EVALUATION OF SMALL HYDROPOWER PLANT PROSPECTIVES IN NORTH-EAST INDIA

BACHELOR THESIS

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Graz, Austria July 2018

I would like to thank the opportunity provided by the TU Graz Intitute of Electricity Economics and Energy Innovation and the trust they placed in me. Specially, I would like to thank Professor Bachhiesl and Karthik Bhat Subramanya, who guided me during this project.

Also, I would like to dedicate this thesis to my family, specially to my parents and my brother, Hugo. They supported me throughout my career and always believed in me. Also, special mention deserves Amara, who encouraged me and helped me to maintain the perseverance during this adventure.

This thesis is written to the best of my knowledge without any copying intention involved. All the references and bibliography are provided to credit the information taken from the sources.

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1. Project dimension and scope. Abstract.

1.1. Objective.

The objective of this project is to study the technical feasibility and the economic viability of installing a Mini/Small Hydropower Plant in one of the potentially rich areas in the North-East region of India. Due to the reach of the national grid, there is scarcity of electricity in this region, and that has been prevailing for several decades. Several planned major hydro power plant projects are planned by the government in this region, however, due to reasons of conflicts like environmental and water sharing problems, these projects are yet to be realized. The alternative is to build small hydro power plants, which do not stop the flow of the rivers and decrease the impacts, both environmental and water sharing.

The analysis discussed in this thesis considers several factors, such as the energy demand, the hydrological source (head and flow), the rainfall data, the environmental impact, the initial investment and the payback period. In addition, a suitable proper hydro turbine type and the number of turbines are also proposed. Also, the rated power and the annual energy produced are to be calculated and presented as the results, and conclusions are drawn from this.

1.2. Methodology.

The scope of this project englobes the hydrological source characterization in the zone of interest, the choice of the exact location, the technological decisions, the environmental considerations, the economic analysis and the electric grid simulations.

Several software packages are to be used to facilitate the search and simulate the different cases and scenarios like: Google Earth Pro, RETScreen Expert and Homer Pro. Google Earth Pro was used to identify the potentially rich areas and other important aspects in the early stages of this thesis, RETScreen was used to evaluate the potential and the viability of several types of turbines normally used in small hydropower plants, and Homer Pro was used to evaluate an overall system including the final selected components and a localized grid in the selected area.

1.3. Justification and possible conclusions.

The selected area for this analysis falls in a region where hydro power potential is available to the most but is the least utilized in India. The transition to green energy in India relies on the major expansion of renewables like Hydropower, and thus the North-East region clearly plays an important role.

Possible conclusions to this thesis include the evaluation and comparison of the use of cross flow turbines and Kaplan turbines, and their benefits to the discussed region: both technical and economic.

2. Hydropower.

2.1. Hydropower Technology.

Hydropower is obtained from water potential, transforming it into mechanical energy and then into electrical energy. It uses the energy from the water of the hydrological cycle. The water of the oceans and water bodies on land are evaporated by the energy of the sun's heat and gets transported as clouds to different parts of the earth. The clouds travelling over land and falling as rain on earth produces flows in the rivers which comes back to the sea. The water of rivers and streams, while flowing down from places of higher elevations to those with lower elevations, loose its potential energy and gain kinetic energy.

Hydropower plants try to take advantage of both kinetic and potential energy. Water pressure is converted by the movement of hydro turbines into mechanical shaft power. Then the mechanical shaft power is used to drive an electrical generator. The hydraulic theoretical power obtained is given by the equation:

$$\boldsymbol{P_0\ (W) = \rho g Q H} \tag{1}$$

where ρ is the density of water (kgm^{-3}), g is the acceleration due to gravity (ms^{-2}), Q is the volume flow (m^{3}s^{-1}) and H is the head (m).

The energy produced is the result of multiplying the theoretical power by an interval of time $\Delta t(s)$.

$$\boldsymbol{E_0\ (J) = \rho g Q H \Delta t} \tag{2}$$

The power output of any hydropower plant is smaller because it is necessary to consider the turbo-generator efficiency.

$$\boldsymbol{P(W) = \eta P_0} \tag{3}$$

It is important to remember that hydro is still the most efficient way to generate electricity. In fact, modern hydro turbines can achieve 90% efficiencies. Nevertheless, the efficiency is reduced with the size, so mini and micro hydro systems tend to be between 60-80% efficiency.[1]

There are several ways to classify hydropower plants: according to the installed power, to the height of the head and according to constitution or purpose.

The categorization of installed power relies on the country. In India, the Ministry of New and renewable Energy (MNRE) makes the following division:

Large Hydro: More than 25000 kW. Non-renewable source.
Small Hydro: Up to 25000 kW. Renewable source.
  -Micro Hydro: Up to 100 kW.
  -Mini Hydro: 101 to 2000 kW.
  -Small Hydro: 2001 to 25000 kW.

Likewise, the classification regarding the height of the head is very simple. Although many other factors are considered, the head hardly influences the type of turbine. High Head (200 m or higher) Pelton turbines are usually used. Medium Head (20 and 200 m), Francis turbines are normally used. Low Head (20 m or lower) Kaplan, Propeller and Cross-flow turbines are used.

Finally, the wide classification according to constitution or purpose differentiates between Run-of-the-river Hydropower plants and Reservoir Hydropower plants:

Run-of-the-river hydroelectric power stations can be built with or without diversion canal. Such plants that do not have diversion, directly exploit the kinetic energy of water, so the speed and water flow determine their power because they do not have any reservoir. On the other hand, the plants with diversion at same level use a water transport canal, called a bypass canal, responsible for carrying the water by an alternative path to its natural path (with less slope and roughness tan the river) and thus create along its extension a greater difference of heights. The water will be driven by a pressure pipe and its energy will be transferred in the turbine to produce the electrical energy in the turbine-generator group. At the end of the process, the water will be returned to the river at an appropriate point so as not to damage the environment. Finally, the diversion can also be made at different level. In this case, the pressure is increased in the pressure chamber and then the water is leaded to the turbine by a penstock.

In the case of Reservoir Hydropower plants one or more dams are used. Water is dammed to a greater height than turbines, which are located at the foot of the dam. These plants allow energy production all year. However, they require greater investment than Run-of-the-river plants, due to increase in requirements of the infrastructure involved.

2.2. Overview of Hydroelectric Turbines.

As previously mentioned, hydro turbines are elements that convert the energy from falling or moving water into rotating shaft power taking advantage of the potential and kinetical energy of this fluid. The best turbine for any hydro project has to be selected depending upon the site characteristics. The most important characteristics are the head and volume flow rate available, although the desired running speed of the generator is also important. Moreover, it is necessary to know previously if the turbine will be expected to produce energy under reduced flow conditions. Depending on the speed, every turbine has power output and an efficiency, so they will tend to run most efficiently at a specific flow, head and speed. *Figure 1.2.1* shows a chart frequently used for selecting the appropriated turbine depending on the head and flow.

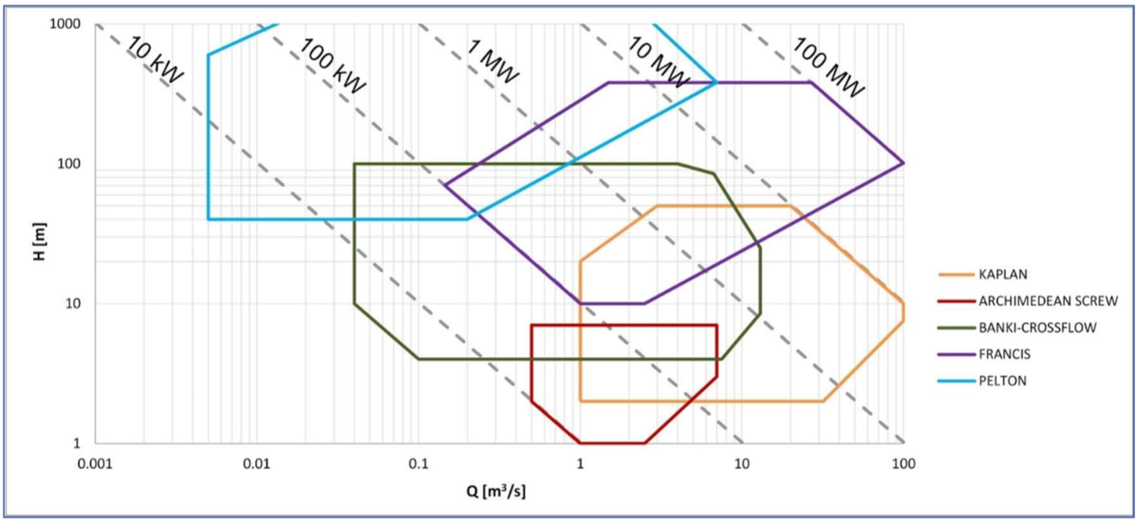


Fig.2.2.1. Hydro Turbine Selection Chart. Source: Alberto Santolin (2017). HPP Design Blog.

There are two main categories of hydro turbines in use: impulse and reaction turbines. As seen, they are divided by their principle of operation.

Impulse Turbine: In principle, the turbine uses the kinetic energy of water to drive the runner and discharges to atmospheric pressure. The runner of impulse turbines operates in air and is moved by jets of water. It is important to remark that the water remains at atmospheric pressure along its passage through the turbine, before and after making a contact with the runner blades. Impulse turbines are usually applied in systems with high head and low flow, but it depends on the specific turbine type. The most famous impulse turbines are: Pelton, Cross-flow and Turgo.

Impulse turbines have simple design and are inexpensive. Recently, they have been applied for low head sites, and their proven effectiveness has made them to become an accepted alternative practice in many countries. Moreover, they have less cavitation problems than reaction turbines and their maintenance is cheaper.

Reaction Turbine: This turbine generates electricity from the water pressure changes along the blades. These turbines are usually appropriate for sites low heads and high flows. The rotor is generally fully submerged and the runner blades are profiled so that pressure differences across them impose lift forces. Propeller, Kaplan, Francis and Kinetic are some examples of reaction turbines.

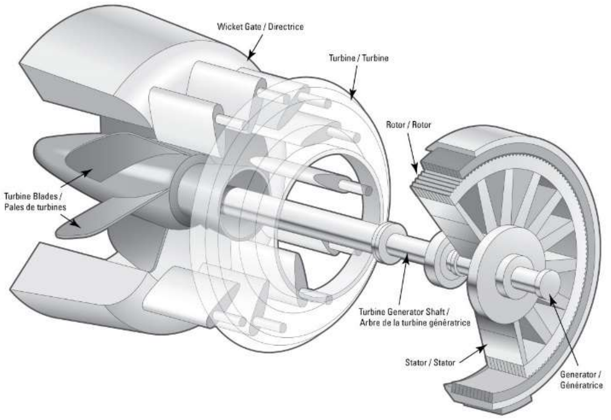


Figure 2.2.2. Hydro Turbine components. Propeller Turbine. Source: Trevor Johnston. Illustration+digital art. (2015)

Apart from the chart shown in Figure 2.2.1., there are several other criteria for the hydro turbine selection such as the specific speed (n_s). The specific speed (n_s) is the speed in r.p.m. at which a turbine of homologous design would operate, if the runner were reduced to a size which would develop one metric horse power under one-meter head. It is given by the following relation:

$$\boldsymbol{n_s = \frac{n\sqrt{P \cdot 1.358}}{H^{5/4}}} \tag{4}$$

where n_s is the specific speed of turbine in r.p.m, n is the rated speed of turbine in r.p.m., P is the turbine output in KW and H is the rated head in meters.

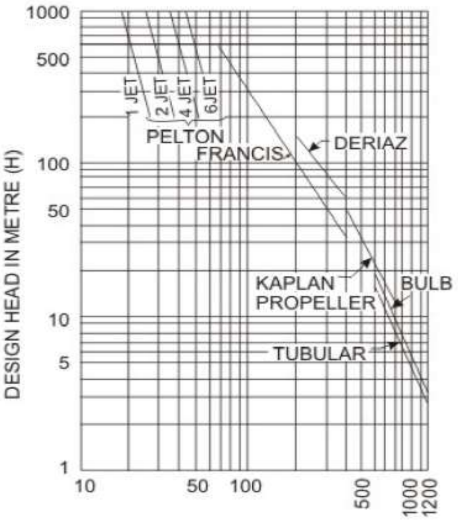


Figure 2.2.3. Specific Speed Chart. Uhunmwangho, R., Odje, M., & Okedu, K. E. (2018). Comparative analysis of mini hydro turbines for Bumaji Stream, Boki, Cross River State, Nigeria. Sustainable Energy Technologies and Assessments, 27(September 2017), 102–108.

Once the specific speed has been calculated and the design head known, the chart shown in Figure 2.2.3. or a similar one can be used to choose the correct turbine.

In addition to the technical applicability, before purchasing a specific hydro turbine, many other factors must be considered, such as the efficiency, the constructability, the cost, the maintenance, the portability and the scope of modularity. Just finding a compromise solution considering all these factors, it is secure to acquire a turbine.

As mentioned, a very significant factor in the comparison of different turbine types is their relative efficiencies at their design point and at reduced flows. As it is shown in *Figure 1.2.4.*, both Cross-flow and Pelton turbines keep a high efficiency in a large range of flow discharges. Additionally, Francis and Propeller turbines need a flow close to the design flow for an efficient performance. However, in the case of the Propeller turbine this problem was solved with the invention of the Kaplan turbine, which has the same operating principle, but with orientable blades that adjust their orientation depending on the flow discharge.

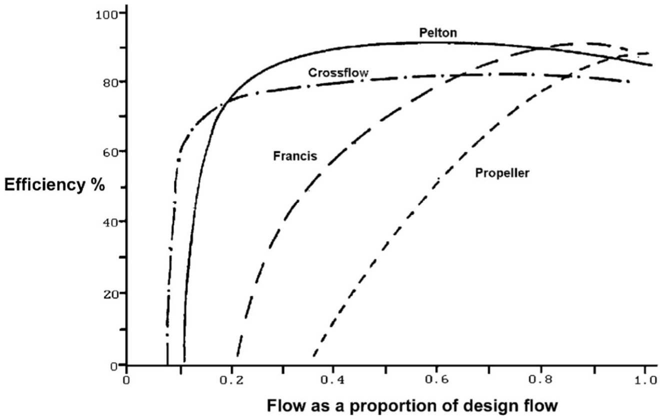


Figure 2.2.4. Hydro Turbine Efficiencies. Source: Paish, O. (2002). Small hydro power: Technology and current status. Renewable and Sustainable Energy Reviews, 6(6), 537–556.

2.3. Small Hydropower Technology (SHP).

Most of the Small Hydropower Plants (SHP) have a Run-of-the-River scheme because the available head in the planned site is not big enough. For this reason, they try to get as much power as possible from the kinetic energy of flowing water. In a typical small hydro scheme with derivation, water is taken from the river by diverting it through an intake at a weir. This weir is a man-made barrier across the river, which maintains a continuous flow through the intake. The water passes through a settling tank or forebay in which the water is slowed down sufficiently for suspended particles to settle out before descending to the turbine. The forebay is usually protected by a rack of metal bars (a trash rack), which filters out elements that might damage the turbine such as stones, timber, or man-made litter. Low-head installations generally involve water entering the turbine almost directly from the weir. A pressure pipe, known as penstock, conveys the water from the forebay to the turbine. Finally, the water taken is returned to the river in an appropriated point. All installations need to have a valve or sluice gate at the top of the penstock, which can be closed when the turbine needs to be shut down and emptied of water for maintenance. When the valve is closed, the water is diverted back to the river down a spillway. *Figure 2.3.1.* shows this scheme using two different configurations. [2]

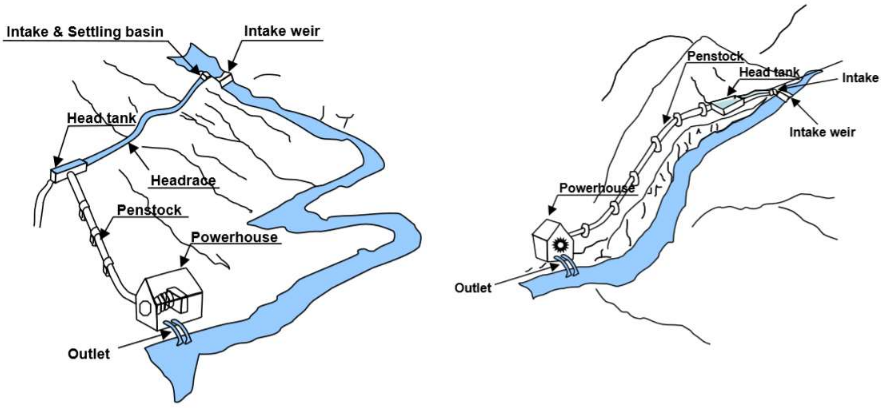


Figure 2.3.1. Run-of-the-river schemes and configurations. Source: Agency, C. (2011). Guideline and Manual for Hydropower Development Vol. 2 Small Scale Hydropower, 2(March).

It is very important to stand out the numerous advantages of SHP:

- SHP is a renewable source of energy.
- No big dams and big water storage are required, so the resettlement and rehabilitation of the population is not necessary.
- Fossil fuels and other petroleum products are not required.
- Low carbon energy production. These projects help to reduce GHG emissions and acid rain.
- SHP is a sustainable source of energy and it is cost effective. That means that simple and inexpensive construction work and equipment are required to establish and operate these projects. Furthermore, the cost of electricity generation is inflation free and the gestation period is shorter and gives financial returns faster than large hydropower.
- SHP development provides is capable to provide electricity, energy, transportation, communication links and economic growth to rural and remotes areas. This characteristic will be very important for the present project due to the properties of the region and the country.
- SHP is much more concentrated energy resource than either wind or solar power, which need big extensions.
- SHP can provide additional benefits such as water supply, flood prevention or irrigation.

Nevertheless, SHP also has some limitations and disadvantages compared to Large Hydro:

- Flow of the river often vary considerably between seasons. This fact limits the firmness of the power output.
- There is always a maximum useful power output. This maximum limit the level of expansion of activities which can take profit of the power.
- The technology is specifically developed for the site characteristics and very few standard elements are used. However, standard technology is being developed, especially standard turbines.
- There can appear some problems with fisheries interests.

In conclusion, SHP is a clean, efficient and interesting source of energy among all renewable sources. The Run-of-the-River scheme with derivation respects the environment considerably, avoiding the construction of dams and squeezing the water resource. Small hydro projects help to provide electricity to remote, rural and isolated areas.

3. Energy generation and current situation in India.

3.1. Review of energy landscape in India.

Energy is contemplated as a key factor in the generation of wealth, social development and improved quality of life in all developed and developing nations around the world. In fact, energy is a basic human necessity nowadays.

The Indian economy is the seventh-largest in the world by nominal GDP. They are behind USA, China, Japan, Germany, United Kingdom and France. Furthermore, India is the third-largest by purchasing power parity (PPP) behind China and USA, and the fifth-largest generator of energy, accounting for 4-5% of the global annual generation. [3]

As it is shown in *Figure 3.1.1.*, around 65% of electricity generation is thermal based (including coal, diesel, gas), almost 14% comes from Large Hydropower and 2% of generation is Nuclear, while the contribution from Renewable Energy Sources (RES) is about 19%.

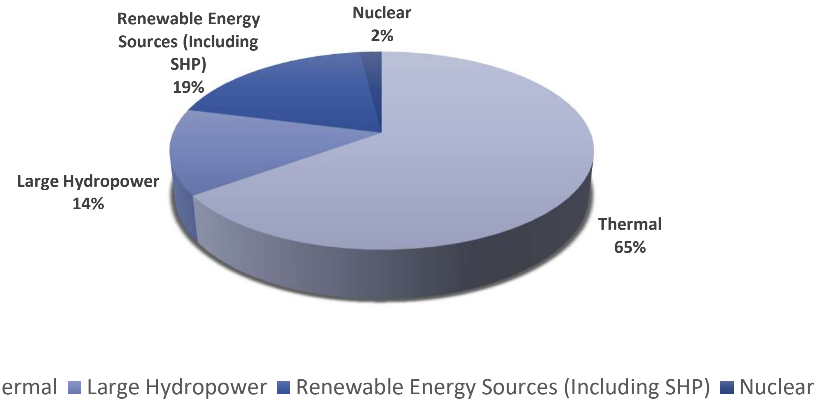
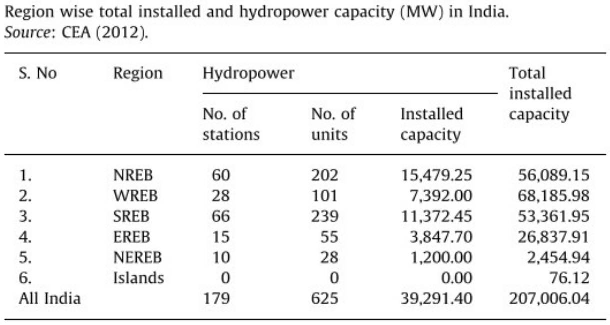


Fig 3.1.1. Indian Energy Share. SourceSharma, N. K., Tiwari, P. K., & Sood, Y. R. (2013). A comprehensive analysis of strategies, policies and development of hydropower in India: Special emphasis on small hydro power. Renewable and Sustainable Energy Reviews, 18, 460–470. Updated- Wikipedia (2018)

Concerning the energy distribution in the country, the Indian power sector is organized into five Regional Electricity Boards such as Northern Regional Electricity Board (NREB), Southern Regional Electricity Board (SREB), Western Regional Electricity Board (WREB), Eastern Regional Electricity Board (EREB) and North Eastern Regional Electricity Board (NEREB). As it is shown in the following figures, there is a remarkable lack of generation capacity in the North-Eastern Region, zone where the project discussed in this thesis is supposed to be developed.



Region wise total installed and hydropower capacity (MW) in India.
Source: CEA (2012).

