Solving an Unsatisfactory Situation in Gokyo, Nepal

Finely Takahashi, Elvin Shoolbraid, Alex Gnaedinger, Jim Wheen and Dylan Gyr

University of Victoria, Eng 110/112 section A01

Victoria, BC, Canada

elvinhasemail@gmail.com, jimwheen@uvic.ca, alexjneddy@gmail.com, finleytak@uvic.ca, dylangyr7@gmail.com

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A. PROBLEM DEFINITION

A.a. Need and goal

A.a.i Team member proposals

Khinalig, Azerbaijan - Elvin:

Khinalig is a remote mountainous village in Azerbaijan, perched high in the mountains at an elevation of 2,350m above sea level [28]. Due to the exposed nature of the environment around the village, temperatures range drastically, from -18C to 20C [27]. This is a problem because the village doesn't have electricity for heating[28] [29]. Instead, all the energy the village uses for heating and cooking comes from burning dried yak dung. This is problematic because this burning releases CO_2 and particulate matter, which are harmful to the environment [8]. This particulate matter is also released into living spaces, which is harmful to respiratory health [8]. The village needs a new way to heat their homes in winter without burning dung, to help mitigate climate change and improve respiratory health outcomes.

There are some features of the local environment that could potentially be harnessed for energy. The mountains have numerous rivers, there is a lot of sun throughout the year, and the high elevation is conducive to consistent high wind speeds.

Inuvik, Northwest Territories, Canada - Dylan:

Inuvik is a remote town in the Northwest Territories of Canada. During the winter Inuvik experiences deathly cold temperatures which forces residents to stay inside. Aside from the extreme cold weather in the winter time Inuvik also struggles with food supply to the town. Due to its remote location shipping food and other materials is very challenging.

Residents in this small town in northern Canada are struggling to afford heating due to a new energy system that requires trucks to haul synthetic natural gas to the city. This type of heating can cost up to $10,000/yr per apartment which is too much for most residents [31]. Not only is this energy expensive but it is also harmful for some kitchen appliances and increases CO_2 emissions more than other energy sources [31]. The price of this new energy system is causing residents to not be able to afford their# groceries and other essential good. Residents are desperately in need of an alternative energy system that is more efficient and less expensive.

The Indian Rann of Kutch Marshes - Finley:

The Rann of Kutch marshes are seasonal marshes located in the Thar desert [21]. The land is inhabited by the Agariya people, who have lived here for centuries and have only one means of livelihood – salt production [21]. In winter the harvest season begins, and the Agariyas live here for six to seven months in shacks beside their salt flats [21].

According to a study conducted by the National Institute of Occupational Health in Ahmedabad, the farmers suffer from skin lesions, severe eye problems owing to intense reflections off of the white surfaces and tuberculosis [21]. A salt worker of Kutch does not often live beyond 60 years [21]. Rann of Kutch also has a scarce supply of drinkable water, the nearest supply being around 6 km whose journey must be made on foot [21].

Children growing up in these salt fields are deprived of education and proper facilities. Lack of education is largely responsible for the cycle of exploitation and poverty the salt farmers face for generations [21].

Cambridge Bay, Nunavut - Alex:

Cambridge bay is a remote northern community located in the Kitikmeot region of Nunavut on Victoria island [3]. Besides the deathly cold temperatures faced by locals in the winter months, the remoteness of the community offers many challenges [3]. Food security is a major issue for local residents who have long depended on traditional foods, whose availability is becoming compromised due to climate change [2]. Power is generated by a limited number of diesel power stations with frequent outages and challenges in transportation, as the fuel must be carried in tankers through the dangerous northern straits which freeze over during the long winter season [1][4].

There are, however, some potential sources of energy to tap into. Beneath the frozen cap of sea ice, abundant ecosystems continue to thrive during the winter months capturing available sunlight and producing biomass [5]. The northern straits experience strong currents at certain times of year. Solar, wind, and geothermal energy are also being investigated [6]. A possible ally is the Canadian High Arctic Research Station (CHARS) who are studying various initiatives for food and energy security in the northern territories [7].

Gokyo, Himalayas - Jim:

Gokyo village is in Nepal’s Sagarmatha National Park, and is located at an elevation of approximately 4700m [15]. The trek to Gokyo is included in the trip itinerary of many on route to Everest Base Camp and because of this the popularity of the route has experienced exponential growth over the last few decades [15]. The economic benefits of tourism in the region have allowed for employment in these mountain areas, providing opportunities for seasonal and permanent employment for local communities [16]. However, the growth of tourism has also led to an increase in heating and energy problems. As of 2007, the energy consumption of trekkers was double that of local people [16]. Following trends, that number would be even greater now. This has led to an unsustainable use of wood and yak dung for fuel.

Not only are these resources limited, their fumes are also toxic for humans and the environment (specifically particulate matter from yak dung). It’s necessary for Gokyo village to develop a renewable energy option as the continuation of current practices is unsustainable.

A.a.ii Selection of problem

As a team we decided on studying a possible solution for Gokyo Village due to personal connection and distinction of the situation. One of our group members had visited the village on a standard trekking route to Everest base camp and described the harsh living conditions that the locals face throughout the year due to minimal options for energy. The situation of Gokyo village is unique as the main source of energy is limited and produces unhealthy fumes affecting both humans and the environment. So as a team our project would not only tackle the village's energy problem, but improve the health of the villagers, and the local economy by accounting for the growing tourism industry (project solution would solve multiple problems).

A.a.iii Problem statement

Due to the scarcity of combustible materials in the Himalayan region locals are highly dependent on burning yak dung as cooking fuel and in order to heat their homes [11]. Though the use of yak dung as fuel is an ancient tradition which allowed for the settling of the Himalayan plateau by early peoples, it has negative consequences for the health of the villagers and for the surrounding environment [11][8]. Furthermore, the collection and processing of yak dung is an extremely labour-intensive process. Variable climate conditions and seasonal population make it difficult to predict how much fuel must be stored for the winter months, and the massive seasonal influx of tourists means current supplies of yak dung may not be sufficient to support demand in the near future.

A.a.iv Detailed description of location

Gokyo Village is located on the shores of Dudh Pokhari, one of the biggest lakes, bordering Gokyo village. The lake itself has numerous streams that flow from the main source, eventually discharging the water into the Dudh Koshi headway. The lake has a surface area of 0.42 ± 0.7% km^2 [13]. The village also borders the Ngozumpa Glacier, one of the largest glaciers in nepal, with an area of 80 km^2(see ***Fig. 1.*** for a topographical view of the village and surrounding terrain) [13].

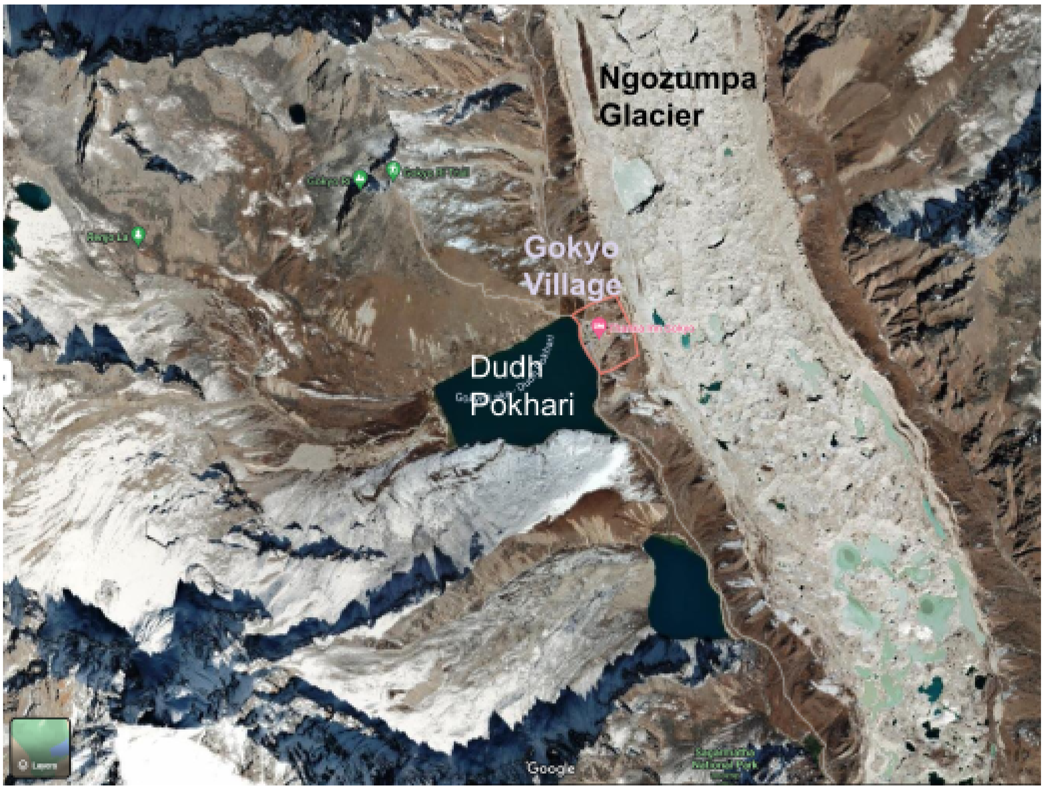


Fig. 1. *Topographic map of Gokyo village and the surrounding terrain [26].*

A.a.v Client identification

Our project client is EcoHimal, a non for profit organisation based out of Salzburg Austria with years of experience developing connections with the local people of the Everest region. The company generates funding and helps develop projects that target infrastructure, conservation, and sustainable tourism development; while preserving cultural heritage [12]. The Organization has generated funding for past energy initiatives in the Everest region and has implemented a small hydro-power station in Namche Bazaar [12]. Due to experience in the region EcoHimal will understand the challenges, and necessary costs of implementing a long term renewable energy solution, leading to successful collaboration in the project proposal and design process.

A.a.vi Goal

Based on the needs identified for residents of Gokyo, Nepal we can identify some concrete goals which our design solution must meet :

1. Reduce emissions of chemicals and particulate matter which are harmful to human health.

2. Reduce emissions of chemicals and particulate matter which are harmful to the surrounding environment.

3. Reduce the workload required of residents to acquire the fuel they need to heat their homes and cook their food year-round.

