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Decentralized Renewable Energy Options for Himalayan States in India

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Summary

Energy system in the Himalayan mountain regions is complex due to the wide variations in availability and demand of energy resources. Mountain inhabitants are traditionally dependent on bioenergy resources like fuel wood, agro and animal residues for meeting their energy requirements for heating, cooking, etc. Per capita fuel wood consumption varies with seasons and regions as 0.48–1.32 kg/person/day (Solan), 1.9–2.68 (Shimla) and 0.89–2.91 kg/person/day (LahualSpiti). Dwindling forest resources limit availability of fuel wood while commercial sources like LPG and kerosene fail to meet the domestic energy demands due to logistic and economic constraints. Hence, the inhabitants are forced to follow inefficient and ad hoc usage of juvenile forest trees (thus hindering regeneration), agro and animal residues disregarding their alternative utilities. This deteriorates the ecological harmony and demands for sustainable resource planning in the regional level. Ecologically sound development of the region is possible when energy needs are integrated with the environmental concerns at the local and global levels. The need to search for decentralized renewable, alternate and non-polluting sources of energy assumes top priority for self-reliance in the regional energy supply. This demands an estimation of available energy resources spatially to evolve better management strategies for ensuring sustainability of resources. The spatial mapping of availability and demand of energy resources would help in the integrated regional energy planning. Spatial analyses of the availability of solar energy show that the state receives annual average GHI above 4.5 kWh/m^2/day and a total of 98586056 Million KWh (or Million Units, MU). The lower and middle elevation zone (< 3500 m) with tropical to wet-temperate climate receives higher GHI (>5 kWh/m^2/day) for a major part of the year compared to the higher elevation zone (> 3500 m) with dry-temperate to alpine climate (4-4.5 kWh/m^2/day). Spatial wind profiles based on high resolution data provide insights to the wind regime that helps in identifying potential sites for wind prospecting. The higher altitude alpine zone in Himachal Pradesh has relatively higher wind speeds compared to lower altitude zones. The minimal but reliable surface measurements in the lower altitude temperate and tropical zones indicate the micro climatic influences and spatial variability in the complex Himalayan terrain. The wind potential in Himachal Pradesh supports small wind technologies like agricultural water pumps, wind-photovoltaic hybrids, space/water heaters etc. This would help in meeting the decentralized energy demand sustainably.

The total tree cover in the study area is 43.51% (Solan), 48.85% (Shimla) and 0.36% (LahaulSpiti) providing annual woody biomass of 517.3–1111.7 kilo tonnes (Solan), 1253.8–3029.8 kilo tonnes (Shimla) and 18.9–63.8 kilo tonnes (LahaulSpiti). The annual bio-energy potential of agro residues (considering 50% for fuel purpose) is 349463 million kcal (Solan), 221562 million kcal (Shimla) and 2678 million kcal (LahaulSpiti). The annual biogas generation potential is 8.7–35.6 million m3 (Solan), 12.9–43.2 million m3 (Shimla) and 0.8–1.9 million m3 (LahaulSpiti). Bio-energy resource crunch is more pronounced in the higher elevations while scarce resource availability scenarios create similar conditions in lower elevations as well.

