RENEWABLE ENERGY TECHNOLOGIES FOR **MOUNTAIN LIVELIHOODS**

ISSUES & PROSPECTS

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Policy Brief 2

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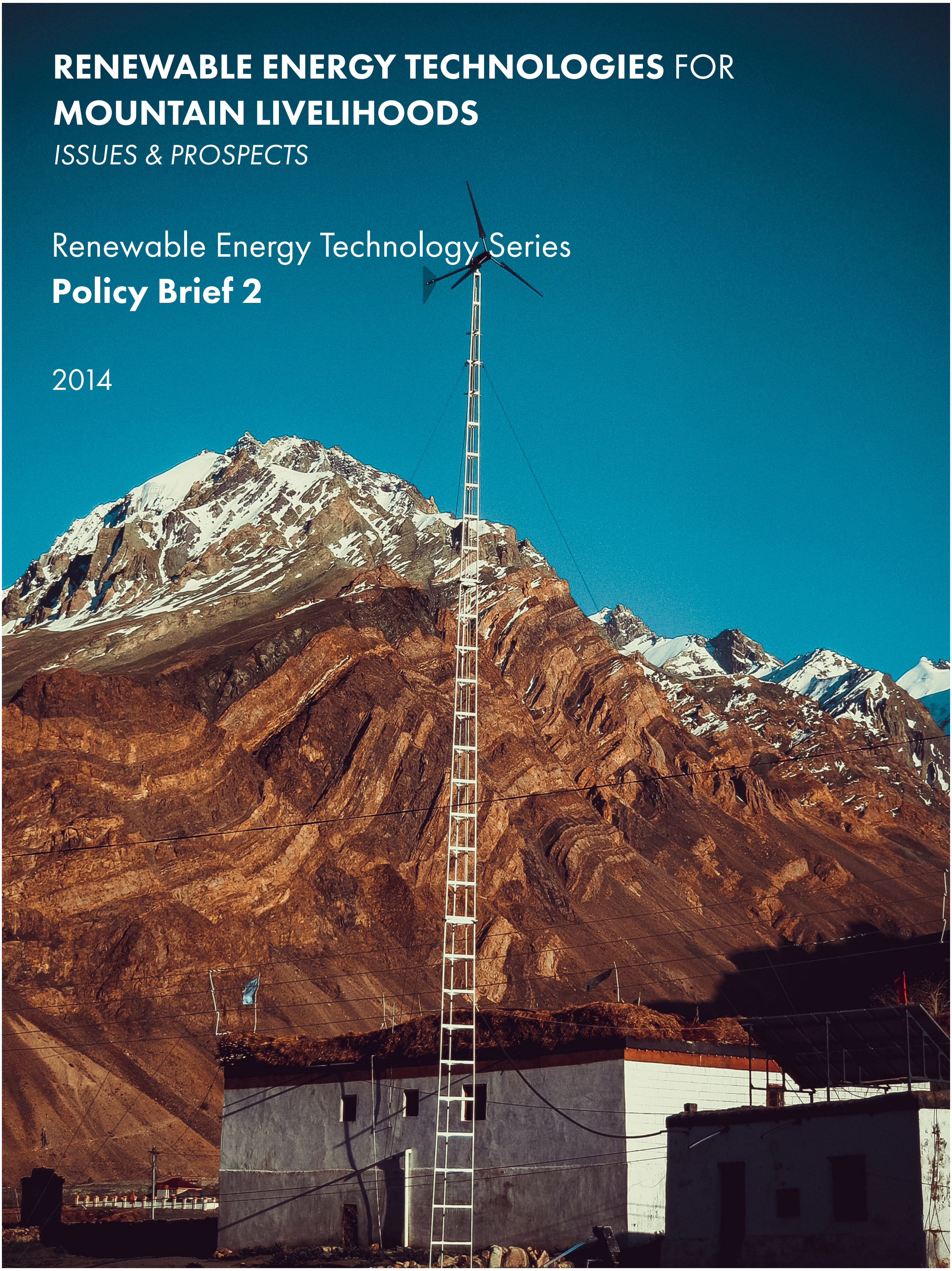


PRAGYA ENVIRON

INTRODUCTION

Energy plays a dual role in the development of regions and communities. As a consumer good, energy consumed in households has a direct impact on the quality of life. As an input into the productive sectors of the economy~ agriculture and industry, it impacts on the development of the entire region. The demand for energy however is increasing at an escalating rate resulting in acute pressure on the available resources.

