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Regional Bioenergy Planning for Sustainability in Himachal Pradesh, India

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ABSTRACT

Energy system in mountainous regions is complex due to the wide variations in the availability and demand of energy resources. Mountain inhabitants are traditionally dependent on bioenergy resources such as fuel wood, agro and animal residues for meeting their energy requirements for heating, cooking, etc. However, depleting forest resources limit the availability of fuel wood while commercial sources such as 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. The study assesses the bioresource availability and its potential to meet the bioenergy demands of three mountain districts in the western Himalayan federal state of Himachal Pradesh. Regions of bioenergy surplus or deficit are identified for different scenarios. The ecological status of forests and actual availability along with the demand of fuel wood in villages are analysed to highlight the significance of decentralized regional-level bioenergy resource planning. Bioenergy potential assessment (BEPA) – a decision support system (DSS) – to facilitate compilation, analysis, representation, interpretation, comparison and evaluation of regional bioresource has been used to visualize bioenergy status. This supports energy planners and policy makers in efficient disaggregated bioenergy resource planning to mitigate the carbon imbalances while meeting the subsistence and development needs of mountain inhabitants, at least cost to the environment and economy.

Keywords: *Bioenergy, decision support system, sustainability, forest fragmentation*

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1. INTRODUCTION

Mountainous regions are unique in terms of their landscape, climate, vegetation, economic activities and sociocultural aspects. The mountain inhabitants are traditionally dependent on natural resources for their livelihood. Development in these regions historically neglected the diversity and heterogeneity of their ecosystems [1]. As a consequence of the landscape changes due to natural and anthropogenic influences, the ecological integrity and resource sustenance are under serious threat. Clearance of forest resources for fuel wood, fodder, timber, industrial products and agriculture has ensued in forest fragmentation, resulting in human–animal conflicts and scarcity of resources. Carbon dioxide concentration in the atmosphere has been rising alarmingly in the post-industrial revolution era and the current level is about 379 ppm (ppm, parts per million) compared to 280 ppm earlier (pre-industrialization). The Planning Commission, Government of India, in the 12th Five-Year Plan of the country advocates low carbon growth, evident from the proposed actions to reduce India's emission intensity by 20–25% (in 2020) compared to emissions in 2005. This includes policy interventions to reduce emission intensity through fuel-efficiency standards, green building codes and energy efficiency certificates. In this context, numerous challenges to be addressed are burgeoning population coupled with urbanization, industrialization and provision of infrastructure and transport facilities. This necessitates location-specific mitigation strategies to minimize carbon emissions which require sector-wise and region-wise inventory of greenhouse gas (GHG) emissions [2–7].

Forest vegetation, soil and algae in water bodies sequester carbon. India's forest cover (677,088 km^2) accounts for 20.6% of the total geographical area of the country (in 2005) and tree cover for 2.8% [2]. The carbon stocks stored in forests and trees have increased from 6245 to 6662 mt, during 1995–2005, registering an annual increment of 38 mt of carbon or 138 mt of CO_2 equivalent. Estimates reveal that forests neutralize about 11.25% of total GHG emissions (CO_2equivalent) at 1994 level. This is equivalent to offsetting 100% emissions from all energy in residential and transport sectors or 40% of total emissions from the agriculture sector. Forest soil has the potential to sequester carbon. The improvements in agricultural practices would increase the quantity of organic carbon in soil [2–7]. The forest resources with high carbon sequestration potential are being exploited to meet the demand of growing human population, contributing to the increase in GHG. Even though governmental regulations restrict illegal felling of forest trees, this process continue rampantly, depleting forest cover, degrading soil fertility, eroding top productive soil layer and flooding the plains [2].

The holistic and sustainable development of mountainous regions is essentially linked to the management of natural resources and improvements in the conversion and end use of energy through viable eco-friendly alternate technologies. Bioenergy from combustion of bioresources such as fuel wood (including dry litter of leaves, twigs, etc.), agro residues (stalk, straw, cobs, husk, bagasse, etc.) and animal residues has been a traditional predominant energy source for heating and cooking in the mountainous rural energy system. Trees grown on agricultural margins and forests are the major source of fuel wood. It is observed that more than 70% of the total energy consumption of western Himalayan mountainous regions is met by traditional sources, of which nearly 60% is fuel wood. Over 90% of this fuel wood is consumed in households for heating and cooking [3].

Agro residues classified as field-based residues (straw, stalk, cobs, etc.) are used sparingly as fuel apart from fodder and mulch while process-based residues (rice husk, sugarcane bagasse, etc.) are usually discarded. Scarcity of fuel wood in recent times has forced people to depend more on agro residues for domestic heating and cooking needs, leaving the crop lands unfertile. This subsequently has affected the crop yield, resulting in further clearance of forests for cultivation. Apart from these, forced dependence on pine cones, tree bark and weeds with high ash content and low heating values has increased indoor pollution, affecting especially women and children [4]. Livestock is the major source for manure, dairy, meat and draught. Due to the scarcity of fuel wood, rich dried dung cake as alternative fuel deprives agriculture field of nutrients apart from causing pollution on direct burning. Stoves used for burning in mountain areas vary with altitude and most of them are traditional devices with low thermal efficiency [5]. Transition to commercial energy sources such as kerosene and LPG at subsidized rates is noticed in urbanizing landscapes, although there are logistic and economic constraints in supply [3]. Thus, the alternative bioresources as well as commercial sources fail to reduce the burden on forest cover.

Energy demand and supply dynamics in mountainous regions are complex due to the spatial variations in availability and accessibility of resources and their differing usage along altitudinal gradients. This complexity demands detailed studies for improving the regional energy system [2]. Reducing inefficient use of fuel wood and encouraging conservative use of alternative bioresources in meeting the energy demand ensures ecological sustainability. This necessitates the assessment of bioenergy availability (supply) and consumption (demand) to identify the bioenergy surplus or deficit status of mountainous regions for efficient, integrated and sustainable resource planning.

Resource planning at aggregate level neglects the regional paucity of resources and the crisis faced by the inhabitants in meeting their domestic energy demands without feasible alternatives. Regional information on energy resources and patterns of human dependence is vital for efficient planning. The basis of regional integrated energy planning is the preparation of area-based decentralized energy system to meet the subsistence and development needs, at the least cost to the environment and economy. This considers all the socioeconomic and ecological factors of a region essential for long-term success of the intervention. Decision making involves data compilation, analysis and visualization of various scenarios. In this context, regional energy plan through a decision support system (DSS) provides an interactive user-friendly platform with options to compile, analyse, interpret and visualize the information. DSS essentially consists of database, modelling and dialog management subsystems [6]. Bioenergy potential assessment (BEPA) – a DSS designed for bioresource assessment accounts for the bioenergy availability to demand the status of realistic scenarios in the regional level. It facilitates the collection and analysis of available information, the projection of future conditions and the evaluation of alternative energy solutions for conservative resource planning [7]. DSS-based bioenergy resource assessment and planning has been proposed in many regions [8–11]. Regional bioenergy planning and execution through DSS potentially resolves the energy and environmental issues faced by the mountainous regions.

This study assesses the bioenergy resource status of three representative mountainous districts in the federal state of Himachal Pradesh located in western Himalayas. This includes the causal factors for degradation of resources, levels of forest fragmentation, etc. The main objectives of this study are to:

i. quantify the availability of bioenergy resources from woody biomass (fuel wood), agriculture (crop residues) and livestock (animal dung) in the districts of Solan, Shimla and Lahaul Spiti which are representative of different agro-climatic zones of Himachal Pradesh;
ii. assess the bioenergy (mainly fuel wood) demand in the districts;
iii. identify the bioenergy resource status of the districts based on different resource availabilities and demand scenarios and suggest sustainable measures to meet the bioenergy requirements;
iv. visualize the implications of village-level bioenergy resource degradation using geospatial analyses; and
v. demonstrate a DSS to facilitate bioenergy resource planning in mountainous regions.

2. STUDY AREA

Himachal Pradesh is located between 30.38° and 33.21° North latitudes and 75.77° and 79.07° East longitudes, covering a geographical area of 5.57 million ha with 12 districts [12]. 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 to 6700 m, as shown by the digital elevation model (DEM) in Figure 1. Almost one-third of the area is snow covered for 7 months and forms the origin for many rivers. Regions above 4500 m experience perpetual snowfall, and rainfall vary from 50 to 2600 mm along different altitudinal zones [13]. Climate, soil as well as biotic factors in the past (forest fire, shifting agriculture, grazing, etc.) influences the type of vegetation along with other factors such as solar radiation, temperature, moisture, geology, etc. The major vegetation types found in Himachal Pradesh are tropical, subtropical, wet temperate, dry temperate, subalpine and alpine, varying with altitudinal gradients and often overlapping due to changes in climate [14].

The study area covers three districts of Solan, Shimla and Lahual Spiti, focusing on three watersheds of Mandhala, Moolbari and Megad inhabiting village clusters (Figure 1). These watersheds and districts are representative of the different agroclimatic zones in the hill state of Himachal Pradesh. The respective watersheds provide village-level insight significant for the regional study. The physiographic information of the districts and watersheds are summarized in Table I.

Table I: Physiographic Information of the Study Regions.

District	Altitude (m)	Area (ha)	Rainfall (mm)	Total population (2011)	Population density (no./km^2)
Solan	316–2209	193,600	1179–1899	576,670	298
Shimla	713–4984	513,100	847–1330	813,384	159
Lahaul Spiti	2043–6514	1,383,500	332–803	31,528	2
Watershed	**Latitude (°N)**	**Longitude (°E)**	**Altitude (m)**	**Area (ha)**	**River associated**
Mandhala (Solan)	30.87–30.97	76.82–76.92	400–1100	1453	Yamuna
Moolbari (Shimla)	31.07–31.17	77.05–77.15	1400–2000	1341	Yamuna
Megad (Lahaul Spiti)	32.64–32.74	76.46–76.74	2900–4500	1050	Chandrabhaga

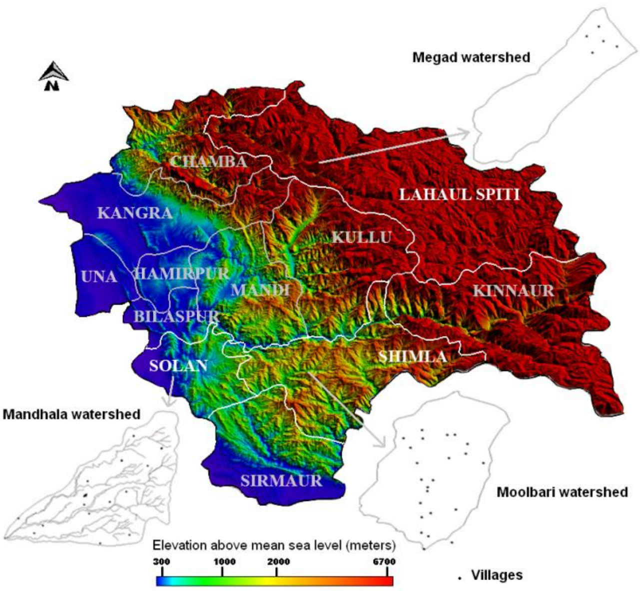

Fig 1: DEM representing the three districts and village clusters in respective watersheds.

