support, as trained locals currently taking on plant operation and revenue collection "helps maintain the commercial viability of the mini grids" [4] throughout Nepal.

While a solar array coupled with an energy storage system likely also has potential for the village, snow covering solar panels in the winter poses a potential problem that would increase the required maintenance of the system. In addition, the most common energy storage system, Lead Acid batteries, operate at lower capacities, power outputs, and potentially over lower life spans at lower temperatures [6]. Ultimately, while both solutions have technically feasibility in the local environment of Gokyo village, solar power would require higher maintenance and provide lower longevity compared to a small hydro plant.

Although both solar and hydro make promising approaches to decrease Gokyo's reliance on Yak dung, a hydro power plant has several advantages including simplicity, output consistency, lower cost, and established support. Hydro’s consistent output characteristics result in no energy storage system requirements, reducing complexity and increasing longevity compared to a solar array coupled with the necessary energy storage. The lack of energy storage also contributes to the substantially lower LCOE of Hydro when compared to solar or other renewable energy sources. Gokyo village has a perfect chance to move away from their environmentally-damaging, health-harming, and labour-intensive energy source, given Gokyo River's potential to support a year-round hydro plant. Additionally, Gokyo residents already endorse hydro power as a proven option, and the Nepalese government has already helped thousands of small villages gain hydro based electricity over the past decades. Further technical feasibility assessments of a hydro power plant, like measuring the flow rate of Gokyo River and the daily energy use of the village both throughout the year, would follow in the process of convincing a funding organisation to move ahead with the project.

References:

[1] S. Malla, “An outlook of end-use energy demand based on a clean energy and technology transformation of the household sector in Nepal,” Energy (Oxford), vol. 238, pp. 121810-, 2022, doi: 10.1016/j.energy.2021.121810.

[2] D. Solomin. " Power for Gokyo: How to Build a Hydro Power Plant in the Himalayas," YouTube, Sep. 16, 2019 [Video file]. Available: https://www.youtube.com/watch?v=F1lx7OQvF74. [Accessed: Oct. 17, 2023].

[3] Q. Xiao, E. Saikawa, R. J. Yokelson, P. Chen, C. Li, and S. Kang, ‘Indoor air pollution from burning yak dung as a household fuel in Tibet’, Atmospheric Environment, vol. 102, pp. 406–412, 2015.

[4] E. I. Come Zebra, H. J. van der Windt, G. Nhumaio, and A. P. C. Faaij, ‘A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries’, Renewable and Sustainable Energy Reviews, vol. 144, 2021. DOI: 10.1016/j.rser.2021.111036

[5] S. Makhdoomi and A. Askarzadeh, “Techno-enviro-economic feasibility assessment of an off-grid hybrid energy system with/without solar tracker considering pumped hydro

storage and battery," IET renewable power generation, vol. 17, no. 5, pp. 1194–1211, 2023, doi: 10.1049/rpg2.12675.

[6] P. Komor and J. Glassmire, "Electricity Storage and Renewables for Island Power: A Guide for Decision Makers," International Renewable Energy Agency, 2012.

[7] B. Robertson, J. Bekker, and B. Buckham, "Renewable integration for remote communities: Comparative allowable cost analyses for hydro, solar and wave energy," Applied energy, vol. 264, p. 114677–, 2020, doi: 10.1016/j.apenergy.2020.114677.

[8] Google. "Himalayas, Nepal" Accessed: Nov 4, 2023. [Online]. Available: https://earth.google.com

[9] "Factsheets: Wetlands of Nepal," World Wildlife Foundation, 2006. Accessed: Nov. 05, 2023. [Online]. Available: https://www.wwfnepal.org/?118803/Factsheets-Wetlands-of-Nepal

[10] "100kw Hydro Generator, Get 100kw Hydro turbine cost from SunecoHydro." Accessed: Nov. 06, 2023. [Online]. Available: https://www.micro-hydro-power.com/100kw-hydro- turbine-generator/

[11] D. Borkowski, D. Cholewa, and A. Korzeń, "Run-of-the-River Hydro-PV Battery Hybrid System as an Energy Supplier for Local Loads," Energies (Basel), vol. 14, no. 16, pp. 5160-, 2021, doi: 10.3390/en14165160.

[12] "Nepal Average Monthly Household Income: Rural | Economic Indicators | CEIC." Accessed: Nov. 29, 2023. [Online]. Available:

https://www.ceicdata.com/en/nepal/household-budget-survey-average-monthly-household-income/average-monthly-household-income-rural