Renewable Energy (RE) is being championed as a vital source of employment and rural growth and as a means of tackling environmental and energy security issues. OECD Green Growth Study links RE to Rural Development and draws on case studies in 16 regions across Europe and North America (OECD, 2012). RE electricity sector grew by 26% between 2005-2010 worldwide and at present supplies about 20% of the earth's total power (including hydro-power). RE entails a multi-faceted flexible policy framework and impacts on livelihoods by:

- Generating extra income for farmers who have diversified, increased and stabilised their income sources
- Creating valuable jobs and business opportunities, in regions with restricted employment prospects
- Ensuring capacity building and community empowerment through skill building and development of institutional structures

LIVELIHOOD DEVELOPMENT VIA RE TECHNOLOGIES IN HIMALAYAN REGION

India has a vast reservoir of RE and one of the biggest programs for establishing RE products and systems (Meisen & Quéneudec, 2006). The India RE Status Report 2014 released at the Green Summit 2014 reports that the overall RE potential from diverse sources is 2,49,188 Mw. The installed capacity of RE is 32,270 Mw or 12.95% of the total potential existing in India, as on March 31, 2014 (MOSPI, 2014). Hence the available market potential points up to enormous growth prospects for RE in India.

Mounting energy demands have in a sense resulted in 'poverty of energy'. The negative balance of energy is even more prominent in the Himalayan region where lack of access to energy is a primary reason for poverty and a constraint to creating livelihood resilience. With central grid connectivity at low levels in the Himalayan region, RE if used and harnessed judiciously via appropriate technologies can facilitate sustainable livelihood (Ref. Table 1 - State wise Estimated Potential of RE in Himalayan region). This article is a policy brief on RE Technologies for mountain livelihoods. The brief examines:

- Potential RE Technologies and their prospects and feasibility for livelihood
- RE Advantage, Limitation and Average Economic Cost of Energy Generation
- Processes and Structures for RE
- Barriers to uptake of REs in mountain regions

RE TECHNOLOGIES AND THEIR PROSPECTS

RE Technologies can have a substantial impact in developing the energy capacity of the mountainous regions. Better access to energy for domestic and productive use via stand-alone or off-grid RE Technologies are more affordable and acceptable to communities, thereby raising their livelihood options. Some of these stand-alone technologies are:

RE TECHNOLOGIES BASED ON SOLAR ENERGY

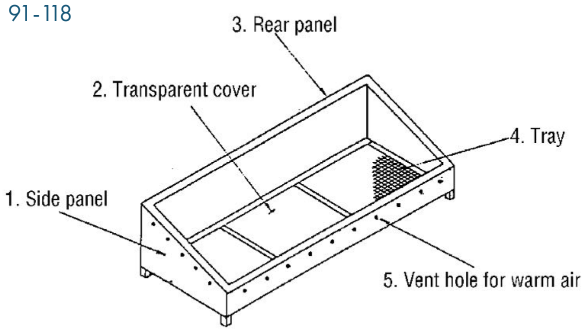
Solar cells convert sunlight into direct current electricity using the photovoltaic effect. The solar cells in a photovoltaic module are made from semiconductor materials. When light energy strikes the cell, electrons are knocked loose from the material's atoms. Electrical conductors attached to the positive and negative sides of the material allow the electrons to be captured in the form of a direct current. This electricity can then be used to power a load, such as a water pump, crop dryer or it can be stored in a battery (Chel and Kaushik, 2011).

Solar Water Pumps are specifically designed to lift water from ponds or streams for irrigation, livestock, horticulture farms, drinking in isolated fields. Solar PV systems are the best option for locations where there is no electricity or scarcity of power supply. A solar PV water pump system consists of a number of solar PV modules mounted on a metal frame that can be turned / tilted to ensure that the modules keep facing the sun throughout the day. The SPV array converts the solar energy into electricity that is used for running the motor pump set. The PV integrated water pumping application is shown in *Figure 1*.

Figure 1| PV Integrated Water Pumping Application
Source: Chel, A., and Kaushik, G. (2010). Renewable Energy for Sustainable Agriculture. Agronomy for Sustainable Development; Springer, Vol.31, No.1, 2011, pp.91-118

Solar Crop Dryers are an effective way to dry grains, fruits, and spices without any power consumption. A basic solar dryer consists of an enclosure or shed, screened drying trays or racks, and a solar collector. The design of a solar crop drying system can be a glazed box with a dark coloured interior to collect solar energy, which heats the air inside the box. The heated air is then moved through the crop material either by natural convection or with a fan. The box type solar dryer with the natural convection principle is shown in *Figure 2*.