2.1. Woody Biomass

Net primary productivity (NPP) of vegetation is the annual increment (t/ha/year) in total standing biomass of the vegetation. Litterfall includes woody biomass shed from forests including leaves, twigs, branches, etc. used as fuel wood [15]. The biomass and NPP in the Himalayan forests increases from tropical to temperate and then decreases towards alpine [16]. The above-ground tree biomass ranges from 80 to 400 t/ha. Litterfall in central Himalayas for an altitudinal range 350–2250 m varies between 4.2 and 7.8 t/ha/year. Of the litterfall in the Himalayan forests, contribution of wood is 9–20% and leaves range between 54% and 82% [17]. The vegetation types as well as biomass and NPP of representative forests and tree species found in the Himalayan terrain are summarized in Table II [18–36].

Table II: *Himalayan Vegetation Types, Representative Tree Species, Standing Biomass and NPP Found in the Study Regions.*

Vegetation		Standing biomass (t/ha)	NPP (t/ha/year)	References
Tropical	*Forest type*			
	Broad-leaved vegetation	276.79		[18]
	Dry deciduous forest	–	14.6–15.7	[19]
	Tropical seasonal forest	–	16	[20]
	Representative trees			
	Khair (*A. catechu*)	76.35	7.63	[21]
	Poplar (*Populus deltoides*)	–	5.9–22.7	[22]
	Bamboo (*Dendrocalamus strictus*)	–	15.8–19.3	[23]
	Siris (*Albizia lebbeck*)	–	8.38	[24]
	Shisham (*Dalbergia sissoo*)	58·7–136·1	12·6–20·3	[25]
Subtropical	*Forest type*			
	Pine forest	210·8	9.9–21.2	[26]
	Pine forest	115.2–286.2	11.0–23	[27]
	Pine forest	200.8–377.1	18.5–24.5	[28]
	Mixed oak forest	163.4–432.6	14.4–18.9	[28]
	Mixed oak forest	426	15.9	[29]
	Representative trees			
	Chirpine (*P. roxburghii*)	113–283	7.6–18.7	[29]
	Chirpine (*P. roxburghii*)	117.53	18.9	[18]
	Banj oak (*Q. leucotrichophora*)	388	13.2	[29]
Wet temperate	*Forest type*			
	Oak forest	197.2–322.8	15.9–20.6	[30]
	Mixed oak	344	15	[29]
	Representative trees			
	Oak (*Quercus sp.*)	285–782	15.5–25.1	[29]
	Deodar (*Cedrus deodara*)	451	28.2	[29]
	Deodar (*C. deodara*)	146.43		[18]
Dry temperate to subalpine	*Forest type*			
	Temperate deciduous	–	12	[20]
	Temperate broad-leaved	–	7–15.6	[31]
	Subalpine forest	–	4.76–19.68 (ANP)	[32]
	Representative trees			
	Silver fir (*Abies pindrow*)	–	18.9	[33]

Fir (*Abies sp.*)	–	7.3–20.0	[33]
Blue pine (*Pinus wallichiana*)	–	13.08	[34]
Spruce (*Picea sp.*)	–	11–14.0	[35]
Maple (*Acer sp.)*	–	10.9 (ANP_{tree})	[36]
Horse chestnut (*Aesculus indica*)	502	16.5	[29]
Horse chestnut (*A. indica*)	–	19.6	[33]
Kharsu oak (*Quercus semecarpifolia*)	–	24.6	[33]
Birch (*Betula utilis*)	172	12.5	[29]
Rhododendron (*Rhododendron sp.*)	40	7.5	[29]

Tropical vegetation dominated by broad-leaved tree species is found below 1000 m in major parts of Solan and minor parts of Shimla districts. The tree biomass ranges from 58.7 to 136.1 t/ha and NPP from 5.9 to 22.7 t/ha/year. Dominance of *Lantana camara* weed is noticeable in the hilly tracts degraded by anthropogenic activities. Plantations of *Acacia catechu* are frequented here. The subtropical vegetation found in Solan and Shimla at an altitude range 900–1500 m is characterized by chirpine (*Pinus roxburghii*) forests. Chirpine has a high regeneration potential and caters to the fuel wood needs of the dependants. The vegetation also includes mixed oak forest of *Quercus leucotrichophora*, locally called as Banj oak. The tree biomass of subtropical vegetation ranges from 113 to 388 t/ha with an NPP of 7.6–18.9 t/ha/year. Beyond the transitional stage of the subtropical vegetation, wet temperate vegetation is observed in minor parts of Solan and major parts of Shimla districts (1200–2500 m). The tree biomass ranges from 146.43 to 782 t/ha with an NPP of 15.5–28.2 t/ha/year. Further high, above 2200 m, the wet temperate vegetation gives way to dry temperate and subalpine vegetation which are coniferous and dry deciduous in nature. Dry temperate vegetation is found in Shimla and Lahaul Spiti and the tree biomass ranges from 40 to 502 t/ha with an NPP of 7.3–24.6 t/ha/year. Above 4000 m (timber limit or tree line), the alpine vegetation favours only short shrub species. Enormous diversity of undergrowths are observed throughout all types of vegetations, however of lesser fuel wood value. The representative fuel wood trees common in these regions with standing biomass and NPP are presented in Table II.

2.2. Agriculture

Agricultural systems in Himachal Pradesh vary with soil, climate, vegetation as well as socioeconomic factors such as market proximity and government intervention. More than 90% of the cropped area in the districts are rain-fed and found on sloping marginal lands and small land holdings. Earlier subsistence-based farming system has given way to cash crops and mechanization [13]. Mixed crop–livestock, vegetable-based perennial plantation and agro-pastoral systems are the common farming practices observed here. Including plantations, the net cropped area in Solan, Shimla and Lahaul Spiti are

39,370, 67,857 and 3292 ha, respectively [37]. Wheat, maize, rice, pulses and oil seeds are dominant in the tropical and subtropical regions, while crops such as millet, barley, buckwheat and dry nuts are common to temperate regions. Fruits and vegetables are profitable, generate more employment and are prominent in regions with access to roads and market. Apple orchards are predominant in wet temperate regions of Solan and Shimla. The subtropical and wet temperate regions are reported to be highly productive in terms of crop yield and are largely agriculture intensive. Farmers in dry temperate regions prefer more of mixed type of farming with livestock for sustenance. Due to unfavourable weather conditions, agricultural productivity is low in upland cold districts like Lahaul Spiti [1].

2.3. Livestock

Livestock includes cattle, buffalo, yak, mithun (*Bos frontalis*), sheep, goat, horse, pony, mule, donkey, pig and camel which contribute nearly one-fourth of the total household farm income in Himachal Pradesh. Large animals are reared for dairy, draft power, transportation and manure while small animals provide meat, wool, etc. Nearly, 75–80% of the households in Himachal Pradesh keep dairy animals and 10% draught animals. The shift to plantation crops as well as mechanization has decreased the demand for draught. It is observed that the number of livestock per household has dwindled in the past few decades. Nevertheless, livestock owners are found to replace low productive cattle and buffaloes with more productive animals [38]. The tropical and subtropical regions have stall-fed and grazed cattle as the major livestock. Wet temperate regions prefer stall-fed cattle while dry temperate regions more of sheep and goats which are grazed in open pastures. Transhumance farming with seasonal migration of people and livestock is observed in Lahaul Spiti and higher reaches of Shimla [1].

2.4. Bioenergy Consumption

Over 90% of the population in Himachal Pradesh lives in rural areas (17,495 villages). Electricity is the source of lighting in nearly 98% of these villages, the others depend on kerosene. Fuel wood satisfies nearly 70% of their heating and cooking needs. Himachal Pradesh is one of the major per capita bioenergy demand state in India with annual fuel wood consumption of 3.2 million tonnes. The state consumed ~1.03 Mtoe (million tonnes oil equivalent) of fuel wood while the national consumption was ~88.40 Mtoe in 2006–2007 [39]. In the rural areas, apart from household heating and cooking, fuel wood is consumed during festivals, marriages, funerals and also burned in margins of agricultural lands to drive away wild animals [40]. Increasing distance for fuel wood collection due to scarcity of forest resources in many cold tribal villages exhaust higher human energy and time [41]. Energy-inefficient traditional cookstoves reported thermal efficiency of 8–13%, contributing to the indoor pollution, affecting women and children [5]. However, improved cookstoves disseminated through the federal programme are being used in certain villages of Lahaul Spiti [40]. Certain studies suggest that kerosene and LPG distribution systems are well developed in the rural areas while continued availability is not ensured and people are hesitant to switch due to lack of awareness and cost factors [42]. Hence, these commercial sources minimally satisfy the rural domestic energy needs.

Fuel wood consumption patterns in different altitudinal gradients were ascertained through field surveys in the three watersheds –

Table III:*Fuel Wood Consumption Patterns in Different Altitudinal Gradients of Western and Central Himalayas.*

Region	PCFC (kg/day)	Elevation	Reference
Western Himalayas			
Himachal Pradesh (rural areas)	1.562	300–6700	[39]
Mandhala watershed, Solan	0.68 ± 0.22	400–1100	This study (ground survey)
Moolbari watershed, Shimla	1.9–2.63	1400–2000	This study (ground survey)
Megadwaterhed, Lahaul Spiti	1.53 ± 0.64	2900–4500	This study (ground survey)
Solan district, Himachal Pradesh	1.32	316–2209	[3]
Shimla district, Himachal Pradesh	2.68	713–4984	[3]
Mandi district, Himachal Pradesh	2.99	–	[3]
Kullu valley	4.3 ± 0.37	1200–1400	[43]
Hill forest (rural areas)	1.89	–	[44]
Hill forest (urban areas)	1.21	–	[44]
Hill non-forest (rural areas), Himachal Pradesh	1.31	–	[44]
Khoksar, Lahaul Valley	1.06–3	3200	[40]
Jahlma, Lahaul Valley	1.02–2.91	3000	[40]
Hinsa, Lahaul Valley	0.98–2.74	2700	[40]
Kuthar, Lahaul Valley	0.91–2.68	2600	[40]
Central Himalayas			
Garhwal Himalaya	1.07–2.80	380–2500	[41]
Garhwal Himalaya, Tehri	1.12–2.44	500–2500	[45]
Garhwal, tropical	2.42–2.52	300–400	[4]
Garhwal, subtropical	1.63–1.7	900–1300	[4]
Garhwal, temperate	1.77–2.32	1900–2400	[4]
Kumaon Himalaya	1.49	–	[46]
Nepal Himalaya	1.23	–	[47]

Mandhala, Moolbari and Megad – apart from comprehensive literature survey of the western and central Himalayas given in Table III [3, 4, 39–41, 43–47]. The per capita fuel wood consumption (PCFC) ranges from 0.46 to 4.67 kg/day in western Himalayas and 1.07–2.80 kg/day in central Himalayas. Eastern Himalayas are the highest consumers of fuel wood, reaching even beyond 4 kg/day [2]. Table III lists the regional fuel wood consumption studies. It highlights that PCFC in Solan is 0.46–1.32 kg/day, in Shimla 1.9–2.68 kg/day and in Lahaul Spiti 0.89–2.91 kg/day. This increase in consumption pattern along the altitudinal gradient is conspicuous due to higher demand for space and water heating in colder regions. This altitude-based variation is observed irrespective of socioeconomic conditions. However, within an altitudinal range, large families consume less fuel wood per capita compared to smaller ones [40, 41].

