RENEWABLE ENERGY TECHNOLOGIES FOR RURAL ELECTRIFICATION IN THE MOUNTAINS

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PRAGYA ENVIRON

INTRODUCTION

Energy is the basic necessity for human activity and lack of energy services is directly associated with key facets of poverty including low educational levels, restriction of opportunity, and conflict. In Social and case specific terms, the poor benefit from better livelihoods and higher standards of living if industrial progress is brought into rural areas and not only fostered in cities (Neupane & Sharma, 2006). In developing countries like India, excessive use of wood is leading to accelerated deforestation, silting due to soil erosion, flooding, and deepening of the fuel wood crisis. The demand for energy however is increasing at an escalating rate resulting in acute pressure on wood, oil and coal, which is depleting rapidly and threatening the global environment and local ecosystems. The global energy scenario is witnessing a gentle shift from these polluting fuels that once dominated the industrial era. This transition is warranted by the fact that limited reserves of extractable coal and petroleum cannot sustain the ever-increasing energy demands of inhabitants on the planet numbered presently, at 7 billion. It is therefore imperative to investigate new sources of energy that are renewable in nature to complement and ultimately replace fossil fuels.

Rural electrification is the process of bringing electrical power to rural and remote areas (Sharma; Tshering, 2006). Electricity is used not only for lighting and household purposes, but also for routine farming operations, irrigation, and processing. Energy access in rural areas of Himalayan Mountains is minimal and the region has since long suffered from severe development neglect. Most of the villages in the valleys are still not electrified and fuel wood alone accounts for 60 - 80% of energy consumed in the region, since they have no choice but to rely on fuel wood gathered from forests for both, heating and cooking. Productive activities as processing and pumping of water for irrigation are also dependent on fossil fuels, which remain scarce due to transportation challenges. Winter activities like handicrafts, weaving, and carpentry, which can provide sustainable, large-scale employment, have suffered enormously due to the growing energy shortage.

Traditional knowledge for managing the energy issue has been developed in the region, but these too are eroding today. For instance, buildings in the cold deserts of the Western Himalayas are made of mud, an excellent insulant. Recent microclimatic changes have affected the stability of the buildings and are forcing people to shift to other building materials. Traditionally, all families reared animals and these were housed in the basement of the family home or around it; the animals' body heat helped in keeping the home warm. Hence, there is an acute need for renewable forms of energy in the Himalayas - to improve the quality of life of the indigenous communities, as well as to enable sustainable economic development of the region.

This paper is a policy brief on Renewable Energy Technologies for Rural Electrification in the Mountains. The paper brings together pertinent findings from research studies and development reports and examines the major concerns and factors for rural electrification in the Mountains and the Village Grid approach for rural electrification. It concludes with the prospects for the major forms of Renewable Energy Technologies. For each of the technologies, the developments and potential in India are defined along with their respective technological processes and details.

KEY CHALLENGES IN RURAL ELECTRIFICATION

Studies on rural electrification state that the major barriers directly affecting energy access for rural masses are:

- Geographically dispersed villages
- Remote locations
- Inadequate focus on local resources
- Inadequate financing structures

The indirect barriers:

- Inadequate interest of private sector
- Unsustainable initiatives
- Poor monitoring
- Ineffective targeting of subsidies
- Unaffordability of energy cost
- Energy crops competing with food crops
- Funding gap
- Sustainability of renewable energy and subsidies

Studies such as - (Reddy & Painuly, 2004; Sadrul Islam, Islam, & Rahman, 2006, World Bank, 2010) spell out further barriers affecting Energy Access for Rural Electrification:

- Hindrances due to Contour Structure and topography in the Himalayas with high altitude and deep valleys makes it difficult for the government to take electricity to these remote areas
- Flexibility in Governmental Policies where experimentation in this sector and perpetual changes in scheme and policies result in delay of rural electrification
- Non-Participation of Public and Private Players in Power sector due to stringent Government policies, lack of profit even after de-licensing of power sector, Cost recovery and Financial Sustainability
- Improper Function of Gram Panchayat and negligence on the part of each department cause delay in the progress of the rural sector;
- Socio-economic issues such as the capital-intensive nature, long gestation period (average 7 years), and social acceptability of large hydropower projects are the sector's biggest challenges.

FACTORS FOR RURAL ELECTRIFICATION

The high-altitude belt of the Indian Himalayas is a ruthless expanse of wasteland and rocky slopes ringed by snow-clad peaks. The communities inhabiting this extremely tough terrain reside in scattered small villages across the valleys and plateaus, cut off from the world due to climatic and infrastructural adversities. These scattered populations have learned to eke out a living from subsistence agriculture and pastoralism during the short, mild summers, as the winters are bitter. The dependence on natural resources is entirely for cultivation, fodder, timber and fuel wood, which has a grave impact on the fragile ecosystem (Banerjee & Baruah, 2006).

Literature on RET's diffusion in rural areas worldwide (US EIA, 2011, Susanto & Smitts, 2010), reveals that although RETs are economically viable, socially beneficial and environmentally safe, there is low diffusion due to financial, political and technological challenges, as mentioned below:

- In terms of finances, national and international policy makers aim to invest public money efficiently and to tap additional financial sources from the private sector. Both are challenging tasks for governments with scarce budgets and multiple competing demands as health or education.
- In terms of political challenges, policymakers have to evaluate what type of investment, in which projects, efficiently promotes access to electricity through RET.
- From a technological standpoint, there are competing rural electrification approaches, which have so far, partially diffused within and between developing countries.

The extent of diffusion differs between approaches and depends on the countries' public support in terms of subsidies, taxes for RET, and the competing non-renewable solutions. The involvement of the private sector also varies between countries as well as between electrification approaches (Bardouille *et* al., 2012).