S. No	Region	Hydropower			Total installed capacity
		No. of stations	No. of units	Installed capacity	
1.	NREB	60	202	15,479.25	56,089.15
2.	WREB	28	101	7,392.00	68,185.98
3.	SREB	66	239	11,372.45	53,361.95
4.	EREB	15	55	3,847.70	26,837.91
5.	NEREB	10	28	1,200.00	2,454.94
6.	Islands	0	0	0.00	76.12
All India		179	625	39,291.40	207,006.04

Table 3.1.1. Region wise total installed capacity and hydropower capacity (MW) in India. Source: Sharma, N. K., Tiwari, P. K., & Sood, Y. R. (2013). A comprehensive analysis of strategies, policies and development of hydropower in India: Special emphasis on small hydro power.

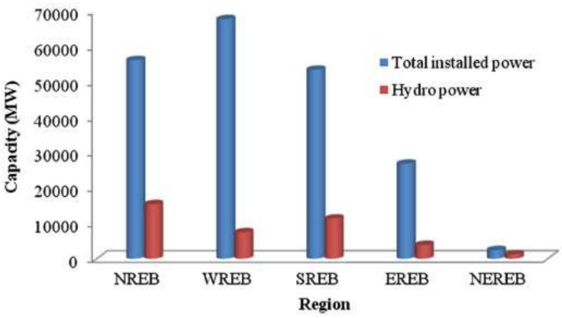


Figure 3.1.2. Installed power and hydropower in India. Source: Sharma, N. K., Tiwari, P. K., & Sood, Y. R. (2013). A comprehensive analysis of strategies, policies and development of hydropower in India: Special emphasis on small hydro power.

The main motivation behind this project emerges when it is discovered that the NEREB has at its disposal an enormous unexploited water potential. In fact, this area has the greatest potential for the installation of SHP in the whole the country.

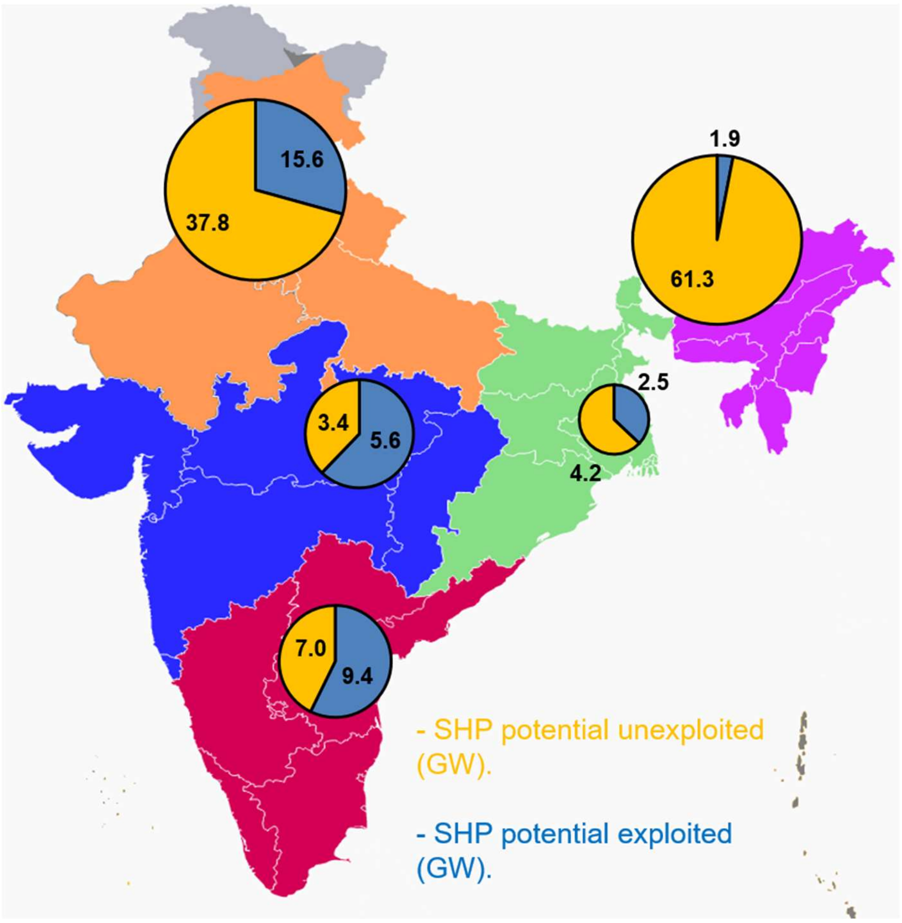


Figure 3.1.3. SHP potential per boards. Source: Karthik Bhat Subramanya. IEE TU Graz.

3.2. Renewable Energies in India.

The economy grows rapidly and that leads to an increase in demand of energy generation, but the problem arises to provide desired quantity and quality of energy in a sustainable way. Furthermore, it is necessary to keep an eye on the environmental problems related with the extraction of energy from several resources. Population, industrialization and pollution are constantly growing up and for that reason the environmental degradation is being increased. In fact, the problem of climate change has become a very critical issue. Fossil fuels such as coal and petroleum are conventional energy sources available in almost every country, but their high prices, depletion and pollution problems forces to explore other clean and sustainable sources for energy generation. The human sustainability depends on the well-being of natural sources.

Figure 3.2.1. Human Being. Source: Nautiyal, H., Singal, Varun, & Sharma, A. (2011). Small hydropower for sustainable energy development in India. Renewable and Sustainable Energy Reviews, 15(4), 2021–2027.

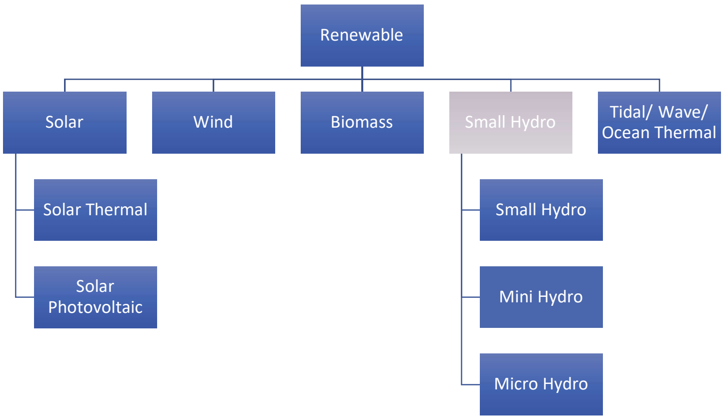


Figure 3.2.2. Renewable energy sources classification. Source: Own creation.

The use of renewable sources is the most interesting and valuable solution to reduce the environmental problems related with fossil fuels. Solar, hydro, wind biomass and geothermal are important sources for renewable energy generation.

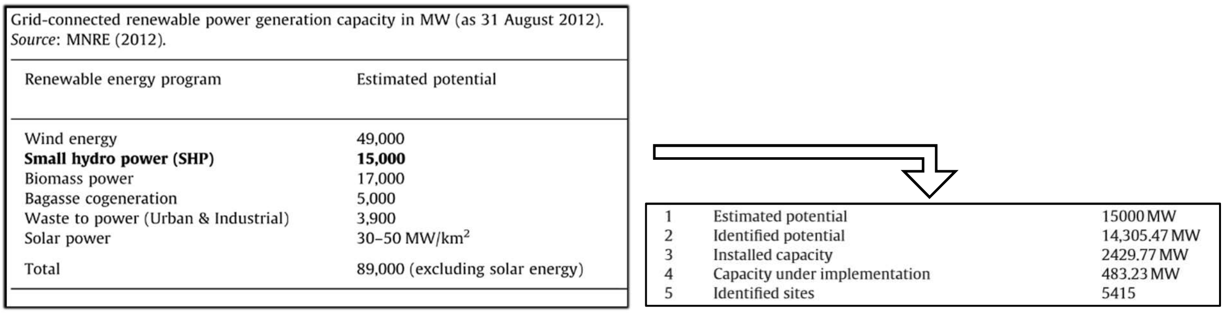
In India, as previously specified, renewable energies occupy a 19% of the energy share. Some sources like wind, photovoltaics and solar water heaters have experimented high growth rates. In case of SHP is still a need to accelerate the diffusion. Others like Tidal or OTEC have still a long way to go if they want to become a competitive source in developing countries like India.

3.3. Small Hydropower in India. Present Situation and National Support Schemes.

Among many other renewable sources, the geography of India supports the development of small hydro projects to increase the energy generation. Small hydropower development is also necessary for proper utilization of water resources. Furthermore, the problem of unelectrified remote and isolated areas can be solved by establishing small hydro projects. As compared to the other electricity generation systems, the energy payback time and GHG emissions in SHP generation systems are less.

In India, MNRE is responsible for micro, mini and small hydro projects up to 25 MW whereas Ministry of Power is responsible for the development of large hydro power projects.

The estimated SHP potential in India is around 15000 MW, but not all of them might be economically and technically viable. In fact, the MNRE identified more than 5000 sites with a capacity of 14,305 MW for establishment of small hydroelectric projects. [4]



Grid-connected renewable power generation capacity in MW (as 31 August 2012).
Source: MNRE (2012).

Renewable energy program	Estimated potential
Wind energy	49,000
Small hydro power (SHP)	**15,000**
Biomass power	17,000
Bagasse cogeneration	5,000
Waste to power (Urban & Industrial)	3,900
Solar power	30–50 MW/km^2
Total	89,000 (excluding solar energy)

1	Estimated potential	15000 MW
2	Identified potential	14,305.47 MW
3	Installed capacity	2429.77 MW
4	Capacity under implementation	483.23 MW
5	Identified sites	5415

Table 3.3.1. Grid-connected renewable power generation capacity in MW. (31 August 2012). Source: Sharma, N. K., Tiwari, P. K., & Sood, Y. R. (2013). A comprehensive analysis of strategies, policies and development of hydropower in India: Special emphasis on small hydro power. *Renewable and Sustainable Energy Reviews*, *18*, 460–470.

In India, 23 state governments have so far announced policies for private sector participation for the development of SHP projects. These states include Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttaranchal and West Bengal.[4]

Among all the mentioned policies the feed-in tariff policy for SHP remains very interesting for the purposes of this project. Feed-in tariffs are a generic description of a policy that pays a price, a ‘‘tariff’’, for the electricity generated by renewable sources of energy that is ‘‘fed’’ into or sold to the grid. As Feed-in Tariff (FiT) is place specific as well as source specific so in each of the electricity regulatory commission adopt different tariff for different renewable sources in India. Though SHP projects in Himachal Pradesh, Uttarakhand, and the northeastern states have a higher capital cost, they also have higher capacity factors due to the hilly terrain and resource availability, so the tariffs offered in these states are less than those offered for projects in other states. Projects below 5MW often have higher capital and operating costs and cannot take advantage of economies of scale. The tariff period for small hydro of less than 5MW has been modified to run for 35 years in order to provide long-term certainty. The tariff period for small hydropower above 5 MW is normally 13 years.[4]

Additionally, the MNRE has been provided support/subsidy for the development of the SHP sector. For SHP projects between 1 and 25 MW, MNRE will provide:

Rs 5.00 crore for first MW and Rs 50 lakh/MW for each additional MW if the project belongs to the state sector.[1]

Rs 2.50 crore for first MW and Rs 30 lakh/MW for each additional MW if the project belongs to the private sector. [4]

These subsides will be considered in the economic analysis of the project. However, both subsidized and non-subsidized cases will be shown.

3.4. SHP diffusion in India.

SHP is the most promising and economically viable form in comparison to other renewable energy technology in India, with an average economic cost of approx. Rs 3.90/kWh or, which is the same, 0.057 USD/kWh. SHP can be provided economical solution for the energy problems in basically off-grid, remote, rural and hilly area in India, where extension of grid system is comparatively uneconomical and along the canal system having sufficient drops. SHP are high efficiency of between 70 and 90%, by far the best of all renewable energy technologies and high capacity factor of about 50%, compared with 10% for solar and 30% for wind. It is a long-lasting and robust technology; systems can readily be engineered to last for 50 years or more and therefore an attractive energy pay-back ratio even for developing countries like India. [4]

It also produces negligible amounts of greenhouse gases and lifespan up to 100 years and therefore an attractive energy pay-back ratio even for developing countries. So, there is growing interest for the development of substantial SHP potential in India. [4]

Several empirical studies have shown that diffusion of SHP projects in India is following S-shaped curve. These curves are characterized by a slow initial growth (small slope of the curve), then followed by a rapid growth (big slope of the curve) and afterwards turning again to another slow growth (small slope of the curve) towards a finite upper limit. *Figure 3.4.1.* shows the Cumulative installed capacity and the Annual electricity production of SHP following a S-shaped diffusion considering both standard and optimistic scenarios.

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[1] 1 crore= $1x10^7$; 1 lakh = $1x10^5$

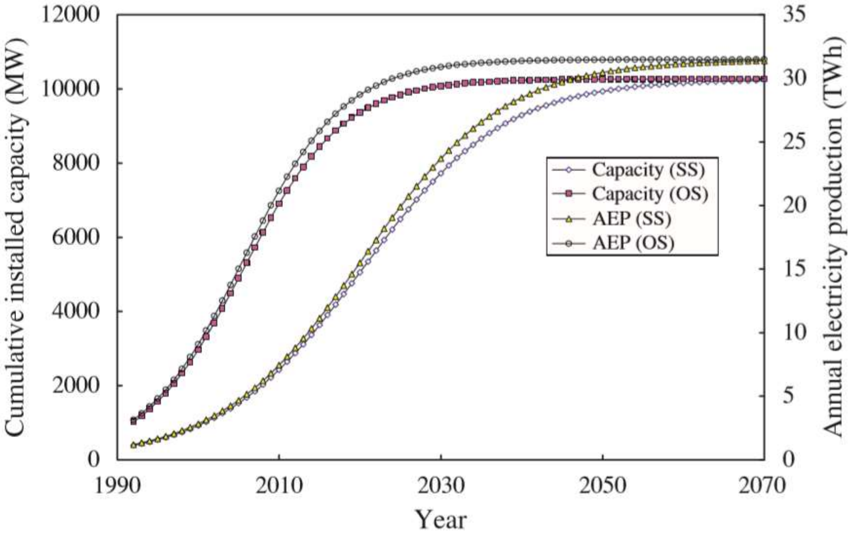


Figure 3.4.1 S-shaped SHP diffusion in India. Source: Purohit, P. (2008). Small hydro power projects under clean development mechanism in India: A preliminary assessment. Energy Policy, 36(6), 2000–2015.

Currently, due to the favorable policies above mentioned and the interest of the investors and entrepreneurs, the growth is in the second phase mentioned, rapidly growing, so now in 2018 can be considered as the proper moment to accelerate the investment and bet on these small hydro projects.

4.Location research and site characteristics.

4.1. Location research.

As previously mentioned, the project has been designed and planned in the North-Eastern region of the country, where there is a remarkable lack of electricity provided by the national grid. The regions in which the possibility of installing a SHP was studied were: Nagaland, Assam, Manipur and Mizoram.

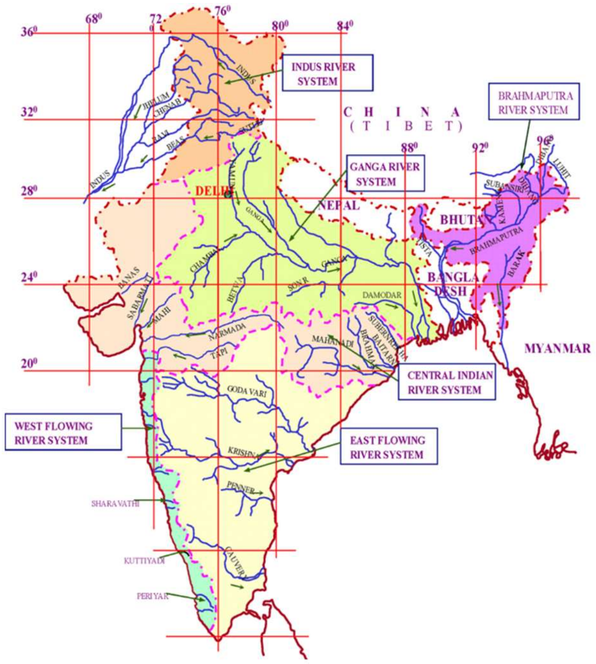


Figure 4.1.1. River systems of India. Source: Nautiyal, H., Singal, S. K., Varun, & Sharma, A. (2011). Small hydropower for sustainable energy development in India. Renewable and Sustainable Energy Reviews, 15(4), 2021–2027.

Figure 4.1.2. Indian regions. Source: Briskwalkers web page.

Furthermore, the software used to analyze the different possibilities and have a general view of the existing rivers in the area and the terrestrial mapping, was Google Earth. Regarding the methodology, the steps followed were:

1. Identifying the most important rivers of the region.
2. Clicking on the "Add Path" tool.
3. Altitude Tab. Altitude relative to sea floor.
4. Drawing the path carefully along the river.
5. Showing the elevation profile.
6. Looking for promising altitude differences and relating them to head jumps. Between 5 and 20 m head along less than 500m were considered promising heads.
7. Clicking on the "Add Placemark" tool in order to remember that promising site.

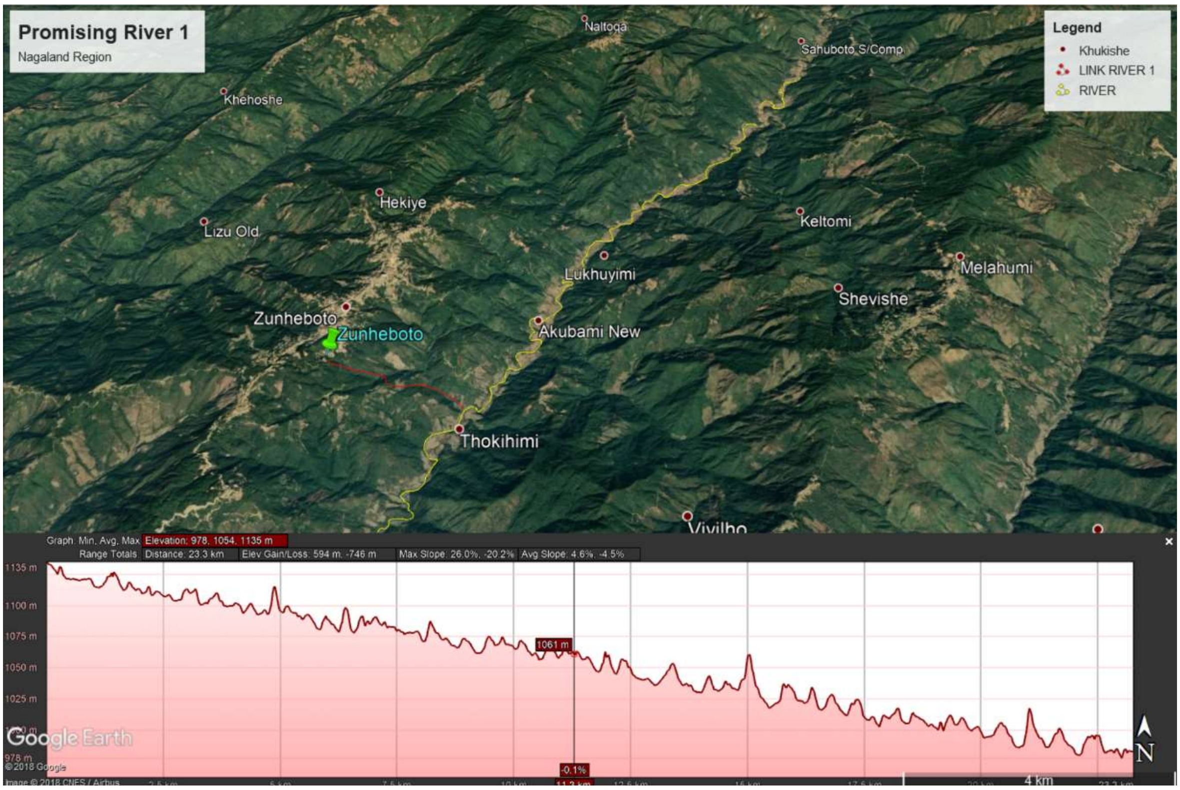


Figure 4.1.3. Source: Google Earth + Own creation.

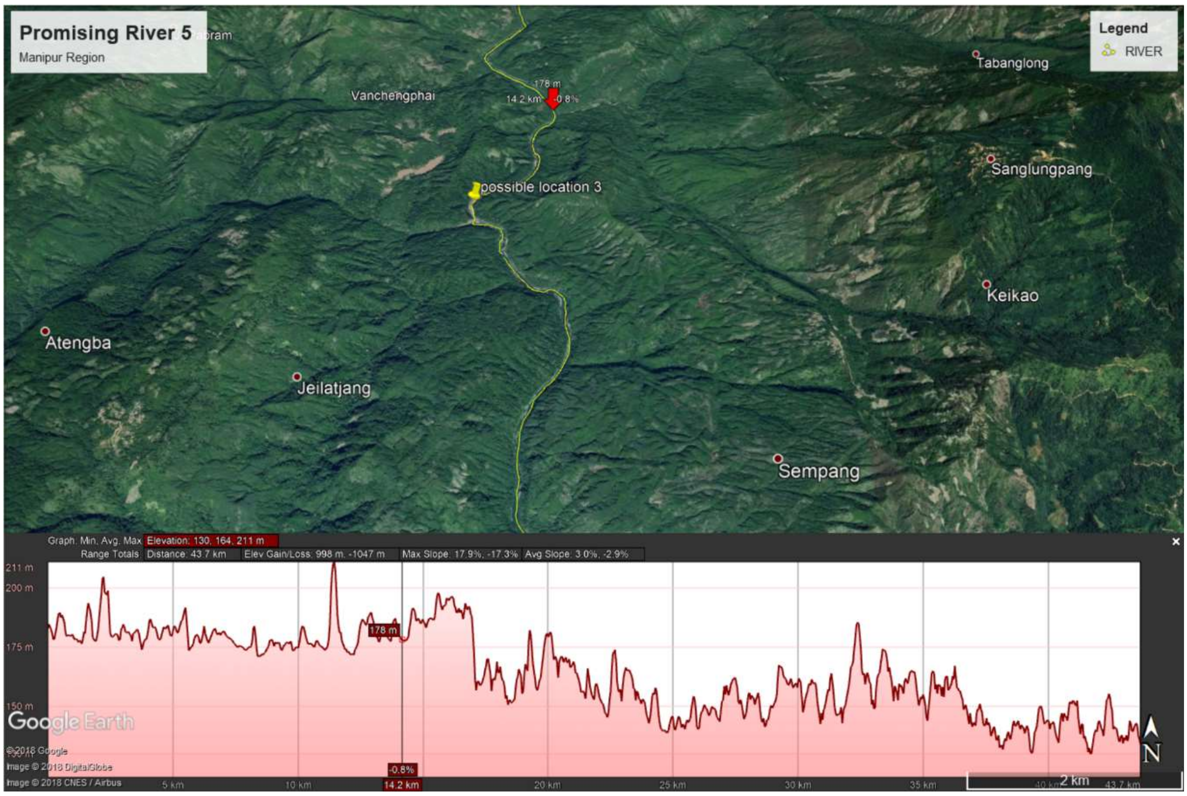


Figure 4.1.4. Source: Google Earth + Own creation.

