Department of Mechanical and Aerospace Engineering

Modelling & Analysis of a Vortex Micro-Hydro Plant & Solar PV Hybrid System for Off-grid Rural Electrification in India

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Signed: Evelin Kurian Date: 23/09/19

Abstract

In developing countries especially India and Africa, electrifying the sparsely remote rural communities is still a challenging issue for the power sector. This is mainly because of the huge costs involved due to inaccessibility, interrupted power supply, and high transmission losses. Hence, establishing that the dependence on a decentralized power system is better than grid power.

In order to meet with the energy requirements of the unelectrified rural communities, the project focusses on a renewable hybrid solution for a village, located along the banks of a perennial river in Central India. The chosen system configuration consists of a low cost, highly efficient and easily installable micro-hydro vortex turbine, that harnesses electricity from the flowing water. This damless run off river scheme technology suitable for low-flow and low-head sites is combined with PV and energy storage since the area receives high annual solar energy.

This system is modelled using HOMER and validated through financial analysis, for both household and community loads of the village. It is modelled based on certain assumptions from previous studies and existing projects, ensuring the results obtained to meet the energy needs, with only a negligible proportion of unmet electricity/year. An economic analysis conducted from the results proved the feasibility of the project. If the energy demands of the system are increased in the future, more vortex micro hydro-turbines can be installed at different locations of the same river, to meet the requirements.

The optimized system enhances the autonomy of renewables with its robust methodology, which can be applied to other similar unelectrified remote rural villages in developing countries, located along the banks of the river.

A solar energy plan is also proposed for the village that takes into account other requirements, such as street lighting, cooking for household and community level, irrigation needs, water supply, and household lighting.

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Chapter 1: Introduction

1.1. Problem Definition

Today 1.1 billion people in the world still lack electricity and amongst them, 80% of people live in rural areas, according to World Economic Forum, 2018. Energy access is defined as “a household having reliable and affordable access to both clean cooking facilities and to electricity, which is enough to supply a basic bundle of energy services initially, and then an increasing level of electricity overtime to reach the regional average" (IEA,2017). The Sustainable Development Goals calls for universal access to affordable, reliable, and modern energy services and aims to increase substantially the share of renewable energy in the global energy mix by 2030 (IEA, 2017).

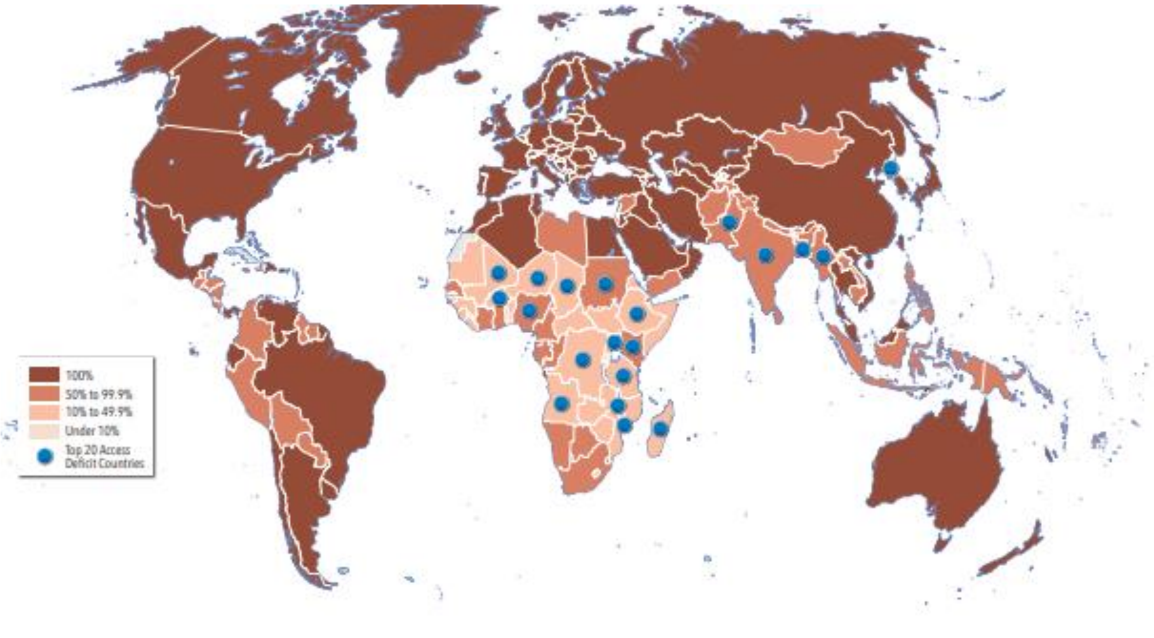

Figure 1: World Population with Electricity Access (IEA, 2019)

Rural electrification has been a challenging issue in developing countries like India, because of the high costs involved due to inaccessibility, intermittent power supply, and enormous transmission losses. Thus, establishing an off-grid electrical source is a better option than depending on centralized grid power for remote rural locations. Considering that rural households have low income, innovative small-scale renewable projects must be designed, making use of the subsidies normally available from the government, for rural electrification and renewable energy. On the demand side, by integrating local communities into the decision-making process and developing ownership within themselves, the off-grid rural electrification projects can be made more sustainable (Reiche, Covarrubias and Martinot, 2000).

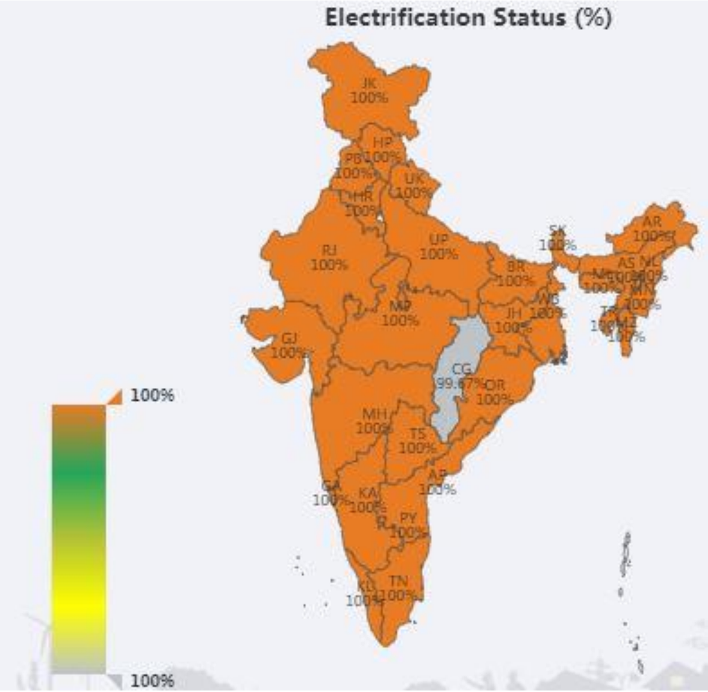

Figure 2: Status of Electrification in India (Saubhagya, 2019)

According to the electrification status in India shown in fig 2, only the state of Chhattisgarh is remaining to be electrified. There are several households in the remote areas that lack access to electricity in this state (see fig 3) and the project focuses on electrifying one such village by an off-grid renewable source.

Figure 3: Household Electrification Rate (Saubhagya, 2019)

1.2. Overall Aim & Objectives

The overall aim is to determine an optimal off-grid renewable solution for a remote rural un-electrified location.

The aim is achieved by accomplishing the following objectives:

- To identify the need for decentralization and achieve a fully renewable energy autonomy.
- To determine the current energy demand of the chosen rural village that is yet to be electrified.
- To develop an optimized model that meets with these energy requirements, by making use of the available local resources.
- To ensure the feasibility of the model technically, economically and environmentally.
- To justify the benefits of designed renewable energy model over grid power.
- To identify a solution for coping with any future increase in demand of the village.
- To produce a methodology which can be implemented in similar un-electrified rural villages.

1.3. Methodology

The methodology adopted fulfils the above objectives and aims by:

Step1- Calculate an hourly demand profile and the total load consumed in a day for residential and community sectors.

Step 2- Determine the exact location of the village to identify the suitable available renewable resources in the area that can be used to design the model.

Step 3- Identify the type of technology for power generation and describe the model.

Step 4- Find the input variables for designing the system architecture that is to be configured in the software.

Step 5- Suggest the cost breakdown of the components used in the system which includes O & M, replacement and cost of installation.

Step 6- Determine the best-optimized model from HOMER ensuring the energy requirements are met and it is economically feasible, with the highest renewable fraction and lowest carbon emissions.

Step 8- Conclude with discussion from the results, challenges and future scope of the project.

1.4. Thesis outline

This thesis includes the following five chapters:

Chapter 1 – Introduction

This chapter gives an insight into the background of the thesis formulation and problems which are to be investigated. The overall aim and specific objectives are established along with the thesis outline.

Chapter 2 – Literature Reviews

A range of papers and researches regarding the challenges of rural electrification, electrifying using renewables, energy statistics of India - current scenario and the scope of renewables. Further, an insight into micro-hydro and solar technologies.

Chapter 3 – Methodology

An introduction to the vortex micro-hydro technology along with design, working, advantages & disadvantages of the system is explained. The various projects and the proposed location of implementing is also investigated. The chapter concludes with energy plan that is proposed for the chosen site location.

Chapter 4 – Energy Modelling

The energy requirements of the village including residential and community loads are calculated and modelling is carried out using software HOMER for analysing the off-grid hybrid model. Input parameters, simulation results, discussion and conclusion for the overall design is explained.

Chapter 5 – Economic Analysis

From the software model developed in HOMER, an economic analysis is performed to calculate the net present cost and levelized cost of the proposed system and to check the level of feasibility.

Chapter 6 – Conclusion & Future Scope

The report is concluded by mentioning that, the objectives of the project are met and the scope of the project in the future is discussed.

Chapter 2: Literature Review

2.1. Challenges of Rural Electrification in Developing Countries

Major challenges for an electrification program in the rural areas include the high upfront costs, low-income consumers scattered around and decentralization of electricity supply grids which are currently being extended (Urmee, Harries & Schalpfger, 2009). These are identified as the main factors leading to low electrification rate in the rural areas. Additionally, there are limited financing availability and institutional weakness mostly exist across the developing countries. Other barriers for developing countries are the added costs of transmission and distribution, over dependence on donors, low electricity demand and low consumption (Ranganathan, 1993).

Another common issue seen in developing countries for rural electrification is that they are not often focussed on an economic rationale decision making, due to political reasons (Urmee, Harries & Schalpfger, 2009). For example, a solar electrification program undertaken by government of Bangladesh was eventually abandoned because the energy Minister made an election commitment to extend grid supply to rural areas, which was not feasible (TP, 2000). Moreover, some of the rural areas are declared as electrified by merely installing a transformer in the village without being connected to any grid. The level of electrification depended on the power line extension in that specific area expressed as the percentage of rural electrification instead of measuring the percentage of electrified households (Bhattacharya, 2006).

A study on Pico hydro-power system of less than 5 kW for developing countries was identified as a cost-effective option effective (Williams & Simpson, 2009). By using standardized system components an approach to low cost design scheme can be achieved. If the equipment is manufactured locally, the costs with respect to the unit energy output are reduced thus making it more feasible than other renewables such as wind, solar or diesel. Even though they will be designed in developing countries the technical quality of the system is not compromised which otherwise will lead to failure of system operation or system efficiency. Moreover, varying cost reductions results in the step back of the technology being implemented in a long-term perspective.

Nevertheless, the issue depends on the implementation techniques and engineering design which is site specific and needs to be customized. If the location has abundant hydro sources to produce electricity, Pico hydro provides the most feasible option of all hydropower plants which are both environmentally safe and an off-grid system. Relatively, a low cost per energy unit output is achievable using economical equipment that also provides high efficiency. Although the technology can be widely used, the Pico hydro system has to be specifically designed considering the requirements of the location. In order to bring out the best of this technology to the rural communities at local level, a need for organizational and technical capacity growth is necessary. Both Pico and micro-hydropower are expected to have reduced technological advancements compared to other renewable sources.

In Africa, Pico-hydro technology is ideal as it has a high potential due to lower installation costs and reliable energy production for equipment (electrical and mechanical). The engineering design for this system incorporates a pump as turbine technology and a Pico power pack. However, the authors agree that effective co-ordination between entrepreneurs at local level and NGOs are absent as the flow of communication regarding any system inquiries is not effective (Williams & Simpson, 2009).

A paper focusing on a community based micro-hydro technology and its approach to achieving rural electrification was examined. It is noted that a perennial flow of a stream with a reasonable velocity can be used for hydro village electrification., with a reasonable flow of water and a difference in the elevation produces energy. Theoretically, amount of energy produced depends on the velocity of flow and height difference, as derived from the law of conservation of energy. Loss of energy occurs in transformation at the infrastructure level and a typical system serving communities has a maximum overall efficiency of 60% (Shreedhar,2015). Hence, during the design, construction and implementation stage, the need to utilize maximum useful energy with least losses is essential.

A weak policy framework is also a barrier to a low rate of renewable programs as seen in many studies. High capital cost, lack of subsidies and financing, low-income users, dependency on a donor, political reasons and lack of technical know-how, the major factors concerned with electrification (Urmee, Harries & Schalpfger, 2009).

2.2. Rural Electrification using Renewable Sources

According to the studies regarding the energy consumption in villages, it was identified that countries like India, Bangladesh, Nepal, and Myanmar constituted 70% of the total energy consumed (Shafiq, 2016). To counter the rural energy issue, the authors proposed that the energy supply, needs to be improved technologically using cost-effective systems and by reducing the social impacts and mitigating the environmental issues (Cherni. et. Al, 2007).

Access to energy can be made through the deployment of off-grid renewable technologies instead of waiting for a national grid power connection. In the context of electrification, it is necessary that the grid also reaches the scarcely distributed households and not just the main village area (Kemler, 2007). This study mentions that there exists spatial heterogeneity within the villages, with some households having more access to electricity than the others.