VILLAGE GRID APPROACH FOR RURAL ELECTRIFICATION

A village grid is defined as an isolated (i.e., off-grid), small (sizes vary between 5 kW and 500 kW) grid that powers a rural village with renewable energy-based electricity (ESMAP, 2007; Bardouille *et* al., 2012). The village grid's purpose is to connect one or more power sources to the households and other consumers (such as schools or medical centres) of a village and balance the load with the supply. Village grids are highly beneficial where centralised electrification approach is not the most economic or feasible option, such as in the case of remote areas (Alex *et* al, 2009)

The core components of a village grid are synchronisers, transformer(s), potentially a battery backup to address intermittency of the sources, switchgears and the respective software to balance the load with the supply from the power plant(s), and the wiring. In the case of a power source that produces direct current (DC), additional inverters are needed to feed the alternating current (AC) village network. Power sources can be both non- and renewable energies. The choice depends on the availability of (natural) resources and influences the system's design since renewable energy sources such as solar PV or wind are intermittent and require storage and balancing components. The load is determined by the electricity demand of the village, which depends on number of households, their electric appliances (TVs and radios), the requisites of the social infrastructure (e.g., schools and health centers) and businesses (e.g. rice mills, processing plants), and their respective consumption patterns (Kodama *et* al, 2000; Freris, 1990).

While village grids typically serve one common purpose, no single standard design exists because each village grid has to be adjusted to the context where it is implemented. The final design thus heavily depends on factors such as the amount and variability of supply and demand, and the availability and cost of materials and power sources. Despite the advantages of renewable energy-based village grids (RVGs) as a rural electrification approach, large-scale diffusion of RVGs has not yet taken place. This is in spite of an estimated market potential of 28 million households (an equivalent of 3.1 billion EUR, with a forecasted annual growth rate of 13% from 2012 to 2020), successful examples on all continents (Bolivia, Cambodia, India, Indonesia, Mali, Nepal, Nigeria, Philippines) and promotion by development agencies and international organizations (Bardouille *et* al., 2012).

POTENTIAL FOR RENEWABLE ENERGY TECHNOLOGIES

Renewable Energy Technologies have traditionally been perceived to be too expensive to be of any practical use, especially when adverse effects of fossils fuels on human health, climate and ecology are taken into account. Increasingly, several forms of renewable energy and techniques are fast becoming viable with RVGs as the best option to improve rural electrification at low environmental cost. Compared to solar lanterns and household-based systems, RVGs offer more electricity and allow for productive use and social infrastructure in addition to household purposes (UN AGECC, 2010).

RVGs are often more cost-effective in inaccessible, mountainous regions in comparison to grid extension (Lin *et* al, 2003). Additionally, national grids are often unreliable due to outdated equipment and a lack of generation capacity. Hence, if designed well, RVGs can achieve better reliabilities (IEA, 2010). Furthermore, national grids typically rely on non-renewable energies for electricity production and hence cause environmental issues (IEA, 2012b). Thus, RVGs best fit the purpose of rural electrification, are environmentally compatible and potentially contribute more towards poverty reduction than the available alternatives (Kanagawa and Nakata, 2007; Takada and Charles, 2007).

Photovoltaic (PV) systems have already been in use during the last decade, while wind systems are now receiving increasing attention for off-grid power generation (Zhou *et* al, 2010). In windy areas, wind energy production can be an appropriate technology (Ferrer-Marti *et* al, 2011). But with rising demands, hybrid systems that combine wind and solar energy sources are a promising generation option (Zhou *et* al, 2010). Other hybrids also can be used depending on feasibility as the resources vary with geography. Most stand-alone electrification projects based on wind and solar energies consist of an individual system that means each consumption point (households, health centres and schools) has its own generators (Leary *et.* al. 2012; Lemaire, 2011). As an alternative, micro grids can be used as a generation point that produces energy for a number of consumption points (RVGs).

Kirubi *et.* al. (2009) highlight the several advantages micro grids have over individual systems:

- When using those configurations, user consumption does not depend on the resource in its location
- Equity between user consumption is improved by relying on the same generators
- Costs can be reduced by economies of scale
- A greater flexibility in consumption is permitted: consumption can promptly be increased due to special days, admission of new users or development of productive activities

Despite its advantages, a large extension in micro grids may cause problems due to increasing cable cost (Nfah *et.* al. 2008). Thus, the design of stand-alone hybrid renewable energy projects is highly complex, as it requires the supply of energy resources to every point of the community and aims a balance between micro grids' extension and individual electrification (Ferrer-Marti *et.* al. 2013). In recent years, considerable research has been conducted on the prospects and design of autonomous electrification systems at village level in developing countries through the use of renewable energies (Saheb-koussa *et.* al. 2009; Bekele & Tadesse, 2012; Akella *et.* al. 2007). We discuss the prospects for the main forms of renewable energy.

SOLAR ENERGY

Solar technologies are an extremely promising renewable resource considering their ever-increasing output efficiencies and ability to be utilized in a variety of locations. The intrinsic qualities of solar energy make it a beneficial utility, especially for India.

POTENTIAL AND APPLICATION AREAS

Most parts of India get 300 days of sunshine a year, which makes the country promising for solar energy utilization. India's solar power reception is about 5,000 trillion kWh per year. In addition, the average radiation in tropical and sub-tropical regions located in developing countries can be compared to that of annual global radiation of about 1,600 – 2,200 kWh/m^2. So far, photovoltaic (PV) generation has been limited to small installations, but throughout India there are 750,000 installations, generating a total of about 58 MW.