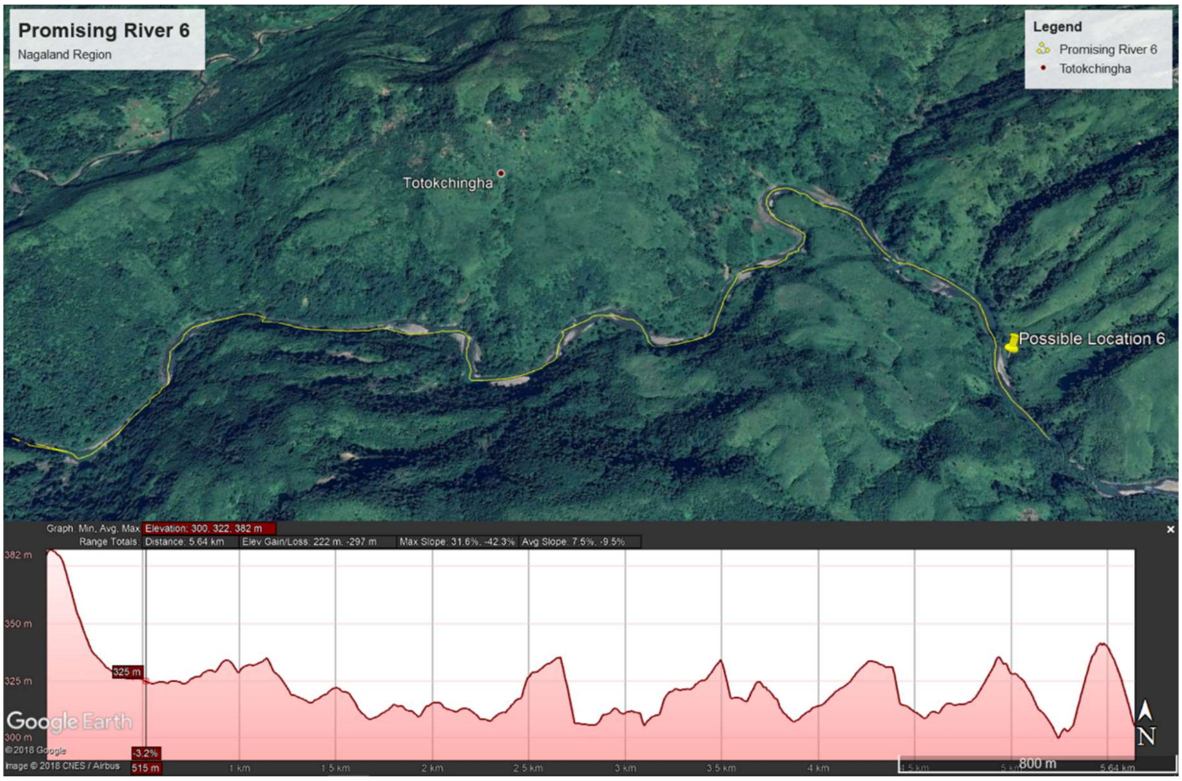


Figure 4.1.5. Source: Google Earth + Own creation.

4.2. River selected for the project. Chosen site.

After investigating different promising rivers analyzing the elevation profile, it was concluded that the most interesting site for the implementation of the project was located on the Barak River, between the regions of Mizoram and Manipur. More specifically, the small power plant would belong to the region of Manipur, but the nearest substation, whose name is Tuirial, is found in Mizoram. The coordinates of the SHP are:

Latitude: 24°14'23.89"N
Longitude: 93° 1'34.31"E

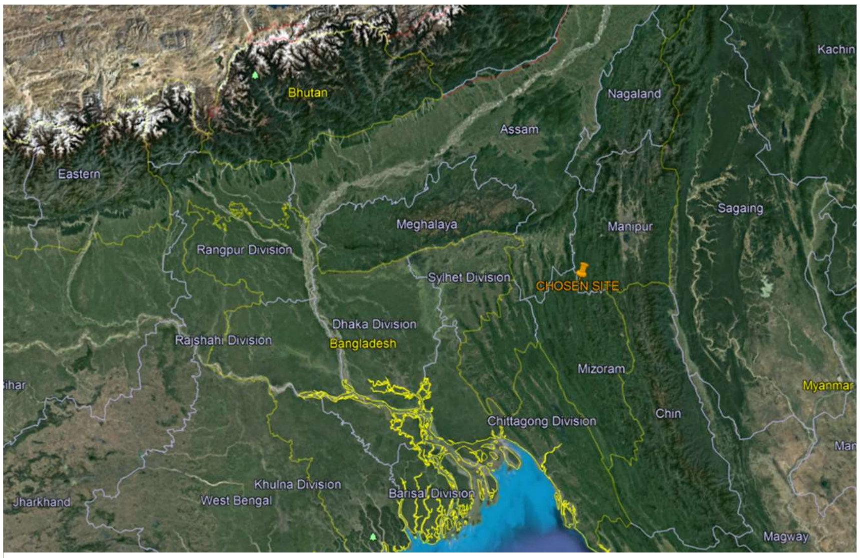


Figure 4.2.1. SHP location. Source: Google Earth.

In this location there is a head of 24 m along 470 m length. Moreover, the geography of the terrain allows the installation of an artificial canal and everything which is necessary to build a Run-of-the-River small hydroelectric power plant.

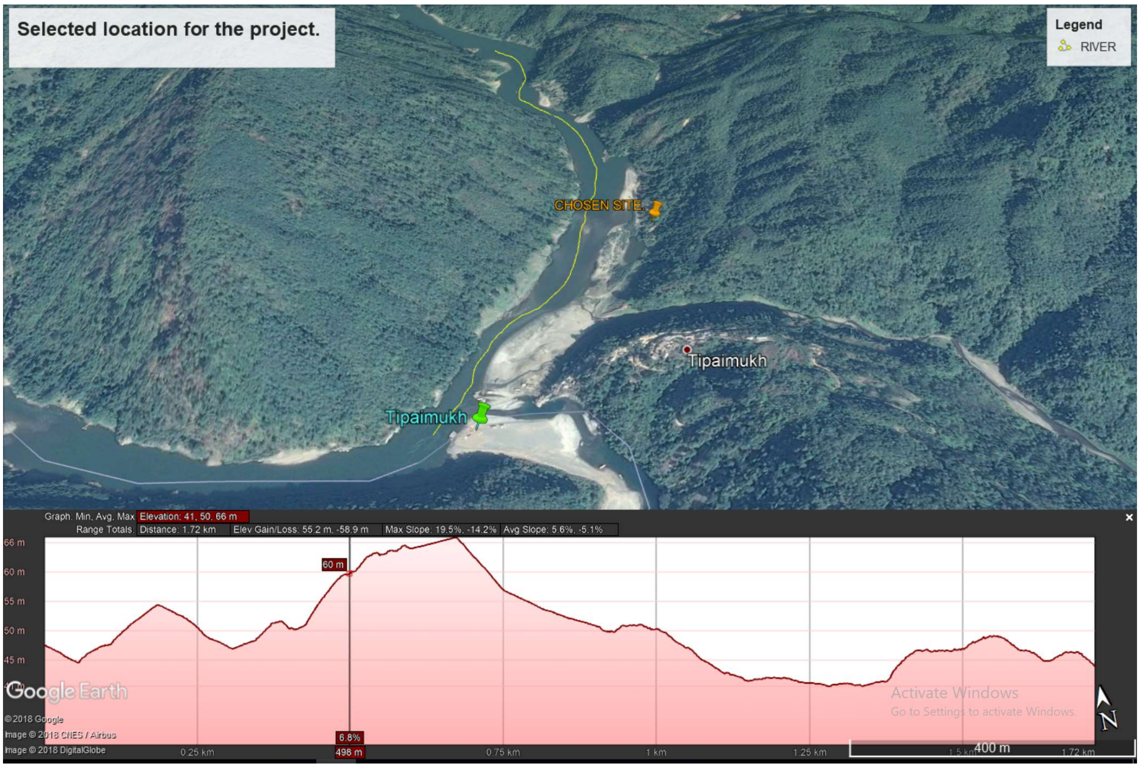
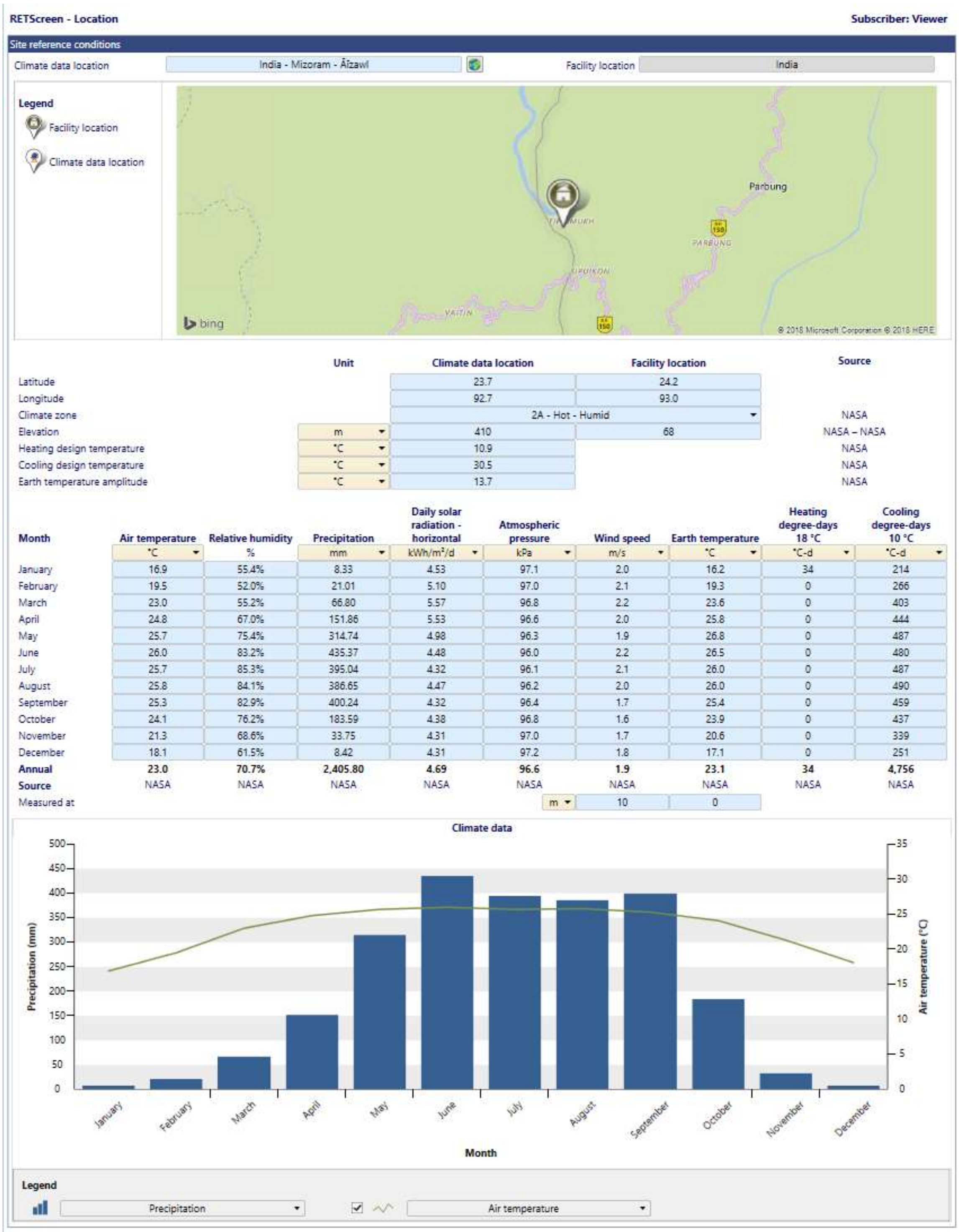


Figure 4.2.2. Selected location for the project. Source: Google Earth + Own creation.

Figure 4.2.3. Elevation profile. Source: Google Earth + Own creation.

The river Barak is one of the largest rivers of the country and its flow changes seasonally depending on the precipitations. It rises in the hill country of Manipur State, where it is the biggest and most important of the hill country rivers. The Barak Basin covers the States of Assam, Manipur, Mizoram, Nagaland and Tripura. From Assam, it enters Bangladesh, where the Surma and Kushiyara rivers begin, and is a part of the Surma-Meghna River System. The Barak River is the single largest contributory river to the northeast region of Bangladesh. The major tributaries of the Barak are all in India and are the Jiri, the Dhaleshwari, the Singla, the Longai, the Madhura, the Sonai, the Rukni and the Katakhal. The topography of this region is characterized by hills, hillocks, plains and low lying waterlogged areas. Generally, winter lasts from December to February and the period is rather dry (*Figure 4.2.4.*). The climate of the Barak Basin is sub- tropical, warm and humid. The annual rainfall ranges from 2 500 mm to 4 000 mm. The periods from March-April and October-November are defined by low erratic rainfall with occasional hailstorms. The period between May and September is defined by high rainfall with a risk of floods (*Figure 4.2.4.*). The seasonal distribution of rainfall indicates that while total annual rainfall is satisfactory, the distribution is uneven and most of the rainfall is confined to the period between June and August. Normally, the temperature ranges from a minimum of 12,2°C in January to 25,4°C in August and the mean maximum of 24,3°C in January to 36,0°C in August. [5]



RETScreen - Location **Subscriber: Viewer**

Site reference conditions

Climate data location: India - Mizoram - Āīzawl
Facility location: India

	Unit	Climate data location	Facility location	Source
Latitude		23.7	24.2	
Longitude		92.7	93.0	
Climate zone		2A - Hot - Humid		NASA
Elevation	m	410	68	NASA – NASA
Heating design temperature	°C	10.9		NASA
Cooling design temperature	°C	30.5		NASA
Earth temperature amplitude	°C	13.7		NASA

Month	Air temperature °C	Relative humidity %	Precipitation mm	Daily solar radiation - horizontal kWh/m²/d	Atmospheric pressure kPa	Wind speed m/s	Earth temperature °C	Heating degree-days 18 °C °C-d	Cooling degree-days 10 °C °C-d
January	16.9	55.4%	8.33	4.53	97.1	2.0	16.2	34	214
February	19.5	52.0%	21.01	5.10	97.0	2.1	19.3	0	266
March	23.0	55.2%	66.80	5.57	96.8	2.2	23.6	0	403
April	24.8	67.0%	151.86	5.53	96.6	2.0	25.8	0	444
May	25.7	75.4%	314.74	4.98	96.3	1.9	26.8	0	487
June	26.0	83.2%	435.37	4.48	96.0	2.2	26.5	0	480
July	25.7	85.3%	395.04	4.32	96.1	2.1	26.0	0	487
August	25.8	84.1%	386.65	4.47	96.2	2.0	26.0	0	490
September	25.3	82.9%	400.24	4.32	96.4	1.7	25.4	0	459
October	24.1	76.2%	183.59	4.38	96.8	1.6	23.9	0	437
November	21.3	68.6%	33.75	4.31	97.0	1.7	20.6	0	339
December	18.1	61.5%	8.42	4.31	97.2	1.8	17.1	0	251
Annual	**23.0**	**70.7%**	**2,405.80**	**4.69**	**96.6**	**1.9**	**23.1**	**34**	**4,756**
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 4.2.4. Climate data. Source: RETScreen Expert (NASA).

4.3 Tipaimukh Dam.

After a deeper investigation of the site, it was discovered that a large dam is planned to be built in that location. The purpose of the dam is flood control and hydroelectric power generation. It is planned to be 390 m long and 162.8 m high. The project will have an installation capacity of 1500 MW, supplied by ten 150 MW Francis turbine-generators or six 250 MW Francis turbine-generators. [6]

The Tipaimukh Dam Project has caused a lot of confrontations with the inhabitants of the zone and the Government of Bangaldesh and for that reason it has not been carried out so far.

For more than 15 years, communities in both Manipur State (northeast India) and Bangladesh have resisted the proposed Tipaimukh Dam on the Barak River. The 163 meter dam has sparked controversy in both countries over India's failure to provide public consultations and information sharing with both Bangladesh and indigenous communities. Most of the electricity would be sold to cities outside the region. According to the Sinlung Indigenous People Human Rights Organization (SIPHRO) of India, "the process for choosing [the project premises] ignored both the indigenous people and the recommendations of the WCD (World Commission on Dams)." Tipaimukh Dam rests in an ecologically sensitive region in one of the most seismically volatile areas on earth. The dam will submerge more than 275 square kilometers of forests and displace 60,000 people in Manipur, including the indigenous Zeliangrong and Hmar communities, and negatively impact 40,000 people in Bangladesh. One Lungthulien villager from Bangladesh explains his situation thus: "The Tuiruong (Barak) flows like the blood that keeps us alive. The endless talk for damming the river has brought us nightmares as we are never told what the structure would be like."

According to critics, the Indian government never officially informed its lower riparian neighbor about the construction of the dam it planned to build 100 kilometers from its border. The dam will virtually dry up Bangladesh's Surma and the Kushiara Rivers, thus choking the northeastern region of Bangladesh. Experts predict that the dam will disrupt the seasonal rhythm of the river, agriculture, irrigation, fisheries, drinking water supply, navigation and ground water levels with negative impacts for both wildlife and the people living along its banks. (International Rivers Blog Webpage)

Figure 4.3.1. Source: International Rivers Blog

Figure 4.3.2. Source: Six Degrees

For all these reasons, the present Run-of-the-River Small Hydropower Project is going to be proposed as an alternative to the Tipaimukh Dam. The objective is to minimize the environmental, social and economic impact without giving up the generation of sustainable and clean energy for the inhabitants of the area.

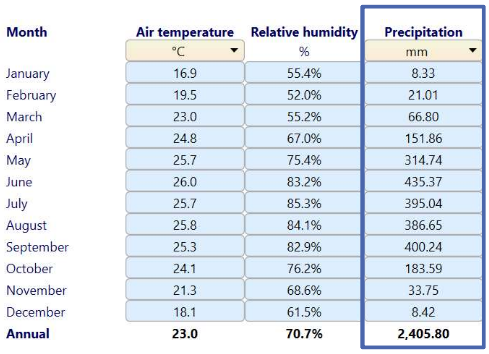
4.4. Hydrological data. Flow Duration Curve and design flow.

The flow duration curve is a chart that shows the percentage of time that an exact value of flow discharge is equaled or exceeded. The FDC allows to choose the design flow more efficient (nominal flow), and from this, the value of ecological flow (defined by administrative decision), and the minimum technical flow of each of the turbines, to assess the power plant and the annual production expected in an average hydraulic year.

Barak river, as previously mentioned, is a large river and its Flow Duration Curve is not directly available on the Internet. For that reason, it was necessary to make a slight approximation using the following data:

Maximum Flow= 4721.88 m^3/s.
Minimum Flow= 71.04 m^3/s.[7]

Precipitation data of the area:



Month	Air temperature	Relative humidity	Precipitation
	°C	%	mm
January	16.9	55.4%	8.33
February	19.5	52.0%	21.01
March	23.0	55.2%	66.80
April	24.8	67.0%	151.86
May	25.7	75.4%	314.74
June	26.0	83.2%	435.37
July	25.7	85.3%	395.04
August	25.8	84.1%	386.65
September	25.3	82.9%	400.24
October	24.1	76.2%	183.59
November	21.3	68.6%	33.75
December	18.1	61.5%	8.42
Annual	**23.0**	**70.7%**	**2,405.80**

Figure 4.4.1. Precipitation data. Source: RETScreen Expert (NASA)

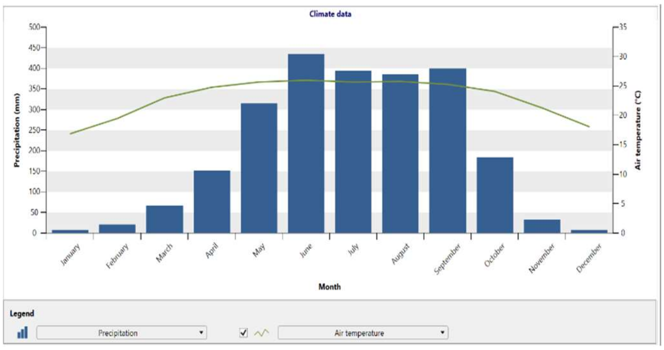


Figure 4.4.2. Precipitation chart. Source: RETScreen Expert (NASA)

The ice melting is not a source of water for Barak river. Therefore, it was considered that the flow is directly proportional to the precipitations.