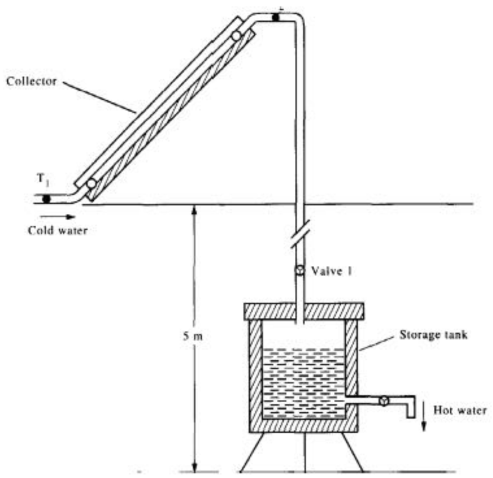
Figure 2| Box Dryer
Source: Chel, A., and Kaushik, G. (2010). Renewable Energy for Sustainable Agriculture. Agronomy for Sustainable Development; Springer, Vol.31, No.1, 2011, pp. 91-118



Solar crop dryers help farmers in post-harvest processing, long-term storage and eventually cause better quality product and higher earnings.

Figure 3| Box Dryer

Source: Chel, A., and Kaushik, G. (2010). Renewable Energy for Sustainable Agriculture. Agronomy for Sustainable Development; Springer, Vol.31, No.1, 2011, pp.91-118



Solar Water Heaters use the sun to heat either water or a heat-transfer fluid, such as a water-glycol antifreeze mixture, in collectors generally mounted on an unshaded, south-facing roof. The heated water is then stored in a tank similar to a conventional gas or electric water tank. Solar water heaters consist of collectors, storage tank, insulation, piping, transparent cover and depending on the system, electric pumps to circulate the fluid through the collectors. The schematic solar water heating system is shown in Figure 3. Although the initial cost of solar water heaters is high, the fuel (sunshine) will always be free.

Greenhouse heating is an agricultural application of solar energy for both heating and lighting. Solar greenhouses are devised to collect solar energy in sunny days and also to store heat for use at night or during periods when it is cloudy. Solar greenhouses can either be stand alone or attached to houses. Solar greenhouses have glazing, oriented to receive maximum solar heat during the winter. They utilise heat-storing materials to retain solar heat and have huge amounts of insulation where there is little or no direct sunlight. Passive solar greenhouses are a good alternative for small farmers as they are a cost-efficient method to lengthen the growing season.

Solar Energy A Viable Answer

- ✓ Most of the mountainous region gets 300 days of sunshine a year for approximately 8 hours a day
- ✓ Direct sunlight can be converted into electricity by using Photovoltaic (PV) technology
- ✓ If properly sized and installed, PV based applications are reliable, long lasting and need little maintenance

Solar Powered Cold storage/refrigerators are a promising solution for cooling and preserving perishable food items such as milk, fruits and vegetables, without the requirement for costly diesel-powered generators. Conventionally solar-powered refrigerators and vaccine coolers employ a combination of solar panels and lead batteries to store energy for cloudy days and at night in the absence of sunshine to keep their contents cool. These fridges need heavy lead-acid batteries that are likely to weaken, particularly in warm climates. The batteries also entail maintenance, should be replaced every 3 years, and disposed off as hazardous wastes that may cause lead pollution. These problems and the resultant higher costs act as major barriers for the use of solar powered refrigerators in developing regions.

Solar Concentrators provide total steam cooking system for thousands of people for student hostels, universities, hospitals, communities, temples, and hotels. For example, one concentrator of 64 sq mt. can cook for 500 people in 1 hour. Cooking will be by steam inside the kitchen. Solar Concentrators can also be used for agro processing and for solar power generation running steam engines and generators.

These RE technologies based on solar energy would promote sustainable agriculture - solar photovoltaic water pumps and electricity, greenhouse technologies, solar dryers for post-harvest processing, and solar hot water heaters.