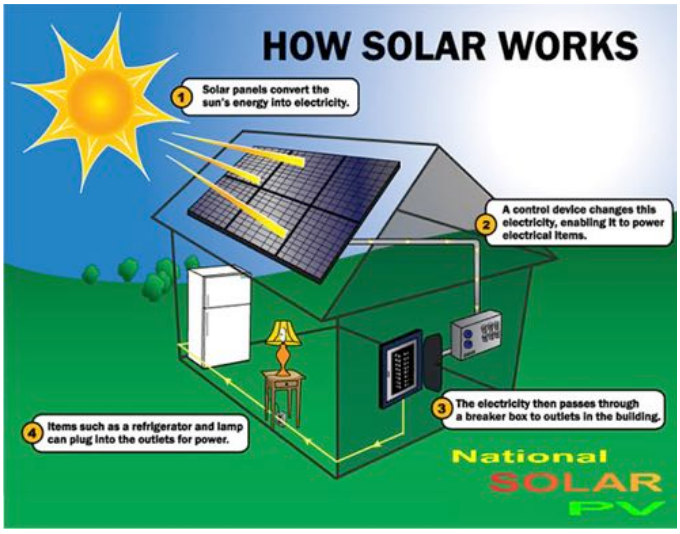
In Lahaul & Spiti, Himachal Pradesh, there are almost 325 sun days per year and an average of 8 hours of sunshine per day year round, hence the solar energy option is best suited for meeting the daily energy needs. Presently people of these regions use solar PV module primarily for water heating and lighting. There is a lack of awareness among the local population about the benefits of renewable sources and use of these devices is minimal. The state of Himachal Pradesh receives average Global Horizontal Insulation (GHI) above 4.5 kWh/ m^2/day and a total of 98,586,056 MU annually.

Seasonally, Himachal Pradesh receives an average insulation of 5.86 - 5.99 kWh/m^2/day in the summer months of March, April & May. 5.69 - 5.89 kWh/m^2/day in the monsoon months of June, July, August & September & a little lower 3.73 - 3.94kWh/m^2/day in the winter months of October, November, December, January and February. The regional availability of GHI in Himachal Pradesh is influenced by its topography, seasons as well as microclimate (HIMURJA). The colder and higher elevation zones could utilize solar energy for: (a) room/water heating which significantly reduces dependence on fuel wood; (b) Lighting based on photovoltaic technologies especially in isolated and un-electrified areas.

APPLICATIONS - PHOTOVOLTAIC TECHNOLOGY

Solar cells, also called photovoltaic (PV) power technology uses semiconductor cells (wafers), converts sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect. Because of its versatility, whether on a small scale (telephone callbox) or in larger scale applications (homes and commercial buildings), PV can provide clean energy from an abundant and free fuel source - the sun. *Fig.1* illustrates how solar works. Solar panels convert the sun's energy into electricity. A control device charges this electricity, enabling it to power electrical items. The electricity then passes through a breaker box to outlets in the building.

Figure 1 | Photovoltaic Technology



At the household level, PV systems can either replace or supplement utility generated electricity. In stand-alone PV electric systems, the power generated is stored in a battery and used as needed. In grid-connected systems, power from the utility grid can serve as a back-up source on cloudy days or when electricity use is unusually high. Some examples of existing PV operations are: Water pumping, Communications, Lighting and Refrigeration.

ADVANTAGES

- **Free Fuel:** Once the equipment is purchased and installed, the bulk of PV costs are complete. While the up-front capital costs are relatively high, fuel costs are zero for the lifetime, hence PV systems will be more economical
- **Simple Maintenance:** Because of the simplicity of PV systems, maintenance and repair costs are low

- **High Reliability:** PV systems are durable, can work effectively for years. With no moving parts, PV is a reliable energy source in all types of climates and weather conditions

- **Environmentally Benign:** PV systems are silent and do not emit environmentally damaging substances into the air or water

- **Modularity:** Panels can be installed as needed and upgraded as the demand for power grows. Furthermore, additions can be made while the original system continues to operate

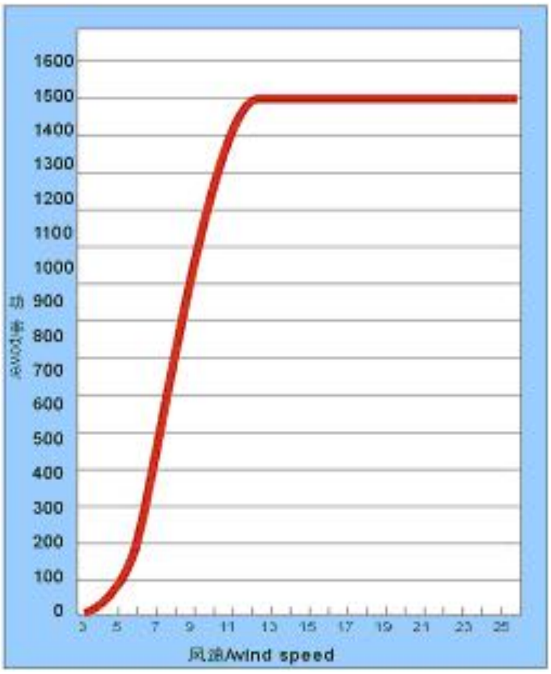
WIND ENERGY

Wind speed values mostly below 4 m/s show that large-scale commercial power generation might not be feasible in the lower stretches of the Himalayas. The slow speed could be used for small wind technologies like agricultural water pumps, wind photovoltaic hybrids, space/water heaters which might help in meeting part of the energy demand on a sustainable basis. While Europe and North America have the largest installed capacity of wind turbine capability; China, India, and the developing world have the biggest potential for wind power (Lin et. al, 2003). In India, the Wind Resource Assessment Program, coordinated by the Centre for Wind Energy Technology (C-WET) has so far covered 31 States and Union Territories involving establishment of about 1,244 wind monitoring and wind mapping stations.

POTENTIAL

Government of India, Ministry of New and Renewable Energy aims to commercialise grid interactive wind power and 233 potential sites have been identified. The potential for wind power generation for grid interaction has been estimated at about 48,500 MW taking sites having wind power density greater than 200 W/sq. m at 50 m hub-height with 1% land availability in potential areas for setting up wind farms at 12 ha/MW.