For the village Degalras, only after the successful construction of substations will they have access to electricity (The Pioneer, 2016). Moreover, even with grid access, there are several power outages occurring using the no cost-effective tariffs for electricity.
Constraints on decentralization generally dealt with user conflicts, high political costs and lack of administration or know-how of the management services.

For a sustainable system to be implemented, various factors need to be taken into account (Feron, 2016):

- Decentralization and participation go hand in hand and all other sustainability dimensions should be equally considered accountable and transparent, throughout the decision-making process.

- Reliability of the system and its cost-effectiveness are essential indicators for an economically sustainable electrification solution, ensuring the affordability of the system from the initial investments to the lifetime operation and maintenance.
- Enforcing environmental policies and regulations requires the awareness of the civil society to minimize and mitigate the issues on the environment. Energy solutions should address the environmental concerns such as GHG emissions, biodiversity loss, deforestation, air quality or noise needs to be raised.
- Socio-cultural conditions have to be met for the successful implementation taking into account the accuracy of technology and increased accountability within the local community through an inclusive approach.

Adopting a regulatory framework and standards favours electrification of rural households for a sustainable system. Technological enhancement through effective participation and adaptable process to meet needs of the population also lead to a strengthened formal institution. Electricity generation not only has benefits in agriculture such as irrigation and crop processing but also improves the standard of living in rural villages.

Availability of renewable energy sources is variable depending on the site location because different areas possess variable types of energy sources. The output can be controlled either with the installation of individual large renewable plant or using an integrated renewable energy system. The latter option is widely used in the world today for a decentralized model of rural electrification.

The renewable-powered isolated grid connections for the rural areas are identified as clean energy as well as a sustainable solution for Indonesia (Blum, Wakeling & Schmidt, 2013). Although the conventional rural electrification challenges are met by the expensive grid extension or diesel-powered villages, both of these options are characterized by their greenhouse gas emissions and high operating costs. One of the main reasons for not selecting renewables despite its advantages is that private sector fails to provide investments for clean energy-based village grid and instead leave the responsibility for the governments. Governments, on the other hand, commit to a conventional and centralized solution leading to low diffusion of renewable systems. The paper focusses on the economics of rural renewable systems and analyses the average cost of electricity in Indonesia for solar and micro-hydro powered villages to the conventional diesel operated villages, in order to identify the difference in cost (Blum, Wakeling & Schmidt, 2013). It also takes into account abatement costs of CO2 emissions and mitigation strategies.

The results from the paper indicated, micro-hydro is used over diesel for powering, which makes it more competitive. Moreover, micro-hydro plays a positive role in the carbon emission abatement costs with potential for carbon reduction. Further, it has the lowest generation costs compared to all sources while attracting subsidies from the government. The deployment of this system can lead to a substantial improvement in the electrification rate with zero carbon emissions. The village technology sector will be improved eventually with scalable and high quality micro-hydro powered manufacturing. This leads to economically developed rural areas in the country. In this study, a methodology pattern similar to this paper is used (Sahoo, 2016).

Another model consisted of an off-grid renewable technology optimized with grid extension for rural electrification, using life cycle cost analysis (LCC). In this case, solar PV and biomass gasifiers were used for generating electricity, combined with the conventional grid connections. An economical distance limit is a distance from the existing grid point which is related to the renewable systems and the model developed produced a match between the grid supply and the renewable energy systems. The working hours of solar and biomass and also the grid availability were taken into account for identifying the LCC of the energy fed into the system. From the results on this study it was determined that biomass systems are most competitive for the low demand areas which are situated far away from an existing grid connection, compared to a solar PV or grid extension (Mahapatra & Dasappa, 2012).

2.3. Energy statistics of India

India holds a share of 4.9% of the total global consumption accounting as the fourth-largest energy consumer in the world (British Petroleum, 2015). Contributing 17% to the world population exceeding 1.2 billion inhabitants, India stands in the South Asian Association for Regional Cooperation (SAARC) as the largest country in terms of gross domestic product (United Nations, 2015). Relatively, the demand for electricity also grows with a high population growth rate and the rising GDP which is expected to increase at 8% per annum until 2030 and beyond that at 6% (Energy Report, 2011).

The primary source of energy for India is coal followed by oil and gas generation. Moreover, the country is also the third-largest producer of coal, in the world after China and United States (Enerdata, 2014). As a result of which India has lot of subsidies for fossil fuels (see fig 4), especially coal as stated by the International Monetary Fund (Coady, Parry, Sears & Shang, 2015). Moreover, the research and development are motivated to focus on the coal aspects such as coal mining and coal transportation which is supported through tax benefits (Ministry of Finance, 2015). While optimizing the energy supply costs, the country faces increasing health costs due to heavy metal emissions which the coal powered plants do not take into account (Buonocore & Epstein, 2011).

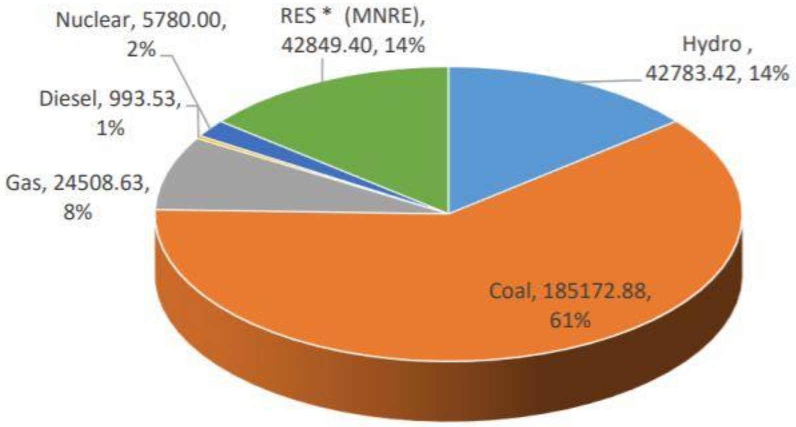

Figure 4: Total Installed Capacity in India (CEA, 2016)

In the context of energy growth, India is making substantial progress but on the brighter side, the government is providing sustainable electricity, trying to bring down the climate effects whilst ensuring electricity reaches all citizens. The average cost of electricity is estimated to become expensive by 2020 from coal power plants whereas, onshore wind and PV costs are expected to reduce, resulting in less usage of coal and stranded power plants in the years to come. The studies show that load factor of the plant has already fallen to 64% in 2015 from 79% in 2007 (Ministry of Power, 2016). Due to this reason the imports of coal are observed to be lower and the statistics indicate a drop in 15% compared to the previous year in 2016 (Buckley, 2016). The stakeholders at ministry of energy in India has identified that an idea of new coal powered plant is expensive option compared to solar plant for which the country has abundant solar energy and, along with solar PV prices expected to fall further in the next decade (Buckley, 2016). The Central Electricity Authority in India proposes that no new coal plants should be added to the current levels as there is already sufficient capacity which will meet the energy requirements until 2022 according to the National Electricity Plan (CEA, 2016).

If the production of coal is expected to rise 5% each year, the studies indicate that the coal reserves will last only up to another 30-40 years. According to the World Institute of Sustainable Energy, a study conducted regarding the electricity production from coal, that has a capacity of 400 TW, is predicted to end by 2032. India is estimated to produce up to 84,000 MW installed capacity of hydroelectric power running at load factors of 60 % efficiency, focussing on renewable energy. The government aims at accelerating a plan for the development of hydro to install 50,000 MW capacity installed by 2026, most of which will be concentrated in the southern regions of the country, approximately by the finish of the 14th- Five Year Plan (Planning Commission, 2006).

A research study conducted for renewable energy in India observed that although there is a major shift since the year 2008, some of the dynamic fields are yet to be researched. The installed capacity has exceeded over 10,260 MW compared to the initial plans for 9000 MW according to the eleventh five-year plan. Biomass installed capacity in India is 17,500 MW which consists of 11% of the total renewable energy production share (see fig 5), indicating a high potential. A continued growth of biomass considering a large number of forests and agriculture that the country possesses is expected, through sufficient incentives and support from the stakeholders (Sisodia & Singh, 2016).

The renewables deployment is expected to be increased by the year 2022 and capacity of 175 GW (100 GW solar and 60 GW wind) is targeted to be installed in India, according to a statement given by the government authorities (Buckley, 2015). The electricity plan drafted by the government of India proposed that a share of 54% from the total electricity produced in the country will be from renewables, 2% from nuclear and remaining 44% from fossil fuels, by the year 2027. Within the 54% renewable electricity share, 43 % is predicted to be from new renewables, which are yet to be installed and 11% from hydropower, but this makes up only 40% of India's target, stated in the Paris Agreement, set for 2030 (CEA, 2016).

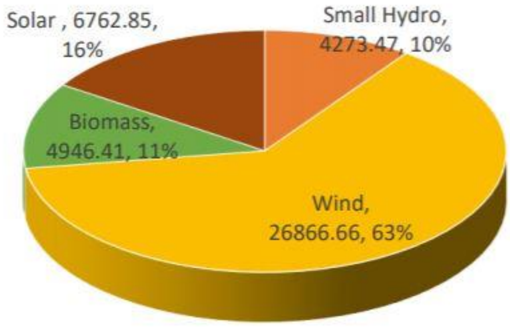

Figure 5: Total Installed Capacity of Renewables in India (CEA, 2016)

The 'Electricity for All' goal by the government requires support from governments all over the world, for the infusion and heavy investments in new technology (UNFCC, 2015). This could be achieved on the basis of in-depth research& development, formulating policies in long-term context, renewables usage in large scales and producing locally manufactured critical raw materials.

In recent years renewable energy sector has been making rapid progress for the development of these technologies which are related to the pledge taken by India for the initiative 'Electricity for All' and the climate changes actions. In the context of attracting renewable energy, India has been ranked the fourth position on a global scale (Ernst & Young, 2012). Moreover, India has made alliance with the sun-belt countries in an 'International Solar Alliance' initiative during COP 21 to form the most powerful alliance which will assist these countries to disseminate and collaborate with each other while working for the same goal (ISA, 2015). The COP 21 which was conducted in Paris helped the stakeholders to make serious decisions in respect to limiting global temperatures variance below 2 degrees, where India supported this motive (UNFCC, 2015).

About 70% of the total country's population belongs to the rural areas, which are depending solely on the natural resources and with the rising population at a rapid rate can lead to complete exploitation of these natural resources. As the demand for energy increases in the coming years, temperatures rise, unpredictable monsoon causing droughts and floods and the rising sea levels will altogether impact the population of India negatively (WBGU, 2007).

The clean energy sector in India offers a wide range of sustainable models. Even if the grid expands there is always a need for modern technologies as the demand increases. In order to meet the energy gaps of the poor, innovative ideas which are simple and easy to implement are encouraged by the government. Moreover, India is offering support for a reliable and adequate power supply, increase the intake of cleaner energy sources, improving the use of resources efficiently, energy security, employment, and entrepreneurship at local levels (SAGE, 2015).

2.3.1. Electrification Scenario

In today’s context, electricity means having an infrastructure for rural electricity, connections to households, providing sufficient amount of power to meet the demands, ensuring the rate of electricity is economical and an efficient sustainable method used for reliable supply.

A study specifically stated that among the countries in the South Asian Association for Regional Development, India especially needs to focus on improving the intake of renewables deployment to maximize the energy sector even to the remote rural areas, eventually promoting economic growth and human lifestyle. As in the case of India, the number of unelectrified houses is related to the economics of nation hence, more the households are out in the light, with clean and continuous electricity supply, the faster the country develops (Breyer, Bogdanov, Choudhary & Gulagi, 2017).

The power sector in India however, is facing challenges over the past few years due to the lack of appropriate fuel, unsuccessful policies related to environmental issues, reluctant financial aids from banks, high distribution and transmission losses, insufficient tariffs, low rate of the economy leading to reduction in the demand of power.

Some of the issues faced in India for a low rate of electrification is summarised in the following points (Electrification in India, 2010):

- Location of villages are in the range of 3 to 80 km from a grid supply,
- Remote areas such as hills, deserts, and forests,
- Dispersed households with around 2 to 200 units of distributed loads,
- consumption during peak hours,
- rural demand for power is low,
- a poor load factor of 0.2 - 0.3 and
- low income consumers with less paying capacity.

The idea of implementing renewable technologies will impact the imports and manufacturing sector. Therefore, if dependence on imports is reduced, then competition within the local markets increases and the research and development of energy storage and their targeted investments also increases. There is another option of innovation, aside from importing and manufacturing strategies. By the method of process innovation, a choice that could be made by the renewable sector can lead to creating efficient models using technologies (solar, wind, micro-hydro) across a wide scale of operations including a village, district or households, available to invent decentralized clean energy system.

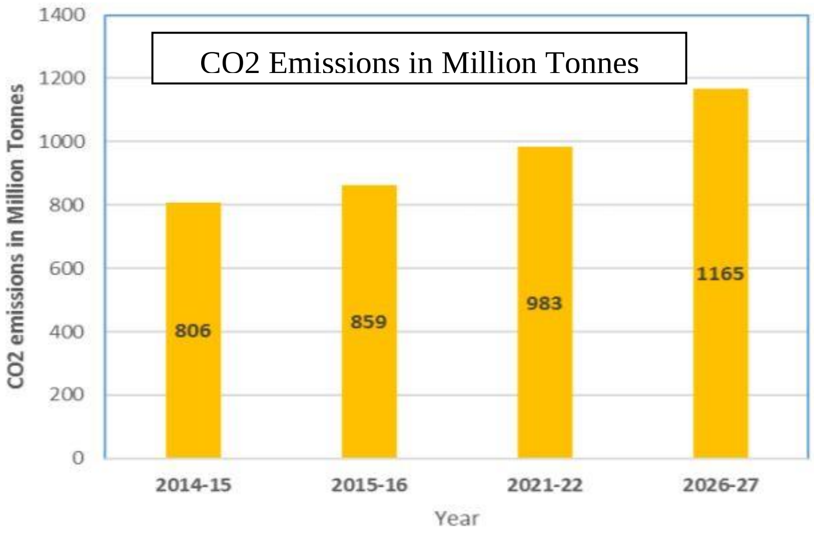

Figure 6: Total CO2 Emissions (CEA, 2016)

Climate change and global warming threats to the environment is another perspective for increasing the deployment of renewable projects globally (see fig 6). Over dependence on fossil fuels and dwindling coal and petroleum resources to meet energy demands are prompting countries to opt for internal resources. Micro-hydro is a local technology which is being used over decades to meet energy demands of the poor. For communities that are yet to be connected to the electricity grid can select micro-hydro solutions which have been a proven successful technology. They are usually operated and owned by the communities itself which provides a better standard of living for the poor with increased education time for children and better safety. The productivity can be extended with more operating hours and all of this achieved on a low budget scheme (Shreedhar, 2015).