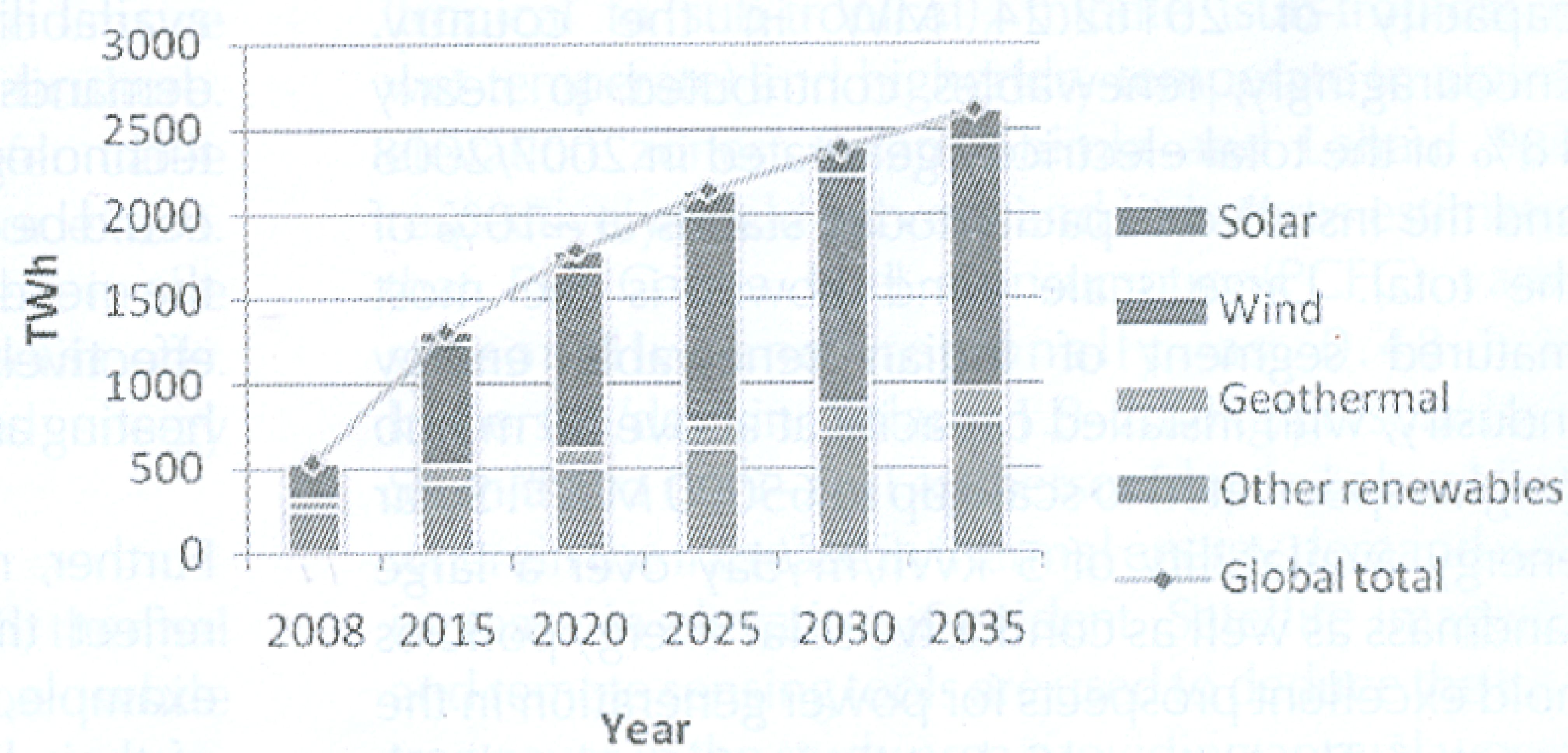
The process of energy planning at present, however, is a highly centralised activity, and district and local level institutions are not playing any significant role in the process. As a result, the energy crisis in rural areas and particularly in mountainous regions is not adequately reflected in national level planning. In addition, decentralised energy development and conservation programmes are not being effectively implemented. This applies to a wide spectrumof programmes, ranging from the enhancement of social forestry to the introduction of energy-saving devices, e.g., improved cooking stoves and space heating devices. Hence, there is a need to look at all locally available and exploitable renewable resources of the region and analyse spatially the demand for energy services. This study has shown that the objective of effective implementation of energy planning cannot be achieved without decentralisation and active participation of the local community. India is fortunate that it has a wide network of local government institutions at the district and lower levels. This can be effective with the capacity building and assigning the local institutions their due role in the implementation and management of the local energy system.

Introduction

Energy is synonymous with social and economic prosperity of civilizations. Natural resources utilized through various energy conversion devices for domestic water heating to energy intensive commercial steel production have made significant improvement to lifestyles. However, exorbitant usage of natural resources especially exhaustible fossil fuels for meeting the ever increasing energy demands has costed our environment and health. In recent times, the impact of fossil fuels on local environment and global climatic changes are conceded by a large populace. The global energy scenario is witnessing a gentle shift from these polluting fuels which 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 in the planet who are 7 billion in number today. Today, renewables like sun, wind, biomass, hydro et al are gaining acceptance as locally available and clean energy resources which could minimize fossil fuel dependency to a great extent.

In the global context, the share of renewable energy consumption grew from 0.6% in 2000 to 1.8% viz. 158.6 Million tonnes oil equivalent (Mtoe) in 2010. This is a considerable shift in energy priority, although the impact of global warming pushes for intensive growth in the sector. Renewables share of total global electricity generation is nearly 1.7% of which installed solar photovoltaic power is 39.8 GW, wind power is 199.5 GW and geothermal power is 10.9 GW. Major part of the renewables based electricity capacity addition is driven by Europe and Eurasia. Renewables have been consistently contributing to 14% of the growth in global electricity generation. Due to congenial government policies in many parts of the world, renewable energy is the fastest growing source of electricity globally and is projected to be above 5 times the existing generation capacity by 2035 [Figure 1]. Biofuels account for 0.5% (59261 ktoe) of the global primary energy consumption, three quarter of which is contributed by the Americas. Biofuel remains one of the only possibilities to sustain a post-petroleum economy[1-3].