Figure 2 | The power speed characteristics (source: Jordan Journal of Mechanical and Industrial Engineering, Ghassan Halasa, 2010)



TECHNOLOGY

Two types of wind turbines namely stall regulated and pitch regulated are being deployed in the country and abroad for grid-interactive power. The stall regulated wind turbines have fixed rotor blades whereas pitch regulated wind turbines have adjustable rotor blades that change the angle of attach depending upon wind speed. Both technologies have their own advantages and disadvantages. Wind turbines are also available with lattice, steel tubular and concrete tubular towers. Airborne Wind Turbines (also known as 'Aerial Kite') are computer-controlled, multi-winged, kite-like structure, developed to float at a height of 2,000 feet and operates at 5 times the height of a regular conventional turbine. *Fig.2* demonstrates the principles behind wind turbine technology. The working is through a tether to a ground station, which basically transfers DC power that is generated into AC power via a power grid (Muljadi & Butterfield, 2001; Koutrulis & Klaitzakis, 2006). This innovation is especially useful for areas located in high mountainous regions with sparse population where the wind speed is also high.

HYDROELECTRIC POWER

Hydropower is an eco-friendly clean power generation method. Wherever there are mountains and streams, hydropower can bring low-cost electricity to isolated communities without polluting the air or water. Most hydropower available around the world can be categorised as large hydro, but this same concept also works on a smaller - and even individual – scale (Kapoor, 2013).

The last two decades have seen a significant growth in hydropower development throughout India. Himachal Pradesh has a vast hydel potential to the tune of approx. 21,000 MW in the five river basins and 3,950 MW (approx.) have been harnessed so far. Of this, a potential of approximately 750 MW is estimated to be in the small hydro sector, based on remote sensing data. Eight projects have been taken up in HP under this program, and they have not all been successful. In Spiti, the Lingti hydel power plant of capacity 2x200 KW has not been able to generate its full capacity, primarily due to the heavy silt load in the rivers (HIMURJA- http://himurja.nic.in/).

Silt removal is a huge problem, and even after the plant's installation, they are unable to meet the designed load due to high silt accumulation. Furthermore, the region being a cold desert, the water in the streams freezes, which affects generation capacity in winters and most hydropower plants remain non-functional during the winters. The grid extension is complex due to dispersed locations of villages and the cost of electrification is high when related to the low-income levels. Such areas have no choice but to depend on off-grid dispersion-type power sources. Mini-hydropower is utilized in areas where hydropower potential exists; other areas utilise mini-grids with new or renewable energy sources such as solar light, wind power and biomass.

Resistance to large hydropower projects arises due to concerns such as the potential for upstream flooding, destruction of agricultural areas, animal habitats and disruption of communities in the affected areas. These factors have affected the attractiveness of large hydropower projects. On the other hand, micro-hydro development for off-grid electrification is hindered by high upfront costs and the need for government support and intervention. However, given the many issues cited earlier plaguing large hydropower projects, the logical step is to focus on smaller, more manageable projects to bring electricity to the rural areas. The Pico-Hydro Power Systems is a shift in this direction

CASE STUDIES - HYDRO

Kirinyaga District, Kenya

A typical pico hydro power plant has been installed in Kathamba, Kirinyaga district, Kenya. This scheme was installed as part of a program implemented by The Micro Hydro Centre at Nottingham Trent University to demonstrate Pico Hydro technology in Sub Saharan Africa. The cost of the penstock, turbine and generator equipment was met by the project funders (European Commission) and all other costs were contributed by the 65 households, to which the scheme now supplies with electricity. The pico-hydro plant uses a Pelton turbine directly coupled to an induction generator that has an electrical output of 1.1 kW. The penstock is 158 m in length, 110 mm diameter PVC pipe. The electrical output of 1.1 kW corresponds to a turbine generator efficiency of 48%. The water source is a small spring with a flow around 90% of the year and has never been known to run completely dry.

Mankulam, Kerala

In Mankulam, an isolated village in Kerala, an INFORSE member, the Malanadu Development Society, has installed two pilot units of 200 w pico-hydro plant. The plant has been operating well and MDS is planning to install 30 units for 30 poor and low-income families in the village.

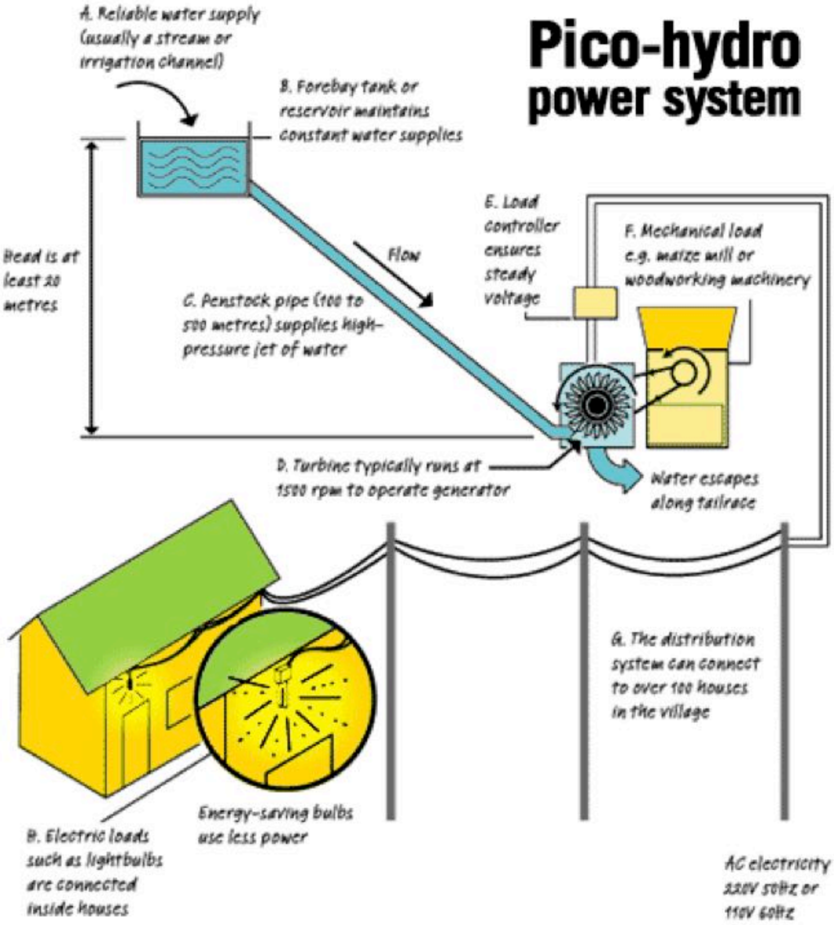
Dakshina, Karnataka

In hilly regions of Malnad and coastal areas of Udupi, Dakshina, Karnataka, the deployment of pico-hydro projects in the last 4 years has lead to a significant change in the energy scenario. Pico-hydro projects have a capacity of up to 5 kW especially targeted to benefit rural communities with access to small streams and rivulets. The developers of these projects are based in UK and from 2007 till date have installed around 400 pico-hydro projects.