A.b. Research

A.b.i Questions for clarifying the problem

In order to better understand the problems which the residents of Gokyo are facing we identified some important questions we needed answered.

a) What are the health effects of burning yak dung indoors?

There are two byproducts of yak dung combustion which are of particular concern. Particulate matter with a diameter of 2.5 µm or less (PM2.5) is of concern for the health of residents as it is associated with cardiovascular disease, respiratory disorders and cancers [8][9]. Black carbon (BC), is another byproduct of yak dung combustion which is linked with respiratory disease and is also a major contributor to global warming, linked to disruptions in the hydrologic cycle and atmospheric circulation in the Himalayas [8].

Studies in Nam Co, Tibet examining concentrations of PM2.5 in households burning yak dung have shown 24h average concentrations of PM2.5 ranging between 1270 and 1670 µg/m3 [8]. With a chimney, average concentrations were slightly lower at 97 µg/m3 [8]. This is far higher than the WHO's air quality guideline (ACQ) recommendation of 5 µg/m3 maximum in the long term, and 15 µg/m3 maximum for the short term-exposure [9].

The WHO does not have a specific AQC for black carbon concentration, however it is recommended to take measures to reduce BC emissions as there is some evidence of its toxicity, though not sufficient evidence to develop a specific guideline [9]. The WHO has a separate guideline for household fuel combustion which specifies recommended emission rates of 0.23 (mg/min) and 0.16 (g/min) for PM2.5 and CO respectively (0.80 (mg/min) and 0.59 (g/min) for well vented areas), another guideline which may be useful in our design process [19].

b) What are the environmental impacts of burning yak dung?

Black carbon emitted during the combustion of yak dung is a byproduct which has been shown to affect climate change in the Himalaya region [10]. In addition to causing heating in the atmosphere due to increased absorption of solar radiation, deposition of BC on the glaciers in the Himalayas reduces the reflectance of the ice and snow, increasing the rate of melting [10]. This causes a positive snow/ice albedo feedback (SAF) loop as increased melt further reduces the reflective surface of the glaciers [10]. The decreased albedo of the ice caps has wide-ranging effects on local climate conditions including snow depth, precipitation, aridity, surface air temperature vegetation cover etc. which may ultimately lead to desertification and land degradation in the region [10].

c) How can we make sure our project is compatible with local culture and customs?

A study in nearby Nepal showed that 74% of locals were aware of the negative impacts of indoor air pollution [8]. Another broader study in Nepal showed that a large proportion of households using mixed and traditional fuels for heating and cooking were unhappy with their cooking fuel [20]. This data suggests locals may be receptive to alternatives.

d) How much energy (TWh) does the village use per year?

A study examining end-use energy demand in Nepal determined that the final energy consumption for the entirety of Nepal in 2017 was 245 PJ (equivalent to 68 TWh) [24]. This includes energy from biomass, electricity, renewable and petroleum sources. Based on extrapolating per capita energy usage from the ratio of total energy used to electricity used by urban people [24], we can come to a rough estimate of per capita energy needs for the village of 1,100 kWh/ capita / yr. From [16, sec 8.11] we find a total bed capacity for Gokyo of 215. However, this report is from 2007, and the tourist industry in Gokyo is expanding. We chose to estimate a population of 300, however a more rigorous energy usage analysis would get real biomass usage data for the whole village and calculate energy consumption based on energy density metrics for that biomass. Based on a population of 300, a yearly energy usage for the village can be estimated as (1,100kWh / capita / yr) * (300 capita) = 330,000kWh/yr. This is equivalent to a continuous consumption of 38kW, however the peak instantaneous consumption is likely much higher.

e) What are the weather patterns (clouds?)

Nepal's climate depends heavily on altitude [22]. Winter occurs from late November to February and typically has little rainfall, with clear weather [22]. High altitude areas are very cold, especially at night. Spring lasts from March to May. Summer is the Monsoon season, lasting from June to August [22].

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	-14.3 °C (6.3) °F	-14.1 °C (6.6) °F	-11.5 °C (11.3) °F	-6.9 °C (19.6) °F	-2.6 °C (27.3) °F	1.5 °C (34.6) °F	2.3 °C (36.2) °F	2.2 °C (35.9) °F	0.4 °C (32.8) °F	-4.7 °C (23.6) °F	-7.8 °C (17.9) °F	-10.2 °C (13.7) °F
Min. Temperature °C (°F)	-18.7 °C (-1.6) °F	-18.5 °C (-1.3) °F	-16.3 °C (2.7) °F	-12 °C (10.5) °F	-7.1 °C (19.3) °F	-1.6 °C (29.1) °F	0.4 °C (32.7) °F	0 °C (32.1) °F	-2.5 °C (27.5) °F	-8.7 °C (16.3) °F	-12.4 °C (9.6) °F	-14.3 °C (6.2) °F
Max. Temperature °C (°F)	-10.1 °C (13.9) °F	-10.1 °C (13.8) °F	-7.5 °C (18.6) °F	-3.1 °C (26.5) °F	0.8 °C (33.5) °F	4.2 °C (39.6) °F	4.4 °C (39.9) °F	4.4 °C (39.9) °F	2.9 °C (37.2) °F	-1.3 °C (29.6) °F	-3.7 °C (25.4) °F	-6 °C (21.2) °F
Precipitation / Rainfall mm (in)	24 (0)	31 (1)	23 (0)	20 (0)	45 (1)	115 (4)	227 (8)	190 (7)	104 (4)	29 (1)	8 (0)	13 (0)
Humidity(%)	37%	43%	53%	65%	73%	84%	94%	94%	88%	60%	40%	33%
Rainy days (d)	3	3	3	5	9	15	21	21	15	3	1	1
avg. Sun hours (hours)	8.1	8.2	8.9	9.1	8.7	6.3	3.3	3.5	5.1	8.2	8.8	8.6

Fig. 2. *Table of weather data for Gokyo Village [23]*

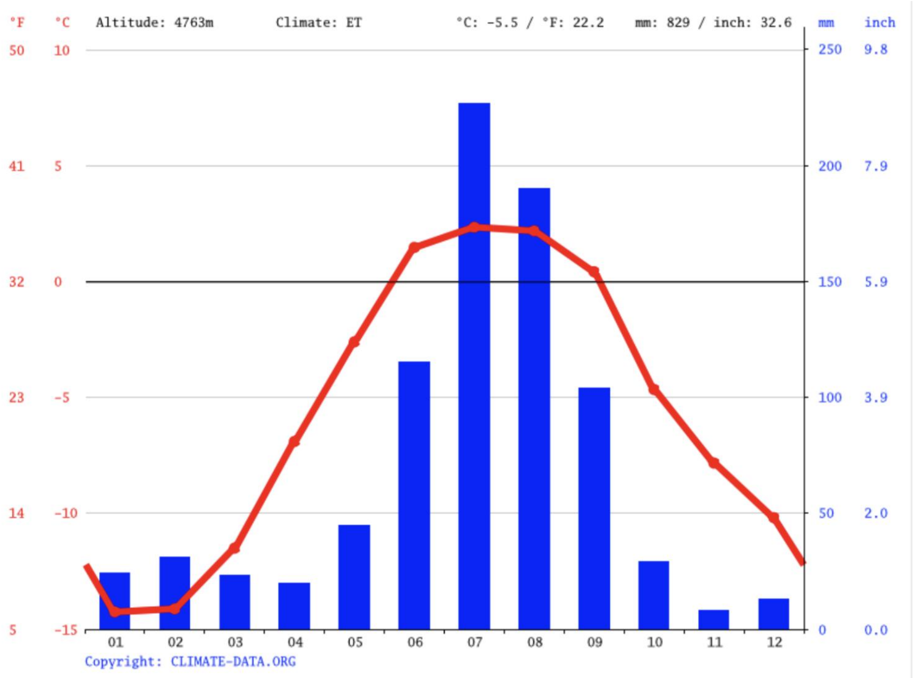


Fig. 3. *Climate graph by month for Gokyo Village [23]*

As seen in ***Fig. 3.***, most rainfall occurs in July, with an average of 8.9 inches of precipitation [23]. The driest month is November, with an average precipitation of only 0.3 inches [23].

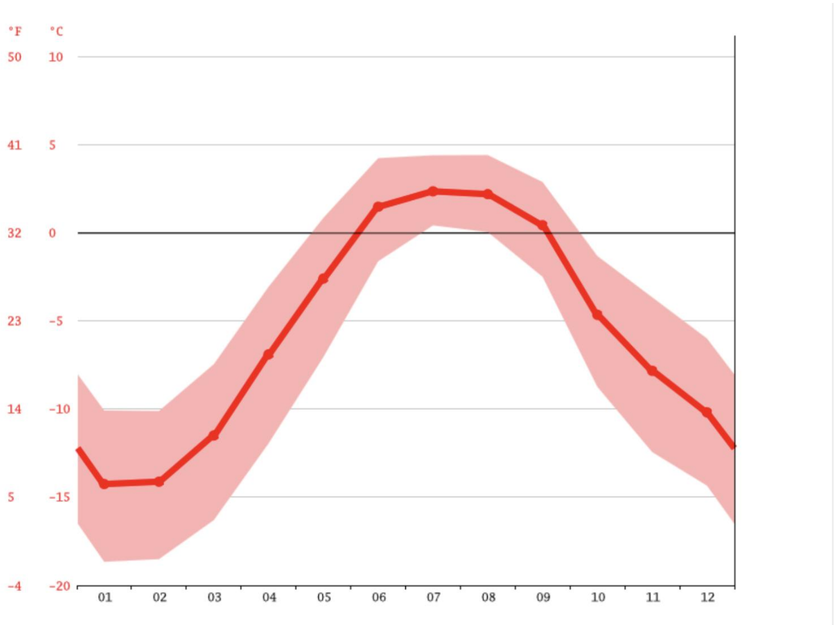


Fig. 4. *Average temperature by month for Gokyo Village [23]*

Due to its elevation, Gokyo experiences extreme temperatures in the winter months of January and February [23]. This is the primary factor in the movement of Gokyo residents to lower elevations during the winter season.

f) What are the characteristics of the river?