The months were sorted according the rainfall, so the FDC has been built using 12 divisions and consequently each month represents 8.33% of the time.

As seen in the following figures, there is a lot of water flow available for the project purposes. Nevertheless, the small hydropower plant of the project is going to take profit of the minimum flow available diverting always the same amount of water through an artificial canal. Therefore, the nominal work flow is 71.04 m^3/s. With this constant and unfluctuating flow rate the SHP is supposed to provide a constant power and a constant annual amount of energy.

PRECIPITATION (mm)	MONTH	Percentage of time the flow is equaled or exceeded	UPPER FLOW LIMIT (m3/s)	LOWER FLOW LIMIT (m3/s)
8.33	June	8.33%	4721.8	3712.93
21.01	September	16.67%	4340	3413.33
66.8	July	25.00%	4284.4	3368.98
151.86	August	33.33%	4193.4	3297.43
314.74	May	41.67%	3413.5	2684.17
435.37	October	50.00%	1991.12	1565.69
395.04	April	58.33%	1646.99	1295.09
386.65	March	66.66%	724.47	569.68
400.24	November	75.00%	366.03	287.83
183.59	February	83.33%	227.86	179.18
33.75	December	91.66%	91.32	71.81
8.42	January	100%	90.34	71.04

Table 4.4.1. Precipitation, proportional flow and FDC. Source: Own creation.

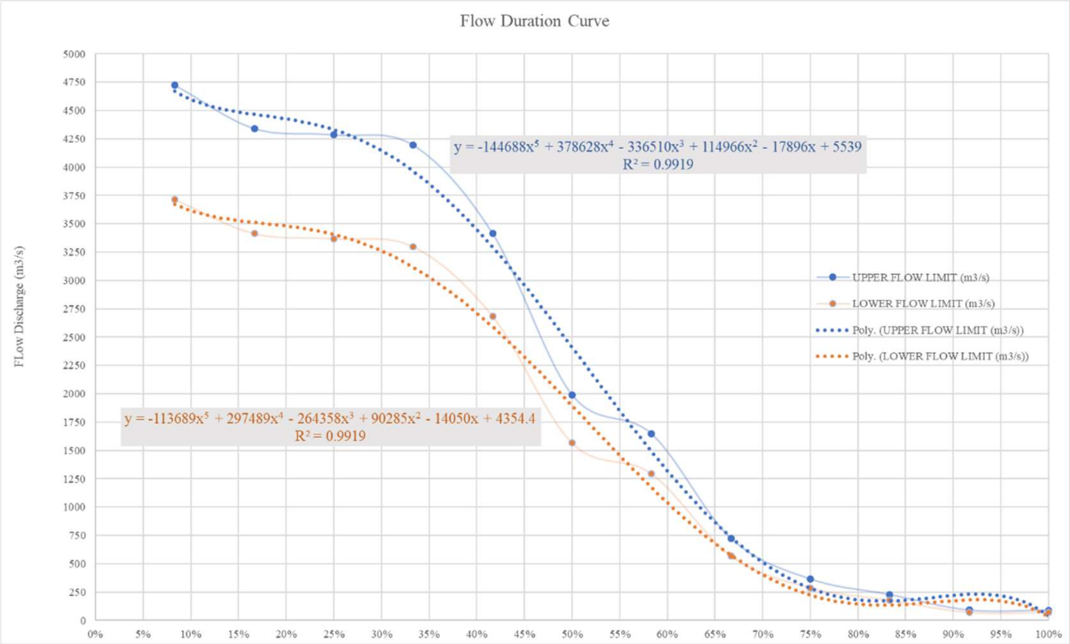


Figure 4.4.3. Flow Duration Curve. Percentage of time (Abscissas) and Flow (Ordinates). Source: Own Creation.

Figure 4.4.4. Flow Duration Curve. Flow (Ordinates) and Percentage of time (Abscissas) Source: Own Creation.

The previous table and charts provide an upper and lower limit for the flow duration curve using, as mentioned, the maximum flow, the minimum flow and the rainfall data. All the curves have been approximated by a function to facilitate the interaction. These curves can be used in a future, for possible expansions in the generation. For example, they allow to check which flow is exceeded the 50 % of the time or the 75% of the time and this data facilitates the subsequent feasibility analysis.

4.5. Position with respect to the national grid and its substations.

The selected site also has a good position with respect to the nodes of the national electricity grid. The Tuirial substation is less than 20 km away, which facilitates the connection of the plant to the electricity grid. As can be seen in *Figure 4.5.1.* the substation is 19.5 km northwest. The coordinates are:

24°21'30.07"N
92°52'56.10"E

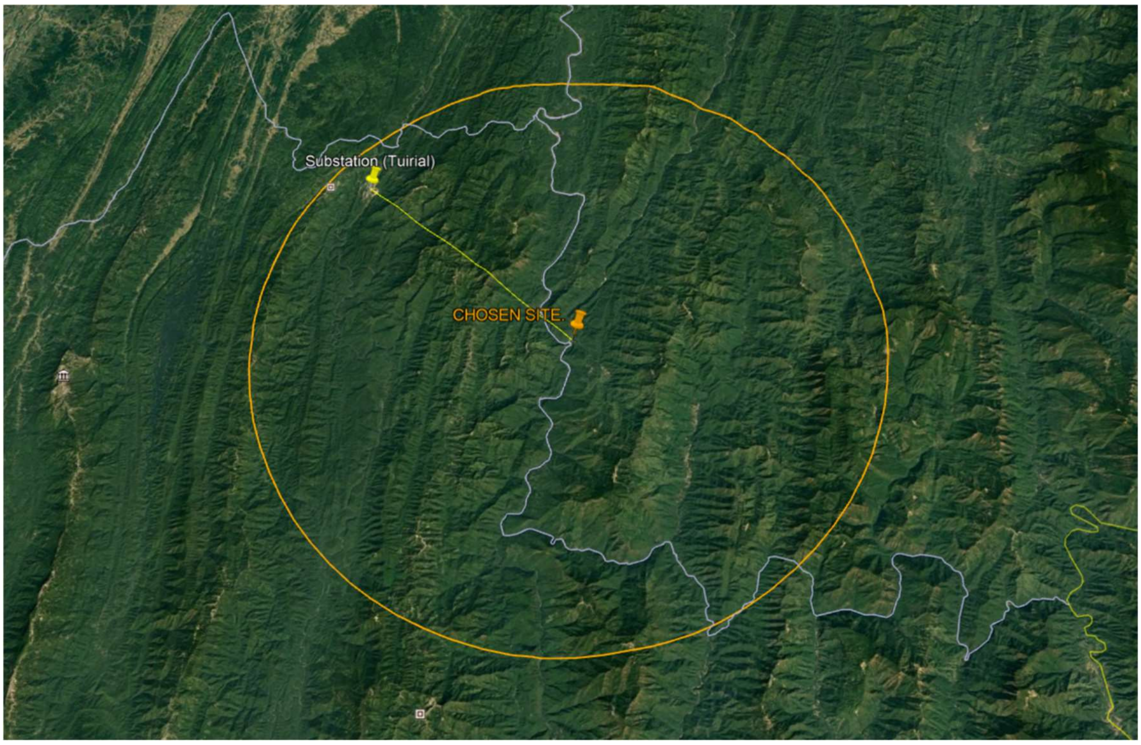


Figure 4.5.1. Tuirial Substation. Source: Google Earth + Own creaton.

As it was introduced in section 4.2, the location of the project belongs to the Manipur region. Therefore, the energy demand of this region will be considered in the following models and simulations. The objective would be to use the generation hydroelectric plant as a point of electricity constant supply and to reduce or eliminate the energy deficit of Manipur, which until the present moment only had a thermal power plant and a small hydropower plant, despite having an abundant water resource.

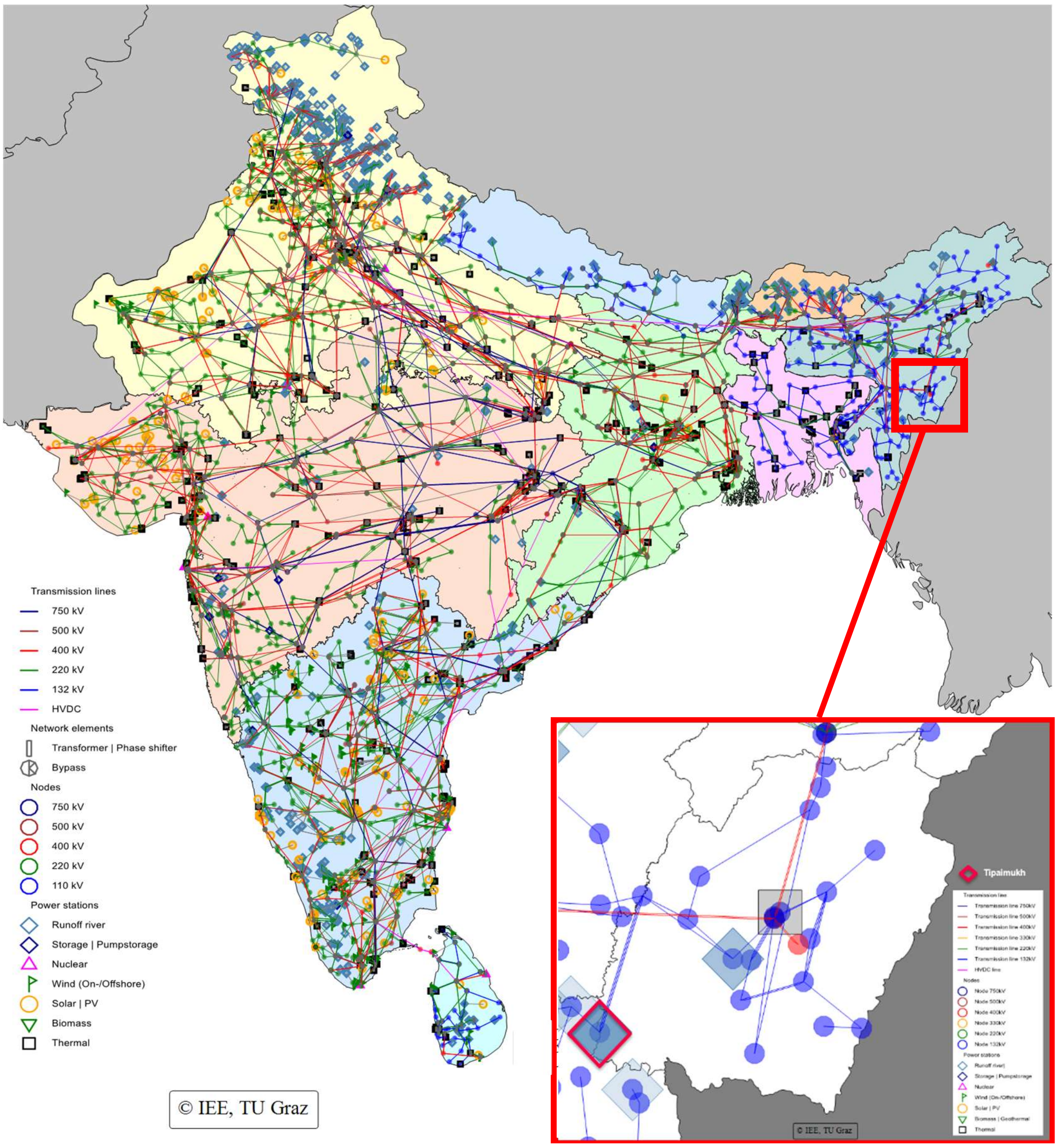


Figure 4.5.2. Indian Electricity Grid. Transmission lines, nodes and power stations. Source: IEE, TU Graz. Bhat Subramanya.

In the detail of *Figure 4.5.2.* it is possible to appreciate the thermal and hydroelectric power stations. Both are located at the center of the region. However, the SHP object of the present project is in the southwestern area of Manipur. Having a third-generation plant properly separated and connected would provide the area a greater security in the electricity supply and a remarkable versatility and quick reaction in case of breakdown in any of the plants, the transmission lines or nodes.

5. Possible Turbines. (Solutions)

Once the nominal flow (Q_n) and the gross head (H) are known, it is possible to utilize the chart previously shown in *Figure 2.2.1*.

On one hand, in the subsequent analysis, an error of 5% on the head measurements was considered. This was done to stay on the side of prudence, avoiding entering too ambitious data, and considering possible errors in the measurements and changes during civil works.

On the other hand, the available flow can be divided into as many turbines as necessary to optimize the water resource. However, all the turbines will have the same size.

Consequently, the work data will be:

$$\boldsymbol{Q_n = \frac{71.04}{n}} \left({m^3}/{s}\right) \;;\boldsymbol{ n = 1, 2, 3, 4} \ldots.$$

$$\boldsymbol{H = 21.08\, m}$$

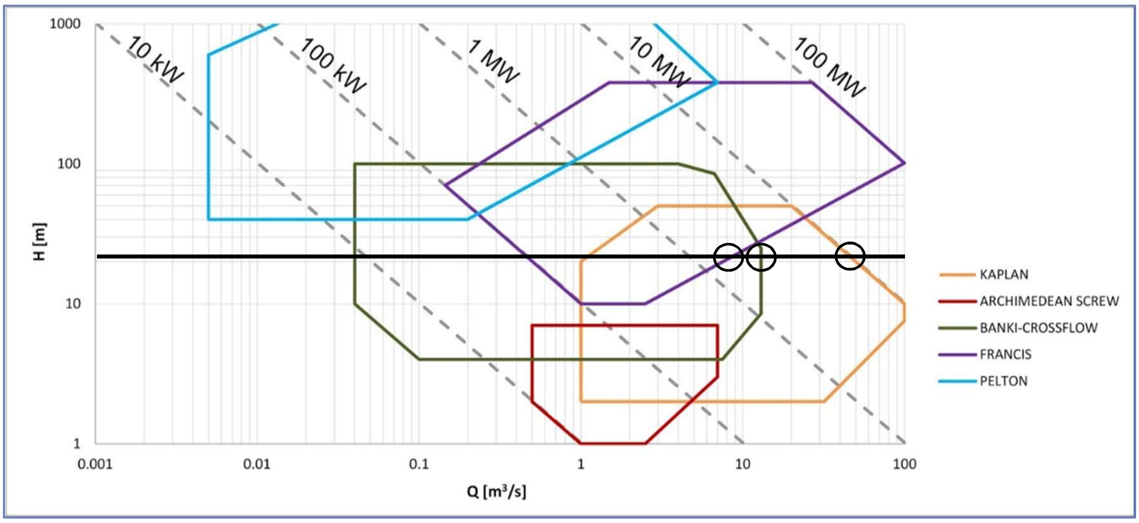


Figure 5.1. Hydro Turbine Selection Chart. Source: Alberto Santolin (2017). HPP Design Blog.

As the black line shows, there are three possible turbines that would be able to take advantage of the resource. These hydro turbines are: Kaplan, Cross-Flow and Francis. Nevertheless, the head available occupies a length of 470 m, which is too much for a Francis turbine and the configuration that it requires. Therefore, the turbines under study will be the Kaplan and the Cross-Flow.

5.1. Kaplan turbine.

The Kaplan turbine is an axial flow reaction turbine. It is a variation of the Propeller turbine including orientable blades. The inlet guide-vanes can be opened and closed to regulate the amount of water that can pass through the rotor. When fully closed they will stop the water completely and bring the turbine to rest. Depending on the position of the inlet guide vanes they introduce differing amounts of swirl to the flow and ensure that the water hits the rotor at the most efficient angle for the highest efficiency. The rotor blade pitch is also adjustable, from a flat profile for very low flows to a heavily-pitched profile for higher flows. This adjustability of both inlet guide-vanes and rotor blades means that the flow operating range is very wide and the turbine efficiency is high and the efficiency curve very flat.

There are variants of Kaplan turbines that only have adjustable inlet guide-vanes or adjustable rotor o blades, which are known as semi-Kaplan's. Although the performance of semi-Kaplan's is compromised when operating across a wide flow range, for applications where the flow does not vary much, as in the derivation canal of the present project, they can be a more cost-effective choice.

Figure 5.1.2. below shows how the efficiency varies across the operating flow range for a full Kaplan, both types of semi-Kaplan and a Propeller (fixed blades and fixed gates). However, both Kaplan and semi-Kaplan turbines can reach an efficiency of 92-93% approximately.

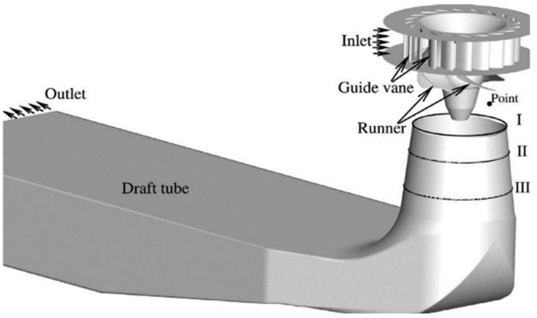


Figure 5.1.1. Kaplan Turbine (Vertical Configuration). Source: Javadi, A., & Nilsson, H. (2017). Detailed numerical investigation of a Kaplan turbine with rotor-stator interaction using turbulence-resolving simulations.

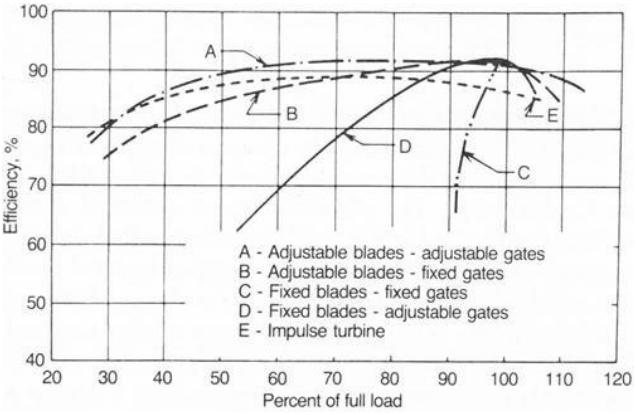


Figure 5.1.2. Kaplan Turbine efficiencies depending on the configuration. Source: Renewables First.

The largest rotors available have 3 to 5 m diameters. These big turbines tolerate a flow of between 30 and 50 m^3/s. For even larger sites multiples turbines tend to be used rather than increasing the diameter further.

Kaplan turbines can be oriented in three different ways; vertical axis, horizontal axis and bulb turbines. The vertical configuration is the most common orientation due to its smaller footprint. (Renewables first, webpage)

5.2. Cross-flow turbine.

The cross-flow turbine can be categorized as an impulse turbine with partial admission that consists of a nozzle and a runner. The nozzle converts potential energy of water into kinetic energy and releases the flow into the runner. The runner geometry is fabricated with two parallel disks connected (welded) by a series of curved blades.[8]

The first impulse occurs when the flow enters in the turbine oriented by the blade injector turbine to the impeller. When this flow has already passed through the inside of the impeller it provides the second impulse, leaving it and the flow falls through the aspiration tube.

This type of turbines has a very wide field of application because they can be installed in exploitations with jumps between 1 and 200 m with a large variation range of flows. The maximum power that can be installed is limited to the range of between 1 and 5 MW.

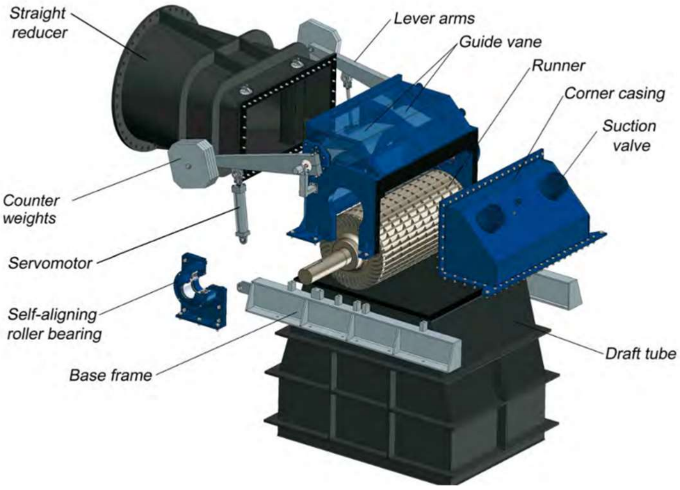


Figure 5.2.1. Cross-flow turbine and its components. Source: The original OSSBERGER® Crossflow Turbine. (n.d.). Retrieved from www.ossberger.de

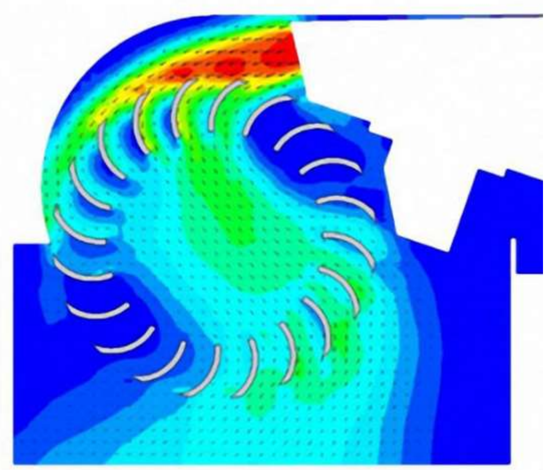


Figure 5.2.2. Flow pattern through the Cross-flow turbine. Source: Chichkhede, S., Verma, V., Gaba, V. K., & Bhowmick, S. (2016). A Simulation Based Study of Flow Velocities across Cross Flow Turbine at Different Nozzle Openings.

The flow pattern is shown in *Figure 5.2.2.* One of the advantages of this flow pattern is that any ingress by leaves, sand, grass is flushed out again by the self-cleaning effect of the rotor, avoiding possible damages. Moreover, given its condition of impulse turbine, any problem of cavitation is eluded.