PICO-HYDRO POWER SYSTEM

Pico-hydro is a term used to describe the smallest systems, covering hydroelectric power generation under 5 kW. Fig. 3 illustrates the technology of the pico-hydro power system. The pico-hydro plant uses a Penstock pipe that supplies high-pressure jet of water to the turbine, which typically runs at 1500 rpm to operate the generator. Depending on its size, a pico-hydro power system may provide a small, remote community with adequate electricity to power light bulbs, radios and televisions, among other appliances.

Figure 3 | Pico-hydro power system



BIOMASS

Biomass is renewable, widely available, carbon-neutral and has the potential to provide significant employment in the rural areas. Biomass, as a renewable energy source, is biological material from living, or recently living organisms & covers all kinds of organic matter from fuel wood to marine vegetation. Biomass includes fuels like wood, agro-waste; Bagasse, rice husk, animal dung. As an energy source, Biomass can either be used directly, or converted into other energy products such as bio fuel (Erdinc & Uzungolu, 2012). About 32% of the total primary energy use in India is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs.

PRESENT SCENARIO

Biomass power generation in India is an industry that attracts investments of over Rs. 600 crores every year, generating more than 5,000 million units of electricity and yearly employment of more than 10 million mandays. Sources include forest residues, rice husk, dead trees, branches, yard clippings, wood chips and even municipal solid waste, hemp, corn, poplar, willow, sorghum, sugarcane. For efficient utilization of biomass, bagasse-based cogeneration in sugar mills and biomass power generation have been taken up under biomass power and cogeneration programs. Currently, India has 537 MW commissioned and 536 MW under construction. Global Potential for use of Biomass for Energy is estimated at 25% to 30% of Global Energy Supply by 2050. The advantages of Biomass Energy are that it can diversify energy supply at reasonable cost, provide rural income and employment and reduce GHG emissions from fossil fuels.

At present, biogas technology provides an alternative source of energy in rural India for cooking. It is particularly useful for village households that have their own cattle. Through a simple process, cattle dung is used to produce a gas, which serves as fuel for cooking. Biogas plants have been set up in many areas and are becoming popular. A mini biogas digester has recently been designed and developed, and is being in field-tested for domestic lighting.

However, Biomass Energy is being used in an inefficient, unhealthy manner with adverse impact of depleting forest reserves and human health with all its consequences on the socio-economic status of the rural population (www.huskpowersystem.com). Use of biomass for energy would be harmful if GHG emission reduction is not achieved and biodiversity loss through Land Use change is not controlled/monitored through suitable safeguards.

POTENTIAL

The current availability of biomass in India is estimated at about 500 million metric tons per year. The estimated surplus biomass availability is about 120 – 150 million metric tons per annum covering agricultural and forestry residues corresponding to a potential of about 19,500 MW (3,500 MW from bagasse-based cogeneration and 16,000 MW from surplus biomass). This apart, about 5,000 MW additional power could be generated through bagasse-based cogeneration in the country's 550 Sugar mills.

Examples and Success Stories include the Impunia grass-based bio mass plant at Jhansi (100 kW) and the biogas generated by Ashoka Biogreen Pvt. Ltd from the plant at village Talwade, Nasik District, Maharashtra. The purity of biogas is about 98% and compressed to 150-bar pressure for filling in cylinders. The upgraded biogas is used for power generation, cooking and industrial application. The slurry of biogas plant is being used as an organic fertilizer in nearby agro fields. The field trials have indicated 150% growth in agro-production and substantial improvements in the quality.

Indian sugar mills are rapidly turning to bagasse, the leftover of cane after it is crushed and its juice extracted, to generate electricity. About 3500 MW of power can be generated from bagasse in the existing 430 sugar mills in the country. Around 270 MW of power has already been commissioned and more is under construction. This development would clean up the environment, cut down power costs and earn additional revenue.

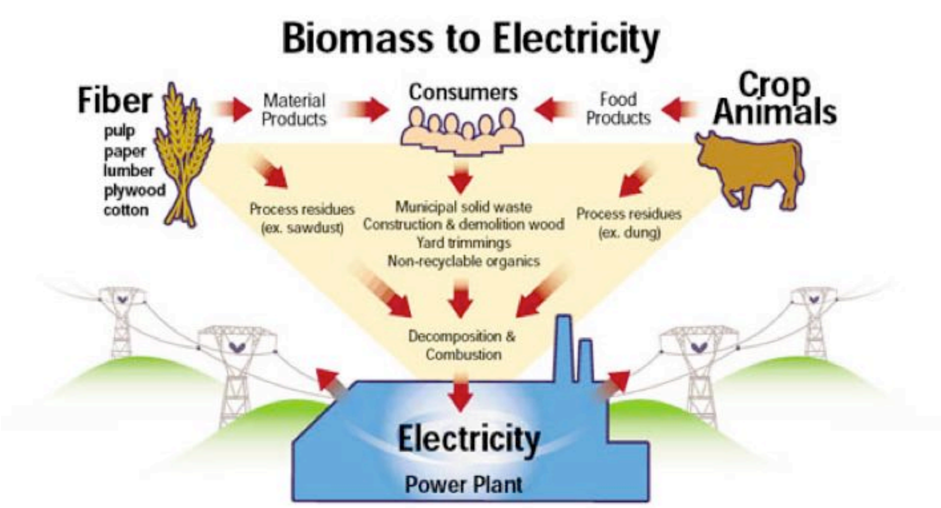
TECHNOLOGY

Combustion - The thermo chemical processes for conversion of biomass to useful products involve combustion, gasification or pyrolysis. Fig.4 presents the Conversion Cycle of Biomass to Electricity. The conventional cycle is used with biomass being burnt in high-pressure boiler to generate steam and operating a turbine with generated steam. The net power cycle efficiencies that can be achieved are about 23 - 25%. The exhaust of the steam turbine can either be fully condensed to produce power, or used partly or fully for another useful heating activity. The latter mode is called cogeneration, which finds application mainly in industries.