There are no recorded statistics on outflow rate from Dudh Pokhari (Gokyo Lake), however we can estimate river characteristics by comparing with other watersheds in the High Himal region. Madi Watershed, a watershed of similar size to Dudh Koshi, was examined to have an average stream discharge rate (l/s/km2) of > 30 l/s/km2 in the High Himal during the dry season (season with lowest recorded flow rate) [25]. We can assume this metric to be roughly the same as the discharge rate flowing from Dudh Pokhari.

Fig. 5. represents the mean monthly minimum and maximum discharge of the Madi Watershed. The rate of change of flow rate throughout the year can be used to estimate the flow rate of smaller streams (Dudh Pokhari lake outflow) as monsoon season begins.

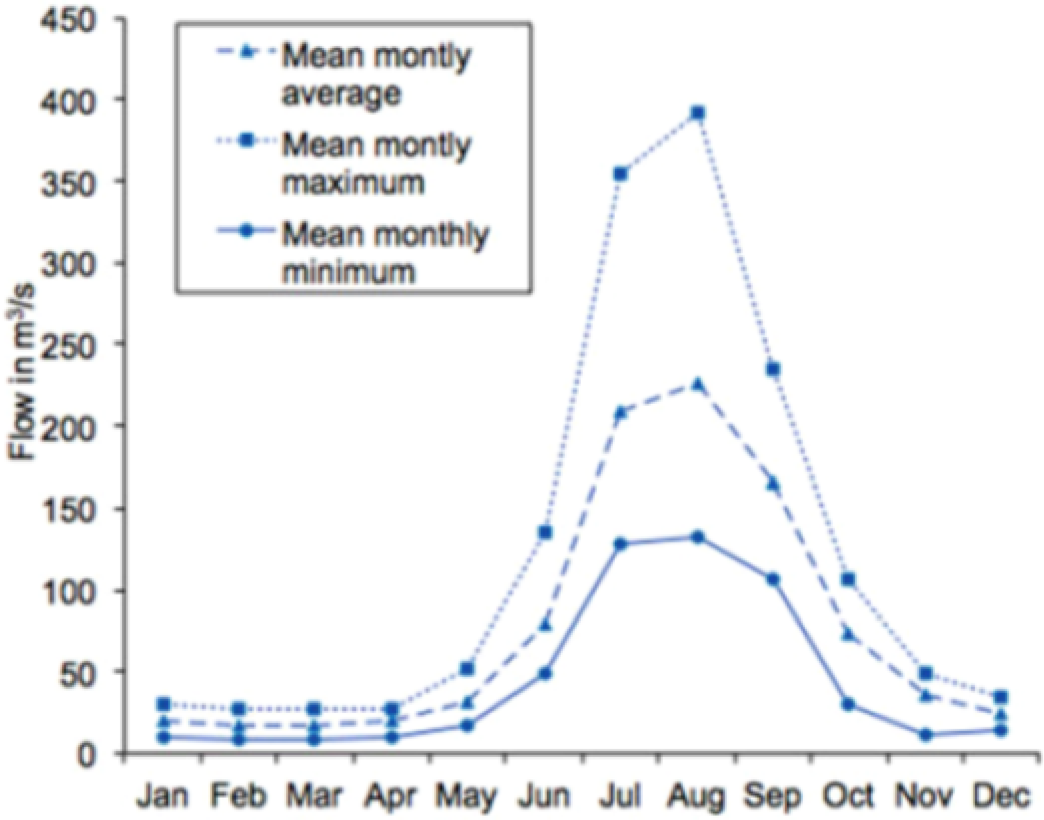


Fig. 5. *Mean monthly minimum and maximum discharge of the Madi Watershed [25]*

A.b.ii Existing Solutions

a) Biomass

It has been shown that improving the efficiency of combustion in biomass stoves even without changing the fuel type used can drastically decrease harmful emissions [14][17]. For example Ming Shan et al. designed a user-friendly semi-gasifier stove with emissions of PM2.5 (0.038 ± 0.013 g MJ–1 d) and CO (2.2 ± 1.1 g MJ–1 d) low enough to rank as Tier 4 within the International Organization for Standardization (ISO) standard for clean cooking, which is the second highest tier [14]. Improved biomass stoves are a simple way to reduce harmful emissions while continuing to use local resources with very little additional infrastructure. A downside is that they are not completely clean.

In their book *The Rocket Mass Heater Builder's Guide*, Wisner and Wisner outline different methods for building highly efficient biomass stoves which capture heat within thermal mass features of the building, and slowly radiate the heat over a long period of time.[41]

b) Biogas

Another existing solution to reduce harmful emissions from biomass combustion is to convert the organic matter into biogas, a byproduct of anaerobic digestion composed primarily of methane and carbon dioxide [18]. Unlike the combustion of biomass such as firewood or animal dung, the combustion of biogas produces no smoke, and hence has none of the associated adverse health effects [18]. Other advantages of biogas is that the slurry remaining after digestion is a potent fertilizer since it retains key nutrients such as nitrogen, potassium and phosphorus which would otherwise be lost in combustion [18]. There is however a concern over contamination for certain types of feedstock [18]. Another downside is that biogas is explosive hence potentially dangerous, and requires significant infrastructure.

There are various options for producing, storing and transporting biogas. In *Prospects and Challenges in Biogas Technology: Indian Scenario*, Kalyanasundaram et al. outline various techniques for producing and storing biogas[42]. Of particular interest are two types of biogas plants approved by the Ministry of New and Renewable Energy (MNRE) in India[33]. In the floating drum style biogas plant (KVIC model) the slurry is produced in a metal tank with a floating drum (which ensures constant pressure), and the biogas is stored in a separate tank[33]. The fixed-dome style biogas plant is built from masonry and buried underground, with digester and gas holder contained within a single unit[42]. It is cheaper to build and lasts longer, but is harder to maintain , whereas the floating drum style is comparatively more expensive to build but is easier to maintain[42].

c) Geothermal

Geothermal remains a largely neglected aspect of green energy in Nepal [32]. This is mainly due to the fact that trained manpower remains largely outdated, and no new effort has been made to train future geothermal operatives [32]. The road network and physical infrastructure is not yet able to handle geothermal electricity generators [32] . There remains huge potential for geothermal energy, but yet few means to harness it [32].

d) Hydro

Hydropower is a renewable energy source that is already relatively accepted in Nepal; The Nepalese government has created the Alternative Energy Promotion Center, helping install and finance over 2000 hydro power mini-grids from 1996 to 2015 [34]. The large meta-analysis of studies on renewable energies for developing countries states "For the places where hydro resources are available, it can be used efficiently without combining with other resources, ensuring a continuous supply of energy" [34]. Nepal's current installed hydro power generation capacity is only 2% that of the theoretical maximum [33].

e) Cost comparison of some Renewable options [30]:

Renewable Energy:	LCOE ($/kWH):	Pros:	Cons:
Hydro Power/diesel generator setup	0.22 USD	Consistent energy, only varies with river	Expensive initial installation, heavy equipment
Solar PV/diesel generator setup	0.46 USD	Highly modular, scalable. Low initial investment.	High fluctuation of output based on weather requires external energy storage, increasing complexity
Wind/Diesel	0.45 USD	No visual harm to rivers or landscape.	High maintenance, semi expensive installation, also requires energy storage system
Geothermal Energy	No data from source	Consistent energy throughout year	Expensive, difficult to install.
Biomass Gasifier	0.25-0.6 USD	Utilizes solid waste, i.e pre existing resources	Involves explosive gasses, therefore potentially dangerous

A.c. Objectives and Constraints

1) Objectives

Environmentally friendly	Our solution should minimize emissions of CO_2 (tonnes/year). Our design should also minimize emissions of black carbon, which has been linked to rapid climate change in the Himalaya region.[10]
Not labour intensive	Our solution should minimize the amount of work (hours/year) which locals must dedicate to gathering and processing their heating/cooking fuel.
Ease of use	Our solution should be easy for locals to use. Ease of use can be assessed through surveys.
Ease of maintenance	Our solution should be easy to maintain with readily available materials and components.
Culturally compatible	Our solution should be respectful of local culture and customs, and have a high adoption rate by locals. Cultural compatibility can be assessed through surveys.