Figure 1: Electricity generation from renewable energy resources projected till 20353



India, a nodal economy in the developing world is part of a slow changeover from polluting fuels towards cleaner alternatives. Fuel wood continues as the mainstay of domestic thermal energy (water/room heating and cooking) needs with obvious stresses on local vegetation resulting from increasing demand. This energy demand is also met by kerosene, biogas and LPG in rural and urban areas. Inefficient fuel wood stoves contribute to higher carbon emissions, health problems and are essentially being replaced by fuel efficient chul has (stoves). The studies have shown that there is a scope for saving to the order of 42-45% by switching over to energy efficient devices at domestic level[4,6]. Transport sector in India thrives on petroleum products largely imported due to limited availability of indigenous crude oil. Biofuel mix in petroleum fuels are being realized in smaller scales as the national policies fail to make a tangible impact. Coal is the principal fuel of Indian electricity basket with 99503.38 MW installed capacity. Other centralized power sources like hydro (38,206.40 MW), gas (17,706.35 MW), nuclear (4,780.00 MW) and oil (1,199.75 MW) contribute to the rest of the capacity. The total electricity generation in 2010-11 reached 811.143 Billion Units (BU) with nearly 10% deficit in supply. The Aggregate Technical and Commercial (AT&C) loss of the order of 30.93% and Transmission and Distribution (T&D) loss of 27.2% are phenomenally high. Even so, India follows further centralized capacity addition with marginal efforts on end user efficiency improvement in actuality. It is in this scenario that locally available renewables achieve significance as decentralized energy resources minimizing losses and pollution to a large extent[4].

As the global energy preferences are taking a paradigm shift, India is challenged to initiate aggressive methods to infuse renewables into its energy mix. India is endowed with renewables like solar, wind, biomass (domestic, agricultural, commercial) and small-hydro, in addition to limited geothermal. These account for 5% of the total primary energy supply and an installed electricity capacity of 20162.24 MW in the country. Encouragingly, renewables contributed to nearly 18% of the total electricity generated in 2007/2008 and the installed capacity today stands at ~10% of the total. Large scale wind power is the most matured segment of Indian renewable energy industry, with installed capacity at above 50 m hub heights speculated to scale up to 65000 MW[10]. Solar energy availability of 5 kWh/m^2/day over a large landmass as well as conducive solar energy policies hold excellent prospects for power generation in the country[5]. The National Solar Mission intends to bank upon the 20 MW/km^2 solar potential for grid interactive and off-grid power generation. Rural electrification has become speedy with the introduction of photovoltaic technologies in rural markets. Bioenergy from domestic and commercial organic wastes is a renewable energy source with immense possibilities in meeting our increasing energy demands, especially thermal[4]. The maturity of renewable energy conversion technologies, costs involved in design-operation-maintenance, sporadic availability of resources etc are factors observed to impede this awaited growth. Nevertheless, in a scenario where the environmental impact of energy generation and usage is considered, renewable resources with an added advantage of decentralized production are competent over any of the conventional fossil fuels.

Energy planning in India continues to be focused on enhancing energy supply with centralized sources rather than local resources, generation rather than efficient utilization and economics rather than environment. It is imperative to move towards Regional Integrated Energy Plan (RIEP) considering locally available renewables in the region, inevitable conventional energy as supplements, optimal energy mix, efficient energy conversion technologies, regional energy demand, viable energy supply, overall system efficiency and minimal local/global environmental impact. Such a decentralized energy plan favour economic development with the sustainable energy and least cost to the environment. The exercise essentially begins with renewable energy resource assessment in pockets of human habitation. It identifies available renewables like solar, wind, biomass, small-hydro, geothermal etc and estimates their spatiotemporal variability. Regional level resource availability studies yield accurate and site specific information. These studies could be in the state, district, taluk and most preferably village level accounting for all the regional aspects, which a national level study might overlook. With the understanding of renewable energy resource availability in a region, based on local energy demands, socioeconomic conditions as well as technology available, a decentralized energy plan could be drafted for the interest area. This minimizes the need for centralized grid extension and also effectively caters to increasing energy needs of heating and cooking, especially in remote areas6.

Further, national energy policies does not always reflect the requirements of specific regions. For example, Himalayan mountains are unique in terms of their landscape, climate, vegetation, economic activities and socio–cultural aspects. This brings along complex dynamics of energy usage in the Himalayan states. Earlier development in these regions neglected the richness of their ecosystems and impacted the environment adversely. Fuel wood continues to be the major source of thermal energy, although inefficiently utilized. Due to fossil fuel based energy consumption, there has been increased pollution and glacial melting in the Himalayan terrain. With increasing population, commercialization and higher energy demands, grid extension for electricity supply appears like an inevitable solution. However, this results in further ecological damages to an already fragile landscape. The holistic development of mountain regions is essentially linked to responsible management and utilization of natural resources[7-11]. A decentralized energy strategy utilizing locally available renewable energy resources through efficient conversion technologies for meeting the regional energy demands in Himalayan states presents an ideal solution. In the broader picture, this helps to intensify renewables intrusion in the global energy mix through decentralized energy plans executed in different regions of the world.