RE TECHNOLOGIES BASED ON WIND ENERGY

Wind power is derived from uneven heating of the earth's surface from the Sun and the warm core. Wind power is produced in the form of electricity by converting the rotation of turbine blades into electrical current by means of an electrical generator. In windmills, wind energy is used to turn mechanical machinery to do physical work, such as crushing grain or pumping water.

Pumping Water using Wind Turbines - Wind turbines are extremely beneficial in locations with shorter rainy season where there is an excessive demand for pumped water. Applications of wind turbine powered water pumps are: domestic water supply, water supply for livestock, drainage, salt ponds, fish farms, and for irrigating small farms. At present, mostly fossil fuel-powered water pumps are used in farms and few wind-powered water pumps have been installed worldwide (Chel and Kaushik, 2011).

Grinding grains using windmills - Wind energy can also be utilized for crushing grains and legumes and can be applied on farms for production of flour.

Small Wind Technologies

- ✓ Wind values mostly below 4m/s show that large-scale commercial power generation might not be feasible in the lower reaches of the Himalayas
- ✓ The slow speed could be used for small wind technologies which are cost effective in medium to long term
- ✓ Wind Energy Projects are exempted from electricity duty by state government(s)

RE TECHNOLOGIES BASED ON GEOTHERMAL TECHNOLOGY

Geothermal energy harnesses the natural flow of heat from the ground. The available energy from natural decay of radioactive elements in the Earth's crust, and mantle is just about equivalent to that of incoming solar energy. The geothermal gradient, which is the difference in heat between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. Traditionally Geothermal power has been restricted to regions close to tectonic plate boundaries. Worldwide, 11,700 megawatts (MW) of geothermal power is online in 2013. An additional 28 GW of direct geothermal heating capacity is installed for heating, spas, industrial processes, desalination and agricultural applications in 2010 (Sharma, and Trikha, 2013).

India has massive potential to become a foremost contributor in producing eco-friendly and cost effective geothermal power. However, power generation through geothermal resources is still in nascent stage. Geological Survey of India has identified about 340 geothermal hot springs in the country. Some of the prominent geothermal resources are in the Himalayas in locations such as Puga Valley and Chhumathang in Jammu and Kashmir, Manikaran in Himachal Pradesh, and Tapovan in Uttarakhand (Fig.4).

Hot Springs for Geothermal Power Plants - When heated water from the hot springs is forced to the surface, it is relatively simple to capture that steam and use it to drive electric generators. In order to set up geothermal power plants, holes are drilled into the rock to capture steam more effectively to drive electric generators.

Figure 4| Chhumathang hot spring located about 40 km north of Puga, Ladakh
Source: Sharma,O.P. and Trikha,P. (2013). Geothermal Energy and its Potential in India. Akshay-Urja; Vol.7, No.1, 2013, pp. 14-18.

Geothermal energy generated and stored in the earth

- ✓ Heat from the earth-geothermal energy heats water that has seeped into underground reservoirs which can be tapped for electricity generation, heating buildings, raising plants in greenhouses
- ✓ Himalayan region is considered the 'geothermal province' of India with more than 300 known geothermal springs

Ground-source heat pumps – These make use of the earth or groundwater as a heat source in winter and a heat sink in summer [utilizing resource temperatures of 4°C (40°F) to 38°C (100°F)]. Geothermal heat pump system consists of a ground heat exchanger, a heat pump unit, and an air delivery system that can be utilized to heating, drying and sterilization purposes. In the winter, the heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger. The heat removed from the indoor air during the summer can also be used to provide a free source of hot water.

RE TECHNOLOGIES BASED ON HYDRO POWER

Hydropower is energy derived from falling or flowing water passing through a water turbine that moves a generator, producing electricity. The estimated potential of small hydro is around 15,384 MW and most of the potential is in the Himalayan States. In remote hilly areas, development of hydro-based power generation of up to 25 MW capacity, classified as small hydropower, leads to rural electrification and local area development. The gestation period of the technology is low and the indigenous manufacturing base is strong.

Micro-hydro system is a viable mechanism for energy production in the Himalayan region, where flowing water is an easily available resource. These systems are easy to use and unlike wind and sun, hydro resource can be accessible 24 hours a day, 365 days a year. Micro-hydro pumps can enable running of irrigation pumps and grain mills, thereby raising agricultural productivity.