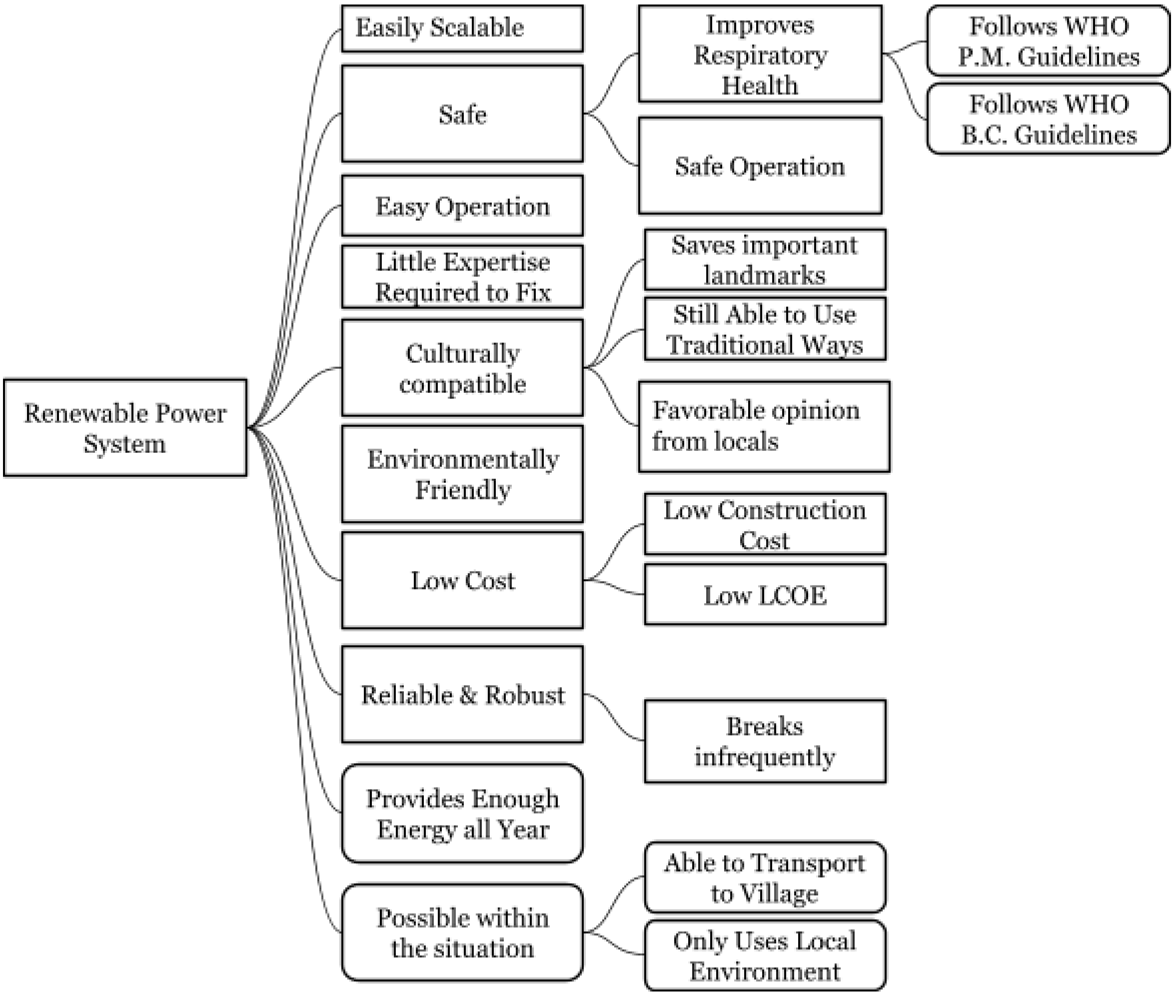
Low cost of construction	Our solution should minimize the cost of installation. Measured in United States Dollar (USD).
Low cost of operation	Our solution should have a minimal cost of operation. This is essential for long-term adoption since the affluence of the region is limited. Measured in Nepalese rupees (NPR)
Robust	Our solution should require minimal maintenance and break infrequently. The metric by which we judge robustness will depend on the frequency and gravity of failure of the system.
Safety	Our solution should be safe to use. Comparative safety of solutions can be assessed using frequency mode and effects analysis (FMEA) which assigns a risk priority number (RPN) to a given solution. The RPN is the product of three factors: the severity of a failure (S), the likelihood of occurrence (O), and the likelihood of detection (D). Each factor is rated on a scale of 1-10 [43].
Scalability	Our solution must be scalable to accommodate a growing tourist population.

2) Constraints

Reliable	Our solution must provide year-round uninterrupted access to heat and cooking for locals.
Improves respiratory health	Our solution must follow PM2.5 and CO emissions guidelines from WHO (maximum concentrations of PM2.5 : 5 µg/m3, CO : 4 mg/m3)[19]
Accessibility	It must be possible to transport all of our solution's components to the village site.

A.d. Criteria

A.d.i Basic criteria tree



A.d.ii Pairwise comparison chart

a) Criteria to compare

1. Safe
2. Easy Operation
3. Little Expertise Required to Fix
4. Culturally compatible
5. Environmentally friendly
6. Low Cost
7. Reliable & Robust
8. Easily Scalable

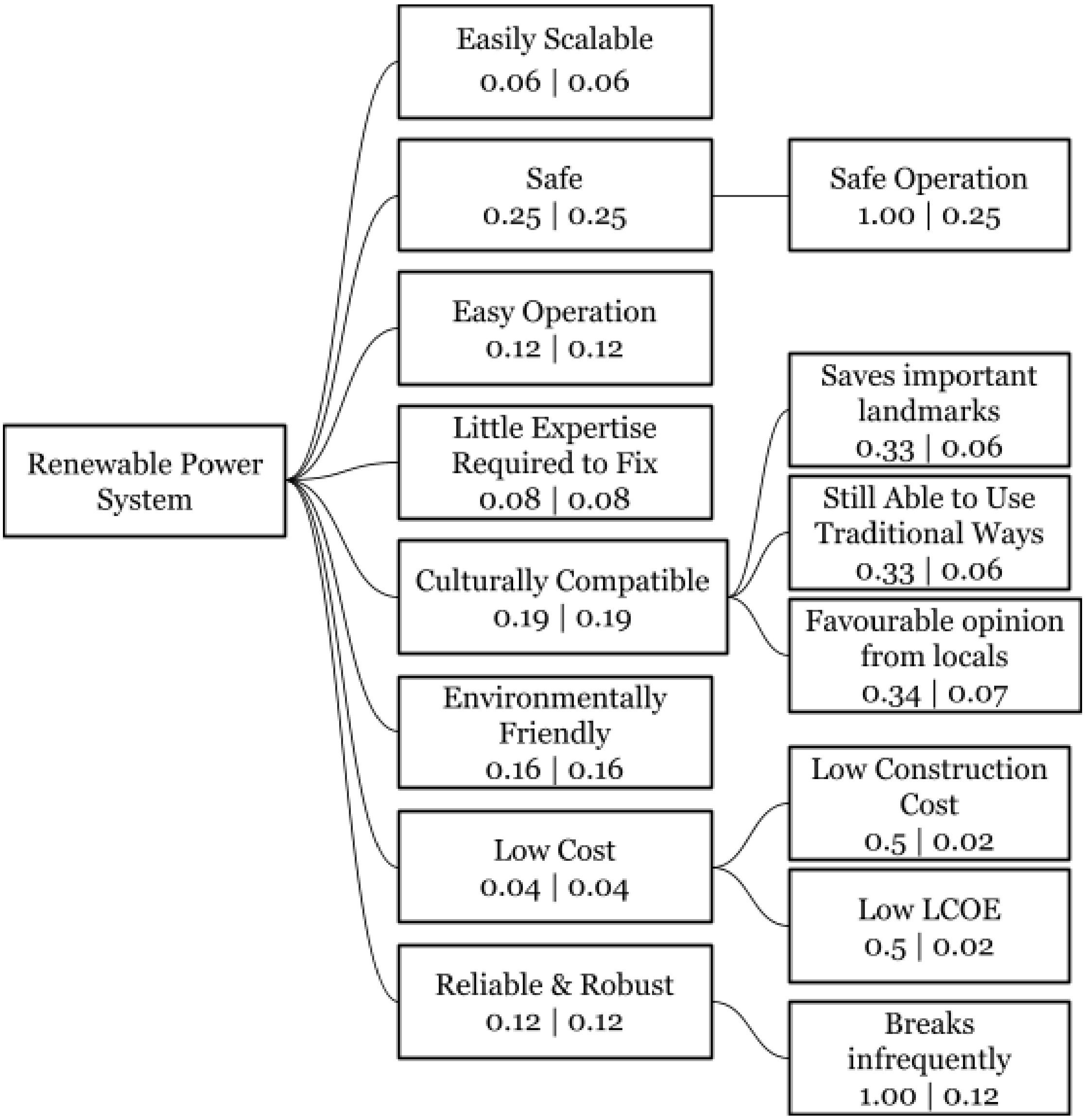
b) Pairwise Comparison Chart

Goals	Safe	Easy operation	Little Expertise Required to Fix	Culturall y Compati ble	Environ-mentally friendly	Low Cost	Reliable & Robust	Easily Scalable	Score:
Safe	x	1	1	1	1	1	1	1	7
Easy Operation	0	x	1	0	0	1	0	1	3
Little Expertise Required to Fix	0	0	x	0	0	1	0	1	2
Culturally compatible	0	1	1	x	1	1	1	1	6
Environment ally friendly	0	1	1	0	x	1	1	1	5
Low Cost	0	0	0	0	0	x	0	0	0
Reliable & Robust	0	1	1	0	0	1	x	1	4
Easily Scalable	0	0	0	0	0	1	0	x	1

c) Reasoning behind pairwise choices

Safety is the highest scoring criteria, due to the serious nature of the consequences of not prioritising human health. A similar methodology was taken in relation to cultural compatibility; To preserve culture and maintain a good relationship, it is important to allow locals to continue traditions as they desire. Environmental preservation is weighted heavily because the unsatisfactory situation is partly caused by disregard for the environment. Reliability and robustness are of utmost importance in the remote village of Gokyo, as technical expertise would need to be trained to locals or brought in expensively in the form of outside experts. Easy operation follows from a similar rationale. Little expertise being required to fix is helpful, but unrealistic, and therefore it is okay to bring in experts to fix things if they are reliable and don't break often.

A.d.iii Weighted criteria tree:



A.e. Revised problem definition

Gokyo village burns Yak dung to heat buildings, which is labour intensive and harmful to humans and the environment. We want to design a safe, environmentally friendly, and culturally compatible way of generating energy and using it to heat buildings. Our solution must be able to provide energy all year, and must follow WHO Particulate Matter guidelines.

B. CONCEPTUALIZATION

B.a Functions:

1. *Captures energy from a renewable source*

The system must capture enough renewable energy from nearby the village to meet energy demands.

2. *Stores energy*

The system must efficiently store the captured energy for use when power isn't being generated

3. *Converts energy into heat for buildings*

The system must effectively convert inputted energy into useful heat, while minimising energy loss.

4. *Uses energy to provide means of cooking*

The system must utilise energy for kitchen appliances such as ovens and stoves.

5. *Transfers energy to buildings from source*

The system must safely transport energy from the source to buildings in the area with minimal disruption to the ecosystem.