3. METHODOLOGY

3.1. Bioenergy Resource Assessment in the District Level

3.1.1. Bioenergy Resource Availability

We employ an integrated approach of compiling data from government agencies and biomass inventorying of fuel wood, agro and animal residues. Primary data include information from ground survey and remote sensing data. Secondary data are collected from respective government departments and literatures of previous studies.

Multispectral, moderate resolution (30 m), cloud-free satellite images from Landsat (TM/ETM/ETM + sensors) obtained in September/October months of 1989/1990, 2000 and 2005/2006 covering the three districts of Solan, Shimla and Lahaul Spiti are collected from Global Land Cover Facility (http://glcfapp.glcf.umd.edu). Since boundaries of the districts derived from Survey of India (SOI) toposheets cover more than one scene, mosaicking (combining the satellite images) and subsequent histogram matching (synchronizing the spectral reflectance of different images) corrections are performed. Bands of geo-corrected (geographic coordinates of satellite images are compared with ground control points (GCPs) satellite images are masked and cropped with the district boundary. Land-use analysis is performed on the satellite images using supervised Gaussian maximum likelihood classification (GMLC) method, categorizing the natural features such as vegetation, water bodies, snow and open spaces. Training data were obtained from field, and higher resolution (at least 15 m) spatial images from Google Earth (http://earth.google.com) were used for pre-classification error correction and post-classification validation. Although we tried to distinguish the land used for agriculture from total vegetation cover and built-up from open space, the varying spectral reflectance in the complex hill terrain due to high relief and shadow deteriorated the performance of the classification algorithm. The extent and temporal change of tree cover (also including horticulture plantation crops such as apple, orange, peach, etc.), short vegetation (shrubs, crops, grassland), water and others (barren land, fallows, rocky terrain, built-up, etc.) are quantified from the classified satellite images with an overall accuracy in the range 75–90%. Vegetation is observed to vary primarily based on altitudinal gradients although species mixing towards upper and lower ranges have occurred in due course of time due to anthropogenic activities and climatic changes [14]. Training data corresponding to the land-use types were derived from field (using global positioning system – GPS) and Google Earth (http://www.googleearth.com) along with the elevation contours generated from DEM. Remote sensing data (2005/2006) of these districts were classified using these training data with the Gaussian maximum likelihood classifier. Classified data were validated with field data and accuracy assessment (Figure 3). This provided the extent and type of vegetation in the district.

The above-ground net productivity of tree biomass (ANP_{tree}) in forest vegetation has been quantified to assess the woody matter available for extraction. About 70–90% of the total forest biomass productivity is shared by trees and the rest by undergrowths of shrubs and herbs [17]. Nearly 60% and above of the total productivity of trees are attributed to the above-ground biomass increment in the forests of Himachal Pradesh. Hence, ANP_{tree} of three practical scenarios of high (75%), medium (50%) and low (25%) for availability of resources are considered. The net calorific values (NCVs) of different tree species is above 4000 kcal/kg (dry weight), as per the literatures [48]. This value is used as energy equivalent in the total bioenergy estimation of woody biomass. The annual bioenergy available (E_{tree}) from tree biomass resource of a particular vegetation type is calculated by Eq. (1)

$$BE_{tree} = Area \times ANP_{tree} \times NCV \quad (1)$$

The extent of agricultural land use was mapped from the remote sensing data and the data from the Department of Economics and Statistics, Ministry of Agriculture, Government of India [37]. The agriculture data includes crop types (cereals, vegetables, pulses, oilseeds, horticulture plantation, cotton, sugarcane, fodder crops and narcotics) with yield of crops (final product) for the years 2000–2005 in the three districts. Horticulture plantations of apple, orange, peach, etc. have been included in the woody biomass estimated using remote sensing data. Biomass residues from vegetables are negligible on field. The agro residues (cereals, pulses, oilseeds, cotton and sugarcane) and their production are calculated from the residue-to-product ratio (RPR) considering the yield of respective crops [49] (Table IV). The NCVs of crop residues identified in the region are observed to range from 3000 to 4200 kcal/kg [49–53] and NCVs of crop residues for three scenarios (namely 3000, 3500 and 4000 kcal/kg) were considered assuming efficient energy conversion. Considering the multiple uses of crop residues as fodder, manure, mulch, etc., the final residue production per area (R) available as fuel is accounted for high (75%), medium (50%) and low (25%) availability scenarios. The annual bioenergy from a particular crop residue is computed by Eq. (2).

$$BEcrop = \text{Gross cropped area} * R * NCV \quad (2)$$

Table IV: *Crop Types, Productivity, Residue Types, RPR and Energy Equivalents Considered.*

Crop	Type	Productivity (t/ha/year)	Residue type	RPR	Energy equivalent (kcal/kg)
Cereals	Rice	1.84	Husk	0.29	3000
			Stalk	1.5	3000
	Wheat	1.47	Stalk	1.6	3500
	Bajra	0	Cobs	0.33	3500
			Husk	0.3	3000
			Stalk	2	3500
	Maize	1.97	Cobs	0.27	3500
			Husk	0.2	3000
			Stalk	2	4000
	Barley	0.86	Stalk	1.3	3000
	Others	0	Stalk	1.4	3000
Pulses	Gram	0.88	Stalks	1.1	3500
	Tur/arhar	0	Husk	0.3	3000
			Stalk	2.5	3000
	Kharif	0.76	Husk	0.18	3000
			Stalk	1.1	3500
	Rabi	0.67	Stalk	1.2	3500
Oilseeds	Groundnut	0.9	Shell	0.33	4000
			Stalk	2	4000
	Sesamum	0.2	Stalk	1.5[a]	3000
	Rapeseed and mustard	0.49	Husk and Stalk	1.5	3500
	Soyabean	1.37	Stalk	1.7	3000
	Others	0.2[a]	Stalk	2	3500
Others	Cotton	0.72	Shell and husk	2.2	3000
			Stalk	3 t/ha	3000
	Sugarcane	0.87	Bagasse	0.33	3500
			Top and leaves	0.05	3500

Note : *[a]Data for which no references were available and hence approximated based on the conservative values.*

The district-wise livestock population of cattle, buffalo, yak, mithun, sheep, goat, horse, pony, mule, donkey and pig are collated from the livestock population census 2007, Department of Animal Husbandry, Government of Himachal Pradesh [54]. The dung yield per livestock type are given in Table V [15, 48, 55–57] and lower, moderate (average of lower and upper) and upper dung yield cases are considered. Biogas generated based on animal dung vary from 0.036 to 0.042 m^3/kg [15]. However, cold conditions in the study region suggest lower value of 0.036 m^3/kg biogas generation.

Table V: *Livestock in the Study Region and Dung Yield.*

Livestock	Dung yield (kg/head/day)	Reference
Cattle	2.87	[48]
	10	[55]
	3–7.5	[15]
Buffalo	2.65	[48]
	15	[55]
	12–15	[15]
Yak	4.5	[56]
Mithun (*B. frontalis*)	–	[48]
Sheep	0.32	[48]
	0.1	[15]
Goat	0.35	[48]
	0.1	[15]
Horse	1.72	[48]
	6.08	[57]
Pony	–	–
Mule	0.94	[48]
Donkey	–	–
Pig	0.34	[48]
Camel	2.49	[48]

The NCV of biogas is consistently over 5000 kcal/m^3 [58]. Alternative uses of animal dung as direct manure and constraints of dung collection during grazing restrict its availability for biogas generation. Here, three scenarios of high (75%), medium (50%) and low (25%) animal dung availability are considered for biogas generation. The annual bioenergy yield from livestock is calculated as

$BE_{livestock}$ = Total annual dung yield from livestock*Volume of biogas per mass of dung *NCV (3)

Total annual bioenergy available from bioresources including forests, agriculture residues and animal residues in a region is calculated using Eq. (4)

$$BE_{available} = BE_{tree} + BE_{crop} + BE_{livestock} \quad (4)$$

The different scenarios of low (25%), medium (50%) and high (75%) fuel-based availability of the bioresources account for practical constraints in satisfying alternative needs.

3.1.2. Bioenergy Resource Demand

The PCFC in Solan, Shimla and Lahaul Spiti was computed from the data compiled from household surveys and literatures (Table III). Bioenergy resource availability is assessed for the period 2005/2006 and the district-wise population is projected for the year 2006 from 2001 census [59, 60]. Considering 4000 kcal/kg energy equivalence of woody biomass, the domestic heating and cooking energy (mainly bioenergy) demand is given by

$$BE_{demand} = \text{Annual PCFC} \times \text{Population} \times \text{NCV} \quad (5)$$

3.1.3. Bioenergy Resource Status

The total woody biomass production in each district compared to the heating and cooking energy demand of the population indicate the ecological health of the region. The total bioenergy availability (including woody biomass, agro residues and animal dung) to bioenergy demand ratio gives the bioenergy resource status of the region.

$$BE_{status} = BE_{available}/BE_{demand} \quad (6)$$

The different scenarios of high (75%), medium (50%) and low (25%) biomass availability are compared with the lower, moderate and upper case bioenergy demand. If the value of E_{status} is above 1, the region is surplus in bioenergy resources while a ratio below 1 denotes deficit. A bioenergy-deficit status emphasizes adopting innovative and sustainable practices of enhancing the resources while improving the end-use efficiency of the devices [15].

3.2. Bioenergy Resource Assessment in the Village Level

Bioresource assessment at the district level provides an overview of the bioenergy status. However, the availability and consumption vary spatially and regionally. In order to understand the bioresource availability dynamics, the ecological status of the forest as well as the actual availability of the bioresources in the villages for meeting their bioenergy requirements have been studied. Fragmentation of forests is one of the decisive parameters in the availability of bioresources. Also, an attempt is made to spatially analyse the degradation levels with the demand centre villages in the watersheds of Solan and Shimla districts.