Cross-flow turbines are also known as Banki-Michel or Ossberger turbines in honor of its inventors. Nevertheless, the company founded by Fritz Ossberger is the leading manufacturer of this sector.

Due to the latest research, small modifications and improvements have been included in the design, allowing this turbine to reach 85% efficiency or even more. (*Figure 5.2.3*).

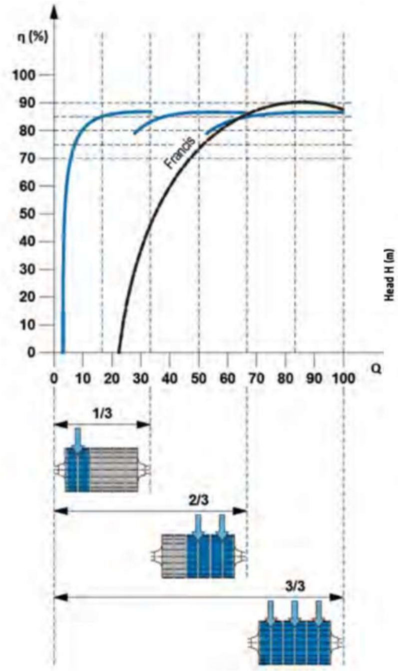


Figure 5.2.1. Cross-flow Ossberger turbine efficiency. Source: The original OSSBERGER® Crossflow Turbine. (n.d.). Retrieved from www.ossberger.de

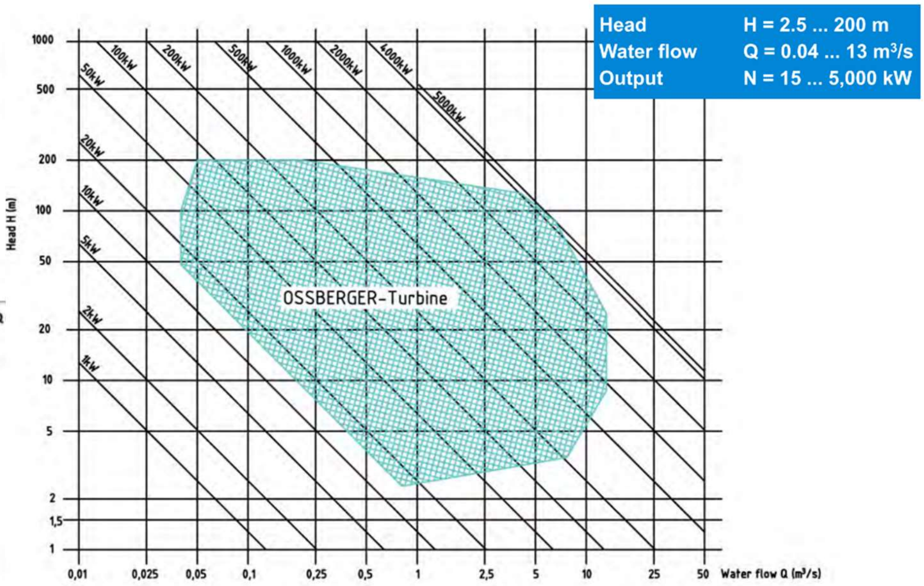


Figure 5.2.1. Cross-flow power output chart. Source: The original OSSBERGER® Crossflow Turbine. (n.d.). Retrieved from www.ossberger.de

It is also important to add that because of the simplicity of the design and its operating principle; this turbine is considered one of the cheapest in the marketplace.

6. Potential Analysis.

6.1. Calculation of the Rated Power.

At this point, it is possible to make the necessary calculation to obtain the power output of the theoretical small hydropower plant. As introduced in section 2.1, the theoretical rated power is calculated as:

$$\boldsymbol{P_0\,(W) = \rho g Q H} \qquad (1)$$

Where, substituting with the available data,

$\rho = 1000\ kgm^{-3}$
$g = 9.81\ ms^{-2}$
$Q = 71.04\ m^3s^{-1}$
$H = 22.8\ m$

the theoretical rated power obtained is:

$$\boldsymbol{P_0 = 15{,}889{,}374.72\ \left(\frac{kg\cdot m^2}{s^3}\right) = 15{,}889{,}374.72\ \left(\frac{J}{s}\right) = 15{,}889{,}374.72\ (W) = 15.889\ (MW)}$$

Nevertheless, it is very important to remember that this is not the real power output of the plant. It is necessary to consider now the different energy losses throughout the process. There will exist hydraulic losses in the water passages (including penstock losses, canal losses, localized losses, etc.), miscellaneous losses in conveyance structures and generator losses when converting the mechanical energy into electric energy. Consequently, the theoretical rated power must be multiplied by the different efficiencies:

$$\boldsymbol{P = \eta_t \eta_h \eta_m \eta_g P_0} \qquad (5)$$

Where,

η_t is the turbine efficiency
η_h is the hydraulic efficiency
η_m is the efficiency, considering the miscellaneous losses
η_g is the generator efficiency

The turbine efficiency will depend on the turbine type. On one hand, for Kaplan and Semi-Kaplan turbines a typical efficiency value at peak flow is 92.5%, as shown in *Figure 5.1.2*. On the other hand, current Cross-flow turbines exceed 85% efficiency.

In a small hydro system, energy is lost as water flows through the water passages. These losses are called hydraulic losses and a value of 5% is appropriate for most small hydro plants. Nevertheless, considering that the derivation canal and the penstock are considerably long, it has been taken a value of 6% for these losses. Therefore, the hydraulic efficiency has been considered as 94% in both cases.

The miscellaneous losses accounts for hydraulic losses other than in a tunnel, canal or penstock, which are accounted for separately. An appropriate and typical value for these losses is 1%. However, to stay prudent and in the worst-case scenario, it will be considered a value of 1.5%. Consequently, the efficiency considering the miscellaneous losses is 98.5%.

Generator efficiencies goes from 93% to 97%. Generators in the range of a few MW (as the present project) have a efficiency of around 95-96%. [9]

Once all these data are known, it is possible to calculate the real power output of both small hydropower plants.

-SHP including Kaplan / Semi-Kaplan turbines:

$$\boldsymbol{P(Kaplan) = \eta_t \eta_h \eta_m \eta_g P_0 = 0.925 \cdot 0.94 \cdot 0.985 \cdot 0.95 \cdot 15.889 = 12.298\ MW}$$

-SHP including Cross-flow turbines:

$$\boldsymbol{P(Cross\_flow) = \eta_t \eta_h \eta_m \eta_g P_0 = 0.85 \cdot 0.94 \cdot 0.985 \cdot 0.95 \cdot 15.889 = 11.880\ MW}$$

7. Economic analysis. RETScreen simulations.

RETScreen is a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis.

RETScreen empowers professionals and decision-makers to rapidly identify, assess and optimize the technical and financial viability of potential clean projects. This decision intelligence software platform also allows managers to easily measure and verify the actual performance of their facilities and helps find additional energy savings/production opportunities.

Figure 6.2.1. RETScreen Expert workflow. Source: RETScreen Expert software.

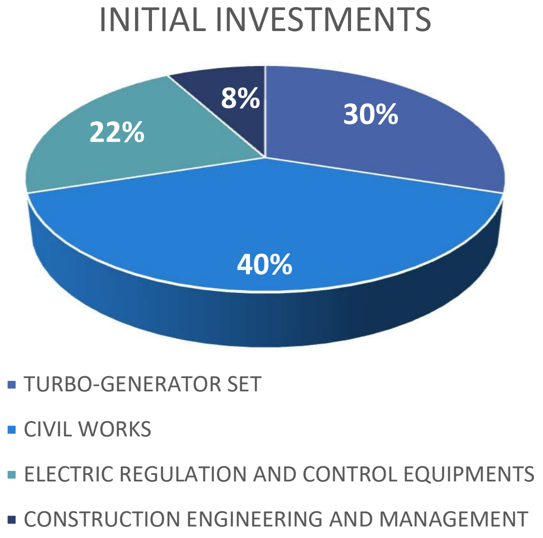


Figure 6.2.2. Initial investments share. Source: Mishra, S., Singal, S. K., & Khatod, D. K. (2012). Costing of a Small Hydropower Projects.

Inside the framework of this project, RETScreen Expert was used to analyze the economic feasibility and to compare the results after the theoretical implementation of both Kaplan and Cross-flow turbines separately, depending on the efficiency and costs of each of them.

In both cases it has been considered the same distribution of investments. The initial investments include the turbo generator set (30%), the civil works (40%), the electric regulation and control equipments (30%), and the construction engineering and management (8%). [10][11]

Moreover, it has been considered that the annual costs, including operation and maintenance, represent a 3% of the initial costs of the turbo generator set. [12]

According to an analysis that was made in the United Kingdom, the plants between 1 MW and 7 MW have installed capital costs between 3,400 USD/kW and 4,000 USD/kW. Smaller power plants have higher capital costs and larger power plants have lower capital costs. Considering the previous calculations, the SHP of this project is planned to produce between 11 and 13 MW. For this reason, the aforementioned interval was used to calculate the costs with a safety margin.

The sale of electricity is a very fluctuating market in this country. The average price of electricity is between 0.07 and 0.08 USD/kWh. Nevertheless, in the simulation it was assumed the sale of electricity to the grid at a price of 0.04 USD/kWh. This was done in order to restrict the price of the electricity in the grid to make selling of electricity less desirable for the designed energy system. In this way, it will be more profitable to use electricity in the Manipur region instead of selling it to the national electricity grid.

7.2. Case 1. Kaplan turbine.

For the economic feasibility analysis of the Kaplan small hydropower plant, it was supposed the construction of a small weir in the derivation canal including vertical Kaplan turbines, due to their lower ecological footprint. As already was mentioned, the derivation canal is supposed to provide a constant flow of 71.04 m^3/s. Taking this flow into account, and knowing that the maximum working flow for a Kaplan turbine is between 30 and 50 m^3/s, the implementation of two equal turbines was introduced into the simulation. Consequently, the working flow of each turbine was 35.52 m^3/s.

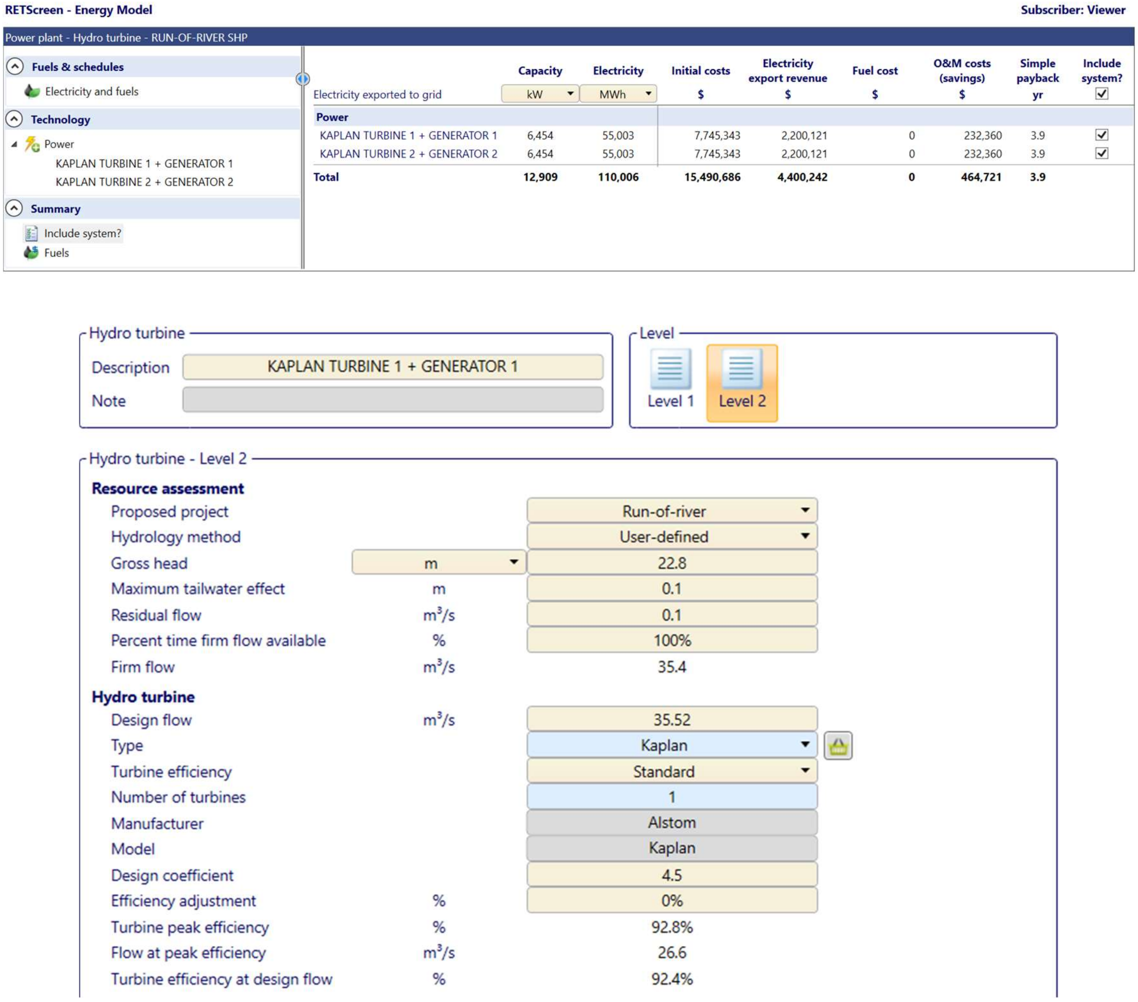
It is very important to know that the price per kW of each turbo-generator set will hardly depend on the specific project and the companies do not provide estimation prices easily. Nevertheless, it is known that the Kaplan and Semi-Kaplan turbines are some of the most expensive turbines in the marketplace, due to the complex design and implementation. For that reason, it was considered the Kaplan turbine implementation as the most expensive scenario, using a cost of 4,000 USD/kW, of which 1,200 USD/kW correspond to the turbo-generator set.

As can be seen in the following figures, all the aforementioned technological and hydrological inputs were entered into the energy model sheet of RETScreen Expert. In this section, very important data were introduced such as the type of hydroelectric power station, the head, the flow rate, the type and model of the turbine, the different energy losses and the efficiency of the generator. In the case of the efficiency of the turbine, the software has predetermined values depending on the turbine and, in the case of the Kaplan turbine, the values provided by the program were considered as totally valid, since they were adjusted to the curves found in other sources of information, such as catalogs of suppliers.

The first economic inputs were also introduced, such as the cost of the turbo-generator set (1,200 USD / kWh) and the operation and maintenance costs per year (36 USD / kWh-year).

In this section, the software is already able to provide some very important outputs, such as the power generated by each turbo-generator set, the capacity factor, the energy provided after one year and the annual profits obtained from selling to the network electricity that generated energy. In addition, it provides the total cost of each turbo-generator set (7,745,360 USD) and the total annual operation and maintenance cost.

In the scenario, consisting of the implementation of 2 Kaplan turbines, the software results in a power output of 6,454 kW in each turbo generator set, yielding a total power of 12,908 kW for the entire plant. Likewise, each turbine generates a total amount of energy of 55,003 MWh per year, providing benefits of 2,200,121 USD / year. With two turbines, the annual energy generated is 110,006 MH and the benefits are 4,400,242 USD/year.



RETScreen - Energy Model **Subscriber: Viewer**

Power plant - Hydro turbine - RUN-OF-RIVER SHP

	Capacity	Electricity	Initial costs	Electricity export revenue	Fuel cost	O&M costs (savings)	Simple payback	Include system?
Electricity exported to grid	kW	MWh	$	$	$	$	yr	☑
Power								
KAPLAN TURBINE 1 + GENERATOR 1	6,454	55,003	7,745,343	2,200,121	0	232,360	3.9	☑
KAPLAN TURBINE 2 + GENERATOR 2	6,454	55,003	7,745,343	2,200,121	0	232,360	3.9	☑
Total	**12,909**	**110,006**	**15,490,686**	**4,400,242**	**0**	**464,721**	**3.9**	

Hydro turbine

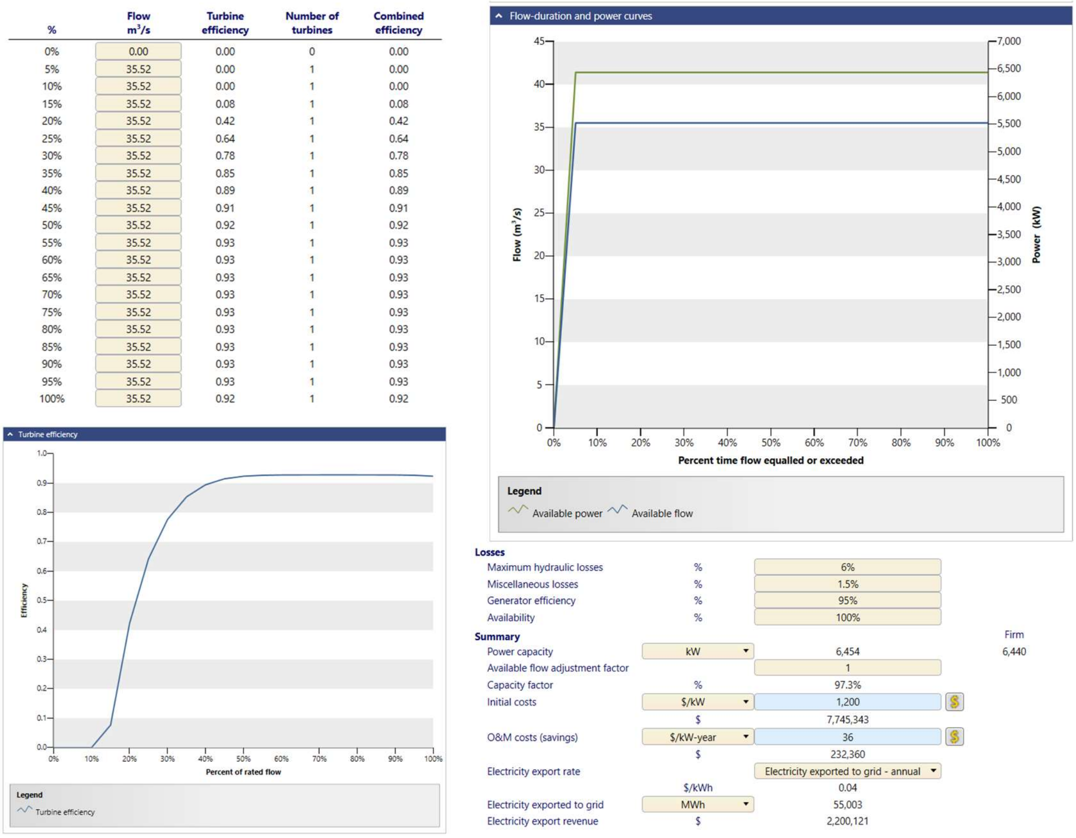
Description: KAPLAN TURBINE 1 + GENERATOR 1

Note:

Hydro turbine - Level 2

Resource assessment		
Proposed project		Run-of-river
Hydrology method		User-defined
Gross head	m	22.8
Maximum tailwater effect	m	0.1
Residual flow	m^3/s	0.1
Percent time firm flow available	%	100%
Firm flow	m^3/s	35.4
Hydro turbine		
Design flow	m^3/s	35.52
Type		Kaplan
Turbine efficiency		Standard
Number of turbines		1
Manufacturer		Alstom
Model		Kaplan
Design coefficient		4.5
Efficiency adjustment	%	0%
Turbine peak efficiency	%	92.8%
Flow at peak efficiency	m^3/s	26.6
Turbine efficiency at design flow	%	92.4%

Figure 7.2.1. Energy model Sheet Kaplan turbines. (1/2). Source: RETScreen Expert.



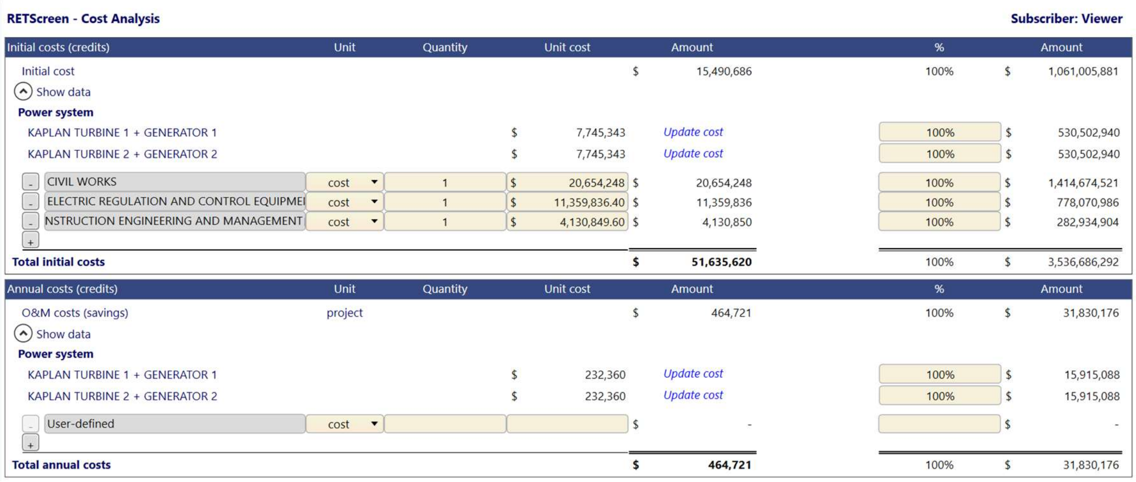
%	Flow m³/s	Turbine efficiency	Number of turbines	Combined efficiency
0%	0.00	0.00	0	0.00
5%	35.52	0.00	1	0.00
10%	35.52	0.00	1	0.00
15%	35.52	0.08	1	0.08
20%	35.52	0.42	1	0.42
25%	35.52	0.64	1	0.64
30%	35.52	0.78	1	0.78
35%	35.52	0.85	1	0.85
40%	35.52	0.89	1	0.89
45%	35.52	0.91	1	0.91
50%	35.52	0.92	1	0.92
55%	35.52	0.93	1	0.93
60%	35.52	0.93	1	0.93
65%	35.52	0.93	1	0.93
70%	35.52	0.93	1	0.93
75%	35.52	0.93	1	0.93
80%	35.52	0.93	1	0.93
85%	35.52	0.93	1	0.93
90%	35.52	0.93	1	0.93
95%	35.52	0.93	1	0.93
100%	35.52	0.92	1	0.92

Losses

Maximum hydraulic losses	%	6%	
Miscellaneous losses	%	1.5%	
Generator efficiency	%	95%	
Availability	%	100%	
Summary			Firm
Power capacity	kW ▾	6,454	6,440
Available flow adjustment factor		1	
Capacity factor	%	97.3%	
Initial costs	$/kW ▾	1,200	
	$	7,745,343	
O&M costs (savings)	$/kW-year ▾	36	
	$	232,360	
Electricity export rate		Electricity exported to grid - annual ▾	
	$/kWh	0.04	
Electricity exported to grid	MWh ▾	55,003	
Electricity export revenue	$	2,200,121	

Figure 7.2.2. Energy Model Sheet Kaplan turbines. (2/2). Source: RETScreen Expert.