Case Study: Micro-hydro plant in Udmaroo village, Ladakh

- ✓ A 32 kVA capacity, presently generating 20-25 kVA micro-hydro plant was set up in Udmaroo village of Nubra Valley, Ladakh in 2008 by LEDeG
- ✓ Prior to the installation of plant, the village was secluded from the mainland with no mode of employment and declining interest in agriculture
- ✓ The plant had an affirmative impact on livelihood options ~WSHG ran an oil extraction and flour milling enterprise
- ✓ Fruit processing and carpentry enterprise was set up
- ✓ Capital investment was recovered in 2 years due to savings on diesel fuel

Source: www.greenpeace.org

RE TECHNOLOGIES BASED ON BIOMASS ENERGY

Biomass as a RE source, is biological material from living, or recently living organisms from fuel sources such as: wood, agro-waste, bagasse, rice husk, animal dung, and marine vegetation. Biomass power generation attracts investments of over Rs.600 crores every year in India, producing in excess of 5,000 million units of electricity and 10 million man-days employment.

Biomass Gasifier - The cycle used is conventional with biomass being burnt inside a high-pressure boiler to produce steam and running a turbine with the generated steam. The exhaust of the steam turbine can either be fully condensed to create power, or used partially or fully for another heating activity. Locally available biomass resources such as wood chips, rice husk, cotton stalks and agro-residues can be combusted and used directly in cooking or lighting applications with the help of a biomass gasifier.

Case Study: Biomass Gasification of Silk Industry

- ✓ Silk industry in India is characterized by high fuel consumption of 3,15000 tons in a year of which only 12% is efficiently consumed
- ✓ To improve fuel efficiency in sericulture sector, TERI introduced biomass gasification technology
- ✓ Fuel savings went up to Rs 745 per day ,with increased productivity, reduced pollution and increased profit margin by users, leading to improved livelihood standards

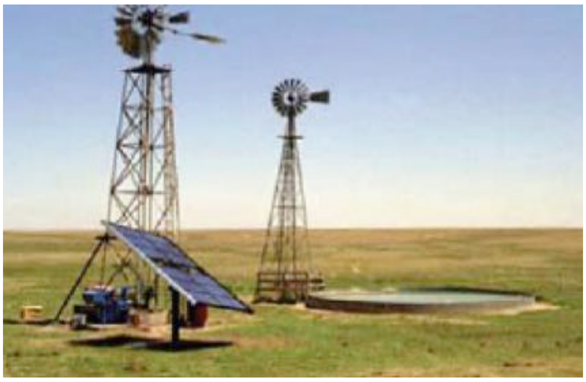
Biogas plants are an established RE technology for methane gas production of clean power generation from waste products, as cattle dung and human waste. The technology is valuable particularly in agricultural, waste treatment or animal processing where there is surplus manure, farm or municipal waste.

HYBRID SYSTEMS

Hybrid technology systems combine two or more RE technologies with the aim to achieve efficient systems such as Wind-solar photovoltaic, Solar-Biomass hybrid systems. Hybrid systems are ideal for distant and inaccessible applications such as communication stations and rural villages.

Solar-Wind Hybrid - Small wind aero-generators in hybrid mode with solar panels are helpful for off grid RE based electricity generation. Solar-wind hybrids are beneficial in mountain regions where wind and solar resources are naturally invariable. Windmills are set up in concert with solar cells array and connected to the grid with a battery. Typical capacities are in the range of 1 kW to 10 kW for the solar panel and wind turbine combined system, and can be used for applications such as water pump and electricity, dryer, hot water heater. Fig. 5 presents the PV windmill integrated water pump.

Figure 5| PV Windmill Integrated Water Pump
Source: Chel, A., and Kaushik, G. (2010). Renewable Energy for Sustainable Agriculture. Agronomy for Sustainable Development; Springer, Vol.31, No.1, 2011, pp.91-118



Solar-Biomass Hybrid is a combination of a photovoltaic array integrated with a biomass generator, which can be used in areas where there is indigenous availability of both renewable resources. It consists of a PV array, a battery bank, a biomass generator, a charge controller and a DC/AC converter (Pradhan et al., 2013). The technology can be used for developing cold storage and for supplying grid quality power supply to remote regions.