Cogeneration In Sugar Mills - Sugar industry has been traditionally practicing cogeneration by using bagasse as a fuel. It can also produce significant surplus electricity for sale to the grid using same quantity of bagasse. For example, if steam generation temperature/pressure is raised from 400oC/33 bar to 485oC/66 bar, more than 80 kWh of additional electricity can be produced for each ton of cane crushed. The sale of surplus power generated through optimum cogeneration would help a sugar mill to improve its viability, apart from adding to the power generation capacity of the country.

Gasification - Biomass gasification is a process of converting solid biomass fuel into gaseous combustible form (called producer gas) by means of partial oxidation carried out in a reactor called gasifier at elevated temperatures. For power generation, biomass gasification technique consists of three major components: gasifier unit, gas production unit, internal combustion (IC) engine.

Figure 4| Biomass conversion cycle



HYBRID RENEWABLE ENERGY TECHNOLOGIES FOR RURAL ELECTRIFICATION IN THE MOUNTAINS

Hybrid technology systems combine two or more technologies with the aim to achieve efficient systems. Possible combinations are:

- Wind-solar photovoltaic (PV) hybrid systems
- Thermal-solar hybrid systems
- Hydro-solar hybrid systems
- Biomass-hydro hybrid systems
- Wind-diesel hybrid systems
- Fuel cell-gas turbine hybrid systems
- Wind-fuel cell hybrid systems

Hybrid systems combine numerous electricity production and storage units to meet the energy demands of a given facility or community. They are ideal for remote and isolated applications such as communication stations, military installations, islands and rural villages (Climatetechwiki.org, 2015). Several examples of implementation of different types of hybrid technologies can be observed throughout the world with relatively few cases in the mountains:

- One of the oldest PV hybrid systems and at the same time the first 'large scale' PV system in Europe was installed in 1983 at the island of Terschelling in the Netherlands. At the Higher Maritime School 'Willem Barentsz' a 43 kWp PV system was coupled to a 75 kW wind turbine and a large battery bank.

- In Curaçao, the Netherlands' Antilles, since March 1984 the local radio station 'Radio Hoyer' uses a PV powered transmitter, with a battery and a diesel backup. The system is installed on the top of the mountain Tafelberg, and is remotely monitored from the capital Willemstad.

- The Mexican Hybrid Solar Thermal Power Project is a solar thermal/natural gas-fired hybrid power plant in Baja California Norte with a total net installed capacity of about 300 MW.

- The Wilpena Pound power station of South Australia combines a 100-kWp PV system, a battery storage of 400 kWh, an inverter and a 440 kWp diesel generator.

- In Thailand, PV-wind-diesel hybrid systems were installed in 1999 at PhuKradung, a high-elevation national park in Loei Province, and at Tarutao, an island in a marine national park in Satun Province, Thailand.

Stand-alone hybrid electrification systems that use renewable energy sources are a suitable alternative to provide electricity to isolated communities in a reliable and pollution-free manner (Erdnic et al, 2012). Hybrid systems generally have a relatively high investment cost, which makes smaller projects unattractive to the investors, lenders, project developers and manufacturers. Similarly, these technologies have several technical barriers which include: requirement of redundant generation systems, a time limitation for the generation of electricity, need for sophisticated control systems and storage systems, and transmission line losses. Other aspects in the implementation chain of these hybrid technology systems in developing countries could be the limited credit worthiness for potential investors; absence of a power purchase agreement with energy users (e.g. through the grid operator); absence of energy or power systems in the villages; lack of human capital to properly operate the power plants and lack of financing partners. Some hybrid systems are discussed in detail in the following sections.

SOLAR-THERMAL ENERGY

Solar thermal technologies enable us to produce hot water from the sun's energy for use in homes, factories, hotels, and for many other applications. Solar thermal systems are being used in homes, hospitals, and industrial plants around the world. Solar thermal facilities can operate effectively in virtually any climate, from hot deserts to the earth's coldest regions. In addition to direct-use applications, solar thermal technology can be used to generate electricity. Today's solar thermal power plants produce about 0.005 Quads (480 million kWh) of energy each year - that's enough energy to power more than 45,000 homes. At their current production rate, solar thermal power plants displace 325,000 tons of carbon dioxide emissions every year. Solar thermal technologies work mainly through Passive System- through building systems and Active system-Concentrated Solar Power (CSP).

Solar thermal systems can use flat plate collectors to capture the sun's energy and transfer it either directly or indirectly to household, water or heating systems. Fig.5 illustrates the solar thermal system and how it works. Each collector contains an absorbing surface (called an absorber plate) and an insulating container (generally a metal box) that supports a transparent glazing material (usually glass). Heat from the sun is trapped by the collectors and absorbed by the plate. In typical installations, collectors are mounted on the roof of a building and oriented to achieve maximum exposure to the sun. One or two collectors are used in a typical household system. During cloudy weather or periods of excessive hot water use, backup heating can be used. These systems can save homeowners up to 3,000 kWh annually.