Energy Options for Himachal Pradesh

The state of Himachal Pradesh located in the Western Himalayas (30.38°– 33.21° N, 75.77° – 79.07° E) covers a geographical area of 5.57 million hectares with 12 districts. The agro–climatic zones in the state are defined by altitude, climate, soil, precipitation and other geophysical parameters. It has a complex terrain with altitude ranging from 300 m to 6700 m. The major vegetation types found in Himachal Pradesh are tropical, sub–tropical, wet-temperate, dry-temperate, sub–alpine and alpine, increasing with elevation and often overlapping[12-14]. According to 2011 census, the state has a population of 6.86 million. Within the state, livelihoods of people vary along the elevation zones and representative vegetation. Farming, horticulture, cattle rearing and tourism are the prominent sources of livelihood. The tropical, sub-tropical and wet-temperate parts of the state are more commercialized and favour intensive horticulture. The dry temperate to alpine zones prefer cattle rearing and subsistence farming to a major extent. The more urbanised hubs and tourist areas in the state are observed to have service based livelihoods. These complexities also result in varied energy usages and trends.

In the mountain state of Himachal Pradesh, thermal energy needs increase with elevation while vegetation becomes scantier towards alpine zones. As a result fuel wood consumption varies as 0.48–2.91 kg/person/day. This creates paucity of fuel wood in higher regions and people tend to depend on lower quality and polluting biomass. Kerosene consumption ranges as 0.23–0.43 liters and LPG consumption as 0.82–2.47 kg per capita per month from rural to urban area. Transporting LPG to inaccessible regions is a laborious task for the people residing in higher terrains. Himachal Pradesh has a commissioned electricity capacity of 6728 MW and the major share of the installed capacity comes from central and joint sector. The state sector produces electricity from 579 MW of majorly hydro (394 MW) and renewable resources (185 MW). It has a connected electricity grid length of 82742 km. Over 98.2 % of its 17495 villages are electrified. At the annual per capita electricity consumption of 829 units, the total consumption was 5814 Million Units (MU). Nearly half of this is consumed by industries and one-third by domestic sector. Since the demand for electricity is expected to increase with population and commercialization, the state intends to expand its capacity to 23000 MW by 2022. The cumulative hydro potential of Beas, Chenab, Sutlej, Ravi and Yamuna is estimated to be 23000 MW and the state is ambitiously planning ahead to utilize it to the best extent[14-16]. Capacity addition based either on central coal based plants or state hydro projects would cost dear to the environment. In this context, decentralized energy options for Himachal Pradesh must be identified and nourished. Our study on bioenergy, solar and wind resources elicits interesting inferences for a decentralized energy plan for the state. Spatial data in addition to ground based information and literatures have facilitated our research on renewables in the region.

Renewable Energy Resources in Himachal Pradesh

Bio-energy: Bio-energy includes energy derived from combustion or digestion of organic materials like wood, animal dung, agricultural residues etc[17]. Our study was based on three districts of Himachal Pradesh, exhaustively representative of lower (tropical to sub-tropical), middle (sub-tropical to wet-temperate) and higher(dry-temperate to alpine) elevation zones: Solan, Shimla and Lahaul Spiti respectively. Field surveys and literatures estimated that Per Capita Fuel Consumption(PCFC) varies seasonally and regionally as 0.48-1.32 kg/person/day in Solan, 1.9–2.68kg/person/dayin Shimla and 0.89–2.91 kg/person/day in Lahual Spiti wherein the increase in thermal energy demand with increase in elevation is evident. Satellite imageries and remote sensing tools are used to deduce the total tree cover in the study area providing annual woody biomass of 517.3–1111.7 kilo tonnes in Solan, 1253.8–3029.8 kilo tonnes in Shimla and 18.9–63.8 kilo tonnes in Lahaul Spiti. This clearly shows the lowest availability of fuel wood in the regions of highest thermal energy demand per capita.

It must be seen if other bio-energy sources are able to supplement this scarcity. The annual bio-energy from agro residues (considering 50% for fuel purpose and the remaining for agricultural practices) like cereals, pulses, oilseeds, cotton and sugarcane grown in the state: 349463 million kcal in Solan, 221562 million kcal in Shimla and 2678 million kcal in Lahaul Spiti, shows highest availability of residues in lower elevation zone represented by Solan. The annual biogas generation potential from animal dung: 8.7–35.6 million m3 in Solan, 12.9–43.2 million m3in Shimla and 0.8–1.9 million m3in Lahaul Spiti, shows highest availability in middle elevation zone represented by Shimla. Agro-residues and biogas based bio-energy in Lahaul Spiti representing the higher elevation zone are limited due to sparse population. Other studies show that, the state has an estimated potential to install nearly 0.332 million family size (2 m^3) biogas plants producing 0.515 million m3 of biogas per day with energy equivalent to about 18011 tonnes of fuelwood. However, due to technical, organizational and social influences, biogas program introduced in the state in 1982 was not successful[18].