3.2.1. Fragmentation of Forests

Forest fragmentation is a process by which a contiguous area of forest is reduced and divided into multiple fragments, ultimately leading to deforestation. Fragmentation of forests is assessed using remote sensing data for Moolbari and Mandhala watersheds of Shimla and Solan districts, respectively.

Multispectral and temporal satellite images covering Moolbari watershed (1341 ha) are downloaded from GLCF (http://glcf.umiacs.umd.edu/data/) and also procured from National Remote Sensing Agency, Hyderabad, India. These include images with diverse spatial and spectral resolutions acquired from Landsat MSS (1972), Landsat TM (1989), Landsat ETM+ (2000) and IRS LISS–III (2007). SOI toposheets of 1:50,000 and 1:250,000 scales are digitized to derive the boundary layer of the watershed, which is used to mask and crop the region out of the satellite image.

Land use (type of features such as crops, built-up, etc. associated to human activities) and land cover (natural features such as tree cover, water body, snow, etc.) analyses are performed on these satellite images using various classification algorithms like GMLC. GCPs for geo-correction and training data for classification of remote data are collected through field investigations using a handheld GPS. Google Earth data (http://earth.google.com) are used for pre- and post-classification validation. Similar methodology is followed for Mandhala watershed (1453 ha) in Solan district. The extent of forest fragmentation is assessed using FRAGSTATS®.

3.2.2. Biomass Degradation Analysis

Biomass degradation analysis maps the resource availability with respect to the bioenergy demand of inhabiting villages in the vicinity. The extent of woody biomass meeting the bioenergy requirements of seven villages in Moolbari watershed is mapped using remote sensing (IRS LISS III) and geographical information systems (GIS) tools. Classification of remote sensing data provided the land use and also helped in mapping the resource availability around each village. The watershed is divided into seven zones using Thiessen polygon method (based on the proximity of the village to the resource availability) such that each zone represents corresponding villages' proximity area (village zonation theme). Multiple ring buffers are drawn around villages at 100 m interval up to 1000 m (10 rings). The buffer themes are clipped using village zonation theme and those falling under other village zones are deleted. ANP_{tree} of forest cover is taken to be 3.6 t/ha/year and PCFC as 2.3 and 1.9 kg/day in lower and upper case demand scenarios, respectively. Finally, thematic maps are created for both the scenarios to understand the level of bioresource degradation.

3.3. DSS for Regional Bioenergy Resource Planning

A DSS for assisting regional bioenergy resource planning is developed using Microsoft Visual Basic 6.0 as frontend and Microsoft Access database as backend [6, 7]. It comprises of different modules enabling data management, processing, interpretation, modelling, projection and visualization (Figure 2). In the database module, the data collected from primary (ground surveys, spatial data) and secondary sources (government departments, records, literatures) are stored in a database which is easily accessible for retrieval, updating or editing. This includes information on forest vegetation, plantation, crops, cattle and other sources of bioenergy. Data redundancy is minimized through normalized data tables. GIS provides the capabilities such as spatial and temporal analysis, querying and visualization which helps the location-based decentralized planning. Land cover land use (LCLU) analysis module calculates the extent of vegetation cover in a region using remote sensing data. Temporal changes in land cover have been analysed for studying the trends of resource availability or degradation. Land-use module helps in mapping the extent of different land-use patterns (agriculture, plantation, forests, etc.) in a region. The flexibility to enrich the database with spatial aspects helps to identify and quantify the local constraints in resource management. Level of analysis module helps in hierarchical data input and analysis. Bioresource yield module computes sector-wise resource yield based on spatial extent (forest, agriculture, plantation, etc.) and productivity. Energy module computes the available energy for the selected bioresource at the selected level. Forecasting module helps in projecting the resource status to future conditions and facilitates alternative approaches so as to reduce possible resource crunch. This enables the planner to access and study bioenergy resource status in the village level to national level in a bottom–up approach of resource planning [7]. The method flow diagram of DSS designed for regional bioenergy resource estimation and planning is given in Figure 3.

4. RESULTS AND ANALYSIS

LCLU analyses of Solan, Shimla and Lahaul Spiti districts are performed and the types of vegetation are identified spatially (Figure 4a–c). The temporal land cover changes for the districts are given in Table VI. Based on analysis of the latest available spatial data (2005/2006), the total tree cover in Solan is 43.51%, in Shimla 48.85% and in Lahaul Spiti 0.36% of the respective total geographic areas (Table VII). The ANP_{tree} estimated for the vegetation types are given in Table VIII. The annual woody biomass produced ranges as 517.3–1111.7, 1253.8–3029.8 and 18.9–63.8 kilo tonnes for Solan, Shimla and Lahaul Spiti districts, respectively. The lower, moderate and uppercase scenarios of availability are listed in Table IX. In all cases, the total availability of the woody biomass is the highest in Shimla, followed by Solan and Lahaul Spiti. The district-wise fuel wood demand for lower, moderate and upper PCFC cases is given in Table X.

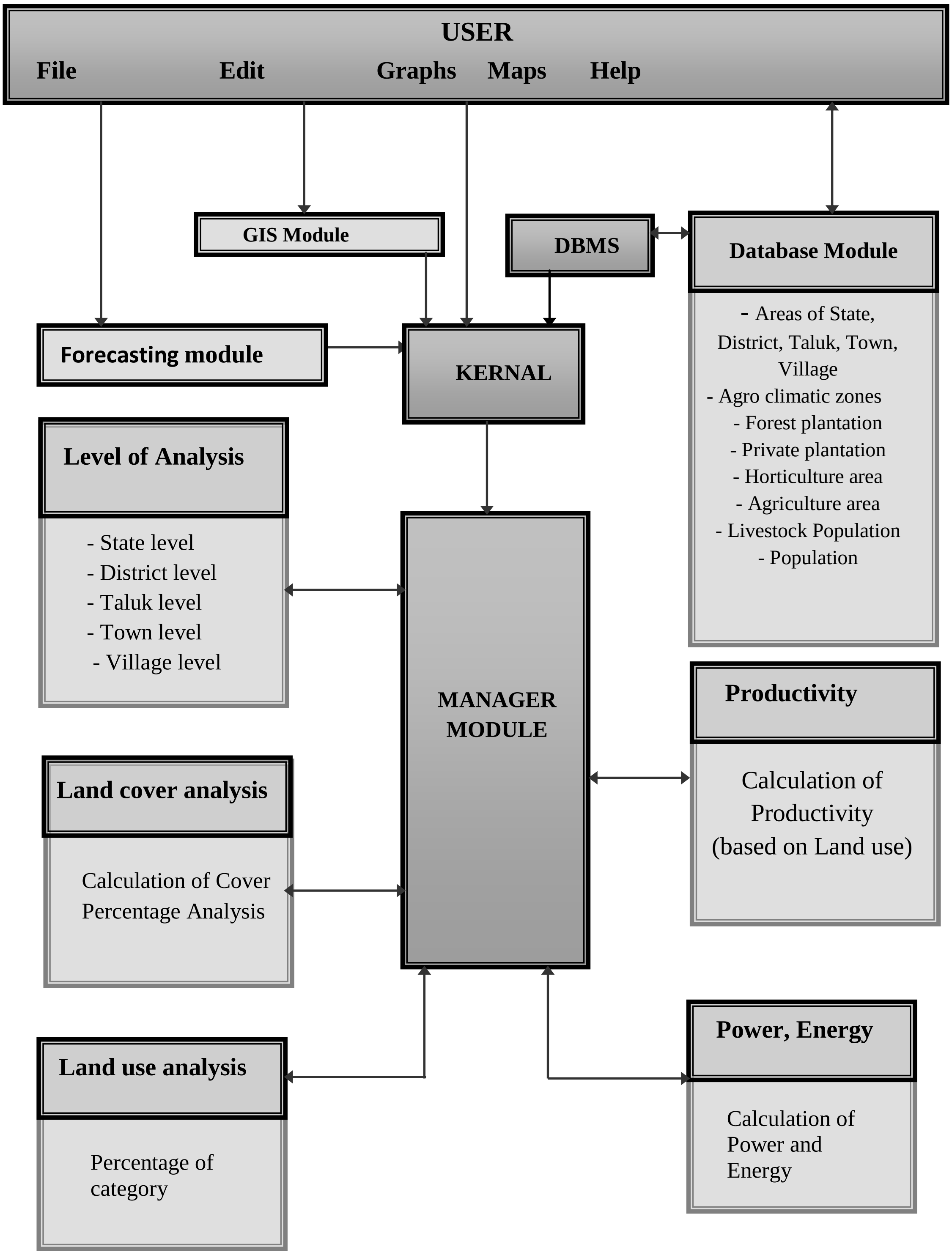

Fig 2:*Design of DSS for bioenergy resource assessment and planning.*

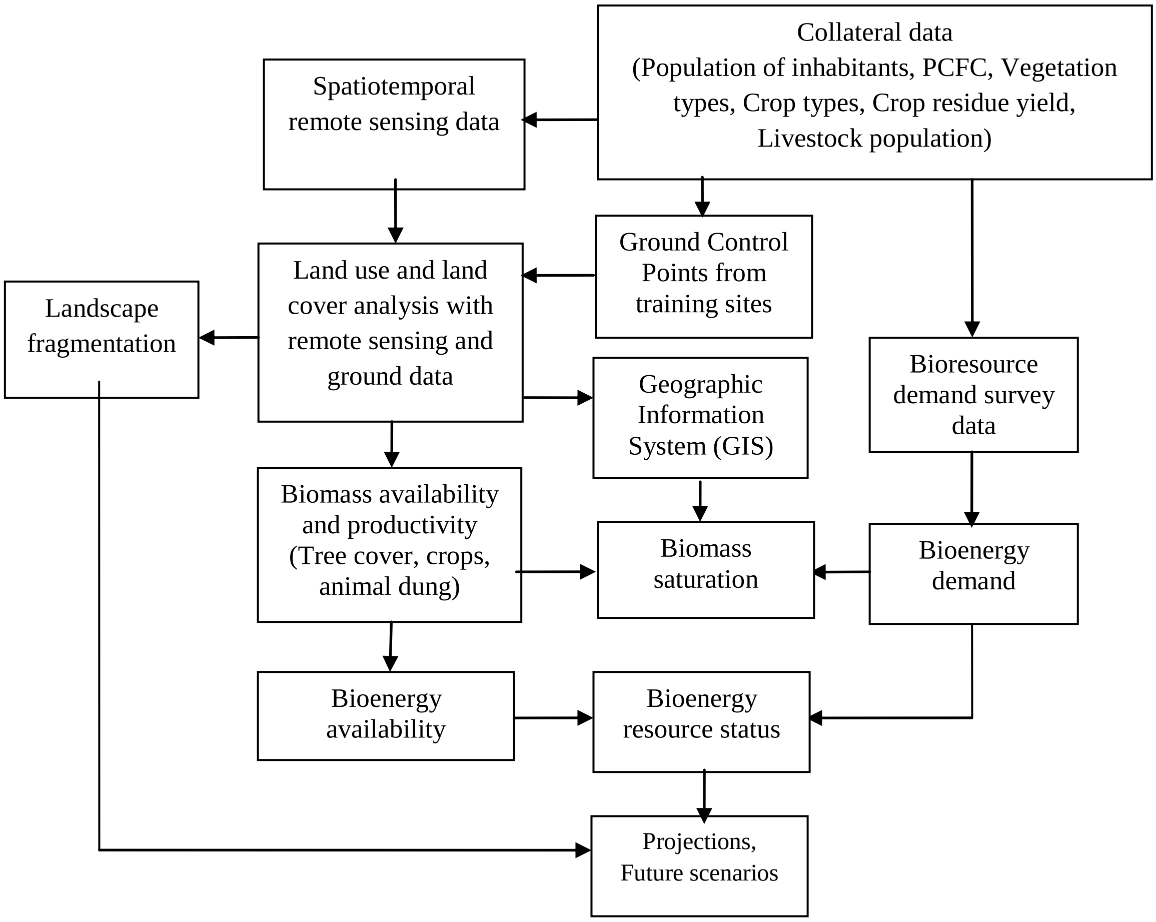

Fig. 3:DSS Methodology for Bioenergy Resource Assessment and Planning.