Concentrated Solar Power (CSP) - CSP is also termed as Concentrated Solar Thermal Power (CST), Solar Thermal Electricity Generation (STEG). The technology uses heat from the sun to generate electricity in much the same way the conventional thermal power station. The sun's rays are focused on a central receiver containing a mineral oil or other thermal carrier. As this liquid gets heated up (reaching temperatures as high as 400C - 600C), it passes though a heat exchanger and generates steam, which is then used to drive a steam turbine. With the present state of technology development and costs involved, the areas having solar insulation levels of 2,000 – 2,500 kWh.m2 are better suited for the technology.

As in any thermal power plant, water is required for raising steam using solar heat. Since the high levels of solar insulation are predominantly in arid areas, this is a matter of concern. However, water consumption can be reduced by as much as 90% using dry cooling, which however would result in a minor 10 % hike in price. Water is also required for washing of parabolic mirrors for maximum performance, but the amount of water required is less than that required for steam.

CASE STUDIES

- A successful example of hybrid technology is a PV-wind-diesel hybrid system in Kythnos Island of Greece in operation since 1983 (see http://www.pvresources.com/en/hybrid.php). The plant utilizes a 100-kW PV array, a 100-kW wind turbine, and a 600-kWh battery and the entire system is connected to the existing distribution grid, which is fed by a 200-kVA diesel generator. Three 50-kVA inverters operate simultaneously to deliver power to the grid.
- The Tortoise Head Guest House on French Island, Victoria, Australia, generates its power from a remote power wind and PV hybrid system that has been operating since 1995. The system includes: 10 kW wind turbine; 840 W PV array; 2 diesel generators of 15 kW and 25 kW; battery storage (wired to produce a system voltage of 120 Volts DC); and a 10 kW inverter to convert the DC into the Australian standard of 240 Volts AC and 50 cycles per second.
- A wind-PV hybrid system is being used at the Samunsan Forest and Wildlife Sanctuary, 60 KM North of Kuching, in Sarawak, Malaysia. The population of the community fluctuates between 20-70 people, including children who return to the community on weekends, tourists and scientists. The system includes: 2.5 kW wind turbines mounted on a 26 m tower; a 900 W PV array; 2 lead acid batteries storing 2 kWhs; 5 kW inverter; 30 kW diesel generator and remote monitoring equipment.
- The largest European PV wind hybrid system is located on the Pellworm Island in Germany. The PV array has the capacity of 600 kW and will be enlarged with an additional 300 kW array. This hybrid system is grid-connected. The eventual 900-kW capacity will enable the production of nearly 800 MWh/year.

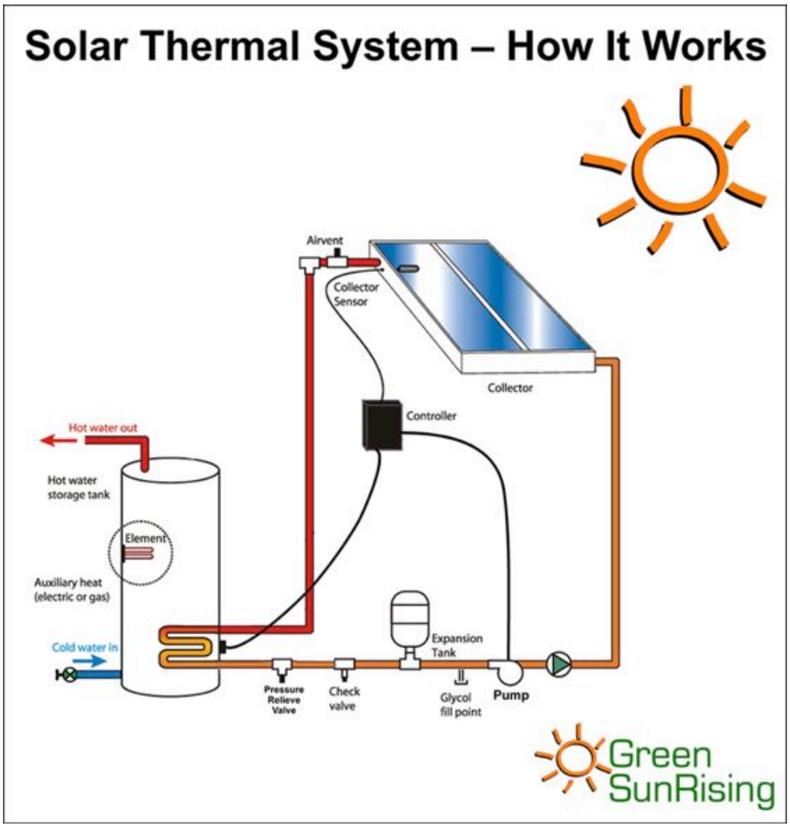
Integrated Solar Combined Cycle (ISCC) - Another possibility of CSP offers is in its integration with Gas based Combined Cycle Power Plants typically known as Integrated Solar Combined Cycle (ISCC) Power Plants. Conceptually the disadvantage of solar based energy generation being not available when sun is not available is taken care by ensuring generation though natural gas, the available solar heat during day time can be utilized for augmenting power generation in steam cycle with scaled up steam generators and Steam, Turbines would help in achieving lower cost of generation from high cost natural gas.

Storage – the USP of CSP technology - CSP technology seeks to address the biggest limitation of solar power- its non-availability when there is no sun. The heat collected during day can be fed into storage tanks – using a medium like molten salt to hold the heat. When needed, that heat can be released to generate steam to run the turbines. Generation from Solar Plant with storage can be shifted to match the utility system load profile. It allows solar to provide power when it is needed most. As a result Storage CSP Plants are able to achieve higher annual efficiencies of up to 50%+. Such peaking power has a high commercial value. Adding storage and extra collector field to serve it pays off when there is good feed-in tariff or good peaking power price.

OTHER SALIENT FEATURES

- CSP technology is based on creation of high temperature, which generates steam or hot gases for STG or GTG
- Best suited where there is high direct solar radiation
- Flexible- storage, backing by other fuel use
- Suitable for peaking energy or for extended hours of generation
- Generally, each installation is tailor-made
- Some options are: ISCC, Direct Steam, Lineal Fesnal Reflectors for lower cost, Molten Salt for storage (freezing a challenge)
- Capability to produce lowest cost, commercial scale bulk electricity
- Capability to dispatch as needed.