With increasing population trends in higher elevation zone and limited energy resources to meet the demand, a resource crunch is created resulting in

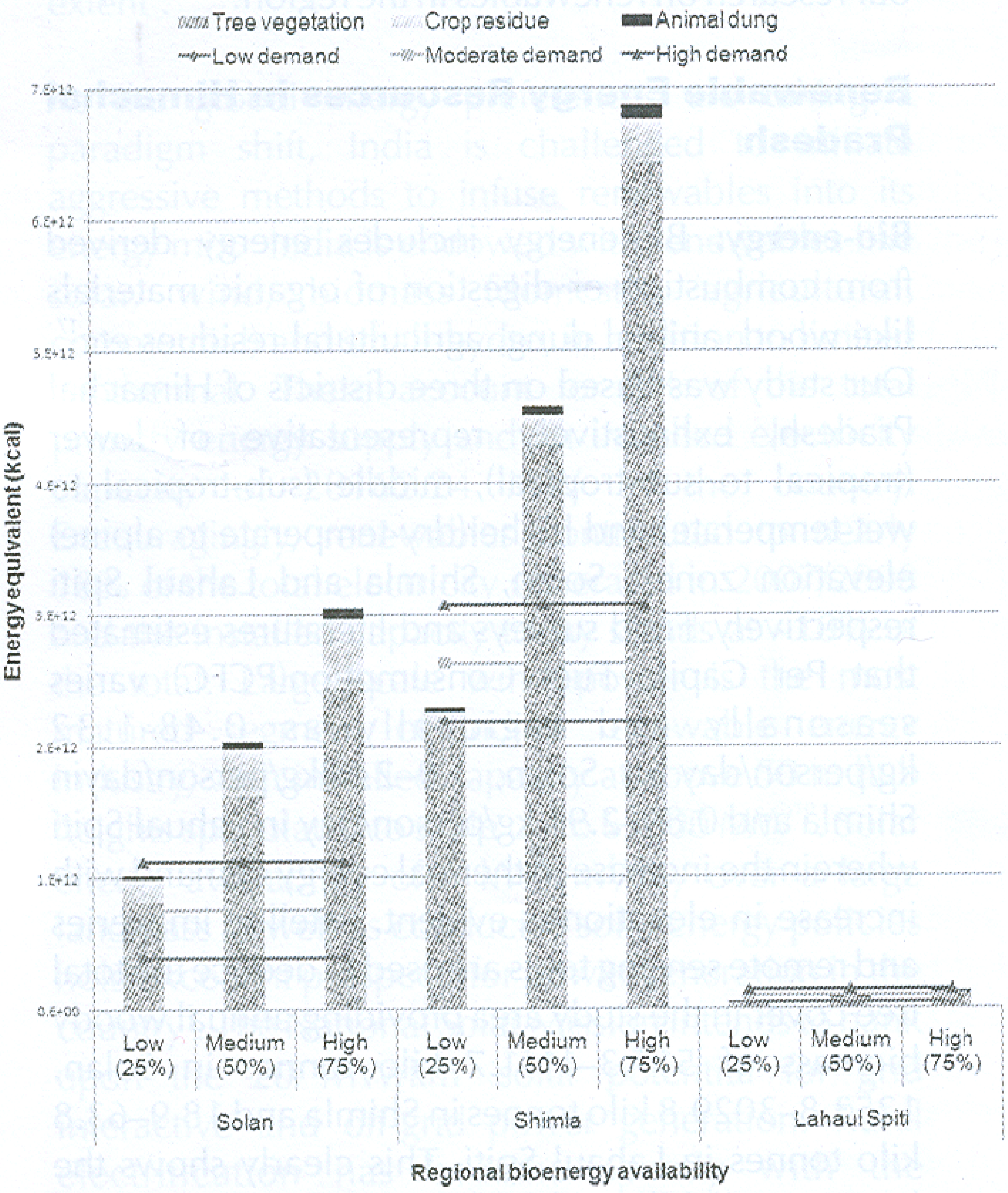


Figure 2: Scenarios of bio-energy availability (25%, 50%, 75%) and thermal energy demand (low, medium, high) in Solan, Shimla and Lahaul Spiti districts of Himachal Pradesh

disastrous ecological impact. Scenarios wherein the thermal energy demands (low, medium or high) of a region are not met by the bio-energy from wood, agro-residue or animal dung based on 25%, 50% or 75% availability of the resource (Figure 2), call for immediate attention to renewable energy alternatives.

Solar energy: Solar resource availability in the state of Himachal Pradesh was assessed using reliable satellite based data from National Aeronautics and Space Administration (NASA) and National Renewable Energy Laboratory (NREL). Spatial analyses using Geographical Information Systems (GIS) shows that the state receives average Global Horizontal Insolation (GHI) above 4.5 kWh/m²/day and a total of 98586056 MU annually (district wise availability given in Figure 3). Seasonally, Himachal Pradesh receives an average insolation of 5.86±1.02 – 5.99±0.91 kWh/m²/day in the summer months of March, April, May; 5.69±0.65 – 5.89±0.65 kWh/m²/day in the monsoon months of June, July, August, September; a little lower 3.73±0.91 – 3.94±0.78 kWh/m²/day in the winter months of end October, November, December, January, February. The regional availability of GHI in Himachal Pradesh is influenced by its topography, seasons as well as microclimate. Study based on elevation gradient shows that the tropical to wet-temperate zone receives higher GHI (>5 kWh/m²/day) for a major part of the year compared to the higher dry-temperate to alpine zone (4-4.5 kWh/m²/day) annually[19]. The former zone is represented by the districts of Solan and Shimla while latter zone by Lahaul Spiti.