PCFC in Solan is 0.48–1.32 kg/person/day, in Shimla1.9–2.68 and in Lahaul Spiti 0.89–2.91 kg/person/day.

Evidently, the higher case of fuel wood demand in Lahaul Spiti cannot be met even by the moderate case productivity of woody biomass in the region. Moreover, the actual availability of woody biomass as fuel wood considering its alternative use as timber is lower than the total productivity in any region. Hence, Practically available fuel wood may not meet the bioenergy requirements of these regions for different demand cases.

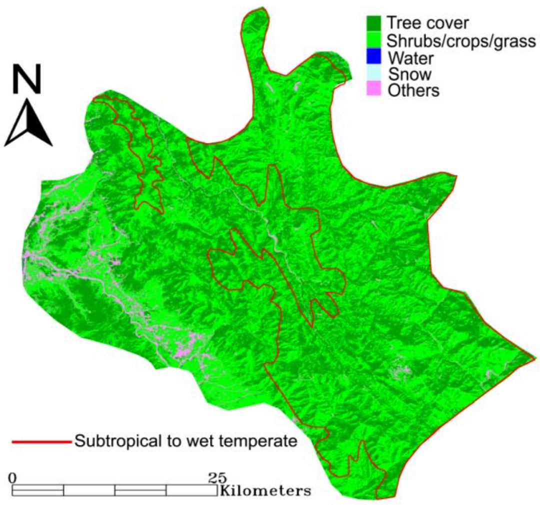

Fig. 4a: Land Cover Classification of 2005/06 Satellite Image with Vegetation Type Identified for Solan.

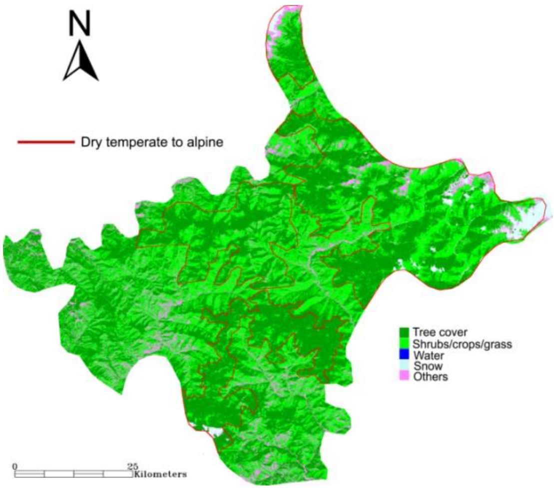

Fig. 4b: *Land Cover Classification of 2005/06 Satellite Image with Vegetation Type Identified for Shimla.*

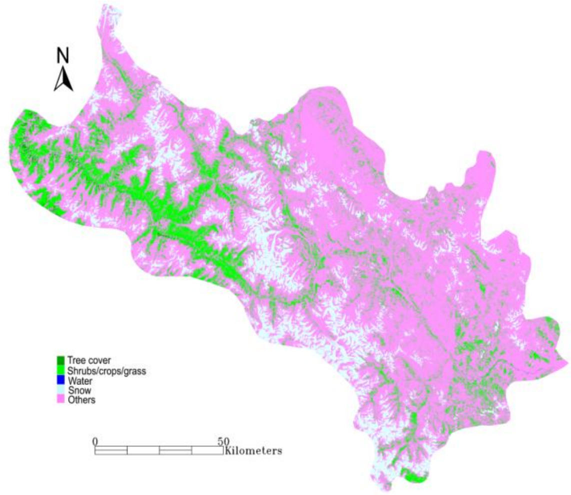

Fig. 4c: *Land Cover Classification of 2005/06 Satellite Image for Lahaul Spiti.*

Table VI: *GMLC-Based Temporal Land Cover for Solan, Shimla and Lahaul Spiti.*

District	Year	Tree cover		Shrubs/crops/grass		Water		Snow		Others	
		ha	%	ha	%	ha	%	ha	%	ha	%
Solan	1989	97,665.43	47.70	101,291.19	49.47	24.37	0.01	0.00	0.00	5774.69	2.82
	2000	94,508.19	46.02	102,382.68	49.85	24.39	0.01	0.00	0.00	8469.95	4.12
	2005	89,354.01	43.51	107,318.57	52.26	26.28	0.01	0.00	0.00	8669.05	4.22
Shimla	1989	249,589.62	52.55	190,807.40	40.17	10.88	0.00	9373.37	1.97	25,176.71	5.30
	2000	232,780.26	48.98	191,295.96	40.25	28.98	0.01	9092.59	1.91	42,074.63	8.85
	2005	231,767.28	48.85	189,457.75	39.93	1.44	0.00	9499.76	2.00	43,766.50	9.22
Lahaul Spiti	1989	7215.61	0.51	166,665.31	11.67	290.46	0.02	253,642.97	17.77	999,896.33	70.03
	2000	8060.11	0.56	226,480.31	15.86	478.74	0.03	216,714.47	15.18	976,327.38	68.37
	2005	5187.92	0.36	203,383.35	14.24	497.75	0.03	200,516.52	14.04	1,018,475.48	71.32

Table VII: *Types of Vegetation Identified and Extent of Tree Cover (in ha) in Different Districts.*

District	Tropical to subtropical	Wet temperate	Dry temperate to subalpine	Total
Solan	40,051.97	49,302.04	0.00	89,354.01
Shimla	0.00	99,474.43	132,292.85	231,767.28
Lahaul Spiti	0.00	0.00	5187.92	5187.92

Table VIII: *The Lower, Moderate and Upper case ANP$_{tree}$ (t/ha/year) Values of Different Vegetations.*

Scenario	Tropical to subtropical	Wet temperate	Dry temperate to subalpine
Lower case	3.375	7.75	3.65
Moderate case	6.8875	10.93	7.98
Upper case	10.4	14.10	12.30

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***Table IX:** Woody Biomass Availability (kilo tonnes/year) across Vegetation Types*

District	Scenario	Tropical to subtropical	Wet temperate	Dry temperate to subalpine	Total
Solan	Lower case	135.18	382.09	0.00	517.27
	Moderate case	275.86	538.62	0.00	814.48
	Upper case	416.54	695.16	0.00	1111.70
Shimla	Lower case	0.00	770.93	482.87	1253.80
	Moderate case	0.00	1086.76	1055.04	2141.79
	Upper case	0.00	1402.59	1627.20	3029.79
Lahaul Spiti	Lower case	0.00	0.00	18.94	18.94
	Moderate case	0.00	0.00	41.37	41.37
	Upper case	0.00	0.00	63.81	63.81

***Table X:** PCFC Estimated and Total Fuel Wood Demand for Different Scenarios for 2006.*

District	Scenario	PCFC (kg/day)	Total fuel wood demand (kilo tonnes/year)
Solan	Lower case	0.46	97.50
	Moderate case	0.89	188.65
	Higher case	1.32	279.79
Shimla	Lower case	1.9	544.28
	Moderate case	2.29	656.00
	Higher case	2.68	767.72
Lahaul Spiti	Lower case	0.89	11.13
	Moderate case	1.9	23.76
	Higher case	2.91	36.39

The annual bioenergy equivalent of agro residues (from cereals, pulses, oilseeds, cotton and sugarcane) in Solan is 698,925 million kcal, in Shimla 443,124 million kcal and in Lahaul Spiti 5356 million kcal. However, we have considered only 50% of the agro residues available for energy purposes (fuel ratio). The total annual production of agro residues and agro bioenergy availability in the three districts are given in Table XI. Figure 5 shows that total annual bioenergy from agro-residues is the highest in Solan and least in Lahaul Spiti. Cereals and oilseeds are the only sources of agro bioenergy in Lahaul Spiti. Among all crops, cereals have the highest bioenergy potential in all districts, followed by pulses.

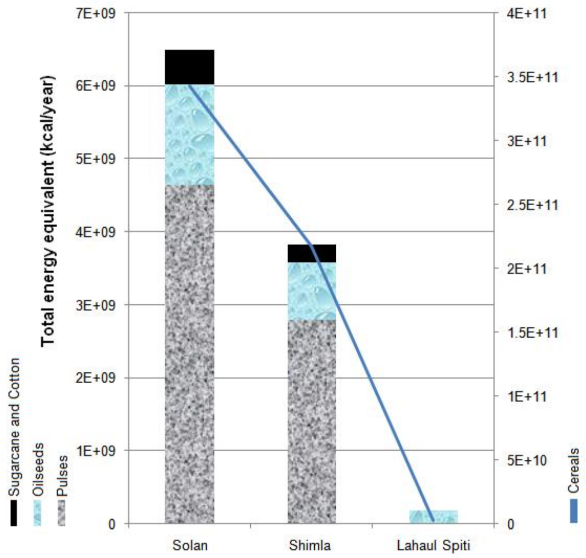

***Fig. 5:** Total Energy Equivalent of Agro Residues Produced in Solan, Shimla and Lahaul Spiti.*

Table XI: *Area, Residue Production and Energy Equivalent for Different Crops in Solan, Shimla and LahaulSpiti*.