Subsequently, in the cost analysis sheet, the rest of the required costs were introduced. Since the 30% investment due to the turbo-generator set had already been introduced in the previous sheet, it was only necessary to enter 40% corresponding to "Civil works", 22% corresponding to "Electric regulation and control equipments" and the 8% corresponding to "Construction engineering and management".



RETScreen - Cost Analysis **Subscriber: Viewer**

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	%	Amount
Initial cost				$ 15,490,686	100%	$ 1,061,005,881
○ Show data						
Power system						
KAPLAN TURBINE 1 + GENERATOR 1			$ 7,745,343	*Update cost*	100%	$ 530,502,940
KAPLAN TURBINE 2 + GENERATOR 2			$ 7,745,343	*Update cost*	100%	$ 530,502,940
CIVIL WORKS	cost ▾	1	$ 20,654,248	$ 20,654,248	100%	$ 1,414,674,521
ELECTRIC REGULATION AND CONTROL EQUIPME	cost ▾	1	$ 11,359,836.40	$ 11,359,836	100%	$ 778,070,986
NSTRUCTION ENGINEERING AND MANAGEMENT	cost ▾	1	$ 4,130,849.60	$ 4,130,850	100%	$ 282,934,904
Total initial costs				**$ 51,635,620**	100%	$ 3,536,686,292

Annual costs (credits)	Unit	Quantity	Unit cost	Amount	%	Amount
O&M costs (savings)	project			$ 464,721	100%	$ 31,830,176
○ Show data						
Power system						
KAPLAN TURBINE 1 + GENERATOR 1			$ 232,360	*Update cost*	100%	$ 15,915,088
KAPLAN TURBINE 2 + GENERATOR 2			$ 232,360	*Update cost*	100%	$ 15,915,088
User-defined	cost ▾			$ -		$ -
Total annual costs				**$ 464,721**	100%	$ 31,830,176

Figure 7.2.3. Cost Analysis Sheet Kaplan turbines. Source: RETScreen Expert.

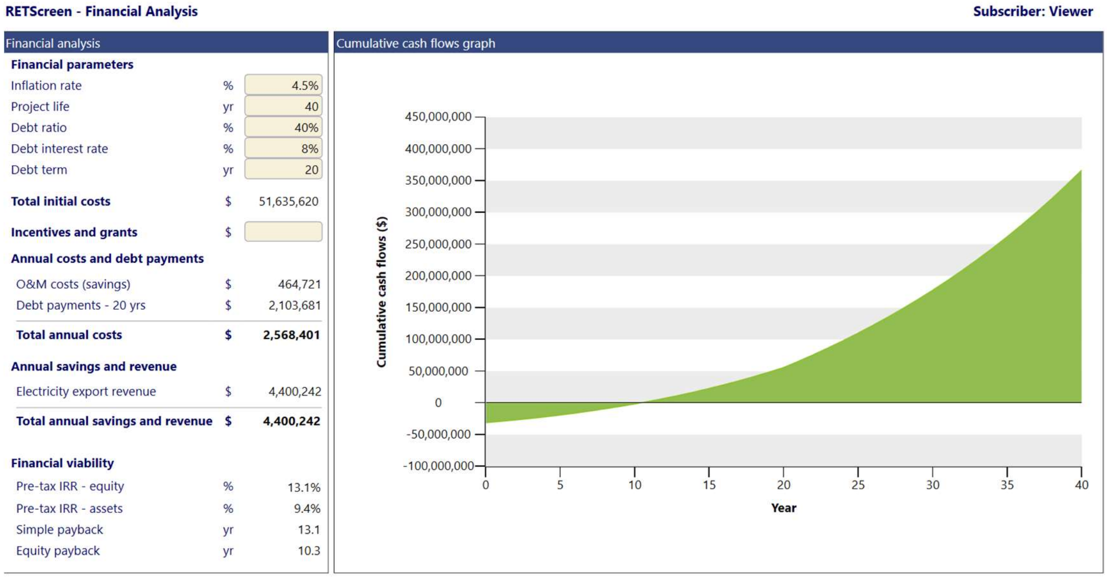
As it is possible to observe, the total sum of the initial costs amounts to 51,635,620 USD. RETScreen also allows to enter a second currency, so it was also possible to express all the amounts in Indian Rupees. Expressed in Rupees, the initial total cost amounts to INR 3,536,686,292. The operation and maintenance costs amount to 464,721 USD/year or 31,830,176 INR/year.

Then, in the financial analysis it was necessary to include some financial parameters.

The inflation rate changes depending on the country and time. Inflation is the increase in the general level of prices. In recent years, the inflation rate in India has been around 4.5%.

The life of the project will be based fundamentally on the life of the turbine, which will be about 40 or 50 years according to the resources.

Regarding to the debt ratio, 60% of own investment and 40% of loan were considered. In developing countries, the debt interest is higher, so it was considered an 8% of debt interest rate. It was also considered a debt term of 20 years, which is half the life of the project.



Financial analysis

Financial parameters		
Inflation rate	%	4.5%
Project life	yr	40
Debt ratio	%	40%
Debt interest rate	%	8%
Debt term	yr	20
Total initial costs	$	51,635,620
Incentives and grants	$	
Annual costs and debt payments		
O&M costs (savings)	$	464,721
Debt payments - 20 yrs	$	2,103,681
Total annual costs	**$**	**2,568,401**
Annual savings and revenue		
Electricity export revenue	$	4,400,242
Total annual savings and revenue	**$**	**4,400,242**
Financial viability		
Pre-tax IRR - equity	%	13.1%
Pre-tax IRR - assets	%	9.4%
Simple payback	yr	13.1
Equity payback	yr	10.3

Figure 7.2.4. Financial Analysis sheet Kaplan turbines. Source: RETScreen Expert.

This financial analysis sheet calculates the total annual costs considering the debt payments and the operation and maintenance costs (2,568,401 USD) and the total annual saving and revenue considering the electricity exported to the grid (4,400,242 USD). It also shows the cash flow chart and the pre-tax IRR-equity (13.1%), pre-tax IRR-assets (9.4%), simple payback period (13.1 years) and equity payback period (10.3 years). This means that the money is returned completely to the investors after 10.3 years and the power plant begins to generate net benefits after 13 years.

7.3. Case 2. Cross-flow turbine.

For the economic feasibility analysis of the Cross-flow small hydropower plant, it was supposed the construction of a penstock and a powerhouse downstream of the derivation canal. As already was mentioned, the derivation canal is supposed to provide a constant flow of 71.04 m^3/s. Taking this flow into account and knowing that the maximum working flow for a Ossberger Cross-flow turbine is 13 m^3/s, the implementation of six equal turbines was introduced into the simulation. Consequently, the working flow of each turbine was 11.84 m^3/s.

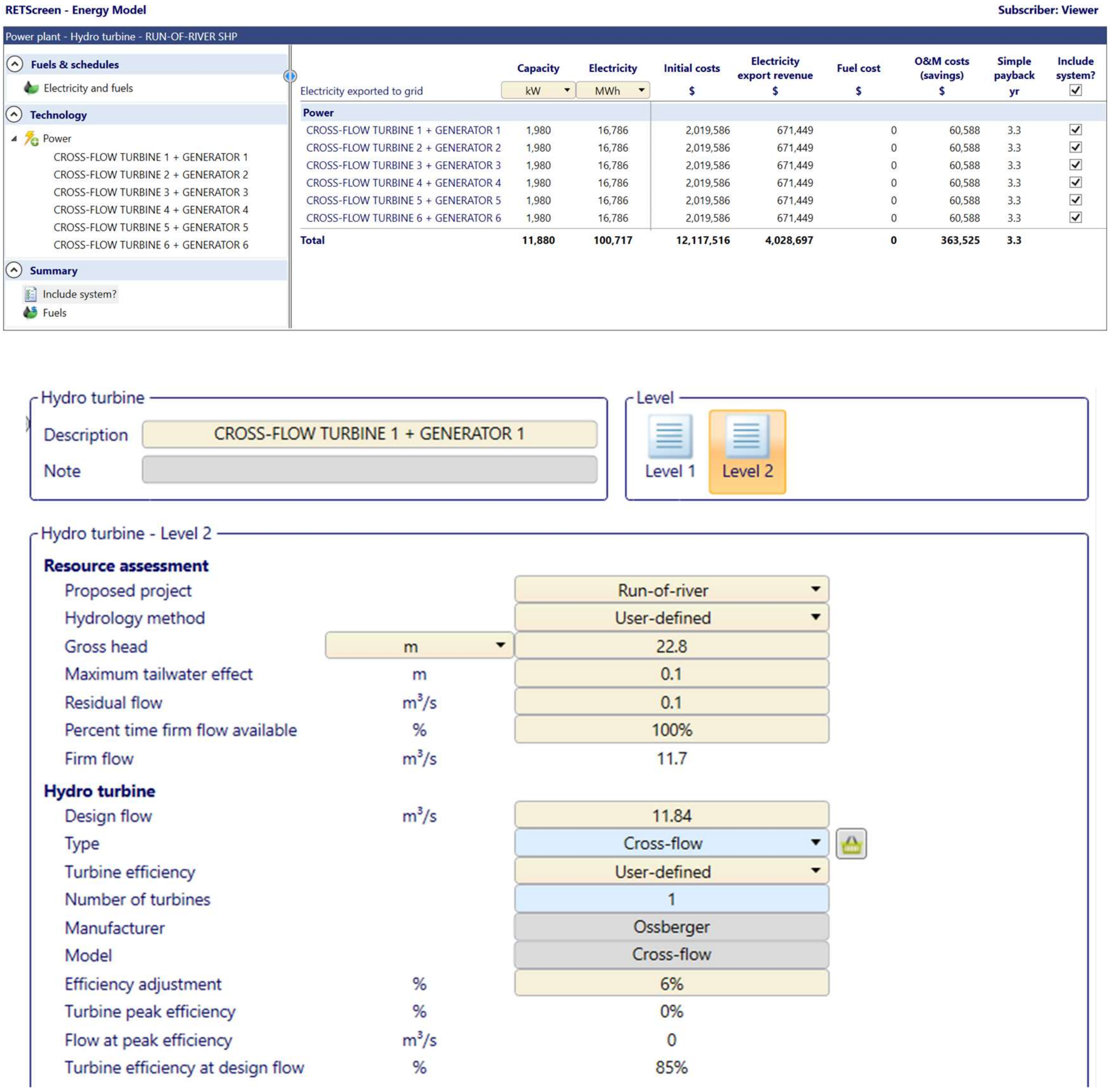
As already has been mentioned, the price per kW of each turbo-generator set will hardly depend on the specific project and the companies do not provide estimation prices easily. However, it is known that the Cross-flow turbines are considerably cheap in comparation with others, due to its easier manufacture. For that reason, it was considered the Cross-flow turbine implementation as the cheapest scenario, using a cost of 3,400 USD/kW, of which 1,020 USD/kW correspond to the turbo-generator set.

As was done in *Case 1*, all the afore mentioned technological and hydrological inputs were entered into the energy model sheet of RETScreen Expert. In the case of the efficiency of the turbine, the software has predetermined values depending on the turbine and, in the case of the Cross-flow turbine, the values provided by the program were not considered as totally valid, since they were not adjusted to the curves found in other sources of information, such as suppliers webpages. For that reason, the efficiency curve was introduced manually, with a peak efficiency of 85%, trying to adjust this curve to the curve shown in *Figure 5.2.1.*

The first economic inputs were also introduced, such as the cost of the turbo-generator set (1,020 USD / kWh) and the operation and maintenance costs per year (30.6 USD / kWh-year).

In this section, the software is already able to provide some very important outputs, such as the power generated by each turbo-generator set, the capacity factor, the energy provided after one year and the annual profits obtained from selling to the network electricity that generated energy. In addition, it provides the total cost of each turbo-generator set (2,019,586 USD) and the total annual operation and maintenance cost.

In the scenario, consisting of the implementation of 6 Cross-flow turbines, the software results in a power output of 1,980 kW in each turbo generator set, yielding a total power of 11,880 kW for the entire plant. Likewise, each turbine generates a total amount of energy of 16,786 MWh per year, providing benefits of 671,449 USD / year. With six turbines, the annual energy generated is 100,717 MWh and the benefits are 4,028,697 USD / year.



RETScreen - Energy Model **Subscriber: Viewer**

Power plant - Hydro turbine - RUN-OF-RIVER SHP

Electricity exported to grid	Capacity kW	Electricity MWh	Initial costs $	Electricity export revenue $	Fuel cost $	O&M costs (savings) $	Simple payback yr	Include system? ☑
Power								
CROSS-FLOW TURBINE 1 + GENERATOR 1	1,980	16,786	2,019,586	671,449	0	60,588	3.3	☑
CROSS-FLOW TURBINE 2 + GENERATOR 2	1,980	16,786	2,019,586	671,449	0	60,588	3.3	☑
CROSS-FLOW TURBINE 3 + GENERATOR 3	1,980	16,786	2,019,586	671,449	0	60,588	3.3	☑
CROSS-FLOW TURBINE 4 + GENERATOR 4	1,980	16,786	2,019,586	671,449	0	60,588	3.3	☑
CROSS-FLOW TURBINE 5 + GENERATOR 5	1,980	16,786	2,019,586	671,449	0	60,588	3.3	☑
CROSS-FLOW TURBINE 6 + GENERATOR 6	1,980	16,786	2,019,586	671,449	0	60,588	3.3	☑
Total	**11,880**	**100,717**	**12,117,516**	**4,028,697**	**0**	**363,525**	**3.3**	

Hydro turbine

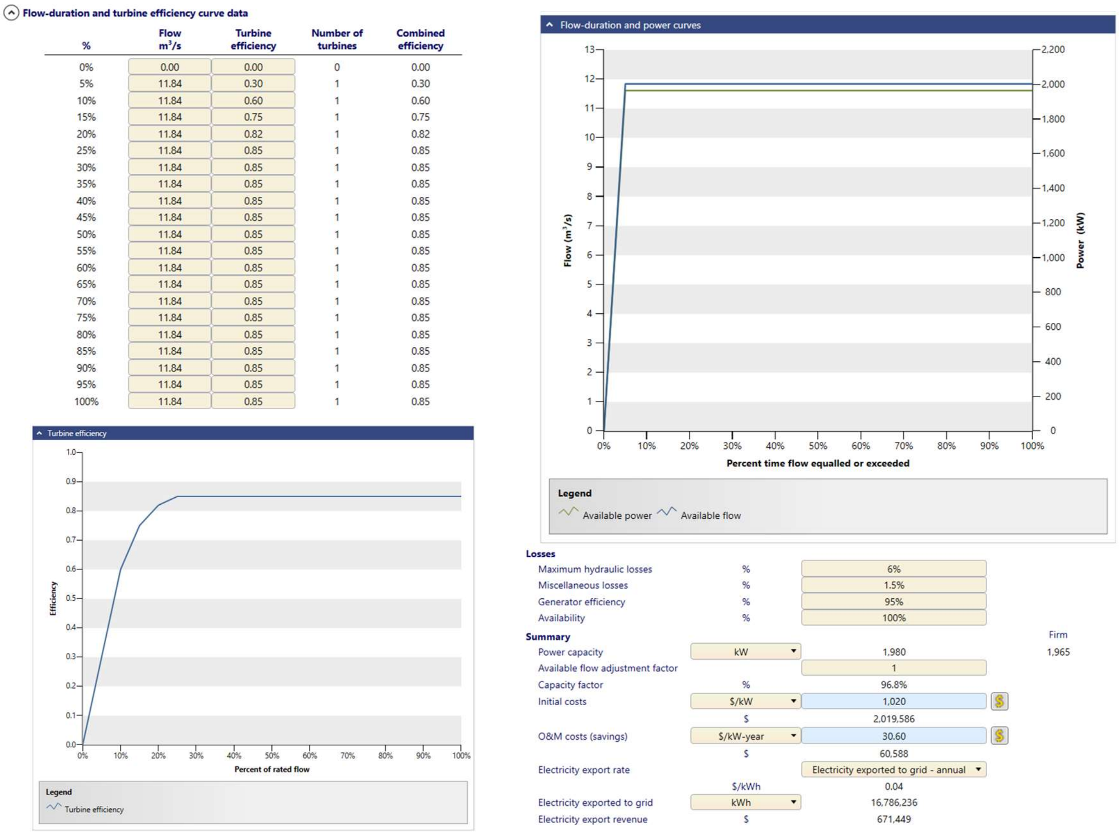
Description: CROSS-FLOW TURBINE 1 + GENERATOR 1

Note:

Hydro turbine - Level 2

Resource assessment		
Proposed project		Run-of-river
Hydrology method		User-defined
Gross head	m	22.8
Maximum tailwater effect	m	0.1
Residual flow	m^3/s	0.1
Percent time firm flow available	%	100%
Firm flow	m^3/s	11.7
Hydro turbine		
Design flow	m^3/s	11.84
Type		Cross-flow
Turbine efficiency		User-defined
Number of turbines		1
Manufacturer		Ossberger
Model		Cross-flow
Efficiency adjustment	%	6%
Turbine peak efficiency	%	0%
Flow at peak efficiency	m^3/s	0
Turbine efficiency at design flow	%	85%

Figure 7.3.1. Energy Model sheet Cross-flow turbines (1/2). Source: RETScreen Expert.



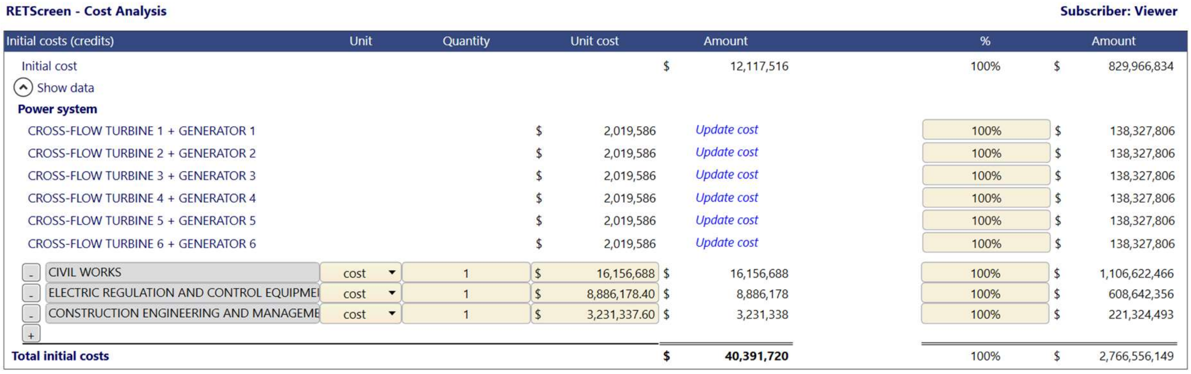
Flow-duration and turbine efficiency curve data

%	Flow m³/s	Turbine efficiency	Number of turbines	Combined efficiency
0%	0.00	0.00	0	0.00
5%	11.84	0.30	1	0.30
10%	11.84	0.60	1	0.60
15%	11.84	0.75	1	0.75
20%	11.84	0.82	1	0.82
25%	11.84	0.85	1	0.85
30%	11.84	0.85	1	0.85
35%	11.84	0.85	1	0.85
40%	11.84	0.85	1	0.85
45%	11.84	0.85	1	0.85
50%	11.84	0.85	1	0.85
55%	11.84	0.85	1	0.85
60%	11.84	0.85	1	0.85
65%	11.84	0.85	1	0.85
70%	11.84	0.85	1	0.85
75%	11.84	0.85	1	0.85
80%	11.84	0.85	1	0.85
85%	11.84	0.85	1	0.85
90%	11.84	0.85	1	0.85
95%	11.84	0.85	1	0.85
100%	11.84	0.85	1	0.85

Losses			
Maximum hydraulic losses	%	6%	
Miscellaneous losses	%	1.5%	
Generator efficiency	%	95%	
Availability	%	100%	
Summary			Firm
Power capacity	kW	1,980	1,965
Available flow adjustment factor		1	
Capacity factor	%	96.8%	
Initial costs	$/kW	1,020	
	$	2,019,586	
O&M costs (savings)	$/kW-year	30.60	
	$	60,588	
Electricity export rate		Electricity exported to grid - annual	
	$/kWh	0.04	
Electricity exported to grid	kWh	16,786,236	
Electricity export revenue	$	671,449	

Figure 7.3.2. Energy Model Sheet Cross-flow turbines (2/2). Source: RETScreen Expert.