6. *Responds dynamically to energy demand*
    a. Sense amount of energy demand
    b. Stop producing energy when none is required or storage is full
    c. Provide controls to allow manual control of power output

Means for 1:
- Hydro power plant running on the nearby river
- Solar energy (solar panels)
- Solar energy captured in biomass
- Wind energy via wind turbines
- Geothermal energy

Means for 2:
- Flywheel battery
- Thermal energy storage
- Pumped hydro storage
- Lithium ion batteries
- Lead Acid batteries
- Continue using dried yak dung
- Biomass converted to biogas through anaerobic decomposition; stored in pressurised container

Means for 3:
- Baseboard heaters
- Radiant floor heating
- Rocket mass heater
- Boiler
- Furnace
- Heat pump

Means for 4:
- Electric cooktops / ovens
- Induction cooktops

- Biogas stove
- High efficiency biomass stove

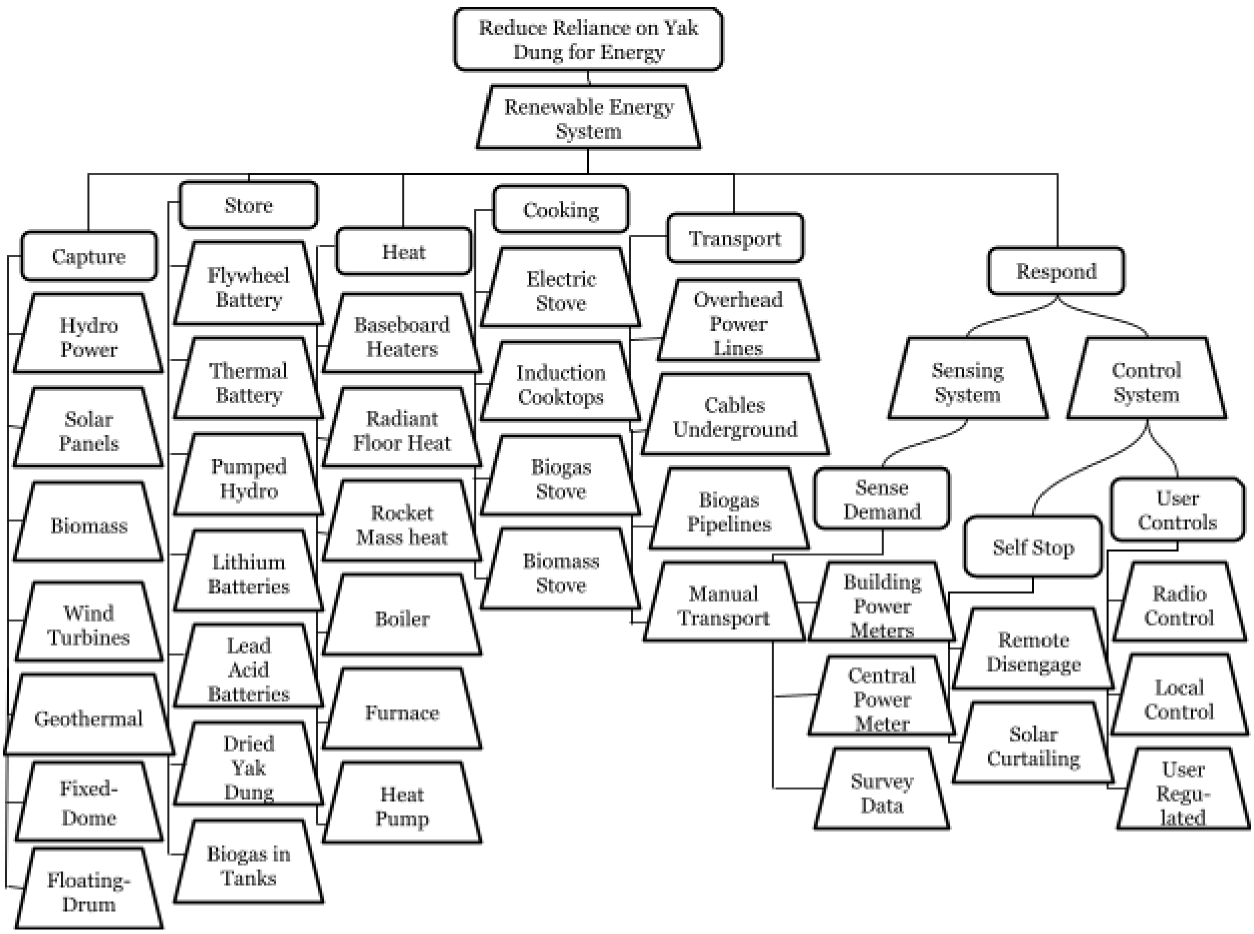
Means for 5:
- Overhead power lines
- Underground power cables (PV cables)
- High pressure steel pipelines (biogas)

Means for 6.a:
- Power metres on all buildings (energy source specific monitors)
- Central power metre
- Survey data

Means for 6.b:
- Hydro turbine remote disengagement system
- Energy curtailment (ex. solar systems designed to adjust angle of the solar panels to reduce sunlight exposure temporarily)

Means for 6.c:
- Radio transmitter control panel
- Control centre located at plant site

B.b Functions-Means Tree:



B.c Morphological Chart

B.c.i General Morphological Chart:

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wind	Geothermal	Fixed-Dome Biogas Plant	Floating-Drum Biogas Plant
Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	CBG cylinders
Heat	Baseboard	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improved Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Meter	Survey Data				
Control Output*	Remote Disengage	Solar Curtailing	Local Control	Radio Control	User Regulated		

*Depending on Capture choice, two options may need to be chosen due to the structure of the function-means tree.

B.c.ii Potential solutions

Solution 1:
The first solution is a hydro power plant with pumped hydro storage, baseboard heaters, electric stoves, and underground power lines, controlled with a radio control system and remote hydro disengagement system based on a central power metre. Some benefits of hydro power generation are the low power generation costs resulting in a low LCOE [34]. In addition, hydro is low maintenance and doesn't break often [34]. Pumped Hydro Storage is a natural choice, as the upper lake (or a water tower at that location) can be used to store energy by pumping water up, and using the hydro turbine to turn it back into energy later. Although, the flow rate may be great enough throughout the year that no energy storage is necessary [34]. Baseboard heaters are cheap to purchase and install, easy to use, and modular. Electric stoves share similar characteristics. Underground power lines have a greater installation cost and planning requirements, however they are less susceptible to avalanches and other adverse weather and are therefore more reliable. A radio control system is of similar complexity to a local control system, but allows quicker access to diagnostics and control, increasing ease of use and safety. A hydro disengagement system is necessary and can be built in. A central power metre serves the same purpose as individual power metres, with lower complexity and lower cost, although the redundancy of the load sensing may be lesser than that of individual metres.

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wind	Geothermal	Fixed-Dome Biogas Plant	Floating-Drum Biogas Plant
Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	Biogas Tanks
Heat	Baseboard	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improved Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Meter	Survey Data				
Control Output	Remote Disengage	Solar Curtailing	Local Control	Radio Control	User Regulated		

Solution 2:
Biomass continues to be stored as dried yak dung, is converted to thermal energy via combustion in an improved biomass stove (for cooking), and stored in thermal mass (stone) to be radiated slowly (via rocket mass heater) throughout homes. Biomass is transported manually, using survey data and user regulation for output control.

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wind	Geothermal	Fixed-Dome Biogas Plant	Floating-Drum Biogas Plant
Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	CBG cylinders
Heat	Baseboard	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improved Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Metre	Survey Data				
Control Output	Remote Disengage	Solar Curtain	Local Control	Radio Control	User Regulated		

Solution 3:
Biomass (yak dung) is converted to biogas through anaerobic digestion in a fixed-dome style plant and stored in compressed biogas cylinders (CBG) which are transported manually to the individual dwellings. Biogas cylinders are hooked up to gas-fired furnaces for heating, and gas-fired stoves for cooking. Energy production is user regulated by adjusting the mass of feedstock added to the biogas digester.

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wind	Geothermal	Fixed-Dome Biogas Plant	Floating-Drum Biogas Plant
Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	CBG cylinders

Heat	Baseboard	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improved Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Metre	Survey Data				
Control Output	Remote Disengage	Solar Curtain	Local Control	Radio Control	User Regulated		

Solution 4:
Biomass (yak dung) is converted to biogas through anaerobic digestion in a floating-drum style plant and stored in compressed biogas cylinders (CBG) which are transported manually to the individual dwellings. Biogas cylinders are hooked up to gas-fired furnaces for heating, and gas-fired stoves for cooking. Energy production is user regulated by adjusting the mass of feedstock added to the biogas digester.

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wind	Geothermal	Fixed-Dome Biogas Plant	Floating-Drum Biogas Plant
Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	CBG cylinders
Heat	Baseboard	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improved Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Metre	Survey Data				
Control Output	Remote Disengage	Solar Curtain	Local Control	Radio Control	User Regulated		

Solution 5:
A solar energy system could be implemented using a lithium ion battery storage system with boilers and electric stoves for heat and cooking. The stored energy could be further transported through underground power cables and monitored with a central power metre. System output would be controlled by energy curtailment, a process that temporarily shuts down electricity generation to minimise grid congestion, and a control centre located at the plant site [39].

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wind	Geothermal	Fixed-Dome Biogas Plant	Floating - Drum Biogas Plant
Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	Biogas Tanks
Heat	Baseboar d	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improves Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Meter	Survey Data				
Control Output	Remote Disengage	Solar Curtailing	Local Control	Radio Control	User Regulated		

Solution 6:
A wind turbine system with lithium battery storage could be a way to capture kinetic energy from the wind and transfer it into energy used for both heating and cooking. The heating would be through a baseboard and the cooking system would use an electric stove. Baseboards are the most sure fire way to keep the entire house warm and electric stove is the best option when considering both economical factors and overall effectiveness. The best way to transport the energy would be through underground cables as they have the least chance of breakdown due to the extreme weather conditions. The best way to sense power demand would be through the use of localised power metres, to see specifically which buildings use the most energy. The best way to control the system would be in a control centre at the plant, where shutdowns are easy in case of extreme weather conditions.

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wind	Geothermal	Fixed-Dome Biogas Plant	Floati ng-Drum Biogas Plant
Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	Biogas Tanks
Heat	Baseboard	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improved Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Meter	Survey Data				
Control Output	Remote Disengage	Solar Curtailing	Local Control	Radio Control	User Regulated		

Solution 7:
Gokyo Nepal has an abundance of geothermal energy and can be stored with thermal energy storage. This thermal energy can be used for radiant floor heating to efficiently heat the homes of Gokyo. The geothermal energy can also be used for cooking purposes in the form of induction stoves. Induction stoves are very effective at heating things fast and more efficient than the average convection stove. Overhead power lines can transport the geothermal energy from the plant to houses in Gokyo. In order to maximise efficiency and control the energy coming from the geothermal plant there can be power metres on all buildings to gauge energy output. These power metres will give data to a central control centre and will allow for easy and safe adjustment of power.