2.3.2. Scope of renewables

Decentralized off-grid renewable systems are one of the options looked at by the government to meet basic needs in rural areas (Planning Commission, 2011) (WWF, 2013). Those locations, where connection to the grid or extension of a power supply is difficult to achieve either technically or economically, the solution would be decentralized operation of the power systems. This will mitigate the issue of common power outages which occurs in the grid systems and meet the basic needs of the communities or households in the far away locations. This can be achieved through long term successful planning required for securing energy, where the resources from renewables will be split into centralized and decentralized sections, minimizing the carbon footprints and reaching the sustainable goals.

For an entire rural community to be electrified, Ministry of New and Renewable Energy (MNRE) in India aimed to introduce renewable technologies such as solar, wind, biomass and small hydro (MNRE, 2017). This was aimed to achieve by using grid extension and franchisee models connected to the tail, hence feeding it into the grid. DDG for diesel power operation for local level generation and, household generation using micro-hydro or solar to meet the basic and primary demands. The rural communities in India still lack extension and interconnection of the grid system and battle of the poor still continues for the demand of power (Kamalapur & Udaykumar, 2011).

Ministry of New and Renewable Energy in India according to the author is in the final process of access to rural electricity all over the country. Considering the current situation of these areas, grid extension is an expensive option but on the other hand almost all parts of the country possess an abundant source of solar energy which will act as an efficient and reliable source for electricity production in the long-term process. Integrating it with biomass can help produce clean energy for cooking gas as well. Thus, the government needs to redefine and incline more renewable schemes to meet the energy gap and provide more incentives from the government for successful implementation.

A study suggested the policies of governments towards MHP systems be redefined by including appropriate construction techniques, replacing conventional technology with the modern system, providing technical training for the local communities and provision of better financial aids (Drinkwaard, Kirkels & Romijn, 2010). In return, the sector will provide improved learning processes over time, to overcome the lack of appropriate technical information lost during the manpower turnover. The organizations in charge of implementing this technology must introduce long-term management structures, focussing on its importance and link efficiently with the local communities periodically post the project completion as well, in order to analyze and monitor the data regularly. This not only benefits a community but indirectly the national economy is improved.

In a case study of MHP system installed in Nepal, it is concluded that an appropriate corporate methodological approach, minimizing political issues and sufficient financial aids for the success of a renewable project (Gurung, Gurung & Oh, 2011). Some of the factors that relate to this are coverage, affordability, quality, profitability, and sustainability of the households. The site faces grid extensions and connection issues as its mountainous area and lacks technical abilities. The demand is rising (see fig 7) and economy is poor making it more challenging to solve the issue. The expensive grid extension has resulted in the isolation of communities in rural areas especially the smaller sized villages with a low electricity load for dispersed poor consumers. For example, the villages in the Himalayas face challenges to meet the basic energy requirements and have to depend on conventional sources such as kerosene, candles, and trees for firewood. Natural resources are exploited at peak and the shift to renewable technologies can result in proper utilization of the resources.

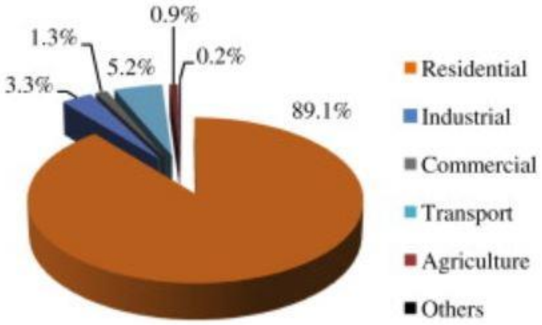

Figure 7: Sector wise Energy Division in India (Gurung, Gurung & Oh, 2011)

The MHP systems have proved to be a working technology in these areas improving also the socio-economic status of the communities. Indirect benefits including income, education, sanitation, health, and environment have helped the households. For example, the electric lights at homes function for throughout the night without any power outages making it a reliable source of dependence. Thus, through this scheme the community was able to receive sustainable, clean and affordable energy, essential for the overall development of the communities in Nepal (Gurung, Gurung & Oh, 2011).

Nevertheless, the constraints of the project that is optimization, planning, and evaluation have to be taken into account which will effectively manage, utilize and develop an MHP scheme in a successful manner.

2.4. A Study of Micro-hydro & Solar Systems

A study for a standalone hybrid system of solar and micro-hydro lead to the result that, it is the lowest cost of electricity production for remote rural villages and uses the parameter of energy load requirements, to satisfy the demands (Kusakana, Munda & Jimoh, 2009). Through this parameter, a technologically active and economically viable hybrid system is identified considering water and solar resources as continuous supply of energy. The software HOMER created optimization models according to the load requirements, operating and installation costs, input system component costs, solar radiation and streamflow (Kusakana, Munda & Jimoh, 2009). This output compared to the conventional electrification methods, diesel powering and grid-extensions was proved to be more viable.

A micro-hydro system implemented successfully in Bolivia provides the results from the insights of various cases, which were analyzed, resulting in positive feedback on the usage of micro-hydropower (MHP) durable (Drinkwaard, Kirkels & Romijn, 2010). Despite MHP being a renewable source, it has several more advantages over the other renewable sources. Rivers are the more concentrated form of energy, unlike solar or wind. The perennial run-off rivers provide electricity all year round irrespective of seasonal changes and can predict the generation of electricity throughout the year. The GHG emissions calculated for the system lifetime is found to be extremely low and practically nil. It is concluded that the operation and maintenance costs are low for this system (Paish, 2002) moreover, the frequency of maintenance is also less, making it more durable.

Once the location of implementing micro-hydro technology is identified through surveying, the equipment with optimum efficiency is selected and different combinations are studied. Using the parameters such as cost, distance, the capacity of overall scheme, safety, environmental aspects, land use, and maintenance are used for the basis of selecting a model for the scheme. The survey aids to design the system using the flow rate, head from the drop of flow, civil works for the location, distribution lines and the demand of electricity of the rural community. Although, design flow rate of the system depends on two factors which are climate changes and pattern of water usage that changes continuously (Shreedhar,2015).

Among all the off-grid systems the micro-hydro technology is identified to be the cheapest. A strategic niche management approach was introduced in the paper to overcome the challenges for the success of MHP systems to provide solutions beyond the common issues. The underlying factors provided an insight into the various aspects responsible for the eradication of the problems faced by this technology not just for the case of Bolivia, but for rural electrification in developing countries as well.

An MHP installed in the villages of Bawan Valley, Indonesia is focussed on an instantaneous system approach, excluding the electricity demand fluctuations required for a robust assessment. As a result of which, during the peak demand times, mostly in the evening, power outages in the system occurred. One of the villages even experienced overloading but current limiting devices were installed and it was not a significant technical issue. With increase in demand for electricity in the households, fluctuations result in the limiting devices to face a by-passing behavioral phenomenon. The demand management of the electricity distribution is varied with the set limits. Thus, this approach of current-limiting is moderated by the electricity distribution companies (Murni, Whale, Urmee, Davies & Hariees, 2012). The local communities have a lower cost of electricity production system compared to the conventional kerosene lamps and generators (diesel & petrol) even though availability of water is variable and a reduction in water level could affect the water supply, this system is preferred by the communities. The operation and maintenance which are efficient social factors, also crucial for the project

The results from micro-hydro system installed in the Bawan Valley villages of Indonesia where hydro resources are promising, indicated a successful production of electricity for the villages all year round (Murni, Whale, Urmee, Davies & Hariees, 2012). The challenges of the system starting from its initial deployment to the impacts of this system in the local communities was ignored due to this. As a result, they are built not only by the private sectors but also by the communities and even the government. Various surveys and energy audits conducted in these villages revolved around the findings that the success of this renewable system not only depended on the technological aspects including system design and O&M but also on appropriate planning strategies and involvement of the community as a whole including stakeholders.

The social factor develops a strong village capacity in rural areas resulting in a successful project. From the several surveys conducted, proper design of a micro-hydro system is crucial although, it doesn’t mention about the river flow data for long-term in this case. Hence, the highly variable and unpredictable output was used for the capacity calculation of the system on the basis of spot readings. The climate changes on rivers are uncertain and according to the researches in developing countries such as Vietnam, India and Sri Lanka, the impacts vary on a regional and global scale (Iimi, 2007). In the rainy season it is expected that the hydrological discharges increase. On the other hand, with the expected global climate changes in the coming years, the overall temperatures are predicted to rise with lower rainfalls. The need of precise data for hydrology considering the varying climate changes is crucial.

Points that are to be considered for successful implementation of micro-hydro technology:

The following aspects needs to be considered for the development and planning of a micro-hydro plant which includes: manufacturing and installation of the system, involvement of local communities, financing aids using subsidies or reduced tariffs, proper maintenance and follow up of the project after completion, and the study of socio-economic aspects of the new implemented technology. These factors can lead to a successful operation of hydro-electric plant and if monitored periodically can help the local communities reach the electrification goals. This eventually leads to better lifestyle and economic developments in the remote rural communities (Fulford, Mosley & Gill, 2000).

A scheme needs to be developed from the hydro data collected over a period of time to design a system for specific power requirement and if the system uses spontaneous data to predict the power of the system it will result in its failure. For example, a cumulative year’s streamflow is the duration used by designers to assist in the designing of flow rate for the scheme. Various methods can be used to determine this including enquiring with the local communities, estimating flow rate in the catchment area using rainfall data or by simply calculating the flow rate at periodic interval for all year round (Shreedhar, 2015).

Chapter 3: Methodology

3.1. Introduction

A run-off river plant is also known as a dam less hydro plant is the technology selected for meeting the demands of the village chosen, as it is located along the banks of river. All over the world especially countries like China, Brazil, and Canada, who have high potential in hydr0-power and installed large hydropower plants, are implementing more of this technology due to the various advantages of this system. On the other hand, countries such as Austria, Norway, Nepal with uneven topography, have also been on the rise for this run-off river scheme. There are various positives to this system mainly it's environmentally friendly nature.

The qualities of the system are listed below:

- The system requires very less maintenance throughout the system lifetime since there is only a single moving component. Moreover, as a means of protecting the system from debris small or large, a trash rack has been incorporated into the system.
- Due to the advantage of low maintenance, the system lifetime is extended to 30 years (Turbulent, 2017), consisting of much longer operation compared to other technologies.
- Regarding the system installation, the turbine can be assembled prior to its delivery, due to the easy and simple structure. The vortex turbine can be transported to the site location easily. This turbine is also the smallest when compared to the others in terms of specific energy levels.
- Usually, a micro-hydro dam power plant has flood risks due to an unsuccessful sedimentation passage causing threat to life, whereas, in this technology, the system does not restrict the flow of water which eliminates this issue.

- Moreover, being a small-scale technology, it can be installed at any site such as a creek, river or stream, ensuring there is enough height (works for low height). The project consumes only very little land space or sometimes even nil, improving the flexibility of the system.

3.1.1. Design of Vortex Micro-Hydro Plant

The vortex turbine as shown in figure 8 consists of the following components (Turbulent,2018):

- Power Point Tracker

Identifies the maximum flow of water for maximum electricity production using a controller developed using algorithms for optimization.

- Trash Rack

To allow in the smooth passage of water, a trash rack is included which will clear blockage due to any debris materials.

- Vortex

The shape of the basin is designed specifically to ensure the safe passage of the fishes and aquatic life, producing a low-pressure vortex for the inlet water. The basin is made of concrete has a lifetime of 100 years.

- Sluice Gate

The flow of water is controlled automatically using sluice gates.

- Hub

Has an anti-corrosive coated impeller hub which is made of cast iron and consists of blades made of stainless steel.

- Electronics

The power electronics devices used in the system have high efficiency and improved reliability, providing long life for more than 15 years of uninterrupted power supply.

- Rotor

For a high yield of electricity during summer and winter, this is designed with tilted blades which can be manually controlled.

- Remote Control

This technology can also be monitored and controlled from any location at any time of the day, as mentioned previously because of a secure remote controller installed into the system. This enhances efficiency, reliability and autonomy ensuring safe operation of the system along with predictive maintenance.

- Generator

Considering the operation of the system is 24/7, the generator is designed for maximum efficiency along with a premium gearbox.

- Remote Control

This technology can also be monitored and controlled from any location at any time of the day, as mentioned previously because of a secure remote controller installed into the system. This enhances efficiency, reliability and autonomy ensuring safe operation of the system along with predictive maintenance.