Crop	Name	Residue type	Area (ha)	Residue produced (t/year)	Energy equivalent (kcal/year)
Solan					
Cereals	Rice	Husk	4742	2530	4.00E + 09
		Stalk		13,088	2.00E + 10
	Wheat	Stalk	24,694	58,080	1.00E + 11
	Bajra	Cobs	0	0	0
		Husk		0	0
		Stalk		0	0
	Maize	Cobs	22,852	12,290	2.00E + 10
		Husk		9004	1.00E + 10
		Stalk		90,037	2.00E + 11
	Barley	Stalk	1682	1880	3.00E + 09
	Others	Stalk	0	0	0
Pulses	Gram	Stalk	315	305	5.00E + 08
	Tur/arhar	Husk	0	0	0
		Stalk		0	0
	Kharif	Husk	1695	232	3.00E + 08
		Stalk		1417	2.00E + 09
	Rabi	Stalk	908	730	1.00E + 09
Oilseeds	Groundnut	Shell	14	4	8.00E + 06
		Stalk		25	5.00E + 07
	Sesamum	Stalk	320	96	1.00E + 08
	Rapeseed and mustard	Husk and stalk	414	304	5.00E + 08
	Soyabean	Stalk	46	107	2.00E + 08
	Others	Stalk	684	274	5.00E + 08
Miscellaneous	Cotton	Shell and husk	53	84	1.00E + 08
		Stalk		159	2.00E + 08
	Sugarcane	Bagasse	189	54	9.00E + 07
		Top and leaves		8	1.00E + 07

Crop	Name	Residue type	Area (ha)	Residue produced (t/year)	Energy equivalent (kcal/year)
Shimla					
Cereals	Rice	Husk	1981	586	9.00E + 08
		Stalk		3031	5.00E + 09
	Wheat	Stalk	15,104	24,891	4.00E + 10
	Bajra	Cobs	3	1	1.00E + 06
		Husk		1	1.00E + 06
		Stalk		5	9.00E + 06
	Maize	Cobs	13,896	8763	2.00E + 10
		Husk		6420	1.00E + 10
		Stalk		64,200	1.00E + 11
	Barley	Stalk	4704	6054	9.00E + 09
	Others	Stalk	4049	4195	6.00E + 09
Pulses	Gram	Stalk	29	33	6.00E + 07
	Tur/arhar	Husk	70	4	6.00E + 06

		Stalk		35	5.00E + 07
	Kharif	Husk	4416	215	3.00E + 08
		Stalk		1312	2.00E + 09
	Rabi	Stalk	48	32	6.00E + 07
Oilseeds		Shell	8	1	1.00E + 06
	Groundnut	Stalk		4	8.00E + 06
	Sesamum	Stalk	40	13	2.00E + 07
	Rapeseed and mustard	Husk and stalk	601	361	6.00E + 08
	Soyabean	Stalk	39	89	1.00E + 08
	Others	Stalk	7	3	5.00E + 06
Miscellaneous		Shell and husk	0	0	0
	Cotton	Stalk		159	2.00E + 08
		Bagasse	0	0	0
	Sugarcane	Top and leaves		0	0

			Lahaul Spiti		
Crop	**Name**	**Residue type**	**Area (ha)**	**Residue produced (t/year)**	**Energy equivalent (kcal/year)**
Cereals		Husk		0	0
	Rice	Stalk	0	0	0
	Wheat	Stalk	81	183	3.00E + 08
		Cobs		0	0
		Husk	0	0	0
	Bajra	Stalk		0	0
		Cobs		39	7.00E + 07
		Husk		28	4.00E + 07
	Maize	Stalk	64	283	6.00E + 08
	Barley	Stalk	592	939	1.00E + 09
	Others	Stalk	107	60	9.00E + 07
Pulses	Gram	Stalk	0	0	0
		Husk		0	0
	Tur/arhar	Stalk	0	0	0
	Kharif	Husk		1	2.00E + 06
		Stalk	27	8	1.00E + 07
	Rabi	Stalk	0	0	0
Oilseeds		Shell		0	0
	Groundnut	Stalk	0	0	0
	Sesamum	Stalk	0	0	0
	Rapeseed and mustard	Husk and stalk	68	96	2.00E + 08
	Soyabean	Stalk	0	0	0
	Others	Stalk	0	0	0
Miscellaneous	Cotton	Shell and husk		0	0
		Stalk	0	0	0
	Sugarcane	Bagasse		0	0
		Top and leaves	0	0	0

Table XII gives the different cases of dung yield from livestock found in Himachal Pradesh. Considering the moderate case of dung yield, total dung generation is the highest in Shimla and least in Lahaul Spiti. Cattles, buffaloes and goats are the major sources of animal dung in Solan and contributes nearly 615.3 kilo tonnes annually. Since these are mostly stall fed, the actual availability is higher in the district. Apart from these animals, Shimla has additional livestock varieties of sheep, horses and mules, together generating 778.7 kilo tonnes of dung annually. The cold district of Lahaul Spiti has cattle, yak, sheep, buffalo, goat and horses, generating 36.6 kilo tonnes of annual dung. Total annual dung yield from livestock, their biogas generation potential and energy equivalents are estimated for lower, moderate and upper case dung yield values (Table XIII). The annual biogas generation in Solan is 8.7–35.6 million m^3, in Shimla 12.9–43.2 million m^3 and in Lahaul Spiti 0.8–1.9 million m^3.

Table XII:*Lower, Moderate and Upper Case Dung Yield (kg/head/day) Considered for Livestock.*

Livestock	Cattle	Buffalo	Yak	Mithun	Sheep	Goat	Horse	Pony	Mule	Donkey	Pig	Camel
Lower case	2.87	2.65	4.50	4.50	0.10	0.10	1.72	1.72	0.94	0.94	0.34	2.49
Moderate case	6.44	8.83	4.50	4.50	0.21	0.23	3.90	3.90	0.94	0.94	0.34	2.49
Upper case	10.00	15.00	4.50	4.50	0.35	0.35	6.08	6.08	0.94	0.94	0.34	2.49

Table XIII: *Livestock Types, Biogas Generation and Energy Equivalent for Different Dung Yield Scenarios in Solan, Shimla and Lahaul Spiti.*

a) **Solan**

Livestock		Solan		
		Total dung (kg/year)	Biogas (m^3/year)	Energy equivalent (kcal/year)
	L	2E + 08	5E + 06	3E + 10
	M	3E + 08	1E + 07	6E + 10
Cattle	U	5E + 08	2E + 07	9E + 10
	L	8E + 07	3E + 06	1E + 10
	M	3E + 08	1E + 07	5E + 10
Buffalo	U	5E + 08	2E + 07	8E + 10
	L	0	0	0
	M	0	0	0
Yak	U	0	0	0
	L	0	0	0
	M	0	0	0
Mithun	U	0	0	0
	L	3E + 05	1E + 04	5E + 07
Sheep	M	2E + 05	7E + 03	3E + 07

	U	9E + 04	3E + 03	2E + 07
	L	1E + 07	4E + 05	2E + 09
	M	7E + 06	2E + 05	1E + 09
Goat	U	3E + 06	1E + 05	5E + 08
	L	2E + 05	7E + 03	3E + 07
	M	4E + 05	2E + 04	8E + 07
Horse	**U**	7E + 05	2E + 04	1E + 08
	L	3E + 04	1E + 03	6E + 06
	M	8E + 04	3E + 03	1E + 07
Pony	U	1E + 05	4E + 03	2E + 07
	L	3E + 05	9E + 03	5E + 07
	M	3E + 05	9E + 03	5E + 07
Mule	U	3E + 05	9E + 03	5E + 07
	L	6E + 04	2E + 03	1E + 07
	M	6E + 04	2E + 03	1E + 07
Donkey	U	6E + 04	2E + 03	1E + 07
	L	2E + 04	9E + 02	4E + 06
	M	2E + 04	9E + 02	4E + 06
Pig	U	2E + 04	9E + 02	4E + 06
	L	9E + 02	3E + 01	2E + 05
	M	9E + 02	3E + 01	2E + 05
Camel	U	9E + 02	3E + 01	2E + 05

Note: L, lower case; M, moderate case; and U, uppercase.

b) **Shimla**

Livestock		Shimla		
		Total dung (kg/year)	**Biogas (m^3/year)**	**Energy equivalent (kcal/year)**
	L	3E + 08	1E + 07	6E + 10
	M	7E + 08	3E + 07	1E + 11
Cattle	U	1E + 09	4E + 07	2E + 11
	L	1E + 07	5E + 05	2E + 09
	M	4E + 07	2E + 06	8E + 09
Buffalo	U	7E + 07	3E + 06	1E + 10
	L	3E + 04	1E + 03	5E + 06
	M	3E + 04	1E + 03	5E + 06
Yak	U	3E + 04	1E + 03	5E + 06
	L	0	0	0
	M	0	0	0
Mithun	U	0	0	0
	L	1E + 07	4E + 05	2E + 09
	M	7E + 06	3E + 05	1E + 09
Sheep	U	3E + 06	1E + 05	6E + 08
	L	1E + 07	4E + 05	2E + 09
	M	8E + 06	3E + 05	1E + 09
Goat	U	3E + 06	1E + 05	6E + 08
Horse	L	7E + 05	2E + 04	1E + 08

	M	2E + 06	6E + 04	3E + 08
	U	2E + 06	9E + 04	4E + 08
	L	6E + 05	2E + 04	1E + 08
	M	1E + 06	5E + 04	2E + 08
Pony	U	2E + 06	8E + 04	4E + 08
	L	1E + 06	3E + 04	2E + 08
	M	1E + 06	3E + 04	2E + 08
Mule	U	1E + 06	3E + 04	2E + 08
	L	3E + 05	1E + 04	5E + 07
	M	3E + 05	1E + 04	5E + 07
Donkey	U	3E + 05	1E + 04	5E + 07
	L	3E + 04	1E + 03	5E + 06
	M	3E + 04	1E + 03	5E + 06
Pig	U	3E + 04	1E + 03	5E + 06
	L	3E + 03	1E + 02	5E + 05
	M	3E + 03	1E + 02	5E + 05
Camel	U	3E + 03	1E + 02	5E + 05

Note: L, lower case; M, moderate case; and U, uppercase.

c) **Lahaul Spiti**

		Lahaul Spiti		
Livestock		**Total dung (kg/year)**	**Biogas (m^3/year)**	**Energy equivalent (kcal/year)**
	L	1E + 07	5E + 05	2E + 09
	M	3E + 07	1E + 06	5E + 09
Cattle	U	4E + 07	2E + 06	8E + 09
	L	0	0	0
	M	0	0	0
Buffalo	U	0	0	0
	L	2E + 06	8E + 04	4E + 08
	M	2E + 06	8E + 04	4E + 08
Yak	U	2E + 06	8E + 04	4E + 08
	L	3E + 03	1E + 02	6E + 05
	M	3E + 03	1E + 02	6E + 05
Mithun	U	3E + 03	1E + 02	6E + 05
	L	4E + 06	2E + 05	8E + 08
	M	3E + 06	1E + 05	5E + 08
Sheep	U	1E + 06	5E + 04	2E + 08
	L	1E + 06	4E + 04	2E + 08
Goat	M	7E + 05	2E + 04	1E + 08

	U	3E + 05	1E + 04	6E + 07
	L	1E + 04	4E + 02	2E + 06
	M	2E + 04	9E + 02	4E + 06
Horse	U	4E + 04	1E + 03	7E + 06
	L	6E + 05	2E + 04	1E + 08
	M	1E + 06	5E + 04	2E + 08
Pony	U	2E + 06	8E + 04	4E + 08
	L	0	0	0
	M	0	0	0
Mule	U	0	0	0
	L	7E + 05	2E + 04	1E + 08
	M	7E + 05	2E + 04	1E + 08
Donkey	U	7E + 05	2E + 04	1E + 08
	L	0	0	0
	M	0	0	0
Pig	U	0	0	0
	L	0	0	0
	M	0	0	0
Camel	U	0	0	0

Note:*L, lower case; M, moderate case; and U, uppercase.*

Considering the multiple uses of woody biomass, agro residues and animal dung, the actual availability of these bioresources for fuel purposes are accounted in high (75%), medium (50%) and low (25%) supply scenarios. Figure 6 highlights these bioenergy availability scenarios (considering moderate case production for woody biomass and animal dung) and their prospects of meeting the lower, moderate and upper case bioenergy demands in the three districts. The bioenergy resource status of the three districts is shown in Figure 7.