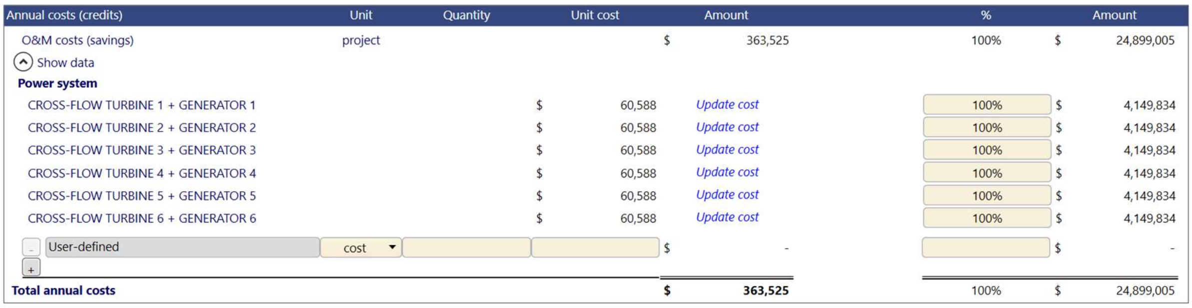
Subsequently, in the cost analysis sheet, the rest of the required costs were introduced. Since the 30% investment due to the turbo-generator set had already been introduced in the previous sheet, it was only necessary to enter 40% corresponding to "Civil works", 22% corresponding to "Electric regulation and control equipments" and the 8% corresponding to "Construction engineering and management".



RETScreen - Cost Analysis — **Subscriber: Viewer**

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	%	Amount
Initial cost				$ 12,117,516	100%	$ 829,966,834
Show data						
Power system						
CROSS-FLOW TURBINE 1 + GENERATOR 1			$ 2,019,586	*Update cost*	100%	$ 138,327,806
CROSS-FLOW TURBINE 2 + GENERATOR 2			$ 2,019,586	*Update cost*	100%	$ 138,327,806
CROSS-FLOW TURBINE 3 + GENERATOR 3			$ 2,019,586	*Update cost*	100%	$ 138,327,806
CROSS-FLOW TURBINE 4 + GENERATOR 4			$ 2,019,586	*Update cost*	100%	$ 138,327,806
CROSS-FLOW TURBINE 5 + GENERATOR 5			$ 2,019,586	*Update cost*	100%	$ 138,327,806
CROSS-FLOW TURBINE 6 + GENERATOR 6			$ 2,019,586	*Update cost*	100%	$ 138,327,806
CIVIL WORKS	cost	1	$ 16,156,688	$ 16,156,688	100%	$ 1,106,622,466
ELECTRIC REGULATION AND CONTROL EQUIPMEI	cost	1	$ 8,886,178.40	$ 8,886,178	100%	$ 608,642,356
CONSTRUCTION ENGINEERING AND MANAGEME	cost	1	$ 3,231,337.60	$ 3,231,338	100%	$ 221,324,493
Total initial costs				**$ 40,391,720**	100%	$ 2,766,556,149

Figure 7.3.3. Cost Analysis Sheet Cross-flow turbines (1/2). Source: RETScreen Expert.

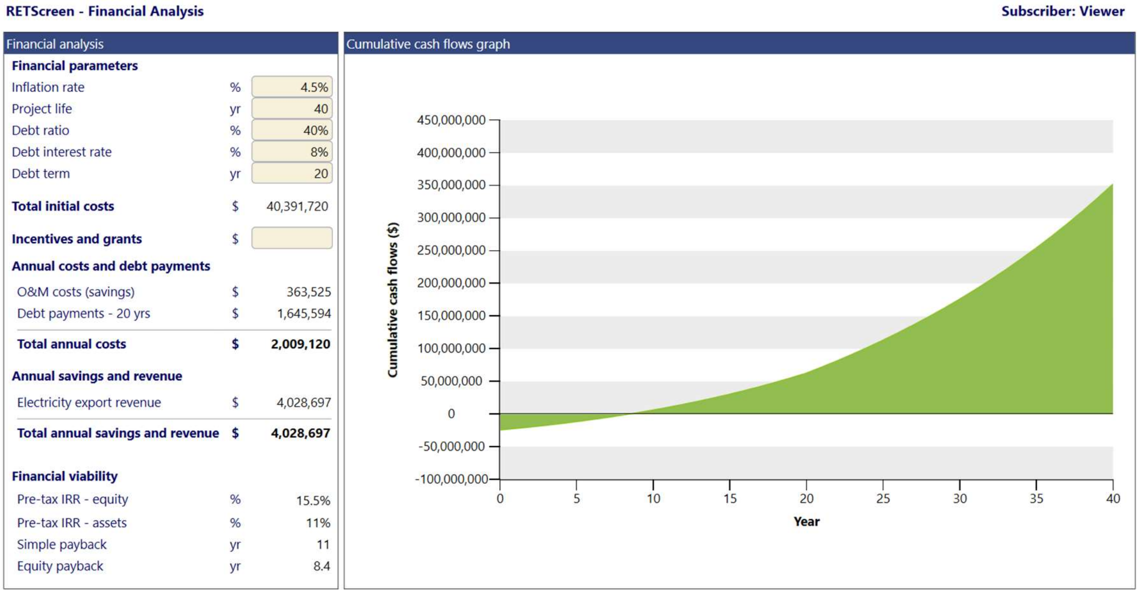


Annual costs (credits)	Unit	Quantity	Unit cost	Amount	%	Amount
O&M costs (savings)	project			$ 363,525	100%	$ 24,899,005
Show data						
Power system						
CROSS-FLOW TURBINE 1 + GENERATOR 1			$ 60,588	*Update cost*	100%	$ 4,149,834
CROSS-FLOW TURBINE 2 + GENERATOR 2			$ 60,588	*Update cost*	100%	$ 4,149,834
CROSS-FLOW TURBINE 3 + GENERATOR 3			$ 60,588	*Update cost*	100%	$ 4,149,834
CROSS-FLOW TURBINE 4 + GENERATOR 4			$ 60,588	*Update cost*	100%	$ 4,149,834
CROSS-FLOW TURBINE 5 + GENERATOR 5			$ 60,588	*Update cost*	100%	$ 4,149,834
CROSS-FLOW TURBINE 6 + GENERATOR 6			$ 60,588	*Update cost*	100%	$ 4,149,834
User-defined	cost			$ -		$ -
Total annual costs				**$ 363,525**	100%	$ 24,899,005

Figure 7.3.4. Cost Analysis sheet Cross-flow turbines (2/2). Source: RETScreen Expert.

As it is possible to observe, the total sum of the initial costs amounts to 40,391,720 USD. Expressed in Rupees, the initial total cost amounts to INR 2,766,556,149. The operation and maintenance costs amount to 363,525 USD/year or 24,899,005 INR/year.

Then, in the financial analysis the same financial parameters than in *Case 1*, were included.



RETScreen - Financial Analysis **Subscriber: Viewer**

Financial analysis		
Financial parameters		
Inflation rate	%	4.5%
Project life	yr	40
Debt ratio	%	40%
Debt interest rate	%	8%
Debt term	yr	20
Total initial costs	$	40,391,720
Incentives and grants	$	
Annual costs and debt payments		
O&M costs (savings)	$	363,525
Debt payments - 20 yrs	$	1,645,594
Total annual costs	**$**	**2,009,120**
Annual savings and revenue		
Electricity export revenue	$	4,028,697
Total annual savings and revenue	**$**	**4,028,697**
Financial viability		
Pre-tax IRR - equity	%	15.5%
Pre-tax IRR - assets	%	11%
Simple payback	yr	11
Equity payback	yr	8.4

Figure 7.3.5. Financial Analysis sheet Cross-flow turbines. Source: RETScreen Expert.

This financial analysis sheet calculates the total annual costs considering the debt payments and the operation and maintenance costs (2,009,720 USD) and the total annual saving and revenue considering the electricity exported to the grid (4,028,697 USD). It also shows the cash flow chart and the pre-tax IRR-equity (15.5%), pre-tax IRR-assets (11%), simple payback period (11 years) and equity payback period (8.4 years). This means that the money is returned completely to the investors after 8.4 years and the power plant begins to generate net benefits after 11 years.

7.4. Case 3. Kaplan turbines including subsides.

As already introduced in *Section 3.3.*, there is an even more favorable scenario in which the state could grant subsidies to impulse the implementation of the plant. The present project was proposed to be economically profitable and to solve the energy problem of the area. However, since the main motivation for this research was to provide energy to a region with needs by taking advantage of the abundant water resources, the approach has been considered more as public rather than private. Consequently, the formula used to calculate the possible subsides provided by the government was:

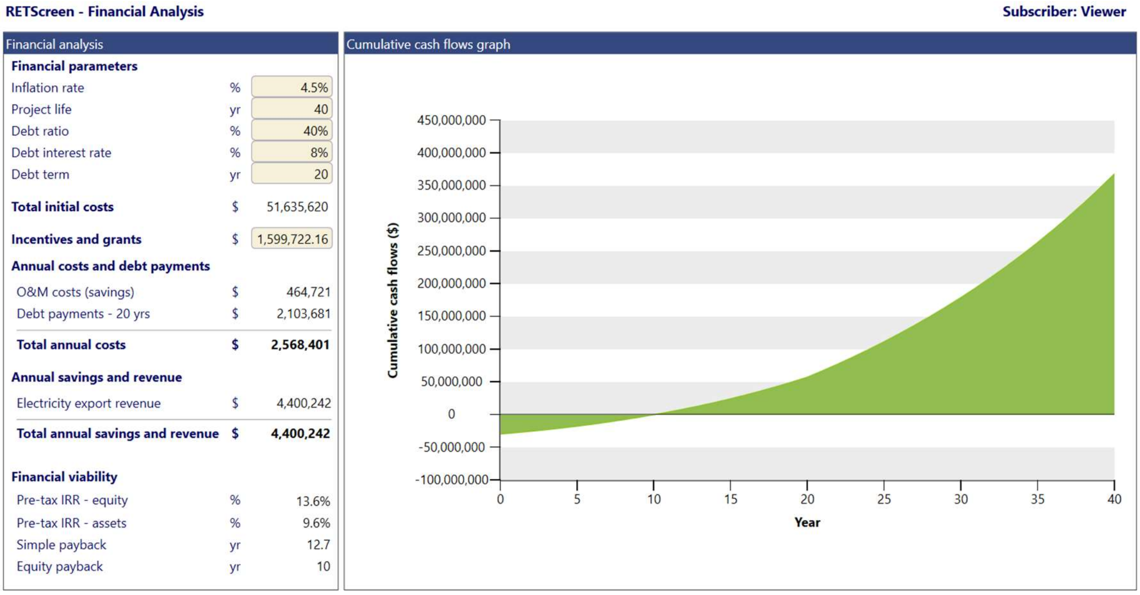
$$\boldsymbol{Subsidies\ (INR) = 5 \cdot 10^{7} + 50 \cdot 10^{5}(P - 1)} \qquad (5)$$

where P is the real power output of the small hydropower plant expressed in MW.

For the small hydropower plant with Kaplan turbines the calculation gave as result:

$$\boldsymbol{Subsidies_{Kaplan}(INR) = 5 \cdot 10^{7} + 50 \cdot 10^{5}\left(P_{Kaplan} - 1\right) = 5 \cdot 10^{7} + 50 \cdot 10^{5}(12.909 - 1) = 109{,}545{,}000\ INR = 1{,}599{,}722.16\ USD}$$

Introducing this value in the financial analysis of RETScreen, the financial viability outputs improved slightly. On one hand, the “pre-tax IRR – equity” increased to 13.6% and the “pre-tax IRR-assets” increased to 9.6%. On the other hand, the simple payback period was reduced to 12.7 years and the equity payback period was reduced to 10 years.



Financial analysis

Financial parameters		
Inflation rate	%	4.5%
Project life	yr	40
Debt ratio	%	40%
Debt interest rate	%	8%
Debt term	yr	20
Total initial costs	$	51,635,620
Incentives and grants	$	1,599,722.16
Annual costs and debt payments		
O&M costs (savings)	$	464,721
Debt payments - 20 yrs	$	2,103,681
Total annual costs	**$**	**2,568,401**
Annual savings and revenue		
Electricity export revenue	$	4,400,242
Total annual savings and revenue	**$**	**4,400,242**
Financial viability		
Pre-tax IRR - equity	%	13.6%
Pre-tax IRR - assets	%	9.6%
Simple payback	yr	12.7
Equity payback	yr	10

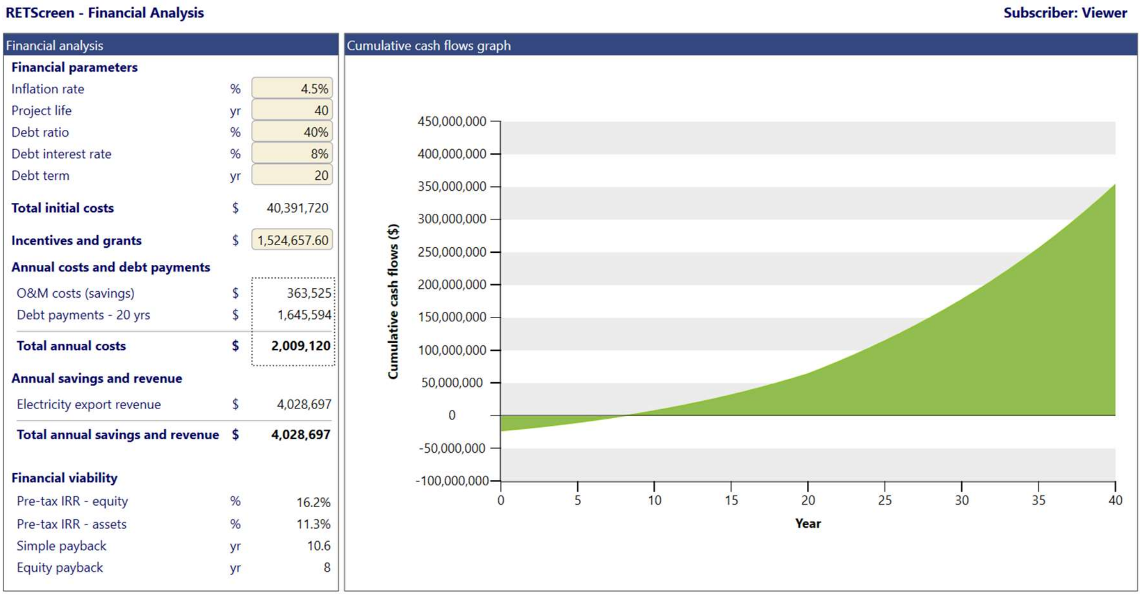
Figure 7.4.1. Financial Analysis sheet Kaplan turbines, including subsides. Source: RETScreen Expert.

7.5. Case 4. Cross-flow turbines including subsides.

For the small hydropower plant with Cross-flow turbines the calculation gave as result:

$$\boldsymbol{Subsidies_{Cross-flow}(INR) = 5\cdot 10^{7} + 50\cdot 10^{5}\left(P_{Cross-flow} - 1\right)}$$
$$\boldsymbol{= 5\cdot 10^{7} + 50\cdot 10^{5}(11.880 - 1) = 104,400,000\ INR = 1,524,657.6\ USD}$$

Introducing this value in the financial analysis of RETScreen, the financial viability outputs improved slightly. On one hand, the “pre-tax IRR – equity” increased to 16.2% and the “pre-tax IRR-assets” increased to 11.3%. On the other hand, the simple payback period was reduced to 10.6 years and the equity payback period was reduced to 8 years.



RETScreen - Financial Analysis

Subscriber: Viewer

Financial analysis

Financial parameters		
Inflation rate	%	4.5%
Project life	yr	40
Debt ratio	%	40%
Debt interest rate	%	8%
Debt term	yr	20
Total initial costs	$	40,391,720
Incentives and grants	$	1,524,657.60
Annual costs and debt payments		
O&M costs (savings)	$	363,525
Debt payments - 20 yrs	$	1,645,594
Total annual costs	**$**	**2,009,120**
Annual savings and revenue		
Electricity export revenue	$	4,028,697
Total annual savings and revenue	**$**	**4,028,697**
Financial viability		
Pre-tax IRR - equity	%	16.2%
Pre-tax IRR - assets	%	11.3%
Simple payback	yr	10.6
Equity payback	yr	8

Figure 7.4.1. Financial Analysis sheet Cross-flow turbines, including subsides. Source: RETScreen Expert.

These results show that the economic viability of the project, whatever the type of turbine chosen, does not depend on the subsidies. However, if the subsidies are granted by the government, it improves the profitability of the investment.

8. HOMER Pro Simulations. Energy models.

8.1. Homer Pro Software information.

The HOMER Pro® microgrid software by HOMER Energy is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. Homer Pro, or HOMER (Hybrid Optimization of Multiple Electric Renewables), simplifies the task of evaluating designs for both off-grid and grid-connected power systems. It allows to answer questions such as:

-Which components are best for this system?

-How many and what size of each component are most efficient?

The large number of technology options, variation in costs, and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations.

To use HOMER, you select and enter information under the Design button to provide the model with inputs, including components (e.g., generator, wind, and solar), component costs, and resource availability. You can also add new components, resources, and loads.

When you click the Calculate button, HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that you can view as a list of feasible configurations sorted by net present cost under the Results button. HOMER also displays simulation results in a wide variety of tables and graphs that help to compare configurations and evaluate them on their economic and technical merits.

HOMER simulates energy systems, shows system configurations optimized by cost, and provides sensitivity analyses.

HOMER simulates the operation of a system by making energy balance calculations in each time step (interval) of the year. For each time step, HOMER compares the electric and thermal demand in that time step to the energy that the system can supply in that time step, and calculates the flow of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides in each time step how to operate the generators and whether to charge or discharge the batteries.

HOMER performs these energy balance calculations for each system configuration considered. It then determines whether a configuration is feasible, (i.e., whether it can meet the electric demand under the conditions that you specify), and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest. (Homer Pro User Manual)

For this analysis, a free version of the software, available for student use, was used.

8.2. Manipur Electric Load.

In this project, Homer Pro software was used to model a complete energy generation and consumption system. The objective of the simulation is to check the viability of the project from a technological point of view, trying to find an optimal and reasonable model that is capable of supplying energy to the population.

The region under study is Manipur, whose approximate electricity demand was calculated by weighing the population of manipur along the the overall North East region, and distributing the demand based on the weightages. The data was made available for this analysis by the IEE. After obtaining the hourly electric load of Manipur for a whole year, we proceeded to filter such data. Since Homer Pro only allows to enter an hourly power demand day per month, it was decided to look for the peak demand day of each month in the data sheet and to introduce them into the software. In this way, the electric load profile obtained included a margin of safety.

	January	February	March	April	May	June	July	August	September	October	November	December
0	9422.19	10696.37	10604.12	11328.74	12171.86	9265.44	9796.57	9542.95	9922.63	9659.10	11194.42	10870.26
1	9146.27	10706.52	10511.34	11098.92	11919.08	8973.86	9676.67	9147.45	9804.07	9653.61	10897.38	10305.29
2	9043.45	10569.43	10222.88	10912.10	11704.73	8774.88	9436.88	9145.49	9641.53	9481.75	10357.87	10186.06
3	9070.87	10535.58	10491.10	10877.38	11728.99	8761.09	9433.02	9421.56	9563.13	9231.27	10406.36	10118.19
4	9168.55	10740.37	10619.31	10776.52	11913.02	9198.45	9887.46	9842.51	9792.60	9809.02	11855.17	11011.51
5	10412.73	11740.61	11405.42	11396.53	12279.04	9618.09	10368.97	10993.77	9920.72	10454.42	12382.56	11877.31
6	12123.06	11832.01	11213.11	11551.94	13134.45	11178.41	11616.26	12260.55	12454.44	10805.46	13538.38	12401.93
7	13392.94	12820.41	12024.53	12140.53	14109.17	12421.55	12484.53	13131.83	12209.68	11803.73	14370.89	14032.66
8	13202.72	12893.18	12108.88	12112.43	14246.68	12037.38	12838.42	13210.15	12873.23	11880.52	15005.37	13630.94
9	12978.22	12170.50	11923.31	11735.46	14262.86	11850.22	12689.51	12691.30	12530.93	11578.85	14195.09	12810.99
10	12527.50	12512.38	11577.49	11801.60	14420.59	11865.98	12844.22	12703.05	12704.95	11485.60	13506.05	13097.15
11	12782.85	11867.55	11049.48	11996.69	14394.31	11290.71	11705.22	12701.09	12441.06	11560.56	13516.15	13128.33
12	12292.72	11999.56	11366.62	12019.84	14699.66	11568.50	12401.38	12409.36	12735.54	11375.90	13281.75	12183.65
13	12532.64	11591.68	11783.30	12201.71	14717.86	10967.61	12192.53	12293.84	12404.73	11474.63	13308.02	12445.96
14	12410.96	11385.20	11908.13	12195.09	15007.04	11018.84	12246.68	11968.82	11756.47	11619.07	13710.13	12077.26
15	12030.51	11953.87	12009.35	11928.91	14859.42	11054.30	12244.74	11984.49	12509.90	11533.14	13469.67	12352.41
16	12416.11	11786.31	11865.96	11512.26	14238.59	10776.51	11896.66	12053.01	11938.14	10926.13	13081.71	11754.41
17	11317.59	11224.41	11314.33	10601.27	13712.81	11016.87	11471.23	12178.32	11475.38	10509.27	12891.77	11292.16
18	11538.67	12365.13	13062.00	12396.80	14675.40	12439.29	12565.75	13674.18	13450.72	12664.88	13944.53	13119.16
19	11324.45	12212.81	12490.13	12173.60	15185.00	13451.92	13356.67	13871.93	13443.07	12502.16	13978.88	13003.59
20	10671.51	11625.53	12495.19	12028.11	14772.46	13245.06	12733.99	13593.90	12982.22	12657.57	13788.94	12922.88
21	10808.61	11053.47	12108.88	12013.23	14183.99	11927.06	11610.46	12732.41	11570.99	11450.86	13211.03	11994.71
22	10075.13	10562.66	11688.83	11834.66	13106.14	10473.11	10502.40	11040.76	10957.16	10991.95	12897.83	11514.11
23	9713.53	10032.92	11216.49	10930.28	12493.40	9834.80	9808.17	10018.72	10140.63	10291.70	12182.52	10995.00

Table 8.2.1. Monthly peak load day (KW). Source: IEE TU Graz. Karthik Bhat Subramanya.