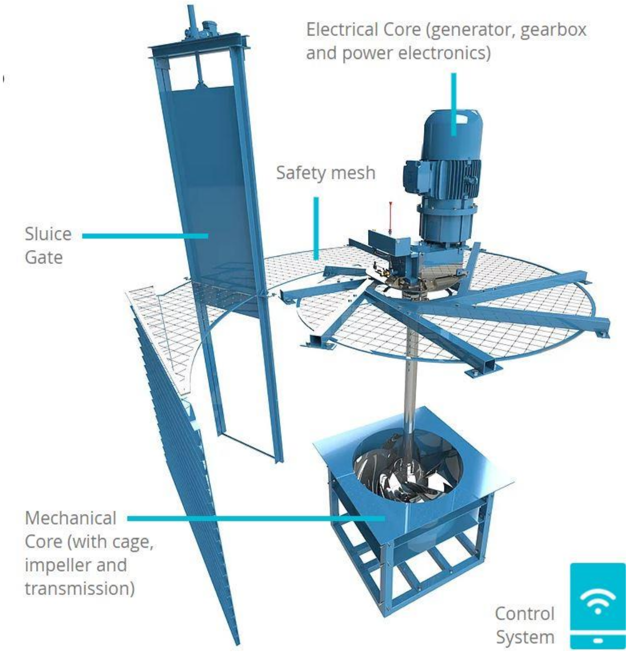

Figure 8: Components of a Vortex Micro-Hydro Model (Turbulent, 2018)

3.1.2. Working

After the fabricated parts are assembled and fitted into the system, inlet and outlet canals and basins are created. Following this at the centre, both generator and impeller are fitted and the water is let in after the wall of the canal or river is broken, which creates the vortex. It consists of a tank and a runner; as the river flows, the water is diverted to the tank, where a vortex is generated with a swirling flow that drives the turbine and then the water is drained out from the bottom of the tank as seen in fig 9 (Nishi, Inagaki). This eliminates the need for a reservoir, large dams or storage tanks. The power generated depends on the area swept by blades, velocity of flow, inlet height and the resistance force (Power C et al, 2016).

Figure 9: Working of a Vortex Turbulent Turbine (Turbulent Vortex, 2017)

The electricity is harnessed from the natural flow of water throughout the day by the turbine, with the added advantage of ensuring safe passage for the movement of aquatic species. This system has a reduced risk of failure and maintenance issues since the only moving part of the system is the generator, with blockage resistance to small and big debris.

In case, debris causes any damage or scratch, painting the system will act as a solution. This works for a height difference range of 1.5-3m and for a minimum of 1000 litre/sec flow. Because of the small and compact design of the system, it can be introduced to various location of the same river with low flow and low head.

The following are the criteria for the successful installation of this technology which includes (Turbulent, 2018):

- The minimum required level of drop lies in the range of 1.5 to 3m and in the case of a drop higher than 5m and for proportionally higher flow, two turbines can even be installed sequentially.
- The flow is expected to be at the least 1 m3/s which has to be preferably a perennial source or with a minimum consistency of nine months.
- In case of the turbine being installed on land, ideally, the location needs to have a road nearby, as that can prevent any unnecessary damage to the environment or road works.
- For remote controlling of the system (optional), for the best operation would be in a location with good receptions ideally.

3.1.3. Vortex Micro-Hydro Power Plant Projects

- For instance, Donhiue village in Chile was installed with a vortex turbine of capacity 15 kW in 2018 (Turbulent, 2018). The civil works of the entire system took less than a week after a concrete basin was installed in two weeks. The available head was 170 cm and the river flow were estimated to be around 16200 L/s (Turbulent, 2018). This installed system is capable of taking up to .1 m diameter of debris and sand, allowing a smooth operation 24/7 providing electricity to their farmland.

- A 15kW vortex turbine project was successfully implemented in Chile in 2017 (Cooke, 2018), delivering power to 300 households and working with an efficiency of 70%. Thus, ensuring the electricity demands of the villages are met through this MHP system

- Similarly, these vortex turbines have been installed in other places as well, such as a 5kW turbine in Chile that provides sufficient electricity for six households and even for a school in Indonesia with a 15-kW vortex turbine (Turbulent, 2018). The operation of this technology has proven to be successful from the installations so far.

3.1.4. Advantages & Disadvantages of the Technology

Some of the advantages of the system are stated below:

- Usually, a micro-hydro dam power plant has flood risks due to an unsuccessful sedimentation passage causing threat to natural habitats and farmlands, whereas, in this technology, the system does not restrict the flow of water, eliminating this issue. Unlike the traditional large power plants, this small-scale technology doesn’t require a reservoir, storage tank or a dam. It makes use of the energy from water resulting in clean power from minimized gas emissions, such as carbon monoxide and methane which could have been the case for traditional systems, consisting of reservoir leading to sedimentation build-up.
- This micro-hydro dam technology has a safe passage for the fishes and aquatic life, causing no threat to life. This is because of the reduced stress from the low revolution of the impeller. The design creates a low-pressure rate of the turbine near the blades resulting in the safe passage of aquatic life.

The run-off river schemes also have the following disadvantages:

- Although they produce electricity all year round the predictability of power is varied depending on the flow of the river and the major drawback being unable to store energy. Depending on the seasons, adaptability to demand is varied, for instance in the winter season if the rivers freeze (not the case for the villages selected) no electricity will be produced, in summer season if the area is dry the flow of water is affected resulting in a lower production of power, but on the contrary rainy season produces results in high electricity production.
- The run-off river scheme is best suited for locations where the flow of river is maximum and has a sufficient head. For instance, near a waterfall or where there is steep drop inflow of water.

The turbine technology implemented in different parts of the world as mentioned above are functioning efficiently nulling out the challenges of system.

3.2. Proposed Location of the System

As discussed previously, the unelectrified remote rural communities in developing countries like India and especially the chosen site location faces challenges like the huge costs for building substations added to that its inaccessibility, interrupted power supply, enormous losses in transmission and even political issues.

The system is proposed for a village located along the banks of a river in Central India. Degalras, a village as seen in figure 10 below, is situated in the district of Dantewada, in the state of Chattisgarh in India with a total population of 177 households in total, spanning an area of 721.31 hectares that comes under the Dakshin Bastar block Dantewada (District Census, 2011). The village has the advantage of a perennial river Shankini which is a subsidiary of Indravati River, flowing through it with a moderately stable velocity of 1.5 m /s (Indravati River Geomorphological Study, 2014).

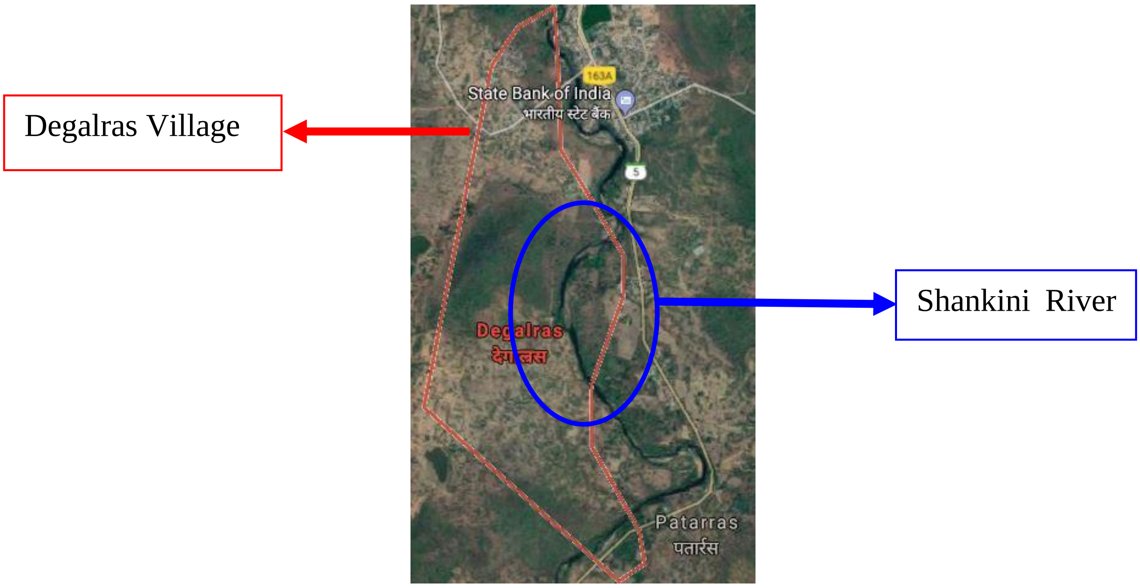

Figure 10: Location of Degalras Village in Chattisgarh, India (Google Map, 2019)

3.3. Energy Plan

Table 1 below indicates the energy planning conducted for the rural village:

Table 1: Energy Plan for Degalras Village

Rural Energy Requirement	Proposed Energy Plan
Lighting	Solar Lantern
Irrigation, Water Supply & Livestock	Solar Water Pump
Street Lighting	Solar Street Light
Cooking/household	Solar Box Cooker
Cooking/community	Community Solar Cooker
Electricity for domestic & community loads	Micro-hydro, Solar PV & Battery

3.3.1. Solar Lantern

Currently, most of the households use kerosene lamps for lighting purposes but the government's scheme is to provide and replace it with cheap solar lanterns (see fig 11), also reducing emissions (MNRE, 2017).

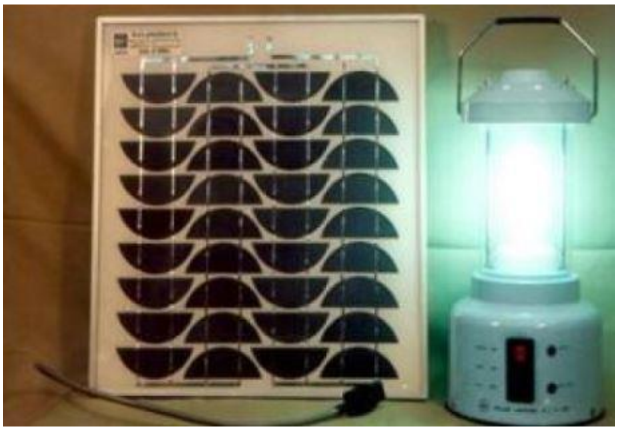

Figure 11: Solar Lantern (MNRE, 2017)

3.3.2. Solar Water Pump

The main economy of the village is from agriculture and there is an energy requirement for irrigation. This irrigation can be met through a solar water pumping system as the region receives high average annual solar radiation, which is available for a subsidy from the government. These pumps can be used to supply water and livestock needs of the village as well. This is implemented by installing the solar pumps down the basin of the river and the diverted water from the river (see fig 12) is pumped to the agricultural fields.

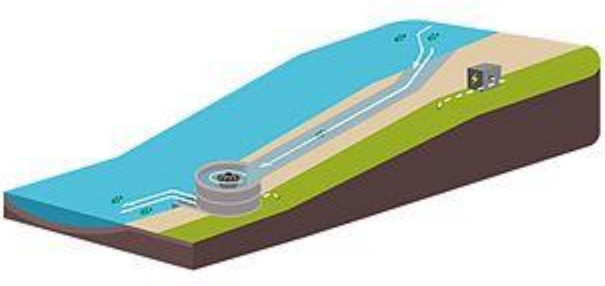

Figure 12: Solar Water Pump to be Installed Down the Basin of River

(Turbulent,2018)

The required capacity of the pump can be calculated from the total size of solar PV array. The solar pump has the following advantages (Solar Water Pump, 2018):

- Low maintenance
- Good life expectancy
- Ideal for remote areas
- Easy installation
- Robust structure
- Maximum power point tracker
- Withstand harsh conditions

The water can also be stored in tanks and used for energy requirements such as livestock, water supply or irrigation depending on the need.

It operates on a low speed and depending on the solar energy, the amount of water is pumped into the tank, having high efficiency while pumping. It consists of a DC brushless motor (see fig 13) to control the electrical energy generated from the solar panels.

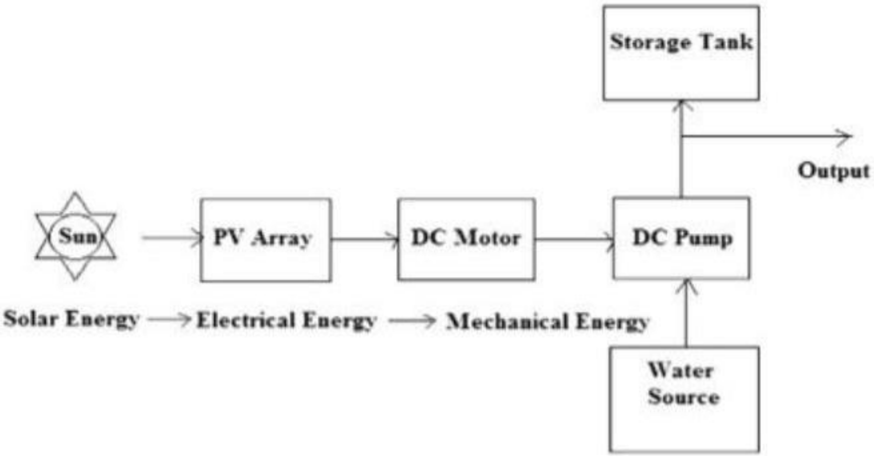

Figure 13: Conversion of solar energy to pump water (Chandel, 2015)

During the rainy season, the water can be stored in the large tank, also useful for low insolation time (summer and winter) and can be installed at different locations in the village, supplying water from the main system. A schematic representation of the design is shown below in fig 14.

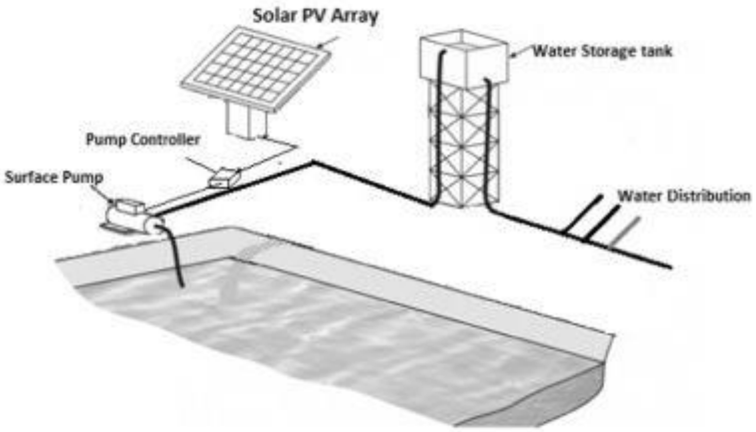

Figure 14: Schematic of Water Solar Pump (Sontake, Kalamkar, 2016)

3.3.3. Solar Street Light

For the street lighting in rural areas, a solar lighting scheme from the government in a nation-wide programme is under progress. A 12 W LED solar street light (see table 2) from a PV module of 75 Wp consisting of a battery 30 Ah for back up to operate for 10-11 hours and working on a voltage of 12.8 V (MNRE,2017). The minimum output intensity from the light is 24 lux measured 4m from under the light, for the first four hours and rest of the time it operates at 12 lux, with an efficiency of 90 % and autonomy of 3 hours with a fully charged Li-ion battery back-up, ideal for village applications (MNRE, 2017). 15 street lamps are proposed for the village chosen that are maintenance free.