In Solan, higher case bioenergy demand cannot be met by the low (25%) bioenergy availability scenario even after including agro residues and biogas energy from animal dung. This scenario points at a bioenergy-deficit status for the region (Figure 7).

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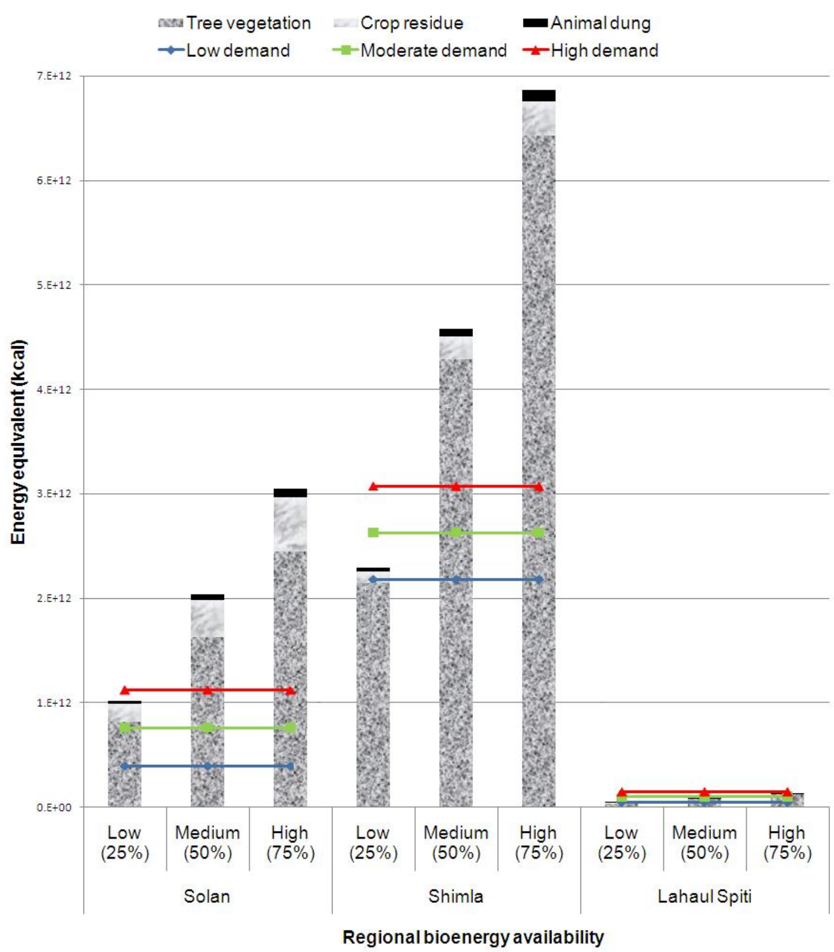

Fig. 6: Different Availability Scenarios of Bioenergy Resources and Cases of Bioenergy Demand in Solan, Shimla and Lahaul Spiti.

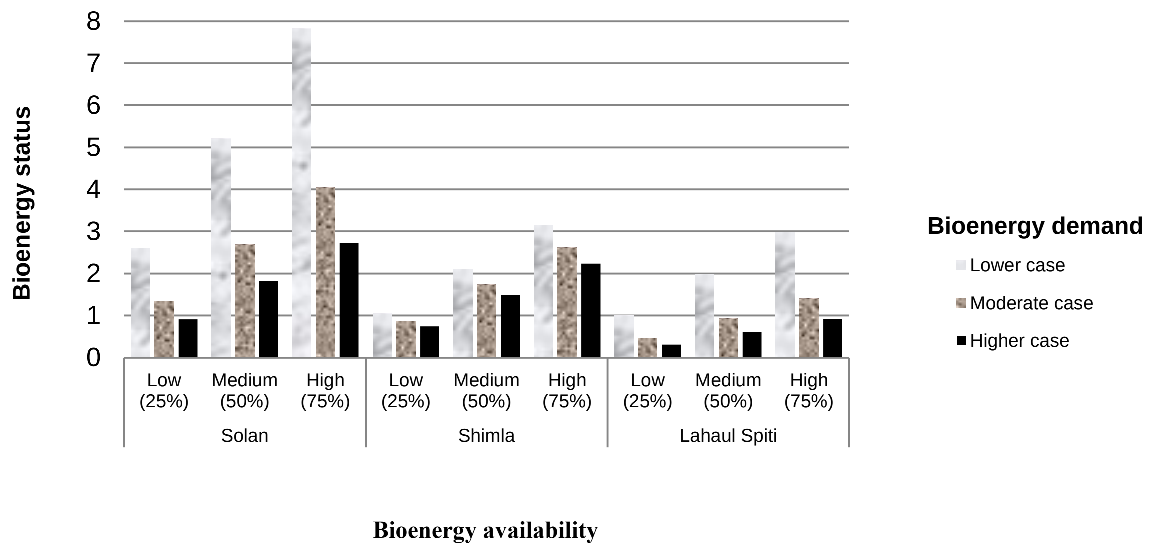

Fig. 7: Bioenergy Resource Status of Solan, Shimla and Lahaul Spiti.

However, moderate and lower case demand is being met by the fuel wood resources. In Shimla, even lower case bioenergy demand is met by the low (25%) availability scenario of woody biomass. Additional bioenergy from agro and animal residues (low) fail to meet the moderate and higher case demand. As seen in Figure 7, this scenario represents a critical bioenergy status for Shimla. However, medium (50%) availability of woody biomass is sufficient for a higher case demand. In Lahaul Spiti, high (75%) availability of woody biomass sustains at least moderate case demand, while medium (50%) availability sustains only lower case demand. Even a high total bioenergy availability scenario cannot sustain the higher case demand of the region. This indicates a very critical bioenergy-deficit status in the cold district of Lahaul Spiti.

Figure 8(a) and (b) represents biomass saturation in the proximity of seven villages in Moolbari watershed for higher (2.63 kg/day) and lower (1.9 kg/day) case bioenergy demand scenarios, respectively. It is observed that the villages of Moolbari, Ganeog, Kiuru and Dochi have limited availability of fuel wood resource in their vicinity and people traverse longer distances to meet their needs. The villages of Tikri and Niaog have relatively higher fuel wood availability while Shanohal has the highest among all. The forest fragmentation study conducted in the same watershed reveals the extent of forest degradation that has occurred from 1972 to 2007 (Figure 9a). The overall accuracy of image classification is between 81% and 89% and results show that the extents of forest cover which was high in 1972 eventually

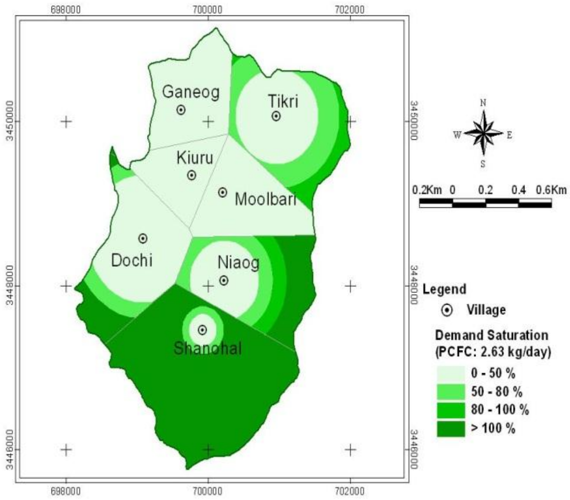

Fig. 8a: *Bio-mass Saturation Map for Moolbari, Case–I.*

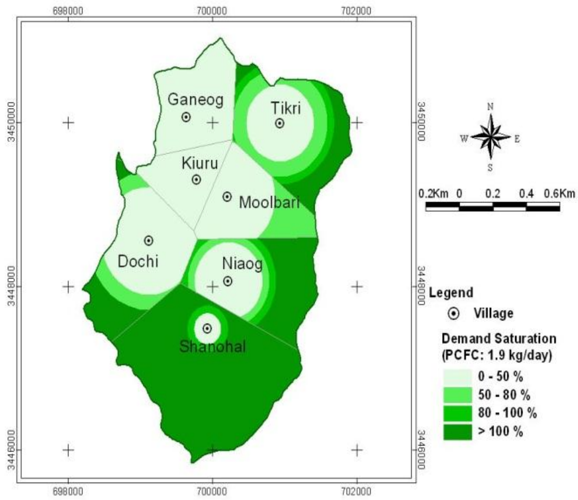

Fig. 8b: *Bio-mass Saturation Map for Moolbari, Case–II.*

declined by 5.59% in 2007. It is observed that the regions prone to higher forest fragmentation levels inhabit villages such as Moolbari, Ganeog, Kiuru and Dochi with lower biomass saturation. This highlights that the anthropogenic influence in forest fragmentation occurred over a period of time.

A similar analysis of the tree cover changes in Mandhala watershed during the period 1972–2007 also exposes the forest fragmentation in its landscape (Figure 9b). Such grassroots-level resource constraints are not discerned in the district-level bioresource assessment and hence call for further disaggregation in assessment studies.