Case Study: Solar-Wind Hybrid System In Lossar Valley

- ✓ A 2.1 KW capacity Solar Wind Hybrid System (SWHS) was established in Lossar valley, Lahaul & Spiti, Himachal Pradesh in 2004 by Pragya
- ✓ Energy generated by SWHS positively impacted the community by serving households, a health and weaving centre
- ✓ The installation facilitated livelihoods by letting villagers carry out productive activities in winters

POTENTIAL FOR RE APPLICATIONS IN LIVELIHOOD SECTORS

The RE Applications can be deployed across diverse livelihood sectors:

Agriculture - Water pumps for irrigation and cattle drinking, poultry lightning, and aeration for aquacultures (energypedia).

Tourism - RE solutions for street, hotel lighting, water heating, cooking would contribute to the sustainable development of tourism.

Sericulture - Bio-gasifiers can enhance the energy capacity and provide better technologies.

Agro-Processing - Biomass and solar powered cold storage, solar powered refrigerators can widen opportunities in agro-processing.

Communication - PV powered cell phones or PV powered satellite phone Kiosks (as in Bangladesh Grameen Shakti operations) can provide market information service.

Other Sectors - RE technologies can affirmatively impact livelihoods in brick making, carpentry, fish hatcheries, and handicrafts.

RE ADVANTAGE, LIMITATION AND AVERAGE ECONOMIC COST OF ENERGY GENERATION

Each RE has Advantages and Limitations and a range of Economic Costs for Energy generation. The cost of delivering electricity in remote areas includes the cost of generation, transmission and distribution of electricity. The cost of delivering electricity in distant areas, sited in the range of 5–25 km is found to vary from Rs. 3.18/kWh to Rs. 231.14/kWh depending on peak electrical load up to 100 kW and load factor, for electricity generated by coal thermal power plants (Nouni et al., 2009). In 2012-13 Conventional power was at an average unit price of Rs 5.71 (Jai, 2014). World Bank Report on Unleashing the Potential of RE in India provides comparative cost data drawn from 180 wind, biomass and small hydropower projects in 20 states (World Bank, 2010).

These studies conclude that micro-hydro, dual fuel biomass gasifier systems, small wind electric generators and photovoltaic systems are financially attractive when compared to grid extension for providing electricity in small remote villages. They become even more attractive and economical in the Himalayas where there is abundance of renewable sources but limited access to on-grid energy. Further, the costs of capital equipment for RE have been steadily decreasing and are likely to continue to decline as technology advances. Table 2 presents RE Advantages, Limitations and Economic Costs of Energy Generation.

PROCESSES AND STRUCTURES FOR RE

India has put in place, considerable policy, regulatory and financial incentives to encourage development of RE and its corresponding technologies. Most noteworthy are: Electricity Act 2003 and National Tariff Policy 2005 – The landmark Electricity Act clearly recognised the responsibility of renewable projects for providing power to the utility grid and in stand-alone systems. Of India's many policy and financial incentives, two have had the most concrete impact on industry growth: wind sector–specific efforts and the umbrella Electricity Act 2003.

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The Policy and Regulatory Framework comprises multiple Institutions such as the Ministry of Power, Ministry of Non-Renewable Energy (MNRE), state governments, state nodal agencies and regional electricity corporations. The Policy and Regulatory Framework comprises:

- Key Legislation - Electricity Act 2003 aimed at fostering competition, private investment, and power for all and National Tariff Policy 2005
- Ministry of Non-Renewable Energy (MNRE) has a direct mandate for RE in all policy and programmatic aspects
- Electricity Act 2003 mandates the State Electricity Regulatory Commission (SERC) to promote generation of electricity from RE sources
- SERCs have the most direct impact on feed-in tariffs, Renewable Purchase Obligations (RPO), and open-access charges
- All central agencies have a state counterpart, which has the final say on how RE projects are developed.
- Specialised Technical Institutions under MNRE - Solar Energy Centre, C-WET, SSS-NRE are focal Institutions for solar, wind and bio-energy.

Apart from these institutions, the Jawaharlal Nehru National Solar Mission (JNNSM) aims to reduce cost of solar power generation through long-term policies, aggressive R&D and domestic production of critical raw materials, components, and products. These manifold Institutions sometimes results in lack of coordination and critical implementation gaps.

BARRIERS TO UPTAKE OF STAND-ALONE PROJECTS IN MOUNTAIN REGIONS

There are several factors which hinder the uptake potential of REs in the Himalayas, these are: small size of transactions; narrow penetration of financial institutes; lack of replicable models for stand-alone projects; lack of awareness amongst public about RE; and underdeveloped value chain. In addition, to the above there are specific financial, infrastructural and regulatory issues that hinder the growth of RE technologies in rural areas.