Table 2: Solar Street Light Specifications (MNRE,2017)

Component	Specification
Lamp	12 W
Intensity of light output	24 lux max, 12 lux min at 4m below light
Efficiency	90%
Autonomy	2-3 days if battery is with full charge
LFP Battery	12.8 V, 30 Ah

3.3.4. Solar Box Cooker for Households

The households use dung cakes and firewood as sources for cooking presently. This can be replaced by solar box cookers, available by the central government on subsidy (MNRE, 2017). There are many types of solar cookers and the one such type is a box cooker, a solar powered oven. It gets heated up when the box is sealed and enclosed. As seen in fig 15, the box is made of a reflector on the outside which could be of any material e.g. mirrored, metallic or flat, to achieve the maximum amount of sunlight on the glass or plastic cover positioned just below it, both being openable. In the inside, it is covered in black with a length of 1-1.5m (Rathore,2015).

For the food to cook, the container is placed inside the box on the surface covered in black. This is then left in the sun and the radiations from the reflector surface fall on the surface inside the box causing the food to heat up, eventually since the heat is trapped in the enclosure because of the black body. They can get up to 150 degrees and works on the same standard principle as that of an oven (Layton,2018).

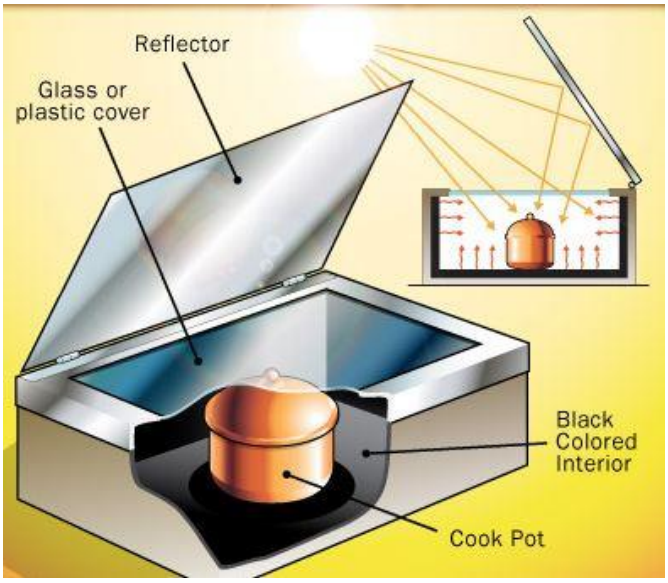

Figure 15: Solar Box Cooker (Rathore,2015)

3.3.5. Solar Cooker for Community-Scale

On a community scale, the indoor solar cooker can be used that can cook food for up to 40-50 individuals in about 1-2 hours (MNRE, 2017). The working mechanism is that a primary reflector placed outside the kitchen of the size 7m2 focusses the rays into the kitchen, while another reflector ensures the reflected rays from the primary is concentrated to the bottom of food (see fig 16) container painted in black (MNRE, 2017).

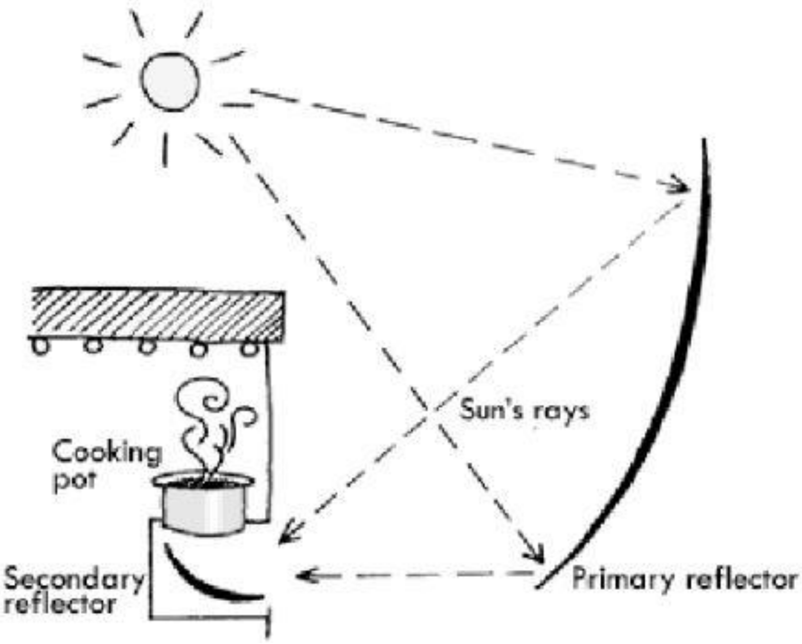

Figure 16: Working of a Solar Cooker (Rathore,2015)

In this way, the food is cooked inside the kitchen and faster as it can reach up to temperatures as high as 400 degrees (see table 3), unlike box cookers. Around two meals can be prepared depending on the availability of insolation and food type. Added to this, it can be used for heating water and with the manual adjusting arms of reflectors they can be positioned to track maximum sunlight. This is ideal for applications in schools, hospitals, and temples, as one such solar cooker can cook for up to 50 persons and bigger sizes up to 100 individuals, simple and affordable technology. Moreover, one big solar cooker can replace an annual usage of 37-40 LPG cylinders (MNRE,2016).

Table 3: Solar Cooker Specifications (MNRE, 2017)

Features	Specification
Size	7 m2
Maximum Temperature	400 C
No of persons/cooker	35-40
Time Taken	1-2 hrs

Chapter 4: Energy Modelling

4.1. Energy Demand of the Village

The consumption of electricity in the village Degalras have been categorized into residential and community loads. Since these villages belong to low-income households, the load profile is created considering average demand for electricity, similar to a rural village in Sub-Saharan Africa (NREL,2018).

4.1.1. Household Energy Demand

Since the un-electrified village belongs to low-income households, the total assumed appliances wattage which includes light, mobile phone/charger, TV, iron, refrigerator and ceiling fan is calculated to be 1274 Watts. The electricity consumption of each these appliances expressed in % derived from the individual appliance wattages is shown in fig 17 below.

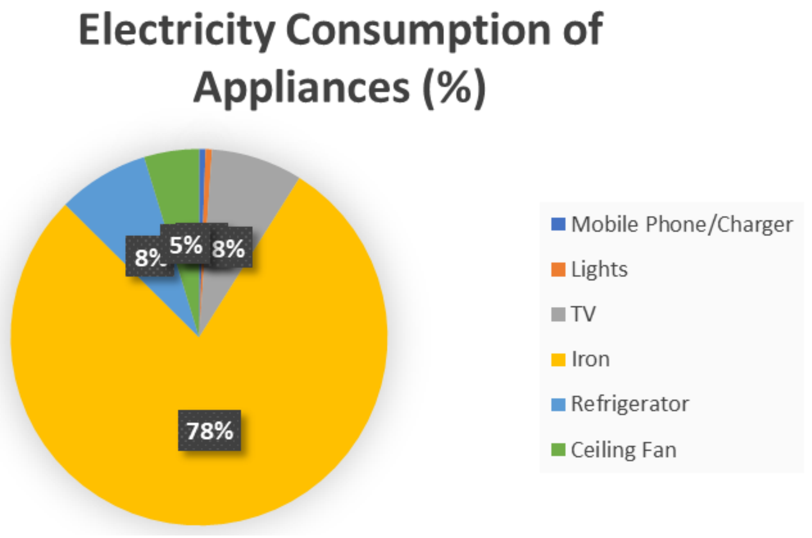

Figure 17: Assumed Appliances Wattage expressed in %

Lights and mobile phone/charger are lower electricity consumed appliances and high wattage includes a ceiling fan, refrigerator, TV, and iron as seen from fig X. Hence, the load profile for households is classified into low wattage and high wattage devices. The count of the appliances and the ownership are shown in table is X, assuming ownership limited to a certain percentage of the total 177 houses.

Table 4: Energy Consumption of Rural Households (NREL,2018)

Assumed Appliances	Appliance Count	Appliance Ownership (%)
Low Wattage		
Mobile Phone/Charger	2	50
Lights	2	75
High Wattage		
Iron	1	10
TV	1	15
Ceiling Fan	2	45
Refrigerator	1	5

The operating hours of the appliances in a day was calculated for a single household, on an hourly basis and the total number of hours determined is shown in fig 18 below.

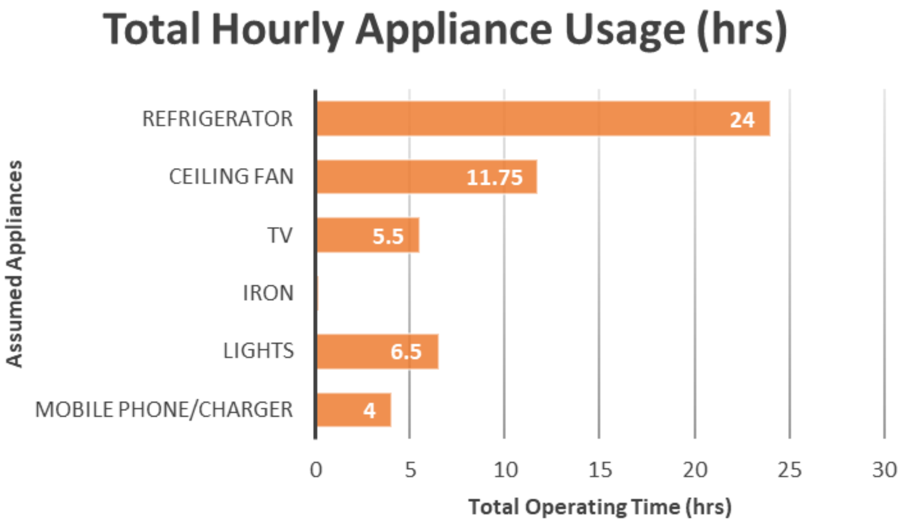

Figure 18: Total Hourly Usage of Appliances/day for a Household (hrs)

Moreover, the operation for a particular time period of the day, especially from 4 PM to 5 AM in the load demand in the households, are higher, since it’s out of the working hours and consumers are assumed to be home. The total load was calculated for a low-income rural household for the village to be 1.0638 kWh/day which is 32.357 kWh/month (Agrawal, Bali and Urpelainen, 2019). A load profile was created on an hourly analysis basis (see fig 19) for a single household taking into account:

Assumed Basic Appliances, Appliance Wattage, Appliance Count, Appliance Ownership and Appliance Operating Time.

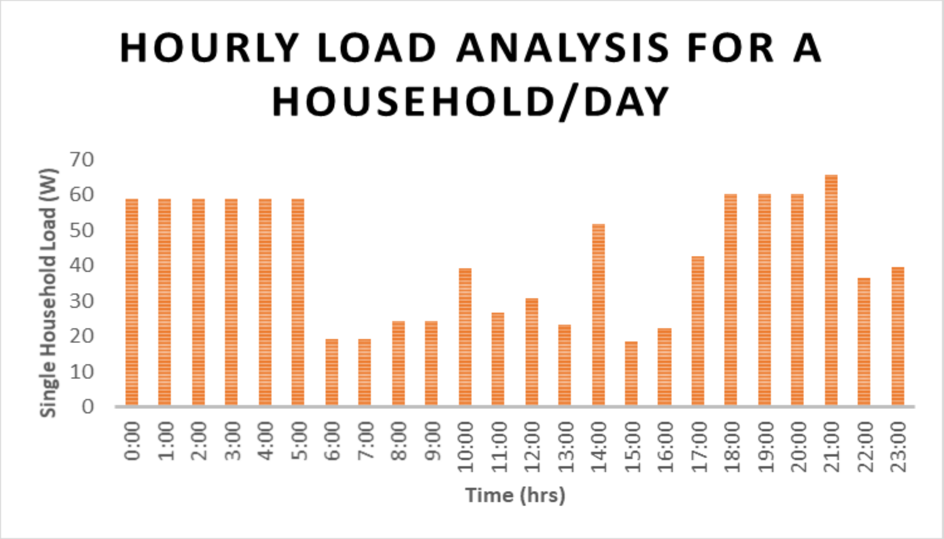

Figure 19: Hourly Load Analysis of a Household/Day

4.1.2 Community Energy Demand

In the case of community load analysis, school, clinic, small shops, street lighting, water pump, and milling are the entities considered. The electricity consumption of each these entities are expressed in % derived from the individual entity wattage (NREL,2018), are shown in fig 20 below. It is noted that milling and water consume most of the electricity and street light (on per light) the lowest.

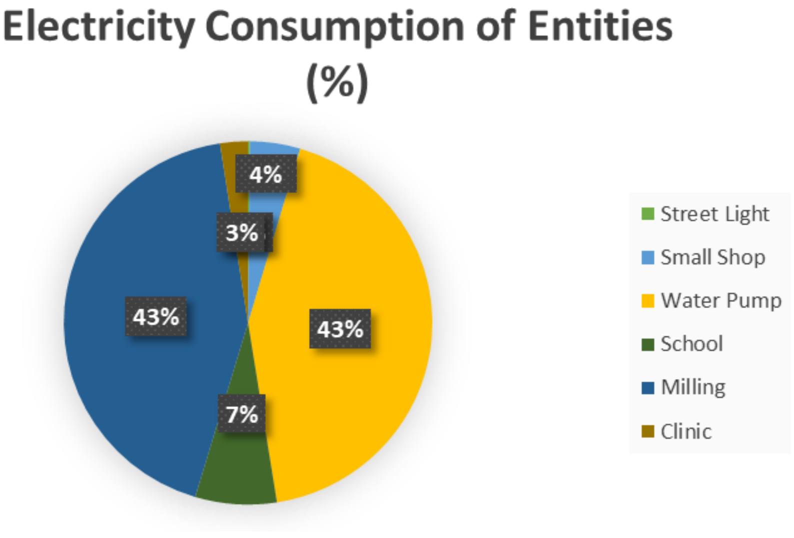

Figure 20: Entities Wattage expressed in %

The total operating time of the entities for a day is mentioned in the fig 21. The values are calculated from an hourly analysis performed for the village for a day.