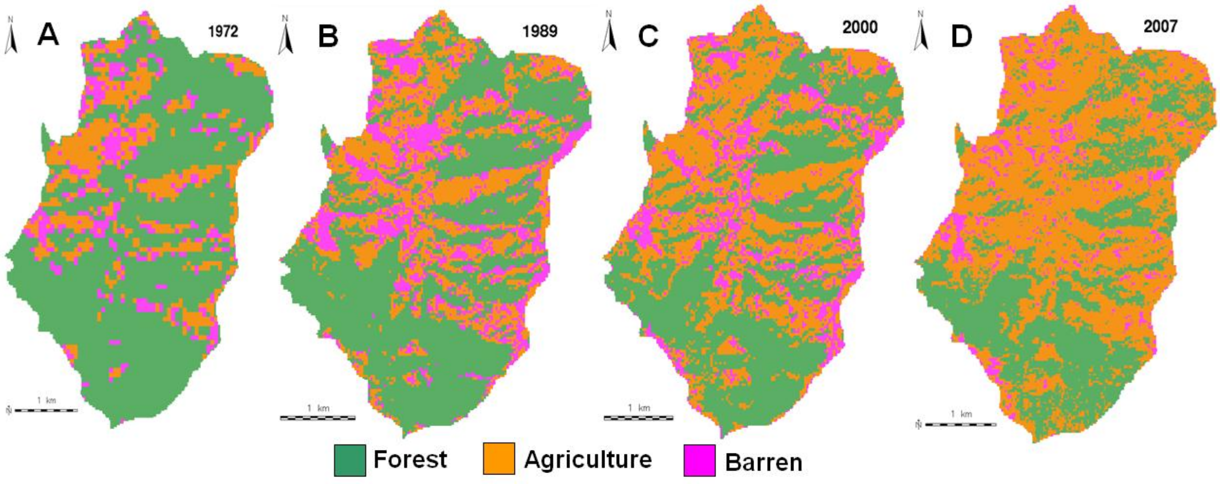

Fig. 9a: *Classified Images of Mandhala Watershed Showing Land Cover and Land Use Changes from 1972 to 2007.*

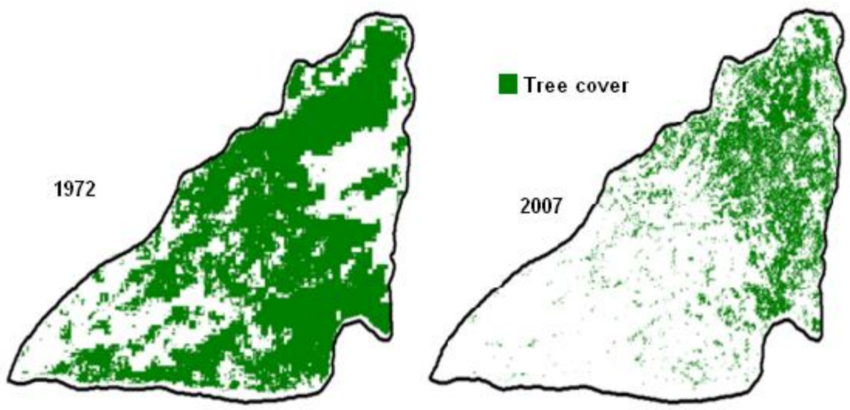

Fig. 9b: *Tree Cover Change from 1972 to 2007 in Mandhala Watershed.*

5. DISCUSSION

The bioenergy resource status of the three districts highlights highly pronounced scarcity of bioresources. The estimations are based on the moderate (average of upper and lower) case of bioenergy production. A possible lower case of production worsens the bioenergy status further. Increase in population results in increasing bioenergy demand and its impact is felt more on regions with higher PCFC. Especially in critical bioenergy-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. In such situations, people tend towards alternative bioenergy resources in an inefficient and *ad hoc* manner with dire consequences of pollution and conflicts with other traditional utilities. 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 bioenergy-deficit regions where even the total estimated bioenergy availability cannot meet the demands of an ever increasing population. Nevertheless, the regions deemed as bioenergy surplus in these estimations should not be marginalized while adopting such methodologies since they are under pressure. Potential bioresource crunch is imminent in the absence of immediate intervention perceptibly leading to deforestation.

Traditional stoves used for burning wood in these hilly regions are thermally inefficient. They emit more smoke, causing health hazards to women and children. Energy efficient, smokeless and innovative ASTRA cookstoves with thermal efficiency above 30% will reduce the fuel consumption by 42% [61, 62]. In mountainous regions, the demand as well as utility of fuel wood varies with altitude, and hence, the traditional designs differ zone-wise. The National Programme on Improved Cookstoves (NPIC) introduced in Himachal Pradesh in 1983 has not given the desired results due to technical and institutional problems. The improved and efficient designs were not accepted by the inhabitants who were used to their traditional models. In recent times, need- and location-specific cookstoves are being designed so as to improve the prospects of social acceptance. Improvements in technical knowhow, institutional support, women awareness, publicity campaigns and subsidies are proposed for long-term success of the national programme [5].

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 m^3 capacity biogas plants in rural regions is enormous [63]. 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 m^3) biogas plants which could produce 0.515 million m^3 of biogas per day with an energy equivalent of about 1801.1 tonnes of fuel wood. However, due to the lacunae in planning, technical, organizational and social aspects, biogas programme introduced in the state in 1982 has not been successful [61, 64]. Performance of biogas plants in colder regions is relatively poor. Warmer climate in lowland regions of Solan and Shimla is conducive for biogas generation with the existing technology. The annual energy from biogas generation is 55,373 million kcal in Solan, 70,081 million kcal in Shimla and 3291 million kcal in Lahaul Spiti, considering the moderate case of production, medium scenario (50%) of availability and lower energy equivalent for conversion. Biogas has enormous potential to replace fuel wood and can save up to 13,843, 17,520 and 823 tonnes of fuel wood annually in Solan, Shimla and Lahaul Spiti, respectively. Livestock in Shimla and Lahaul Spiti also include horse and pony which are mostly stall fed. It has been observed that a 20% replacement of cattle dung can be made by horse dung for operating family-size biogas plants without much reduction in their gas production or encountering any operational problem [65]. The increased grazing-based livestock farming in Lahaul Spiti results in lesser actual availability of animal dung for biogas generation. Stall-fed livestock facilitate dung collection as well as reduce grazing in forests [61]. Hence, site-specific innovative solutions need to be introduced to revamp and enhance the biogas prospects in these hilly regions.

Agro residues generated are to be judiciously utilized for energy without compromising their alternative utilities as fodder, manure and mulch. The annual energy from agro residues is 349,463 million kcal in Solan, 221,562 million kcal in Shimla and 2678 million kcal in Lahaul Spiti, considering the medium scenario (50%) of availability and lower energy equivalents for conversion. This can save up to 87,366, 55,390 and 669 tonnes of trees annually in Solan, Shimla and Lahaul Spiti, respectively. Process-based residue like rice husk has a high energy potential if utilized effectively. Commercial energy sources such as LPG and kerosene distribution system need revitalization so as to ensure wider absorption into the local energy system. As observed in the land cover analyses, Solan, Shimla and Lahaul Spiti have large open spaces. The extent of waste lands could be prospected through government records for energy plantations. Multiple tree species with high growth and regeneration potential need to be introduced in the regions with bioenergy-deficit status as high priority. Species-level mapping of fuel wood trees could be carried out using remote sensing and geospatial tools [66]. The exotic *L. camara* weeds spread in the hills of Solan could be replaced with native trees as energy plantations. The upland regions of Lahual Spiti with critical bioenergy-deficit support lesser vegetation. Hence, certain studies suggest energy plantations in lower altitude tribal villages to sustain the higher energy demands in the higher altitude villages [40]. Energy plantation provides employment opportunities for the mountain people and sufficient time for the natural restoration of degraded forests and helps sequester more carbon dioxide from the atmosphere. Joint forest management practices need to be strengthened through local support.

Importantly, the ultimate benefit of regional bioenergy resource assessment exercise is realized through an efficient and user-friendly BEPA DSS. An executable file is provided for this application and by running this, a form with Login, Level of Analysis and Resources Menu options are displayed. After logging with the user information, the Level of Analysis option is enabled for hierarchical administrative levels of analysis such as state, district, taluk, town and village levels. This option also enables user to input, retrieve or edit data in the database. This includes data entry of forest type, productivity, year of estimate and spatial extent of the forest. Similar options are available for computing bioenergy from agriculture and livestock sectors. The GIS-enabled features of the DSS facilitate simpler interpretation of spatial resource and demand variations as well as their quantification [7]. The complexity in collating, processing, analysing, interpreting and outputting information on bioenergy resources is simplified through the DSS designed. This helps the planner to act according to the regional energy scenarios which are often diluted in the national decision-making process.

6. CONCLUSION

The bioenergy resource statuses of Solan, Shimla and Lahaul Spiti districts are assessed for different resource availability scenarios and demand cases. PCFC varies with seasons and regions as 0.48–1.32 (Solan), 1.9–2.68 (Shimla) and 0.89–2.91 kg/person/day (Lahual Spiti). The total tree cover in the study area is 43.51% (Solan), 48.85% (Shimla) and 0.36% (Lahaul Spiti), providing annual woody biomass of 517.3–1111.7 (Solan), 1253.8–3029.8 (Shimla) and 18.9–63.8 kilo tonnes (Lahaul Spiti). The annual bioenergy potential of agro residues (considering 50% for fuel purpose) is 349,463 (Solan), 221,562 (Shimla) and 2678 million kcal (Lahaul Spiti). The annual biogas generation potential is 8.7–35.6(Solan), 12.9–43.2 (Shimla) and 0.8–1.9 million m^3 (Lahaul Spiti). Bioenergy resource crunch is more pronounced in the higher elevations while scarce resource availability scenarios create similar conditions in lower elevations as well.

Reiterating the importance of further disaggregated bioresource analysis, village-level forest fragmentation and biomass saturation studies are also performed. Proximity of energy demand centers like villages create shortage of fuel wood and increase deforestation. Possible alternatives are proposed for ensuring proper ecological health in the mountain areas. Regional bioenergy resource status could be identified through steadfast methodologies. Site-specific dynamics of bioenergy demand must be understood and effective utilization of fuel wood, crop residues and animal residues should be practised. Cookstoves with thermal efficiency above 30% could ensure optimal fuel wood use. Higher biogas availability from animal residues in lowland regions like Solan could supplement their thermal energy requirements. In the highland regions like Lahaul Spiti, stall-fed livestock must facilitate enhanced dung collection for biogas generation. This also helps in controlling grazing and resultant degradation. Even horse and pony dung are potential sources for biogas generation. Agro residues could be utilized through gasification and other conversion technologies without compromising their alternative utilities as fodder, manure and mulch. For example, process-based residue like rice husk has a high energy potential for community-scale power plants. Better distribution system for commercial energy sources such as LPG and kerosene minimizes the stress on local biomass. Waste and uncultivable lands, especially in bioenergy-deficit regions, should be prospected for multi-species energy plantations with a high regeneration potential. This also provides employment opportunities, gives sufficient time for natural restoration of degraded forests and helps in carbon sequestration. DSS has been designed to support energy planners and policy makers for location-specific decentralized bioresource planning.

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