The comparatively energy intensive livelihoods in tropical to wet-temperate zone, for example, extensive horticulture due to increased commercialization could rely on the substantial solar energy available. Solar cookers in households and communities should be encouraged to reduce fuel wood use for cooking. 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 pockets[20-21].

Wind energy: Wind resource availability in the complex terrain of Himachal Pradesh has been explored considering the fact that wind speeds vary largely based on micro climatic conditions. Since surface wind speed measurements were available only for 13 locations, higher resolution wind speed values were collected from NASA and Climate Research Unit (CRU). These data were scrutinized to

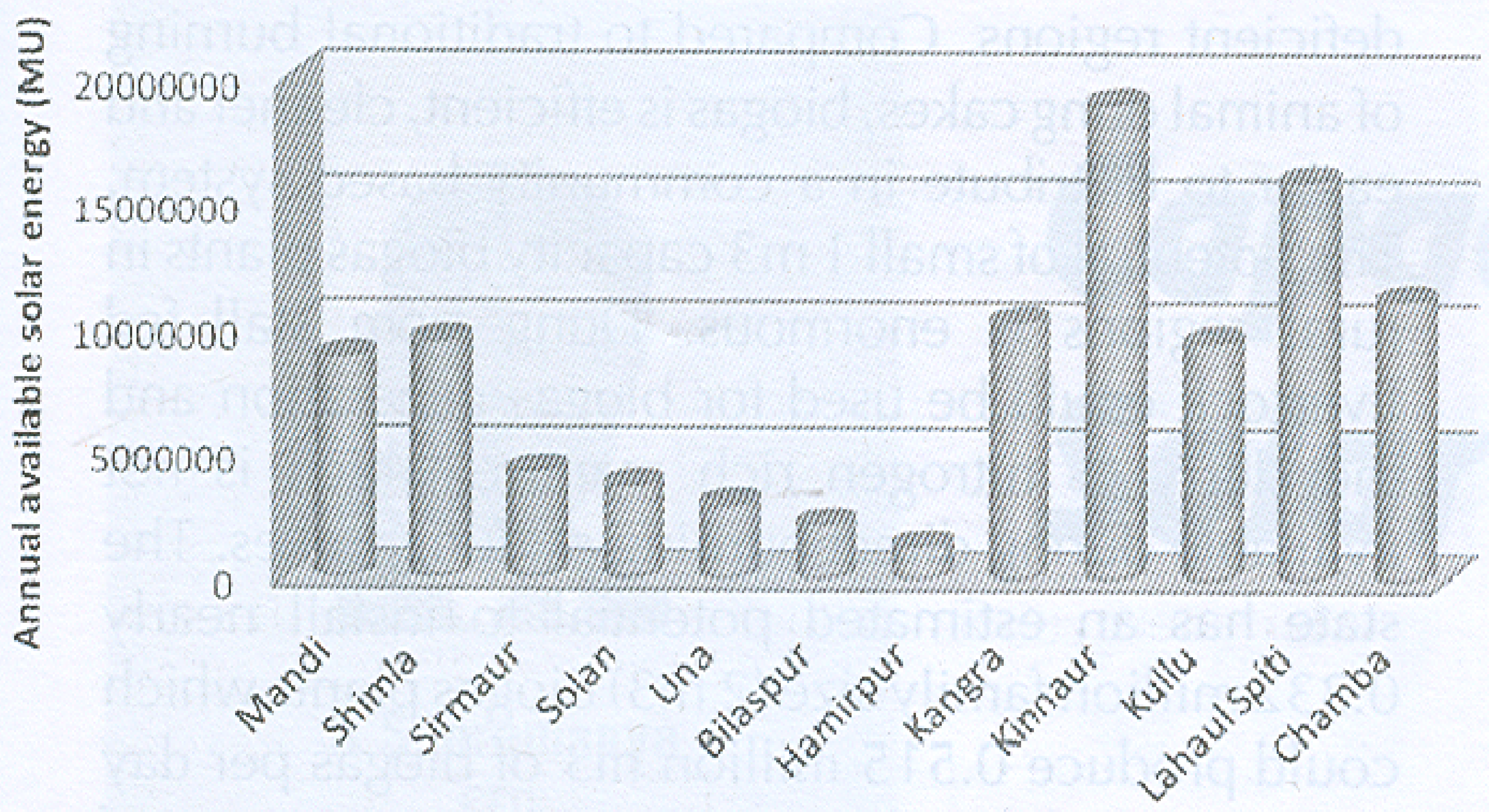


Figure 3: District wise annual availability of solar energy in Himachal Pradesh[12]