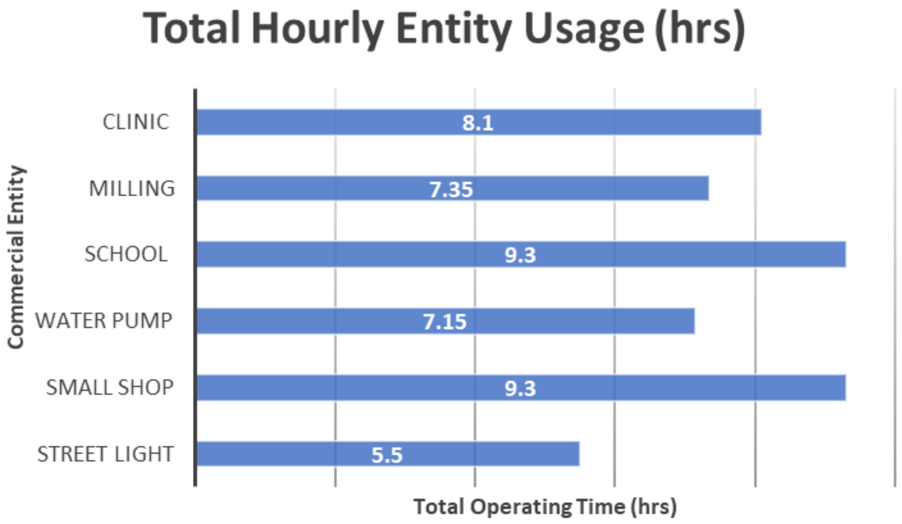

Figure 21: Total Commercial Hourly Operation/day (hrs)

The above figures are assumed for a village but the actual entities count for this village is shown in table 5.

Table 5: Entity Count of the Village

Commercial Entity Type	Entity Count
Street Light	0
Small Shop	1
Water Pump	1
School (lights, computers, fans)	0
Milling	1
Clinic (lights, refrigerator, fans)	0

Depending on the entity wattage, operating hours and appliances count an hourly analysis was conducted and it was calculated to be 17.891 kWh/day which is 544.185 kWh/month (NREL,2018). The peak hours were assumed to be in contrary to the residential load profile starting from 7 AM to 5 PM (working hours). Fig 22 shows a rising demand from 6 AM with the start of the working hours and consistently high demand for a period from 10 AM to 5 PM, after which there is a decline in load.

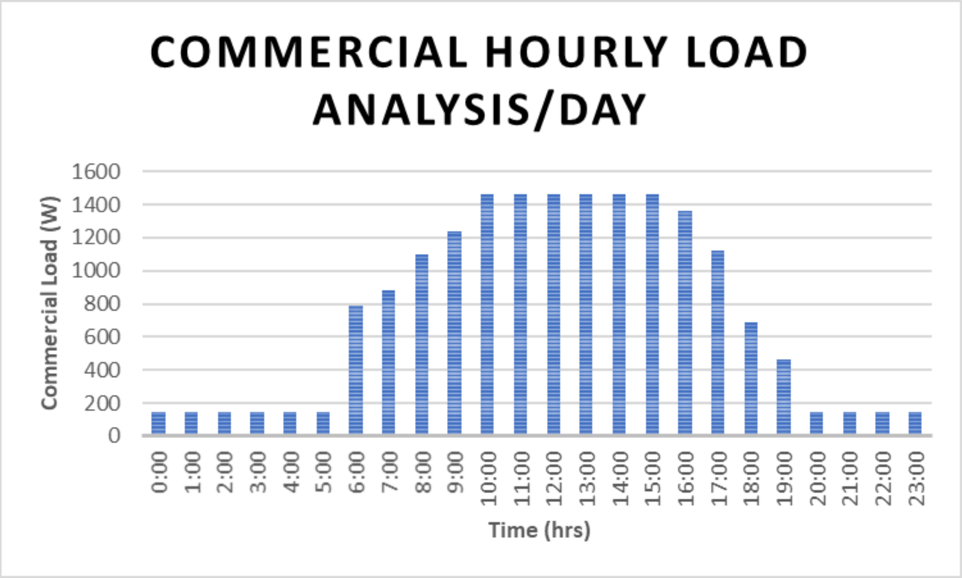

Figure 22: Commercial Load Analysis of the Village/Day

Assumptions have been made with a minimum variation from season to season and weekdays/weekends. The demands considered for the total number of the households in the village which comprises of 177 households in total, and commercial entities, indicating an hourly demand of the rural population.

In a study conducted for the electrification of rural remote areas in the developing countries, the electrical energy consumed in the households and community were calculated to be 0.1 kWh/day and 5.10 kWh/day (public building) respectively (Hallberg & Hallme, 2015). The analysis for a period from morning to evening with a freezer running throughout the day. They assumed the peak demand to be more during morning and afternoon and lower in the night for community entities and vice versa for the residential sector (Hallberg & Hallme, 2015).

4.2. Modelling System Using Software

The energy modelling for this site has been designed using the software HOMER Pro. This Hybrid Optimization Model for Electric Renewable (HOMER) helps in the sizing of a best operational strategy and a corresponding optimized system, through sensitivity analyses. The tool helps calculate the technical and economic feasibility of a configured model, excluding social and environmental impacts (Cherni et. Al., 2007). However, in HOMER Pro input values can be provided for carbon dioxide, particulate matter and sulphur emissions.

In this project, factors such as Levelized cost of electricity, net present value, renewable fraction are used for the analysis.

Levelized cost of electricity is identified as the annual cost of the overall system for the energy generated expressed in (£/kWh) as follows (HOMER,2018):

Equation 1: Levelized Cost of Electricity

$$\boxed{COE = Cann{,}tot/Eserved}$$

Where; COE= cost of electricity (£/kWh)

$Cann{,}tot$ = overall annual cost of the system (£/yr)

$Eserved$ = energy supplied to the load (kWh/yr)

- Net present cost is defined as the present overall cost of the system including operation, maintenance, and installation, for the lifetime of the project expressed in (£) as follows (HOMER, 2018).

Equation 2: Net Present Cost

$$\boxed{CNPC = Cann{,}tot \,/\, CRF(i{,}Rproj)}$$

Where; $CNPC$=net present cost (£)

$Cann{,}tot$= Overall cost of the system/year (£/yr)

i= discount rate (%), $Rproj$ = project lifetime (yr)

CRF= capital recovery factor

- Renewable fraction is the amount of energy from the renewable sources, that is supplied to the load expressed in %, as follows (HOMER, 2018):

Equation 3: Levelized Cost of Electricity

$$\boxed{fren = 1 - (Enonren\,/\,Eserve)}$$

Where; $fren$= renewable fraction (%)

$Enonren$= energy from non-renewables (kWh/yr)

$Eserve$= energy supplied to the load (kWh/yr)

4.2.1. System Configuration

The system modelled for this project consists of a vortex micro-hydro technology, paired with solar PV and lead-acid battery for energy optimization, to meet the energy requirements of Degalras village (schematic shown in fig X).

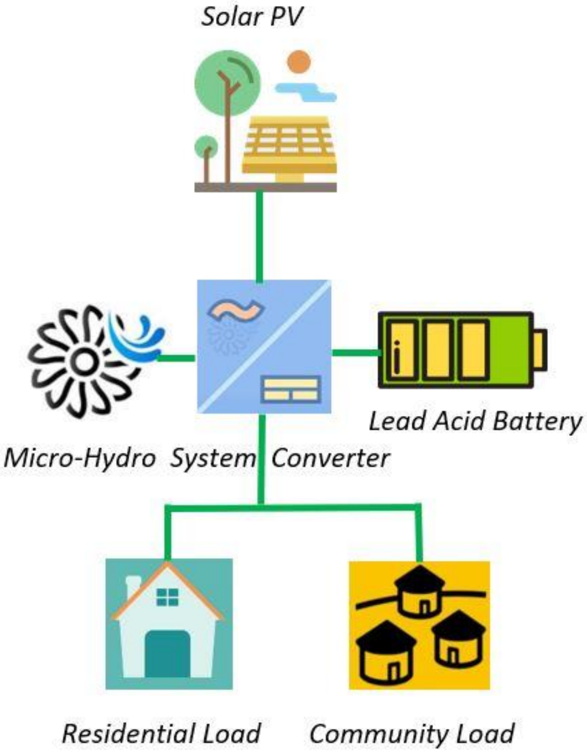

Figure 23: Schematic of Design Layout

After the demand profiles were created for both residential and community load, various input data based on the availability of resources in the village, were analyzed and modelled on the level of complexity and cost, leading to different configurations from the software. From the several simulation configurations the shown figure X was identified to be the best scheme.

4.2.2. Input Components

The hybrid off-grid model designed in HOMER is shown in fig X, for the calculated energy load of the village. The input variables are discussed below.

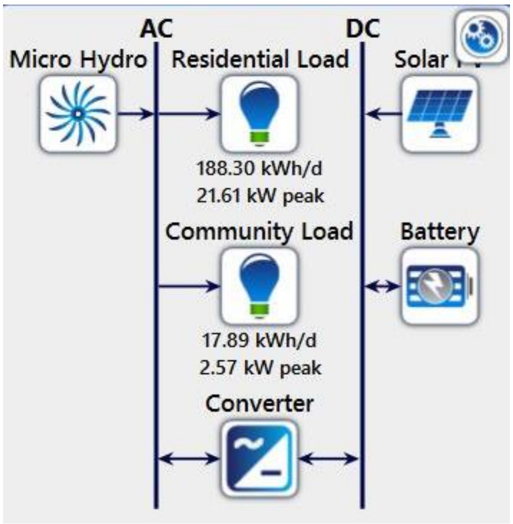

Figure 24: Renewable Hybrid Model Proposed for Village (HOMER, 2018)

I. AC Load

The loads are categorized into residential and community and the calculated values are as follows (Agrawal, Bali and Urpelainen, 2019):

Table 6: Load Input for the System

Residential Load	188.3 kWh/day
Community Load	17.89 kWh/day
Total Load Consumption/day of Village	206.19 kWh/day
Total Load Consumption/year of Village	68729.5 kWh/yr

II. Micro Hydro-10kW

Calculations:

a. Estimation of Head

For a rough calculation of the available head required to install a low-head and flow micro-hydro turbine, methods such as through topographical surveys or detailed maps can be applied. However, in this case, a step-by-step method using plank or string and spirit level is used. Through this method the difference in height between the outlet and inlet of the turbine, that is to be installed, is measured.

In order to find the total head, the upper level/inflow of the water and the outflow has to be calculated and can be done so by, one holding a spirit level and the other a plank (Turbulent, 2018).

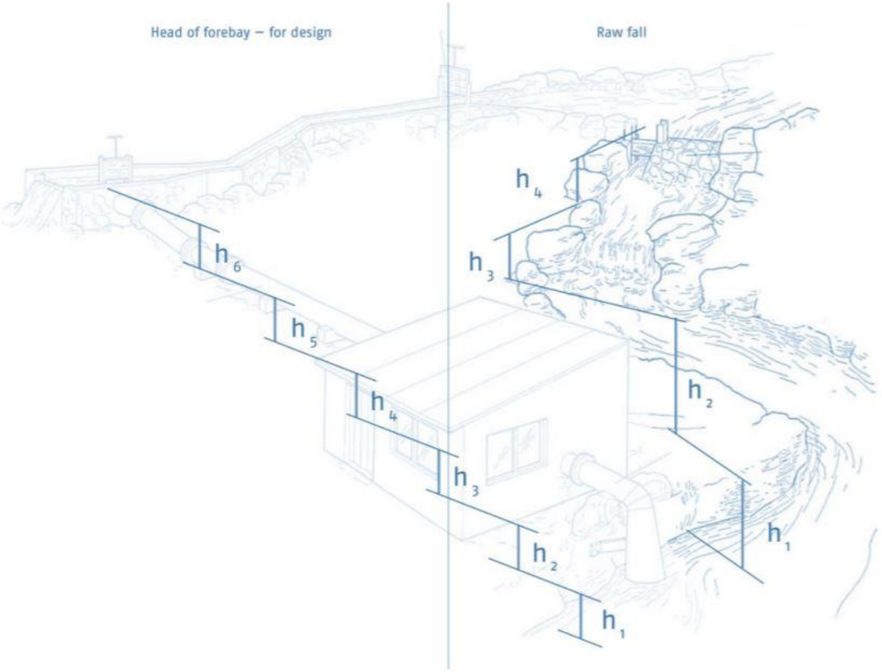

Figure 25: Calculating Available Head for the Vortex Turbine (Turbulent, 2018)

In the case of a long-distance measurement like in this case, length of the river is divided into sections (see fig 25), and each section of the head is determined using plank and spirit level. These multiple sections are equated into the following and then summed up:

Equation 4: Gross Head Equation (Turbulent, 2018)

$$\boxed{\text{Gross Head, } Hg = h1 + h2 + h3 + \ldots + hn}$$

Here in the case of river Indravati, gross head for each section of the river is assumed for a particular length hence, h1=h2=h3=h4=h5= 0.5m and the total head,
Hg= h1+h2+h3+h4+h5= 0.5+0.5+0.5+0.5+0.5= 1.5m (Turbulent, 2018)

$$\boxed{\text{Gross Head, } Hg = 1.5\text{m.}}$$

b. Estimation of Flow

For understanding the suitability of a turbine prior to its installation, flow needs to be calculated and an accurate method is by using technical special devices but, a rough estimation can be performed manually. This step-by-step procedure is called the float method and the following are the steps (Turbulent, 2018):

- *Step 1:* Identify that length of the river/canal where the flow of water is even or has minimum turbulence, this is taken as the length L (metres). For the river Indravati in this case, the length L is assumed to be for 1 metre, as it has a stable flow (Indravati River Geomorphological Study, 2014).