	1	2	3	4	5	6	7
Capture	Hydro	Solar	Biomass	Wing	Geothermal	Fixed-Dome Biogas Plant	Floating-Drum Biogas Plant

Store	Flywheel	Thermal	Pumped Hydro	Lithium Battery	Lead Acid Battery	Yak Dung	Biogas Tanks
Heat	Baseboard	Radiant Floor	Rocket Mass	Boiler	Furnace	Heat Pump	
Cook	Electric Stove	Induction Stove	Improved Biomass Stove	Biogas Stove			
Transport	Overhead Cable	Buried Cable	Biogas Pipeline	Manual Transport			
Sense Demand	Building Power Metres	Central Power Metre	Survey Data				
Control Output	Remote Disengage	Solar Curtailing	Local Control	Radio Control	User Regulated		

B.d Performance Specifications: Included later in the report (p. 31)

C. PRELIMINARY DESIGN

C.a Metrics:

Labour Intensiveness:

Scale	Labour Intensiveness	Scale (percentage of functions automated)
1	Manually Controlled	0%
2	Basic Automation	0-30%
3	Some Automation	30-60%
4	High Automation	60-90%
5	Full Automation	>90%

Environmental Friendliness:

Scale	Environmental Friendliness	Scale (net gCO2 per kWh)
1	Very Low	>800
2	Low	300-800
3	Moderate	100-300
4	High	30-100
5	Very High	<30

*the release of particulate matter was taken into consideration with biomass energy systems

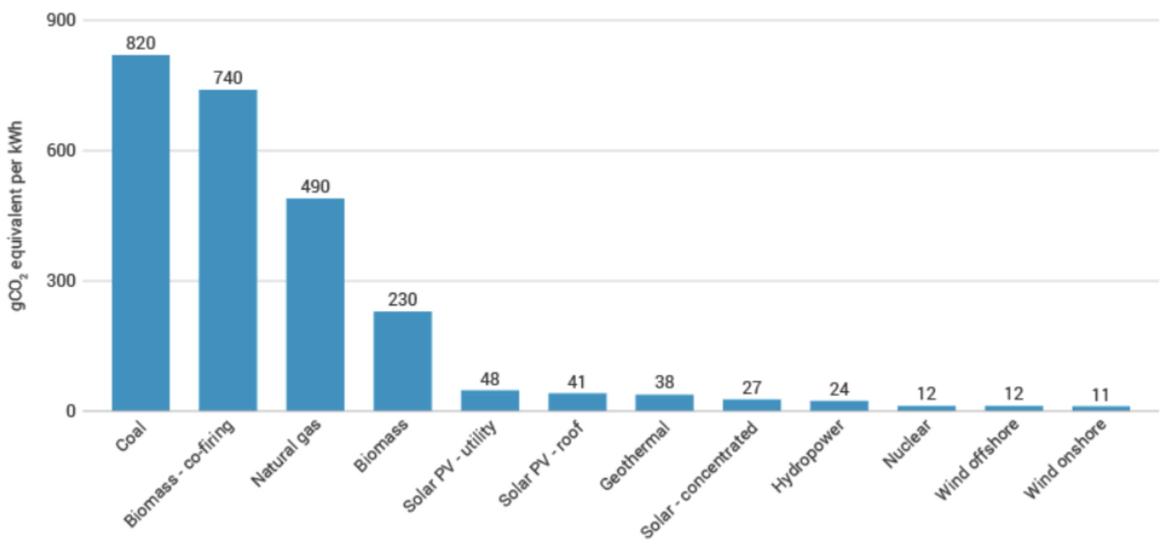


Fig. 6. *Comparing GCO2 equivalent per KWh of multiple energy sources [38].*

Safety:

Scale	Safety (FMEA)	Scale (RPN)
1	Extreme Safety Risk	>500
2	High Safety Risk	250-500
3	Fairly Safe	100-250
4	Safe	50-100
5	Very Safe	0-50

In the context of frequency mode and effects analysis (FMEA) the risk priority number (RPN) of a given solution is the product of three factors: the severity of a failure (S), the likelihood of occurrence (O), and the likelihood of detection (D). Each factor is rated on a scale of 1-10

Cost:

Scale	Cost (LCOE USD)	Scale
1	Very High Cost	> 1 USD/kWh
2	Relatively High Cost	0.5 - 0.75 USD/kWh
3	Medium Cost	0.3 - 0.5 USD/kWh
4	Low Cost	0.15 - 0.3 USD/kWh
5	Very Low Cost	< 0.15USD/kWh

Cultural Compatibility:

Scale	Qualitative Description	Scale
5	Very culturally compatible	>95%
4	Mostly culturally compatible	80-95%
3	Somewhat culturally compatible	60-80%
2	Barely culturally compatible	40-60%
1	Not culturally compatible	<40%

*Surveys given to locals around the area asking if a certain energy system would fit in with the culture of the area (yes/no). Scale is % of people that say yes.

Easy scalability: (Installation cost of minimum increase in power generation):

Scale	Qualitative Description	Scale
5	Very Scalable	<$1000
4	Fairly easy to scale	1000-$10,000
3	Somewhat scalable	$10,000-$50,000
2	Hard to scale	$50,000-$500,000
1	Impossible to scale	>$1,000,000

A more thorough scalability assessment would take into account more factors including locally available resources, however the cost to increase power generation by the smallest possible increment gives some idea of the ease of scaling based on increased demand.

Reliability and Robustness:

Scale	Qualitative Description	Scale
5	Very reliable	Fewer than an average of 1 maintenance issue per year
4	Mostly reliable	Between an average of 1-5 maintenance issues per year
3	Somewhat reliable	Between an average of 5-10 maintenance issues per year
2	A little reliable	Between an average of 10-15 maintenance issues per year
1	Barely reliable	Greater than an average of 15 maintenance issues per year

Expertise required to fix:

Scale	Qualitative Description	Scale
5	Simple, no expertise required	<1 year of energy systems experience
4	Somewhat simple, some expertise required	1-3 years of energy systems experience
3	Fair amount of expertise required	3-7 years of energy systems experience
2	A lot of expertise required	7-10 years of energy systems experience
1	Mastery of systems required	>10 years of energy systems experience

C.b Numerical Evaluation Matrix:

Criteria	Weight	Solution 1		Solution 2		Solution 3		Solution 4		Solution 5		Solution 6		Solution 7	
		Value	*Score*	*Value*	*Score*	*Value*	*Score*	*Value*	*Score*	*Value*	*Score*	*Value*	*Score*	*Value*	*Score*
Easy Scalability	0.06	2	0.12	5	0.30	3	0.18	3	0.18	5	0.30	2	0.18	1	0.06
Labour Intensiveness	0.12	5	0.60	1	0.12	3	0.36	4	0.48	5	0.60	4	0.48	4	0.48
Expertise required to fix	0.08	2	0.16	4	0.32	3	0.24	4	0.32	4	0.32	3	0.24	1	0.08
Reliability and robustness	0.12	5	0.60	5	0.60	5	0.60	4	0.48	2	0.24	4	0.48	4	0.48
Cultural Compatibility	0.19	4	0.76	5	0.95	3	0.57	3	0.57	4	0.76	3	0.57	4	0.76
Environmental Friendliness	0.16	5	0.8	3	0.48	5	0.80	5	0.80	4	0.64	5	0.8	4	0.64
Safety	0.25	4	1.0	4	1.0	3	0.75	3	0.75	5	1.25	3	0.75	5	1.25
Cost	0.04	5	0.2	5	0.2	4	0.16	3	0.12	3	0.12	5	0.2	3	0.12
Total Score			4.24		3.97		3.66		3.58		4.23		3.70		3.87

Some Reasoning Behind Scores:

For all solutions:
Real survey data cannot be collected for this project, so instead scores are based on reasoning taking into account some sources such as in [35] where local lodge owner Tshering Tashi states “It's a big dream for us to build a hydro power in Gokyo." Traditional sources were assessed to have high cultural compatibility due to them being a component of culture.

For solution 1:
Not sure there were any non-obvious scores for this one, so we should discuss friday.

For solution 2:
Scores low on labour intensiveness, since much manual labour is involved in gathering and drying yak dung. The solution was docked some points in the “Environmental Friendliness” category since though the net CO_2 output is 0 (organic matter will decompose and release CO_2 one way or another), combustion is not perfect and therefore trace amounts of particulate matter are still emitted. “Safety” was docked points for the same reason.

For solution 3 and 4:
Safety is a concern when working with biogas as there is a risk of leaks which could lead to asphyxiation/explosions in the worst case scenario. Otherwise, these solutions only differ slightly in their labour intensiveness, robustness and cost as aforementioned in the research section of this paper.

For solution 5:
The score for reliability and robustness of the system is low as solar panels are at greater risk of being affected by variable weather conditions (avalanches, heavy rain/snowfall, strong winds, extremely cold winter temperatures), potentially leading to damage of the energy system.

For solution 6:
The installation and the maintenance required to keep the wind turbines running would be a big barrier in the implementation of this solution. This is mainly due to the sheer size of wind turbines, accompanied with the location of the village. Given that Gokyo has such high altitude and is so remote from other settlements, moving wind turbines into the local area would prove a huge logistical challenge, resulting in a low scalability score.

For solution 7:
The labour involved with the installation of a geothermal power plant would be immense, however when the plant is installed the maintenance is fairly low. Because of low maintenance requirements while working the geothermal energy ranks well for labour intensiveness.

B.d Performance Specifications

Functional Specifications:

1. The emissions of PM2.5 and CO into living spaces must result in less than the maximum concentrations of PM2.5 : 5 µg/m3, and CO : 4 mg/m3
2. Any electrical system must output 120v AC to successfully power appliances such as baseboard heaters or electric stoves.

Design Specifications:

1. The system must be able to operate within a temperature range of -20c - 5c to accommodate for different environmental conditions [23].
2. The physical construction of the system should be robust to resist adverse weather such as heavy snowfall or avalanches.
3. The efficiency of the energy retrieval process and storage system should be at least 70% [40].
4. All electrical appliances should follow CPSC regulations, standards, and laws, to ensure safe operation.
5. Spare components should be stored to increase redundancy for all feasible components of the system (appliances, control electronics, etc.)