evaluate the most probable wind speeds within the state. The data obtained from Climate Research Unit (UK) provided preliminary understanding of wind regime that helps in identifying potential sites for further wind prospecting. Wind speed values mostly below 4 m/s showed that large scale commercial power generation might not be feasible in Himachal Pradesh. The middle and higher elevation zone in the state has relatively higher wind speeds compared to lower tropical zones (Figure 4). These speeds are favorable for small wind technologies like agricultural water pumps, wind-photovoltaic hybrids, space/water heaters etc. Which might help in meeting part of the energy demand sustainably. Ground validation and site specific studies are highly prescribed before installing wind energy technologies[22-23].

Other renewables: Himachal Pradesh has one–third of its geographical area snow covered for seven months and regions above 4500 m experiencing perpetual snowfall and rainfall. These form basis for

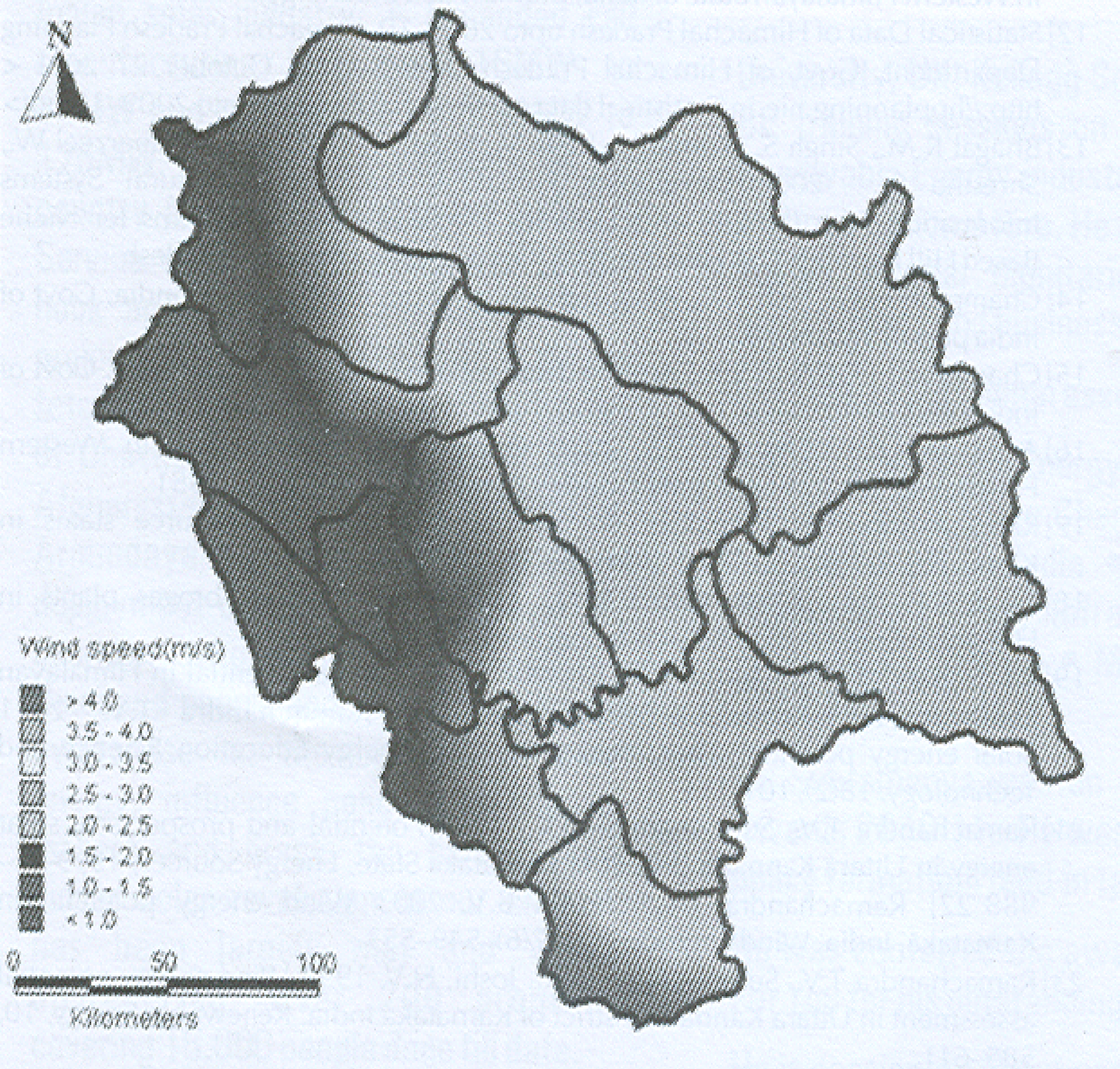


Figure 4: Annual average wind speeds in Himachal Pradesh (data from CRU,UK)

many streams, rivulets and rivers ideal for small-hydro projects meeting local electricity demands with minimal environmental consequences. Reports say that, 323 small-hydro sites were identified in the state with total capacity of 1625 MW out of which 52 projects were completed with capacity of 114 MW. In the urban areas, Municipal Solid Waste (MSW) generation ranges from 0.25 to 0.66 kg/person/day. Large quantities of solid and liquid wastes generated by industries could also be effectively treated and utilized effectively for energy[16]. Such possibilities of alternative renewable energy utilization are to be identified in the state on an extremely regional level[24].