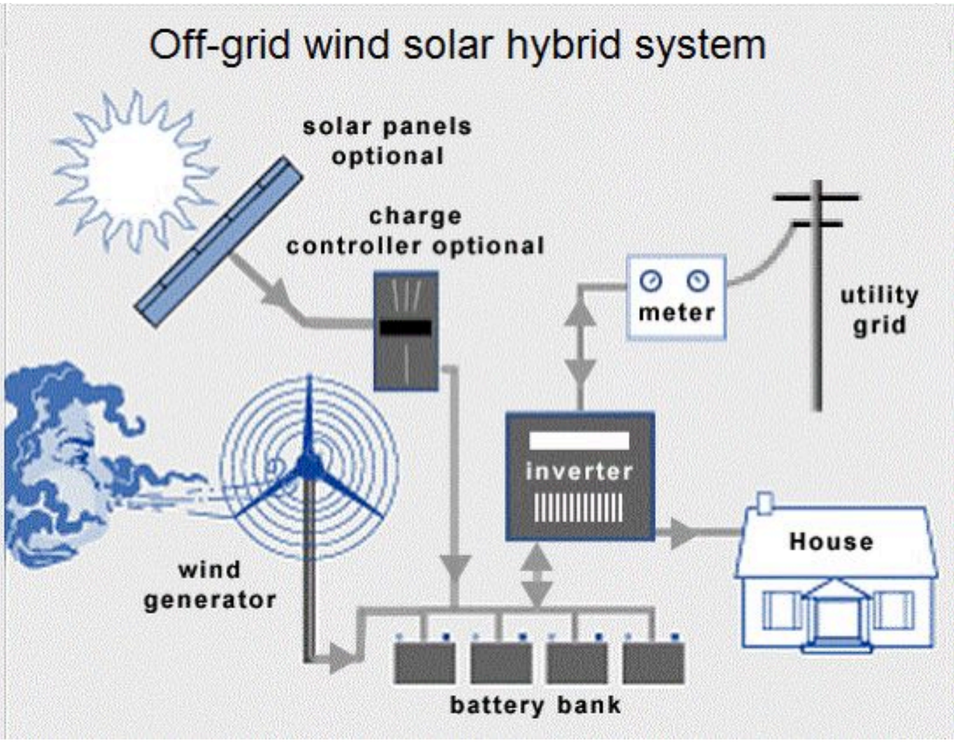
Figure 5| Solar thermal system



WIND-SOLAR HYBRIDS

Wind-Solar hybrid is a system wherein wind speed and amount of sunshine determines the output. Windmills are set up together with solar cells array and connected to the grid with a battery. Fig. 6 presents the off-grid wind-solar hybrid system. The hybrid system uses both wind generator and solar panels and the energy is stored in a battery that is later used as AC for all the household appliances (Halasa, 2010).

Figure 6| Wind-Solar hybrid system



BIOGAS - HYDRO HYBRIDS

The system consists of PV generators, wind generator, biogas, biomass (rice husk), micro-hydro, battery bank, battery charge controller and the dump load. The provisions for the availability of both AC and DC buses are made using converters. The input from solar and wind is directly fed to the charge controller to the battery bank; whereas the input from biogas, biomass (rice husk), micro-hydro is fed by converting them from AC to DC. The dump load is used to put power when the batteries are fully charged. The DC loads are directly supplied from load controller whereas an inverter is used to supply to the AC loads.

CONCLUDING REMARKS AND POLICY PRESCRIPTIVE

Various entities such as; the Indian government, utilities, donor agencies, multi-lateral development banks, NGOs, private companies, and local entrepreneurs are developing and implementing programs to improve access to modern energy services, reduce energy poverty, support local socio-economic development and improve the living conditions of people in rural areas. Needless to say, it is indeed an ongoing process. Limited government resources, limited ability of customers to pay for electricity and unfavourable technical conditions (long distance, low load densities, low average loads) continue to characterise rural electrification. Many countries have shown that rural electrification can be achieved, provided subsidies on the investments and proper institutional arrangements are made available.

For rural electrification in the Himalayas, Hybrid systems can be much more effective along with RGVs. Both central grid-based and decentralised systems are needed to meet the needs of the large number of presently unconnected dwellings. Scattered PV and micro-hydro schemes can be economically attractive when it becomes cost-prohibitive to expand network systems to sparsely populated rural areas. For these small-scale supply schemes it can be easier to obtain funding, despite, in many instances, these options having significantly higher unit costs due to lack of economies of scale. Hybrid power generation systems that combine one or more renewable energy sources with other technologies such as batteries and conventional diesel generators offer improved off-grid generation systems with appropriate operational performance. The following Renewable Energy Technologies would be appropriate for Rural Electrification in the Himalayas:

- RVGs that are isolated (i.e., off-grid) small (sizes vary between 5kW and 500kW) grids, which power a rural village with renewable energy-based electricity and have successful examples on all continents (Bolivia, Cambodia, India, Indonesia, Mali, Nepal, Nigeria, Philippines).
- Solar technologies that have ever-increasing output efficiencies, an ability to be utilized in a variety of locations with optimal access to the sun's rays. Solar energy could be used for: (a) Room/water heating which significantly reduces dependence on fuel wood; (b) Lighting based on photovoltaic technologies especially in isolated and un-electrified areas.
- Pico-hydro generators that could power an entire village as the focus should be on smaller, manageable projects, given the many issues plaguing large hydropower projects.
- Biomass is renewable, widely available, carbon-neutral and has the potential to provide significant employment in the rural areas. The major technologies in Biomass are - combustion, gasification etc. However the colder temperatures in the higher stretches may make it harder for this RET to be successful in higher altitudes.
- Wind solar hybrid technology, hybrid RET in combination with off grid RVGs makes for the most suitable combination in the Himalayas.

The best way ahead for mountain rural electrification could be with a judicious mix of renewable energy technologies and their hybrid variants.

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