The primary reason for the lack of interest in RE investment cited is administrative hurdle. Clearance has to be taken from several agencies such as SERC, wildlife department, pollution board, state nodal agencies; 60% of project cycle time for micro hydropower project is spent in getting government clearances (World Bank, 2010).

Financial Barriers

- ✓ Lack of Uniform Incentive policy
- ✓ Failure to develop least-cost resources first
- ✓ Inadequate funding for small transactions

Infrastructural Barriers

- ✓ Inadequate access to infrastructure
- ✓ Lack of good-quality data

Regulatory Barriers

- ✓ Long gestation period for release of capital subsidy
- ✓ Administrative and operative hurdles

RECOMMENDATIONS FOR RE TECHNOLOGIES

Recommendations that can help in successful implementation of RE technologies should overcome the financial, infrastructural and regulatory barriers and focus on the "know-how" and the "know-why" (UNCTAD, 2010). The recommendations should adopt a holistic perspective and begin with simplifying the several overlapping financial incentives and putting them on sound economic and market foundation. It should make possible financing of RE by encouraging market-driven energy agenda. The national energy policies and plans should set annual investment goals and stratagems for the RE technologies deployment in remote mountain regions. There should be dynamic participation of energy planners at national, regional levels for the right integration of these technologies in development plans. Energy strategies should integrate RE within the larger supply chain of the local economy, such as agriculture, sericulture, and tourism.

Infrastructure barriers should be tackled with investments for communications in the mountainous regions. The key pre-requisite for RE installation is an in-depth understanding of the RE technology. Each RE source whether it is solar, wind or hydro has its own technological specifications. R&D should be tailor-made to the needs of the mountain communities - creating integrative energy system that is stand-alone or off-grid technologies. Streamlining bureaucratic processes for clearances and approvals and advancing towards a unified, light-touch regulation for RE that would help to tackle administrative and operative hurdles. Underpinning all these steps is the need to generate awareness among citizens about the usefulness of RE technologies.

Table 1: Source wise and State wise Potential of Renewable Power in India as on 31.03.2013(In MW)

States	Wind Power	Small Hydro Power	Biomass Power	Cogeneration Bagasse	Waste to Energy	Total	
						Estimated Reserves	Distribution (%)
Arunachal Pradesh	201	1341	8	0	0	1550	1.65
Himachal Pradesh	20	2398	142	0	2	2562	2.72
Jammu & Kashmir	5311	1431	43	0	0	6785	7.21
Sikkim	98	267	2	0	0	367	0.39
Uttarakhand	161	1708	24	0	5	1898	2.02
West Bengal	22	396	396	0	148	962	1.02

Source: *MOSPI; 2014; Energy Statistics 2014; Ministry of Statistics and Programme Implementation;* http://mospi.nic.in/mospi_new/upload/Energy_stats_2014.pdf

Table 2: RE Advantages, Limitations and Economic Costs

RE Technology	Advantage	Limitation	Average Economic Costs of Energy Generation
Solar	• Can be used in remote areas where it is too expensive to extend the electricity power grid. • No fuel, low running costs • Longevity - solar panels can last over twenty years • Green House Gas Emissions (in g/kWh) 98-167 CO_2 and 0.2-0.34 SO_2	• Requires large initial investment. • All the light from the sun is not absorbed by the solar panels. Most solar panels have a 40% efficiency rate which means 60% of sunlight gets wasted and is not harnessed	• Unit costs are estimated to be Rs 12/kWh for solar thermal and Rs 17/kWh for solar photovoltaic • High capital cost and low plant-load factor compared with other RE technologies (World Bank, 2010, p.29) • Cost of production has dropped 60% in 3 years, with price Rs 6.5 a unit (Jai, 2014), expected to drop further
Wind	• Lowest gestation period as compared to conventional energy (Meisen & Quéneudec, 2006). • Does not produce toxic or radioactive waste • Reduces concentrations of CO_2, SO_2, NO_X, thereby reducing acid rain • Low maintenance • Does not create greenhouse gases (each mega-watt hour generated by wind energy helps to reduce 0.8 to0.9 tonnes/year of greenhouse gas emissions that are produced by coal or fossil fuel generation each year) • Green House Gas Emissions (in g/kWh) 7-9CO_2 and 0.02-0.34 SO_2	• Winds do not blow strongly enough to produce power all the time. Electricity from wind farms must have a back-up supply from another source (Meisen & Quéneudec, 2006). • High cost of installation • Lack of spare parts • Lack of skilled technical experts to repair the turbine in case of damage • Low Level of Public Awareness • Land intensive and might impede on agricultural land, leading to loss from agriculture-based revenue • Adverse impact on Biodiversity as they lead to a) loss of top soil b) Loss of habitation of flora and fauna (MNRE, 2013)	• Rs 4.9/kWh (range between Rs 3.8–Rs 5.2/kWh) which is competitive with conventional fuels such as oil and diesel. • Generation cost of wind is highly sensitive to the capacity utilization factor, which is low at 23 percent (World Bank, 2010,p.29).