Name: Electric Load Manipur

January Profile

Hour	Load (kW)
0	9,422.188
1	9,146.274
2	9,043.449
3	9,070.869
4	9,168.554
5	10,412.730
6	12,123.060
7	13,392.940
8	13,202.720
9	12,978.220

Time Step Size: **60** minutes

Random Variability

Day-to-day (%): 0

Timestep (%): 0

Peak Month: **None**

Metric	Baseline	Scaled
Average (kWh/d)	283,21:	283,21:
Average (kW)	11,800.	11,800.
Peak (kW)	15,185	15,185
Load Factor	.78	.78

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost ($): 0

Lifetime (yr): 10

Figure 8.2.2. Electric load introduced in Homer Pro. Source: Homer Pro Software.

Figure 8.2.3. Average Daily Load Profile for each month. Source: Homer Pro Software.

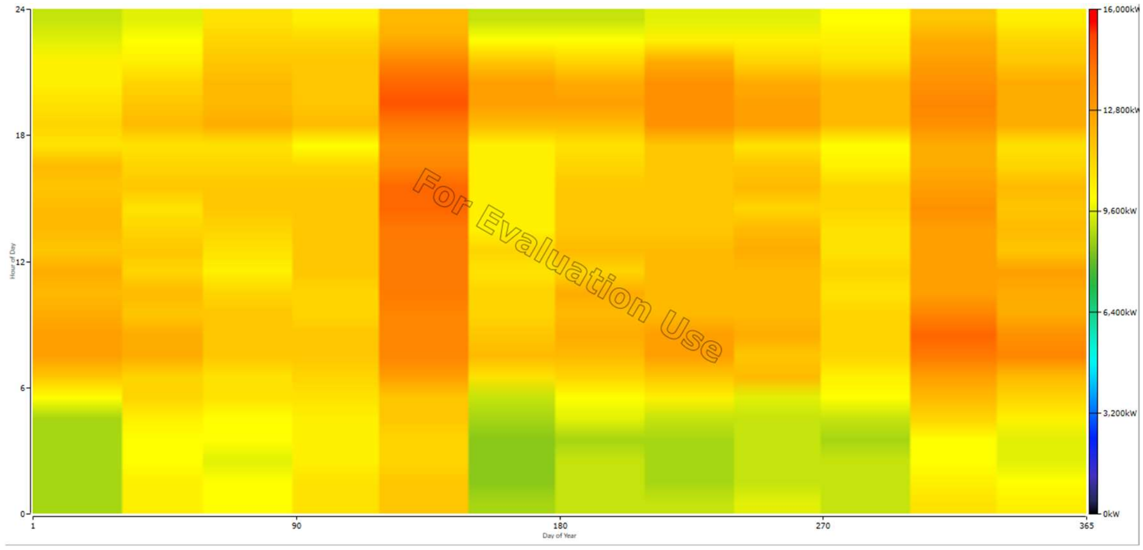


Figure 8.2.4. Daily Load Profile sorted by colors. Source: Homer Pro Software.

Once the electric demand had been introduced manually, the charts and profiles generated by the software showed that May is the most exigent month followed by November. They also showed that the peak demands are reached in the early morning or in the evening. The average daily energy demand is 283,217.76 kWh/d, the average power demand is 11,800 kW and the peak demand is 15,185 kW. Considering that the SHP is planned to produce around 12,000 kW it is possible to know that the hydropower plant will be capable to satisfy the base load of the whole region. Just in peak demand moments will be necessary for the grid to acquire energy from other sources.

8.3. Energy system scheme & inputs.

Once the electricity demand of the region had been included in the system, it was necessary to add the small hydropower plant as the main source of generation and some other components to make the system more robust, sustainable and realistic.

The data of costs, efficiency and capacity that were introduced as inputs in RETScreen were the same that were later introduced in the HOMER model to simulate the SHP in each of the two cases. In addition, a conventional generation thermal power plant (diesel fuel) was added as the second source of energy that would be used in case of failure in the hydroelectric power plant or dissatisfaction of the electricity demand.

On the other hand, a 1MWh lithium-ion battery was added to guarantee the safety of the service if energy reserves were needed during periods of short duration. The inclusion of said battery in the system required adding an AC to DC converter and vice versa to enable its use.

Finally, to make the system completely realistic, the presence of the electrical grid was added in the simulation. The sale price of electricity to the electricity grid was considered low (0.04 USD / kWh) and the purchase price was considered much higher (0.08 USD / kWh). In this way, the system was forced to satisfy the electricity demand instead of selling the electricity produced to the general grid.

The scheme constructed was identical for the two scenarios, changing only the turbine type of the SHP and consequently, its characteristics.

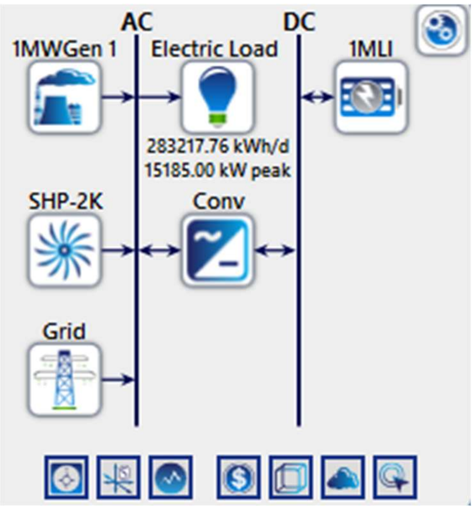


Figure 8.3.1. Energy system scheme including Kaplan turbines in the SHP. Source: Homer Pro.

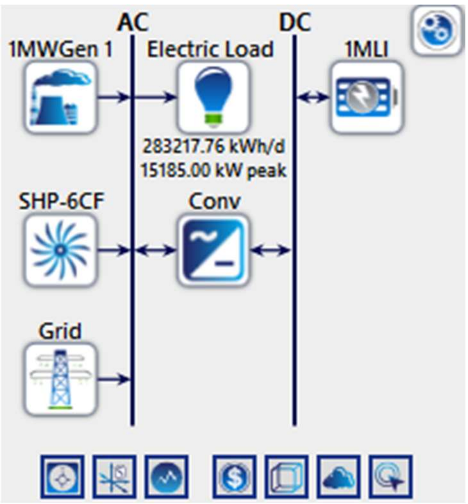
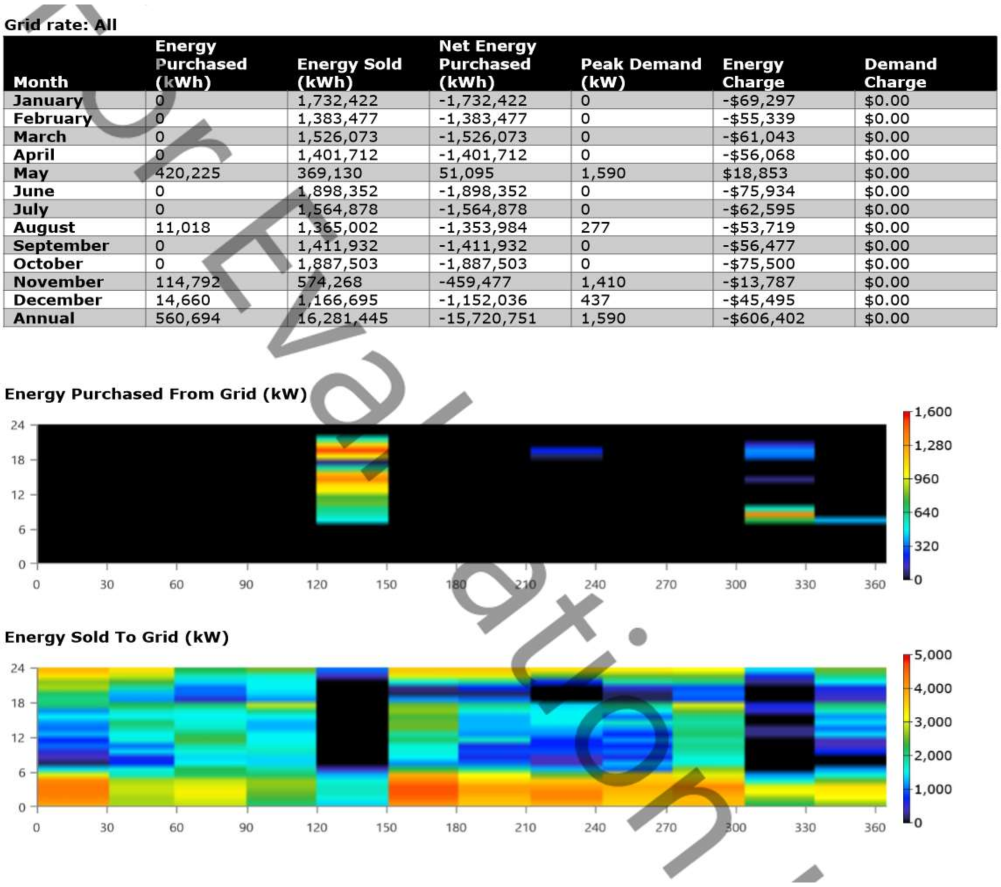


Figure 8.3.2. Energy system scheme including Cross-flow turbines in the SHP. Source: Homer Pro.

8.4. Scenario 1: Kaplan turbines SHP as main source of energy generation.

After simulating the first model, the results were satisfactory. The results sheet offered several feasible configurations including more or fewer components in the solution.

However, all of them showed that safety components such as the conventional generation plant, the converter and the battery were not required if the system was connected to the national grid. The national grid can provide electricity in times of deficit with a lower cost than that derived cost from implementing all the other components. In addition, as can be seen in the following graphics the system is self-sustainable most of the time, always satisfying the base demand and selling the excess of electricity. However, in times of peak demand, such as certain moments of May and November, it is necessary to acquire some electricity from the grid. It is important to remember that the power provided by the SHP is always constant, while the demand is continuously changing.



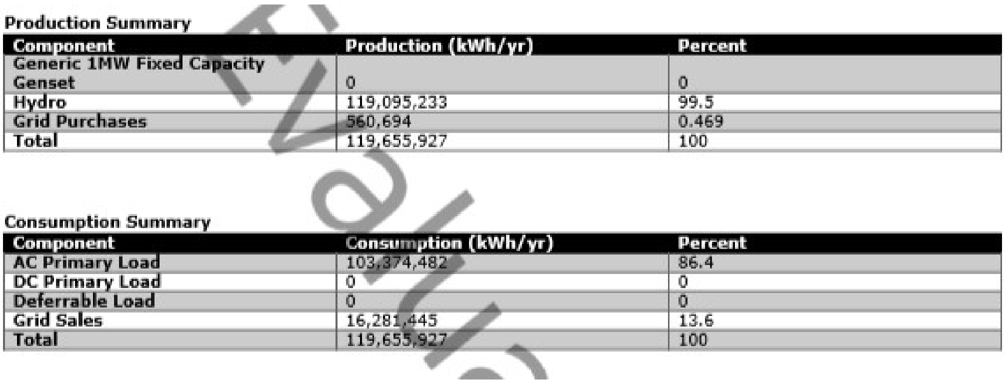
Grid rate: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	0	1,732,422	-1,732,422	0	-$69,297	$0.00
February	0	1,383,477	-1,383,477	0	-$55,339	$0.00
March	0	1,526,073	-1,526,073	0	-$61,043	$0.00
April	0	1,401,712	-1,401,712	0	-$56,068	$0.00
May	420,225	369,130	51,095	1,590	$18,853	$0.00
June	0	1,898,352	-1,898,352	0	-$75,934	$0.00
July	0	1,564,878	-1,564,878	0	-$62,595	$0.00
August	11,018	1,365,002	-1,353,984	277	-$53,719	$0.00
September	0	1,411,932	-1,411,932	0	-$56,477	$0.00
October	0	1,887,503	-1,887,503	0	-$75,500	$0.00
November	114,792	574,268	-459,477	1,410	-$13,787	$0.00
December	14,660	1,166,695	-1,152,036	437	-$45,495	$0.00
Annual	560,694	16,281,445	-15,720,751	1,590	-$606,402	$0.00

Figure 8.4.1. Interactions with the electricity grid. Purchase and sale of energy. Scenario 1. Kaplan turbines. Source: HOMER Pro.

On one hand, the "Production Summary" shows that a 99.5% of the load is satisfied by the SHP, while only a 0.5% is purchased from the national grid in moments of peak demand.

On the other hand, the "Consumption Summary" shows that 86.4% of the energy generated is used to satisfy the AC Primary Load, while there is an excess of 13.6% which is sold to the grid.



Production Summary

Component	Production (kWh/yr)	Percent
Generic 1MW Fixed Capacity Genset	0	0
Hydro	119,095,233	99.5
Grid Purchases	560,694	0.469
Total	119,655,927	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	103,374,482	86.4
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	16,281,445	13.6
Total	119,655,927	100

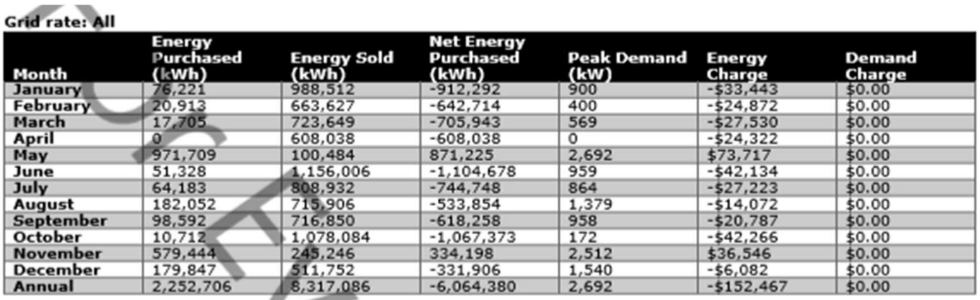
Figure 8.4.2. Production Summary and Consumption Summary. Scenario 1. Kaplan turbines. Source: HOMER Pro.

In conclusion, this first scenario, which uses as main source of energy generation the SHP with two Kaplan turbines is completely feasible if it is connected to the national grid, providing a constant amount of energy that would satisfy the demand the 99.5% of the time, without the need to import energy from external sources.

Nevertheless, it is important to add that a hypothetical off-grid system would be also viable, but more expensive. In this alternative scenario, the safety components would be needed in order to store the energy excess and provide an alternative source in case of failure.

8.5. Scenario 2: Cross-flow turbines SHP as main source of energy generation.

After simulating the second model, the results were also satisfactory. The results sheet offered several feasible configurations including more or fewer components in the solution, as in the previous model. However, all of them showed again that safety components such as the conventional generation plant, the converter and the battery were not required if the system was connected to the national grid. Furthermore, as can be seen in the following graphics, the system is self-sustainable most of the time, always satisfying the base demand and selling the excess of electricity to the grid. However, in this case, due to the lower capacity of the small hydropower plant (less efficiency of Cross-flow turbines) there exist more moments when it is necessary to acquire some electricity from the grid.



Grid rate: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge	Demand Charge
January	76,221	988,512	-912,292	900	-$33,443	$0.00
February	20,913	663,627	-642,714	400	-$24,872	$0.00
March	17,705	723,649	-705,943	569	-$27,530	$0.00
April	0	608,038	-608,038	0	-$24,322	$0.00
May	971,709	100,484	871,225	2,692	$73,717	$0.00
June	51,328	1,156,006	-1,104,678	959	-$42,134	$0.00
July	64,183	808,932	-744,748	864	-$27,223	$0.00
August	182,052	715,906	-533,854	1,379	-$14,072	$0.00
September	98,592	716,850	-618,258	958	-$20,787	$0.00
October	10,712	1,078,084	-1,067,373	172	-$42,266	$0.00
November	579,444	245,246	334,198	2,512	$36,546	$0.00
December	179,847	511,752	-331,906	1,540	-$6,082	$0.00
Annual	2,252,706	8,317,086	-6,064,380	2,692	-$152,467	$0.00

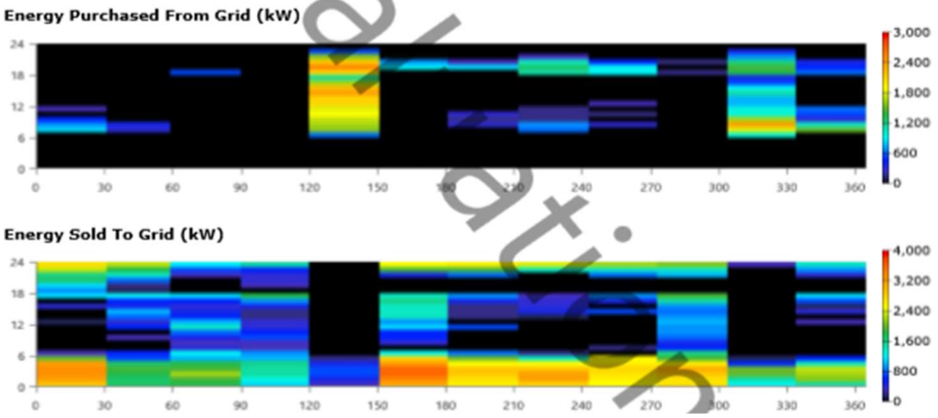
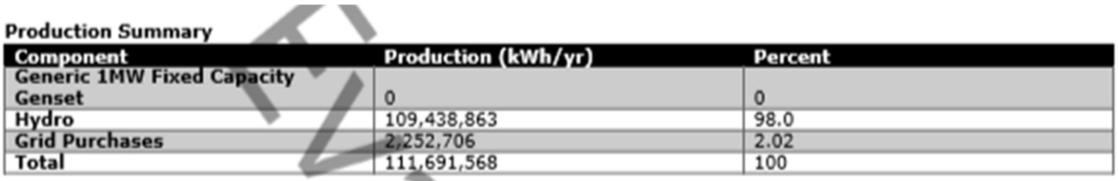


Figure 8.5.1. Interactions with the electricity grid. Purchase and sale of energy. Scenario 2. Cross-flow turbines. Source: HOMER Pro.

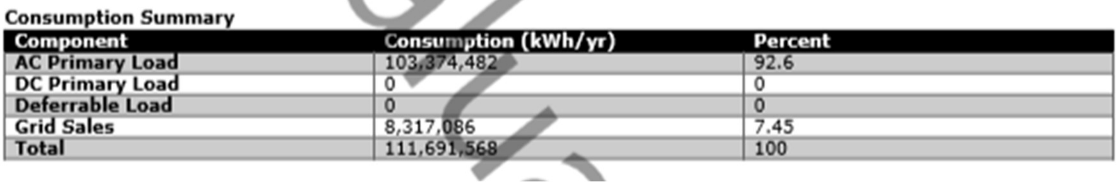
The "Production Summary" shows that a 98% of the load is satisfied by the SHP, while only a 2% is purchased from the national grid in moments of peak demand.

The "Consumption Summary" shows that 92.6% of the energy generated is used to satisfy the AC Primary Load, while there is an excess of 7.4% which is sold to the grid.



Production Summary

Component	Production (kWh/yr)	Percent
Generic 1MW Fixed Capacity Genset	0	0
Hydro	109,438,863	98.0
Grid Purchases	2,252,706	2.02
Total	111,691,568	100



Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	103,374,482	92.6
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	8,317,086	7.45
Total	111,691,568	100

Figure 8.5.2. Production Summary and Consumption Summary. Scenario 2. Cross-flow turbines. Source: HOMER Pro.

Although these results are less favorable, they are also very satisfactory from a technological point of view, because the system satisfies the base load. Moreover, it is necessary to remember that this scenario is cheaper than the first scenario.

As in the first scenario, an off-grid system would be also viable with the proper safety components integrated.

9. Results & Conclusions.

The first and most important conclusion that can be drawn from this project is that north-east India has an enormous water resource available due to the presence of the rivers Brahamaputra and Barak. Despite of this huge water potential, they are at the bottom in terms of installed power. The energy import and dependence of these regions could come to an end with the installation of small hydroelectric power plants like the one developed in this project, along the afore mentioned rivers and their tributaries.

More specifically, this analysis shows that both the Cross-flow and the Kaplan turbine, despite their differences, are two feasible alternatives for the installation of a run-of-the river small hydroelectric power water in the selected location. However, due to the simplicity of its design, the latest advances in efficiency, the nonexistent cavitation problems and its low cost, the Cross-flow turbine stands as the safest and most cost-effective alternative.

	Cost (USD)	Energy produced in 1 year (MWh)	Price/Energy (USD/KWh)	Energy produced in 40 years (MWh)	Price/Energy (USD/KWh)
Kaplan	51635620	110006	0.469	4400240.000	0.012
Cross-flow	40391720	100716	0.401	4028640.000	0.010

Table 9.1. Summarized comparison of scenarios. Source: Own creation.

Likewise, the simulations of HOMER Pro verified that a grid-connected model would be feasible from a technological point of view. However, an off-grid model would need the implementation of back up devices like generators and batteries and extra energy generation sources in order to conform a completely sustainable system.

Finally, it is also possible to affirm that, as it was proved, there is more than one viable alternative to the Tipaimukh dam to generate energy without endangering the inhabitants of the area and allowing the free flow of the river.

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