Decentralized Renewable Energy Plan

Our studies show that fuel wood from depleting forest resources could be substituted by bio-energy from agro-residues and animal dung or solar energy using solar-thermal technologies within the State. Solar energy in the state is apt for decentralized electrification using photovoltaic technologies. This can minimize further centralized grid extension to biodiversity rich regions of the state. Solar water/room heating would be ideal for the higher elevation zones with highest thermal energy demand and limited bioenergy resources for sustenance. Wind energy from relatively higher winds in identified zones could be utilized for small scale agricultural water pumps, wind-photovoltaic hybrids, space/water heaters etc, reducing the dependence on grid connected electricity as well as fuel wood. Renewable energy from small-hydro and municipal waste projects in the state holds further prospects. Hence, it is inferred that renewable energy resources in Himachal Pradesh could be prudently utilized given the technological, socioeconomic, organizational and political factors favour a decentralized energy plan.

Conclusion

Himachal Pradesh reveals an immense opportunity in harnessing locally available and often wasted renewable energy resources for meeting its energy demands sustainably. Intricate understanding of a region, its landscape, climate, social structure, governance etc is essential for effective decentralized resource planning and management. Similar decentralized energy plan in identifying renewables, estimating their availability and studying their feasibility for utilization so as to meet the local energy demands of a region goes a long way in expanding the renewable energy sector in India. Solar potential assessment shows that Himachal Pradesh receives annual average GHI above 4.5 kWh/m²/day. The regional variations in GHI are influenced by its diverse topography as well as seasons. The lower and middle elevation zones (<3500 m) receive relatively higher GHI for a longer duration annually. Entire region receives considerably large amount of solar energy. Solar photovoltaic applications with reasonable efficiencies and costs are viable options. These could substantially improve the energy scenario by providing decentralized energy in the isolated and inaccessible pockets. Spatial wind profiles based on high resolution data provide insights to the wind regime that helps in identifying potential sites for wind prospecting. The higher altitude alpine zone in Himachal Pradesh has relatively higher wind speeds compared to lower altitude zones. The minimal but reliable surface measurements in the lower altitude temperate and tropical zones indicate the micro climatic influences and spatial variability in the complex Himalayan terrain. The wind potential in Himachal Pradesh supports small wind technologies like agricultural water pumps, wind-photovoltaic hybrids, space/water heaters etc. This would help in meeting the decentralized energy demand sustainably. The bio-energy resource status of the three districts highlights highly pronounced scarcity of bio-resources. Especially in critical bio-energy deficit regions like Lahaul Spiti, with the highest PCFC an energy crisis is imminent. The dwindling forest resources may not suffice the domestic, commercial and industrial needs of an ever increasing population. This results in shortage of fuel wood availability even for sustenance Efficient utilization of fuel wood, agro residues and animal dung could however reduce the pressure on forest resources. This demands site specific and innovative solutions with ultimate priority for the bio-energy deficit regions where even the total estimated bio-energy availability cannot meet the demands of an ever increasing population. Nevertheless, the regions deemed as bio-energy surplus in these estimations should not be marginalized while adopting such methodologies since they are under pressure. Potential bio-resource crunch is imminent in the absence of immediate intervention perceptibly leading to deforestation. Traditional stoves used for burning wood in these hill regions are thermally inefficient. They emit more smoke causing health hazards to women and children. Energy efficient, smokeless and innovative ASTRA improved energy efficient cookstoves with thermal efficiency above 30% will reduce the fuel consumption by 42-45%. In mountains regions the demand as well as utility of fuel wood varies with altitude and hence the traditional designs differ zone–wise. Biogas from animal residues is an important alternative energy source in fuel wood deficient regions. Compared to traditional burning of animal dung cakes, biogas is efficient, cleaner and easier to distribute in a community based system. The potential of small 1 m3 capacity biogas plants in rural regions is enormous. Dung from stall-fed livestock could be used for biogas generation and the slurry as nitrogen rich manure which is not available during direct burning of dung–cakes. The state has an estimated potential to install nearly 0.332 million family size (2 m3) biogas plants which could produce 0.515 million m3 of biogas per day with energy equivalent to about 1801.1 tonnes of fuel wood. However due to the lacunae in planning, technical, organizational and social aspects, biogas program has not been successful.

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