RE Technology	Advantage	Limitation	Average Economic Costs of Energy Generation
Geothermal	• Low operating costs due to relatively constant ground water temperature • Indigenous in nature and independent of fluctuation in external supply and demand effects and in exchange rates of fuels • Has 24 hour energy generation capacity • No harmful by-products, little effect on the natural landscape, or nearby environment • Green House Gas Emissions (in g/kWh) 7-9 CO_2 and 0.02 SO_2	• Gestation time for permitting, financing, drilling can take 5-7 years to develop a geothermal energy field. • If harnessed incorrectly, geothermal energy can sometimes produce pollutants • Improper drilling into the earth can release hazardous minerals and gases • Geothermal power plant sites may run out of steam in the long run	• Initial investment of excavation is extremely high • Lack of cohesive data on the economic cost analysis of geothermal RE in India.
Hydropower	• More efficient and less expensive energy source than geothermal, biomass, wind and solar energy • Small hydro does not require much expertise to build and operate. • Green House Gas Emissions (in g/kWh) • Small Hydro :9CO_2 and 0.03 SO_2 • Large Hydro: 3.6-11.6 $CO_2$and 0.009-0.024 SO_2	• Unreliable during prolonged droughts and dry seasons when rivers dry up or reduce in volume • Initial installation cost can be high if damming or dirt work is required • In colder climates, freezing of pipes, etc can be a problem	• Small hydropower at Rs 3.56/kWh is the most economically viable form of RE technology • This resource is most attractive in Himachal Pradesh, Uttaranchal, where the cost is less than the average cost (World Bank,2010,p.28)
Biomass	Biomass absorbs carbon dioxide (CO_2) from the atmosphere for its growth and stores in the plant itself. Electricity thus produced from biomass fuels is carbon cycle neutral (Akella et al, 2009)	• Can lead to air pollution in the form of char if the biomass is not completely combusted. • Initial costs of a biomass boiler/gasifier are quite daunting	• Rs 4.6/kWh (range between Rs 3.9–Rs 5.7/kWh)which is competitive with gas- and diesel-based generation • Availability and price fluctuations of biomass under a regulated market pose a significant risk to scale-up(World Bank, 2010,p.29)

RE Technology	Advantage	Limitation	Average Economic Costs of Energy Generation
Solar-Wind Hybrid	• Solar-Wind complement each other during lean periods, for example, additional energy production through wind during monsoon months compensate the less output generated by solar (Dalwadi & Mehta, 2012) • Emission of carbon and other harmful gases are reduced to approximately 80% to 90%	• Initial cost is high • While solar panels don't need much maintenance other than cleaning, wind turbines require regular maintenance to inspect the blades	NA
Solar-Biomass Hybrid	• In comparison to biomass-only, hybrid operation saves up to 29% biomass • Carbon emission is 2.0878 tonnes/year, significantly less than carbon emissions from conventional sources (Janardhan et al, 2013)	Cost for solar PV is high, thereby raising the cost of initial capital investment	• Initial cost of PV and biomass is around 900,000 Rs/- and the total no. of units generated from the system is 10,136 kwh/ year. • Commercial rate of one unit is 7Rs/- • Payback period is around 12 years, but, given the subsidies offered by the government, , the period will reduce to 6 years. (Pradhan et al, 2013)

Note: Estimates for conventional power~ Economic Costs: Rs 3.08/kWh for coal-based generation and Rs 3.5 kWh for gas-based generation (World Bank, 2010, p.26); Green House Gas Emissions (in g/kWh)by Energy Sources: Coal 955 CO2 and 11.8 SO2. Natural Gas 430 CO2 (Akella et.al, 2009).

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