Procedural Specifications:

1. The output capacity of the system must be greater than the maximum power usage of the village. The average continuous power usage of the village was estimated previously to be 38kW, however the maximum usage is likely much higher. Therefore, a maximum output power of less than 100kW is inadvisable, given the wide margin for error on our estimations. This is a procedural specification because it will depend on the calculation of total energy demand, which can be found as previously shown by multiplying the population by the per capita energy demand. More rigorously, it can be calculated from measurements of total biomass burned in all the lodges multiplied by an energy density value for those biomass sources.
2. The energy storage system should have the same maximum output power as the generation method, to ensure consistent functioning and avoid blackouts under heavy use. For different storage methods, this optimization will look different; For instance, for a chemical battery system, the ratio of series to parallel connections between the batteries will affect maximum output, but for a flywheel system, the size of the generator attached to the wheel will be the determining factor.
3. The energy storage system must be sized to provide energy for the entire duration for which the power generation source doesn't meet demand. This is dependent on the output characteristics of the energy source, meaning that an acceptable sizing is zero if the output characteristics are stable enough.

C.c Design Description:

The finally selected solution is based around hydro power generation. A small, 100kW run-of-the-river power plant can be installed with the intake at Gokyo Lake, and the power house at the lower basin next to the village. For energy storage, based on the rough river flow estimation above, it is possible no storage is required. This is ideal if possible, because it reduces complexity, and cost. However, if energy storage is required, pumped-hydro storage is a perfect fit, because it requires almost no additional infrastructure; The generator plant can double as a pump station, to pump water up from the lower basin back into Gokyo Lake, using electricity from Any source to do so when there is excess. Later, the energy is used again simply by running the hydro power plant. Baseboard heaters will be installed in all living spaces, with accompanying thermostats in each room. This can further improve energy efficiency, because unnecessary heating can be reduced through granular control. Electric stoves may be installed at the discretion of the locals, but obvious locations would include where the biomass stoves currently are. To assist cultural preservation, the choice may be made to keep one or two of the biomass stoves to use ceremoniously, or as a backup heat source. A set of main underground power lines can be dug from Gokyo Lake to the village location, as all pictured in the sketch. From here, a small switching plant building can be constructed to step down the power from the plant for individual buildings, and send it off through smaller underground lines. A central power metre can be installed here, to match output to demand and allow easy access to controls. A radio control system may be used, and kept in a useful location at the locals discretion, to allow remote monitoring and operation of the plant.

Sketch/model:

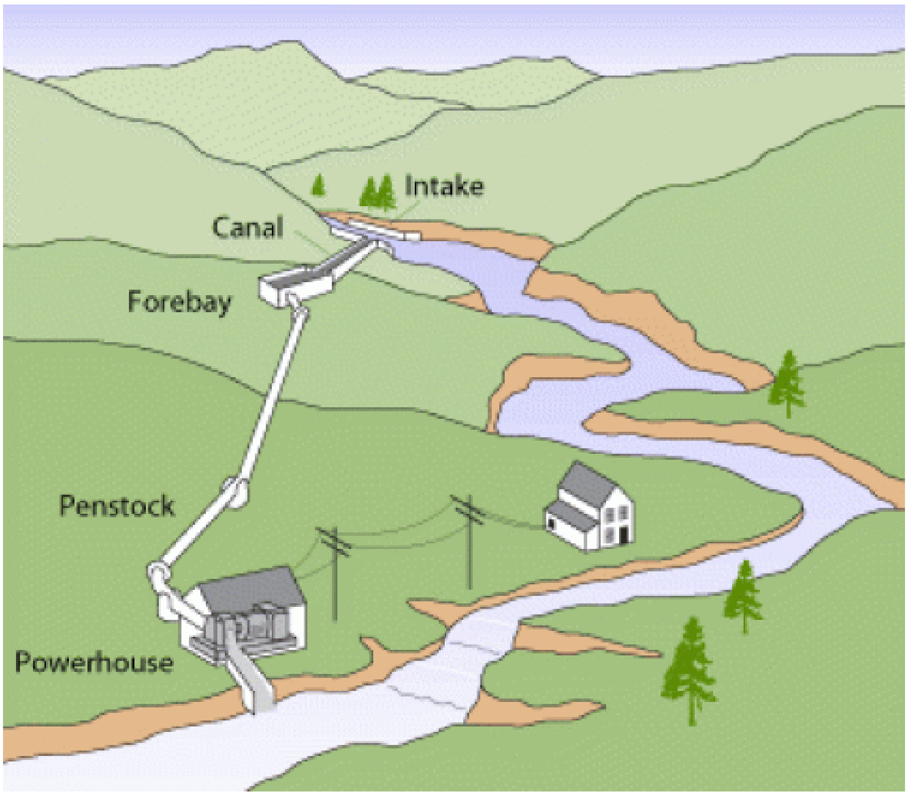


Fig. 9. *A standard run-of-the-river style hydropower generation system [45]*

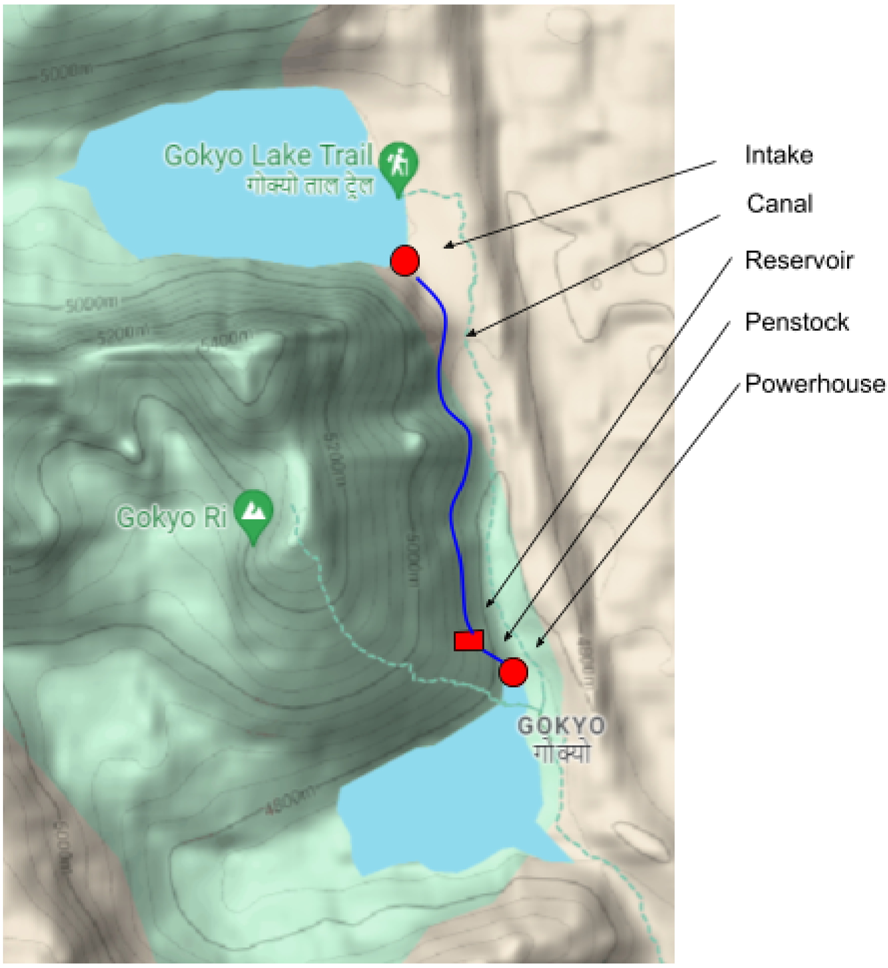


Fig. 8. *Draft of placement of components for hydro-power system. Adapted from [44]*

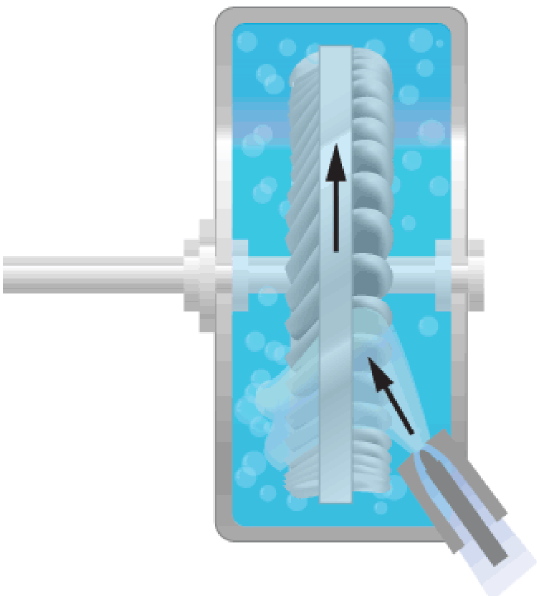


Fig. 10. *A "Turgo" style turbine for efficient energy capture [46]*

Test Methods:

Testing methods for run-of-the-river micro hydro plants are essential to ensure they are an efficient operation. In order to develop an efficient system we must run tests to determine the ideal location for head height and flow rate of the stream. Initially head height could be tested by running a small diameter hose down the section of stream with the greatest visible height drop and taking a vertical measurement[36]. This process could be repeated down the stream until the ideal turbine location is found [36]. In order to determine the initial flow rate of the stream we could dam a section of the stream diverting its flow into a bucket and calculating the time it takes to fill [37]. Once we find a location that maximises both flow rate and head height we would professionally survey the site. With these metrics the power of our system could be calculated with the equation: "[net head (feet) × flow (gpm)] ÷ 10 = W (Power or Watts)" [37].