- *Step 2:* Calculate its cross-sectional area by determining the breadth B (metres) and height H (metres) and substitute into the following equation: area,

  Equation 5: Cross-sectional Area of the River

  $$\boxed{A = B \times H.}$$

  Hence, for a breadth of 1 metre and height also 1 metre the area of the river will be:

  A= 1 x 1= 1 metre square … (1)

- *Step 3:* Next, in order to calculate the velocity-V (metre/second), that length of the float calculated previously is let to accelerate itself initially and then the time-T (second) taken for its travel is measured and equated into:

Equation 6: Velocity of the River

$$\boxed{V= L/T}$$

Therefore, length of the float is 1 metre and for a time of 60s the calculated velocity is (velocity of the river is known to be 1.5 m/s as mentioned previously):

$$V= L/T= 1/.6= 1.5m/s\ldots \ (2)$$

- *Step 4:* Finally, the flow rate-Q (metre3/second) is determined by the equation:

Equation 7: Rate of Flow of River

$$\boxed{Q= V \times A}$$

Then, here the velocity is 1.5 m/s and the area of cross-section is 1m and so the rate of flow from (1) and (2) hence,

$$Q= 1.5 \times 1= 1.5 \text{ m3/s}$$

$$\boxed{Q = 1.5 \text{ m3/s}}$$

c. Vortex Micro-hydro Turbine Model

As mentioned above, with a flow of 1.5m3/s throughout the year (perennial river) and an estimated available head of 1.5m, HOMER identifies the best hydro capacity of 10kW for the turbine. The result obtained was based on a minimum and maximum flow of the turbine which is 20% and 100% respectively. According to a vortex turbine project implemented in Chile, 2017, the efficiency was 70% for an installed capacity of 15 kW, capable of delivering electricity to around 300 households, hence the efficiency of designed turbine is chosen to be the same (Cooke, 2018).This technique eliminates the need for a dam, pipe, canal, storage tank or reservoir.

III Solar PV

In this case, four solar PV panels of capacity 260 kW each are used with a total of 1kW capacity. The annual energy production of electricity from solar panels are 1736 kWh and 4.76 kWh/day as shown in fig 26 (HOMER, 2018). Since the area receives abundant solar energy, it runs throughout the year.

According to the report generated from the global solar energy data, the region receives 1896 kWh/m2 per year which is 5.193 kWh/day is shown in appendix 1.
Hence, the solar panels derating factor is assumed to be 0.8 (Solargis, 2017).

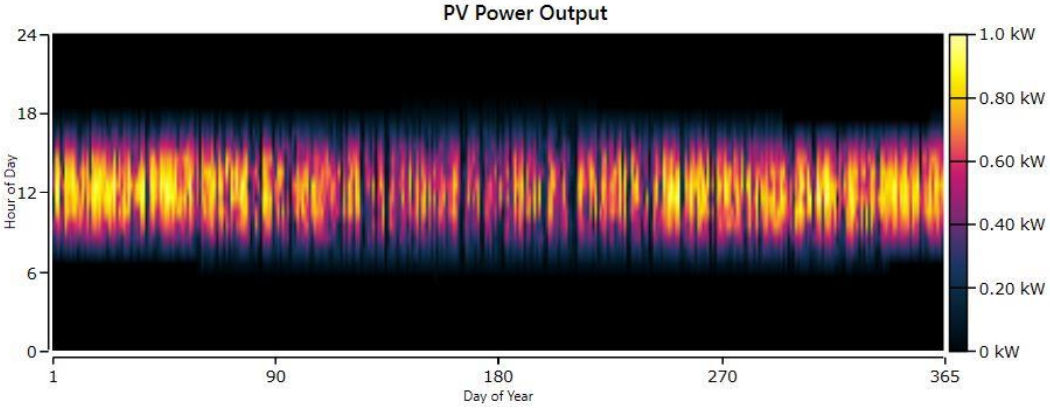

Figure 26: PV Power Output from Panels (HOMER, 2018)

The generic flat monocrystalline PV selected has a capacity factor of 0.19% with a life of 30 years and an efficiency of 30 % (Ebay, 2019).

IV. Energy Storage

For the energy storage part, most commonly used deep-cycle lead-acid Surette 6 CS 25P battery of 1 kWh capacity used in the system. Lead-acid batteries are more widely used in renewable applications because of their characteristics such as uninterrupted power supply, good surge capabilities, easily charged, high performance and low cost. Here, eight batteries from Rolls Battery Company are connected in parallel operating on a bus voltage of 6 V producing energy output of 2945 kWh/yr, having an average life expectancy of 17 years, with an autonomy of 3.38 hrs/day. The capacity curve of the deep-cycle lead-acid battery is shown in fig 27, indicating the discharge current for capacity variation.

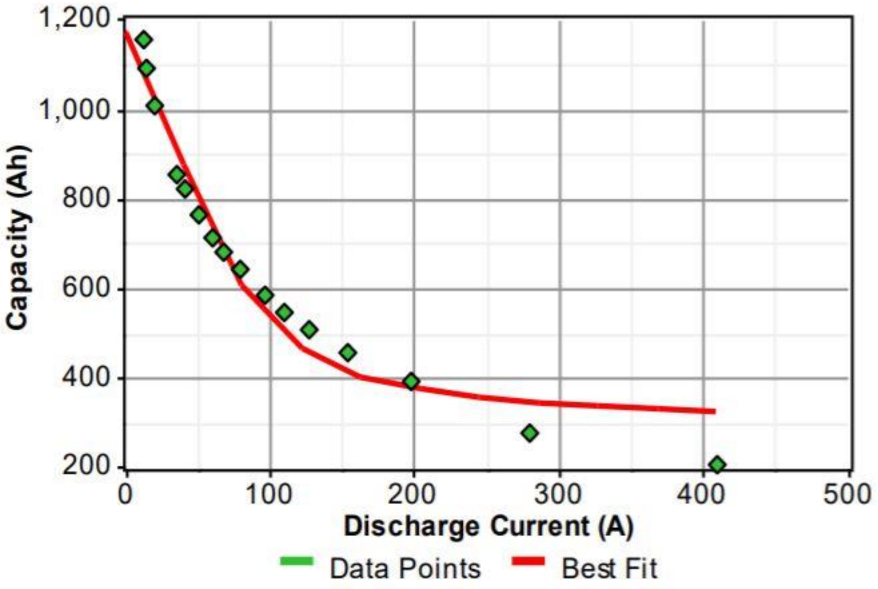

Figure 27: Capacity Curve of Deep Cycle Lead Acid Battery (Mishra, 2013)

V. Power Converter

The chosen converter has a capacity of 23 kW with a capacity factor of 0.286 and an annual energy output of 75,241 kWh, operating throughout the year. It has an efficiency of 93% and a life expectancy of 20 years.

4.3. Simulation Results & Discussion

The renewable hybrid model was designed for residential and community load profiles having an energy consumption of 188.3 kWh/day with 21.61 kW peak and 17.89 kWh/day with 2.57 kW peak respectively. The hybrid consists of a 10-kW micro-hydro, solar PV array of 1 kW, Surette 6 CS 25P lead-acid battery and a power converter of 23 kWh, to meet the energy demands of the village chosen. The project has a discount factor of 3% and is designed for 20 years.

4.3.1. Vortex Micro- Hydro Turbine

The pipe head loses are minimal hence assumed to be 5% and turbine has a nominal capacity of 13.2 kW. The technology modeled in HOMER produces annual energy of 110,212 kWh/yr, which is 98% of total energy generation. Since the river is a perennial source, the operation of the vortex turbine will be for 8760 hours producing electricity all year round. The turbine designed in HOMER has the characteristics from the Turbulent technology vortex turbine and has a 3-phase induction generator that is submersed and water-cooled (Technology, 2018).

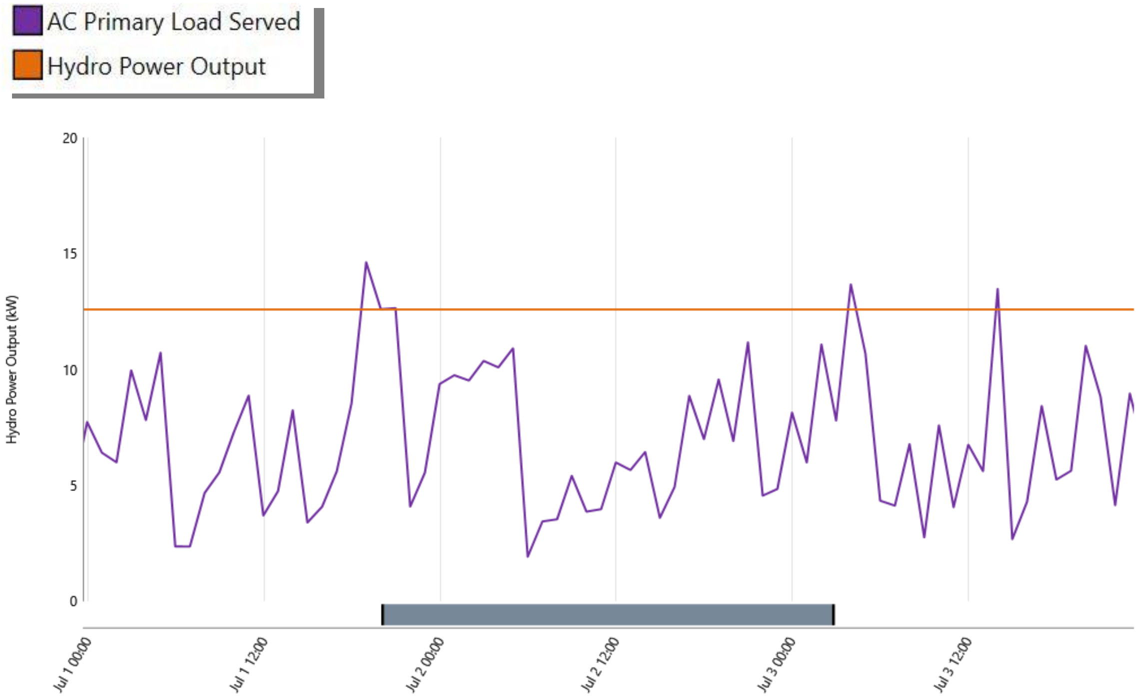

Figure 28: Vortex Micro-Hydro Turbine Output Serving Ac Load

The energy generated from the turbine is stable throughout the days (see fig 28) and is capable of meeting the energy requirements of the village as seen in fig X above. During certain peaks, the technology, however, fails to meet the energy demand. For this reason, the system is backed with PV and battery.

4.3.2. Solar PV & Lead Acid Battery

The region receives abundant solar energy and the design capacity of the PV in the system is only 1 kW so again, a variation of 10% between the months is assumed (Energy Data, 2017). From fig 29, it is noted that only 1.55% of the total energy which is 1736 kWh/yr generated is from solar and has a maximum output of 0.966 kW. It is evident that solar PV has a capacity factor of 0.2 %, however, is much lower than hydro (0.95%), since energy output is not consistent.

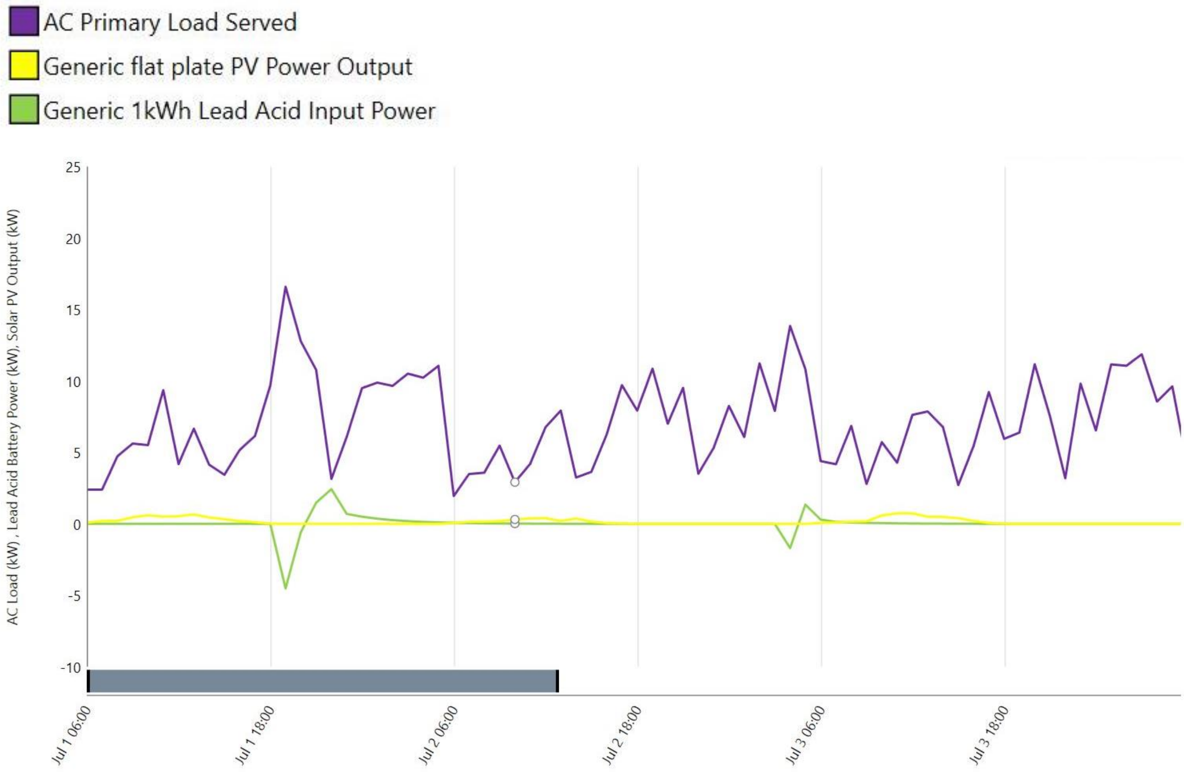

Figure 29: Solar PV + Energy Storage Serving AC Load

4.3.3. Overall System

From the monthly production of electricity from the renewable sources as shown in fig 30, the hydro turbine has high performance, since the village benefits from a perennial river source. Hence, if the demand increases in the future an additional micro-hydro of 5 kW or 10 kW can be added to the system, to meet the energy requirements.