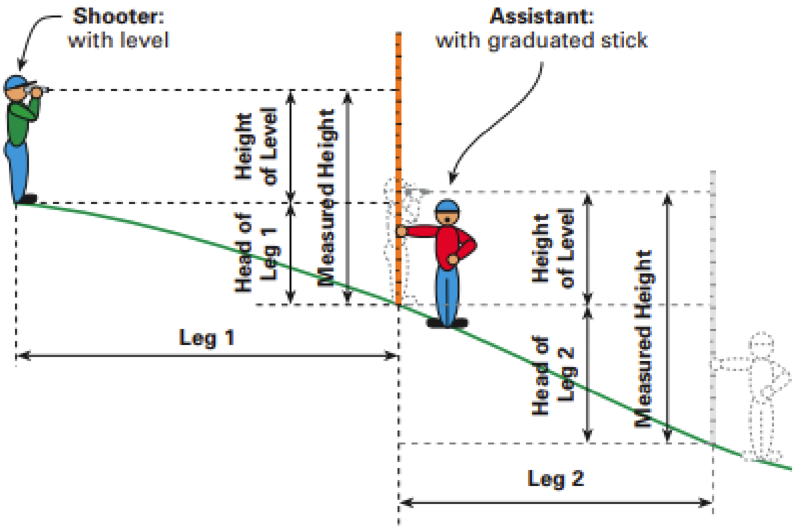


Fig. 7. *Measuring head height for a micro hydro system [36].*

D. Project Management

D.a. Linear Responsibility Chart:

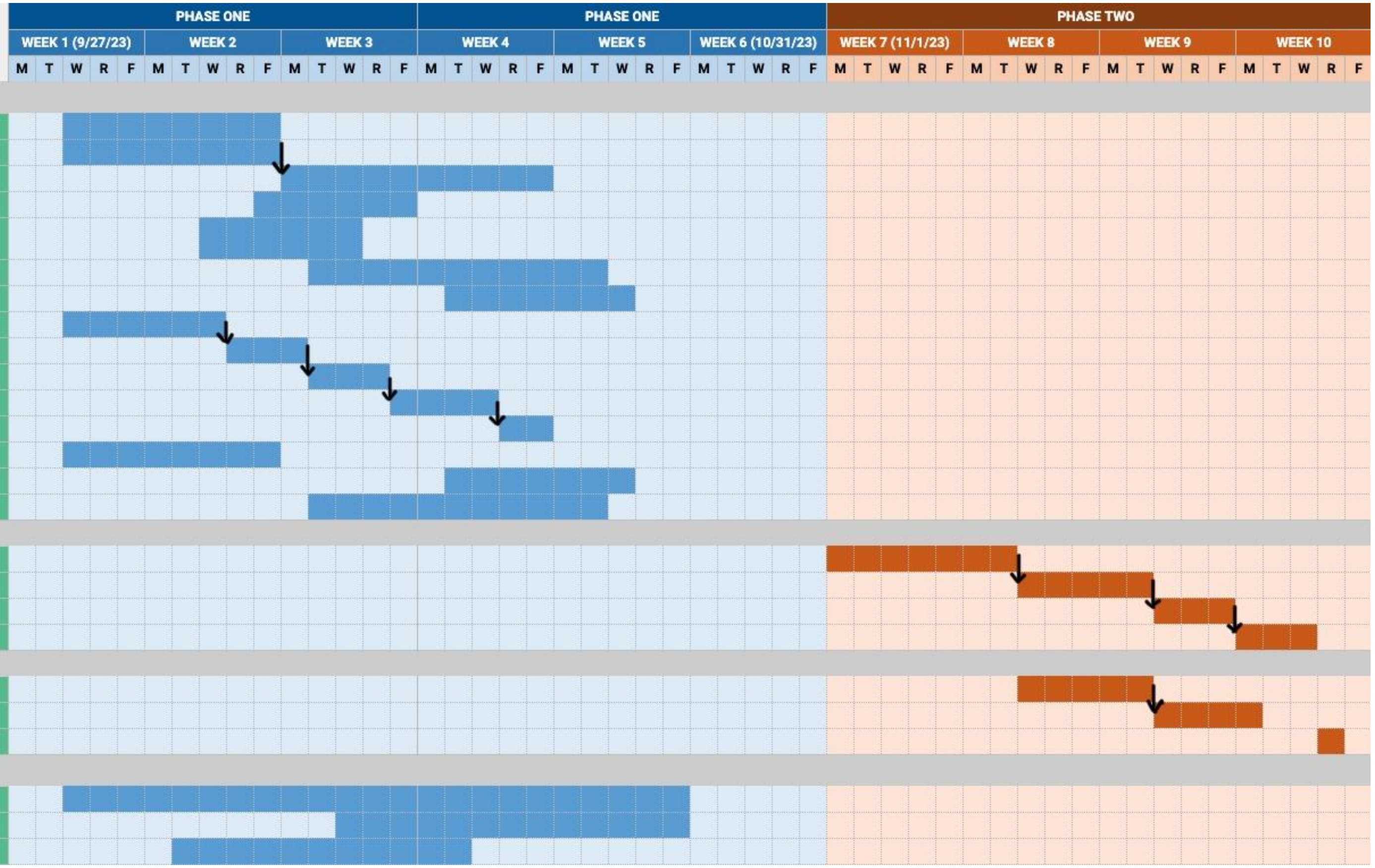
Legend: **1 - Primary Responsibility** **2 - Support/Work** **3 - Must be Consulted** **4 - May be Consulted**	Alex	Dylan	Elvin	Finley	Jim
Project Initialization:					
Create List of Possible Needs	**2**	**2**	**2**	**2**	**2**
Select a Need	**2**	**2**	**2**	**2**	**2**
Explanation of Choice	**4**	**4**	**4**	**4**	**1**
Create List of Potential Clients	**3**	**3**	**3**	**3**	**1**
Client Selection with Explanation	**4**	**4**	**4**	**4**	**1**
Initial need statement	**1**	**4**	**4**	**4**	**3**
Create Initial Goal Statement	**1**	**4**	**4**	**4**	**4**
Project Management (P1):					
Input Tasks into Gantt Chart	**3**	**1**	**3**	**3**	**3**
Finalise Linear Responsibility Chart	**3**	**3**	**3**	**1**	**3**
Begin Tracking Schedule	**3**	**1**	**3**	**3**	**3**
Remove Duplicates of Text From Other Documents	**2**	**2**	**2**	**2**	**2**
Problem Definition:					
Draft Design Objectives	**1**	**3**	**2**	**3**	**3**
Research Questions	**2**	**2**	**2**	**2**	**2**
Research existing solutions	**1**	**4**	**2**	**4**	**4**
Draft Constraints	**2**	**2**	**1**	**2**	**2**
Finalise Objectives and Constraints	**2**	**2**	**2**	**2**	**2**
Draft Criteria Tree	**3**	**3**	**1**	**3**	**3**
Finalise Criteria Tree	**3**	**3**	**1**	**3**	**3**
Create Pairwise Comparison Sheet	**2**	**2**	**1**	**2**	**2**

Finalise Pairwise Comparison Sheet	**2**	**2**	**2**	**2**	**2**
Create Weighted Criteria Tree	**3**	**3**	**1**	**3**	**3**
Finalise Client Problem Statement	**3**	**3**	**1**	**3**	**3**
Final Check by Oct 30	**2**	**2**	**2**	**2**	**2**
Conceptualization:					
Draft function list	**2**	**2**	**2**	**2**	**2**
Finalise function list	**2**	**2**	**2**	**2**	**2**
Function Means Tree	**3**	**3**	**1**	**3**	**3**
Morphological Chart	**1**	**3**	**3**	**3**	**3**
List Performance Specifications	**3**	**3**	**1**	**3**	**1**
Preliminary Design:					
Metrics	**2**	**2**	**2**	**2**	**2**
7 distinct solutions	**2**	**2**	**2**	**2**	**2**
Numerical Decision Matrix	**2**	**2**	**2**	**2**	**2**
Design Description					
Design description	**3**	**3**	**1**	**3**	**3**
Test method description	**3**	**3**	**3**	**3**	**1**
Design Sketch	**1**	**3**	**3**	**3**	**3**
Project Management (P2):					
Gantt Chart	**3**	**1**	**3**	**3**	**3**
Linear Responsibility Chart	**3**	**3**	**3**	**1**	**3**
References:					
Full bibliography	**2**	**2**	**2**	**2**	**2**
In-text citations wherever needed	**2**	**2**	**2**	**2**	**2**
Presentation:					
Need	**3**	**3**	**3**	**3**	**1**
Problem Definition	**1**	**3**	**3**	**3**	**3**
Design Criteria and Constraints	**3**	**3**	**1**	**3**	**3**
Functional Analysis	**3**	**3**	**3**	**1**	**3**

Conceptual Design	**3**	**1**	**3**	**3**	**3**
Design Selection	**3**	**3**	**3**	**1**	**3**
Design Solution	**3**	**3**	**1**	**3**	**3**

D.b. Gantt Chart

TASK TITLE	TASK OWNER	START DATE	END DATE	DURATION	PCT OF TASK COMPLETE
Problem Definition					
Need and Goal	Shared	9/27/23	10/6/23	9	100%
Create initial goal statement	Alex	9/27/23	10/6/23	9	100%
Research	Shared	10/8/23	10/27/23	19	100%
Research on renewables	Elvin	10/7/23	7/14/23	7	100%
Talk to Trekking company and locals	Jim	10/3/23	10/10/23	7	100%
Health Planning	Alex	10/10/23	7/21/23	11	100%
Finding potential organizations	Jim	10/17/23	10/24/23	7	100%
Objectives and Constraints	Shared	9/27/23	10/4/23	7	100%
Add objectives and constraints	Alex	10/5/23	10/8/23	3	100%
Criteria Tree	Elvin	10/5/23	10/8/23	3	100%
Pairwise comparison chart	Shared	10/13/23	10/17/23	4	100%
Weighted Criteria Tree	Shared	10/19/23	10/21/23	2	100%
Problem defintion statement	Shared	9/27/23	10/11/23	9	100%
Finding potential organizations	Jim	10/17/23	10/24/23	7	100%
Explanation for village choice	Jim	10/10/23	7/21/23	11	100%
Conceptualization					
Functions	Shared	11/3/23	11/17/23	14	100%
Functions mean tree	Elvin	11/7/23	11/14/23	7	100%
Morphological chart	Alex	11/15/23	11/18/23	3	100%
Performance specifications	Shared	11/21/23	11/24/23	3	100%
Preliminary Design					
Metrics	Shared	11/7/23	11/14/23	7	100%
Numerical evaluation matrix	Shared	11/16/23	11/20/23	4	100%
Design Description	Shared	11/23/23	11/24/23	1	100%
Project Management					
Gantt Chart	Dylan	9/7/23	10/27/23	30	100%
Formal Project Proposal Document	Shared	10/11/23	10/27/23	16	100%
Linear responsibility Chart	Finley	10/3/23	10/17/23	14	100%



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