The seasonal division of the performance has not been performed because, as mentioned previously the flow of river is throughout the year and is only negligibly affected by the weather conditions (State of India's Rivers, 2016). Hence, a variation of 10 % between the months is chosen. Also, the peak demand scenarios are comparatively lower for rural remote areas because the village currently, has not yet been electrified.

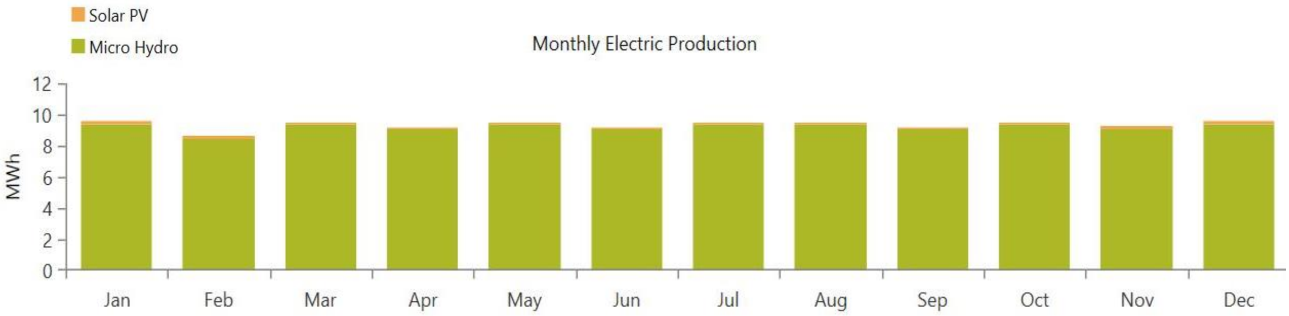

Figure 30: Monthly Electricity Production of the Model serving the Load

The total AC primary load to be served was 75,241 kWh/year and the hybrid model produced total annual energy of 111,949 kWh (solar-1736 kWh/yr and hydro 110212 kWh/yr). The unmet electrical load is negligible of approximately 0.02 % but, the system has excess electricity of 33,593 kWh/yr (30%) as shown in Table 7. The renewable fraction is 100% since non-renewables are not used and CO2 emission, as a result, is much lower.

Table 7: Off-grid Hybrid Renewable Model

Renewable Fraction (%)	1
Excess Electricity (%)	0.3
Capacity Shortage (%)	0.049
Reduction of CO2 Emissions (%)	0.99

The surplus energy, however, can be used for running electric fans or light up community halls, temple or mosque automatically in the village when excess energy is identified.

Chapter 5: Economic Analysis

To ensure the feasibility of the proposed model, an economic analysis has been performed. With the fluctuations in cost and advancements of the technologies, the following analysis identifies the implementation benefits of the plan for rural village. The configuration was chosen that meets the energy demand of the village is shown in table 8, along with the capacity and quantity of the technologies. The capacity factor and its corresponding energy production per year, which is used in the model are mentioned to determine the relative costs.

Table 8: System Components and Quantity

Technology	Energy Production (%)	Capacity Factor	Capacity	Quantity
Micro-Hydro	98.4	0.95	10 kW	1
Solar PV	1.55	0.198	1 kW	4 x 260 W
Power Converter	-	0.373	23 kW	1
Battery	-	-	6.91 kWh	8

The cost breakdown is shown in table 9, used as inputs to HOMER software. The price of the vortex turbine from Turbulent technology has been chosen as the price of the micro-hydro turbine, with almost no operation and maintenance cost (Technology, 2018). The replacement cost is considered for the core components of the turbine.

Table 9: System Cost Breakdown

Technology	Capacity	Cost (£) x Qty	Replacement Cost	Operation & Maintenance Cost
Micro-Hydro	10 kW	60,000 x 1	30,000	0
Solar PV	1 kW (4 x 260W)	650 x 1	200	10
Battery	Surette 6CS25P	820 x 8	700	5
Power Converter	30 kW	300 x 1	150	0

A solar PV of 1 kW which has four 260 Watt panels chosen has a guarantee of 30 years on minimum yields of 80% (Ebay, 2019). The deep cycle lead-acid battery from Rolls Company has a durable casing to protect from leakage or breakage, ensuring low maintenance and operation having a lifetime of 15 years (Off-grid, 2019). The cost of the system converter has been selected from a previous study (Damrongsri, 2018). From the cost distribution in fig 31, 80% of the cost is spent on the vortex turbine but having high energy generation capacity compared to other technologies.

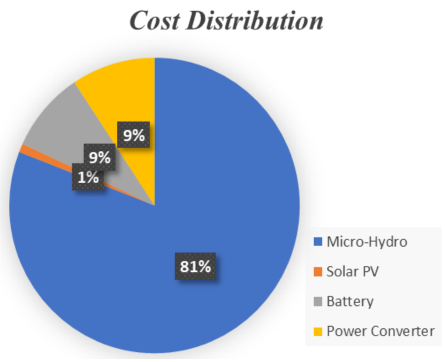

Fig 31: Cost Distribution of System (%)

The system architecture has a levelized cost of £ 0.079/kWh and the total net present cost to be £ 77,063 for a village of 177 households (see Table 9), calculated from the configuration cost mentioned in table 10.

Table 10: Total Cost of the Off-grid Hybrid Renewable Model

Micro-Hydro	£ 60,000
Solar PV	£ 650
Battery	£ 6560
Power Converter	£ 6900
Total Initial Capital Cost	£ 74160
Levelized cost	£ 0.07922
Total Net Present Cost	£ 77,063
Operating Cost	£ 225

The state of Chhattisgarh in Central India is installing hydro power project in the district of Degalras village (The Pioneer, 2016). However, the COE of a new hydro plant is expected to be £ 0.83/kWh or more (The Economic Times, 2018), indicating this system generates a lower tariff of £ 0.79/kWh.

Regarding the energy plan for the village requirements (see table 1) such as solar lantern, solar street lighting, solar water pump, solar box cooker for household and solar cooker for community scale are available on subsidy or for free from the government, hence, not included in the analysis (MNRE, 2017).

Chapter 6: Conclusion & Future Scope

6.1. Conclusion

To conclude, the objectives of the project of determining an optimal off-grid renewable solution for a remote rural un-electrified location were met as follows:

- To identify the need for decentralization and achieved a fully renewable energy autonomy:
  As discussed earlier, the rural electrification is unable to achieve its full potential mainly due to factors such as high costs associated with inaccessibility, inadequate power supply, and transmission losses. Through this project, a renewable automized off-grid system was developed, with 100% renewable fraction.

- To determine the current energy demand of the chosen rural village that is yet to be electrified:
  The current energy demand of the un-electrified village of 177 households was identified to be 75,241 kWh/yr, calculated from the energy load profiles created for both residential and community load.

- To develop an optimized model that meets with these energy requirements, by making use of the available local resources:
  A vortex micro-hydro technology generating 110213 kWh/yr, optimized with solar PV generating 1736 kWh/yr and a deep cycle lead-acid battery for storage, with total annual energy production of 111,949 kWh/yr, is the designed model to meet the energy requirements of village.

- To ensure the feasibility of the model technically, economically and environmentally:
  Since the energy requirements of the village are met and the value of excess electricity being in a reasonable range, the model was identified to be technically feasible. The economic analysis performed in software produces a

COE value of £ 0.7 /kWh which compared to a future electrical power source for the village is determined to be lower, ensuring economic feasibility of model. The renewable fraction from the software developed model was 100% with lowest CO2 emissions proving environmental friendliness.

- To justify the benefits of designed renewable energy model over grid power: The government is planning on installing a hydro plant for this un-electrified village. Apart from the benefit of low tariff of the designed model, the village will not face negative social impacts from hydro plant since, vortex micro-hydro turbine for run-off river is damless with no reservoir and a fish-friendly technology, causing no disruption to land or natural habitat, unlike hydro plant. Moreover, system is safe from risk of floods or droughts and no displacement of local communities.

- To identify a solution for coping with any future increase in demand of the village: With any increase in energy demand in the future, a vortex turbine can be added to the system, since it is evident from the simulations that stable annual energy output is produced mainly because of the perennial nature of river.

- To produce a methodology which can be implemented in similar un-electrified rural villages: The robust methodology developed for producing the model can be extended to the nearby un-electrified villages in the state, located along the banks of the river.

Hence, since the objectives of the project are model the aim of implementing an off-grid power source for the un-electrified village has been achieved.

6.2. Future Scope

- The model can be seen as a roadmap of an effective planning strategy for electrifying houses using an off-grid hybrid renewable model.
- Through a more detailed sensitivity analysis from the software HOMER, for instance: the design excludes choice for 15 kW hydro turbine and a 10 kW

turbine is used along with solar PV for optimization, the system efficiency can be improved.

- With successful commercialization such as better subsidies from the government and low technology costs for renewables in the market, the model can be made more viable.

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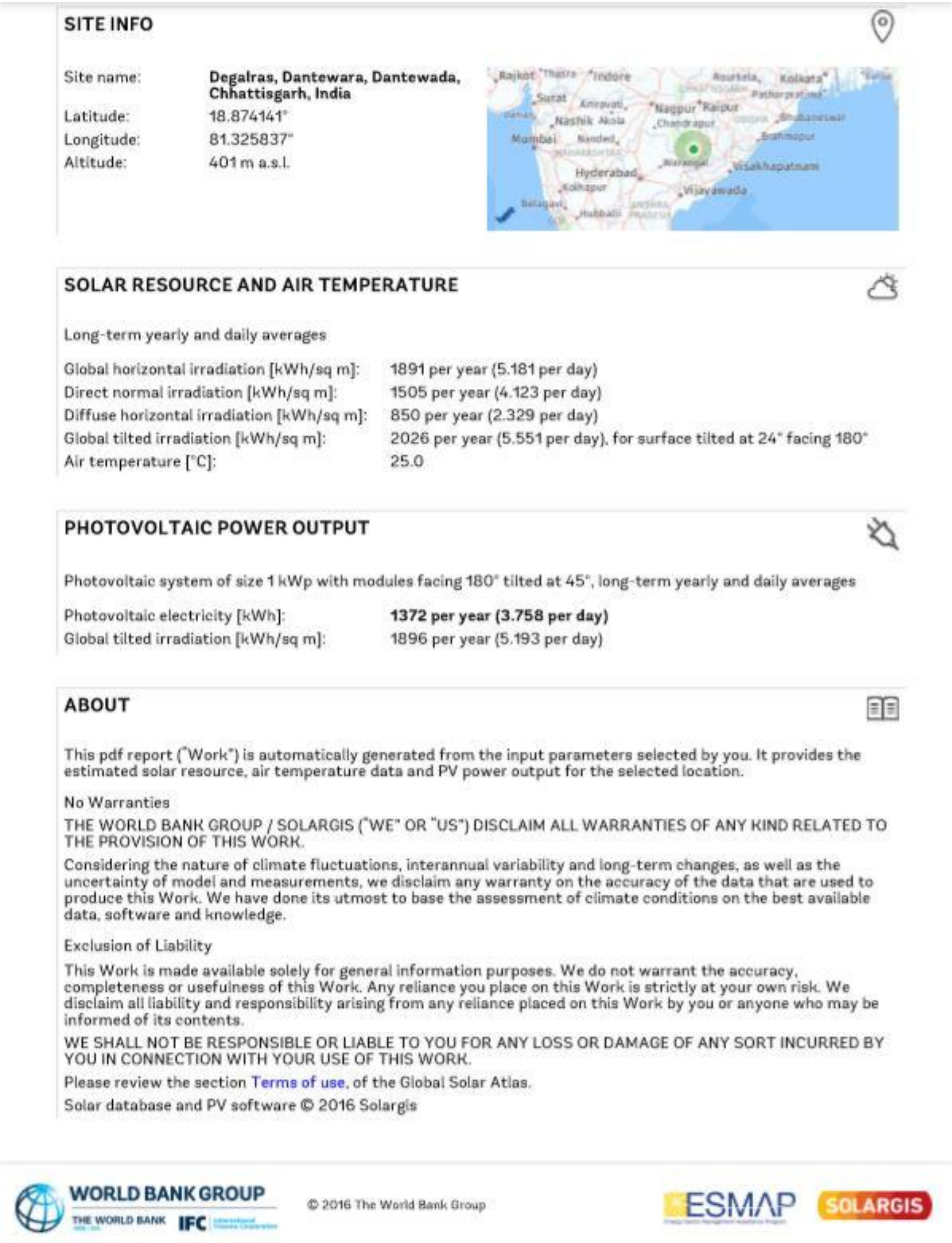
Appendix-1



SITE INFO

Site name:	**Degalras, Dantewara, Dantewada, Chhattisgarh, India**
Latitude:	18.874141°
Longitude:	81.325837°
Altitude:	401 m a.s.l.

SOLAR RESOURCE AND AIR TEMPERATURE

Long-term yearly and daily averages

Global horizontal irradiation [kWh/sq m]:	1891 per year (5.181 per day)
Direct normal irradiation [kWh/sq m]:	1505 per year (4.123 per day)
Diffuse horizontal irradiation [kWh/sq m]:	850 per year (2.329 per day)
Global tilted irradiation [kWh/sq m]:	2026 per year (5.551 per day), for surface tilted at 24° facing 180°
Air temperature [°C]:	25.0

PHOTOVOLTAIC POWER OUTPUT

Photovoltaic system of size 1 kWp with modules facing 180° tilted at 45°, long-term yearly and daily averages

Photovoltaic electricity [kWh]:	**1372 per year (3.758 per day)**
Global tilted irradiation [kWh/sq m]:	1896 per year (5.193 per day)

ABOUT

This pdf report ("Work") is automatically generated from the input parameters selected by you. It provides the estimated solar resource, air temperature data and PV power output for the selected location.

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The figure shows the solar report for the village of Degalras, Chhattisgarh, Inda, generated from Solargis, Energy Data.