Pine Needle Energy Potential in Conifer Forest of Western Himalayan

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ABSTRACT

The present study estimates the energy potential of pine needles in the western Himalayan territory. Both a single point estimation approach and tree-canopy density approach were carried out to determine the net annual pine needle litterfall for different types of conifer forest. The annual net and gross pine needles yield in the year 2018 have been estimated to be 67.99 million tonnes and 59.02 million tonnes respectively. It provides an annual primary energy (APE) potential in electric and thermal energy form. The calculated thermal energy varied from 1.16-1.34 pJ which can provide a backup of 0.09-0.1 billion kWh. Thus, the pine needle offers a source of renewable fuel with excellent combustion characteristics of 18.64 MJ/kg. Additionally, the massive pine needles would result in a net increment of economic energy to the Himalayan regions and also control the threats of forest fires and, most importantly, scale-down the environmental pollution.

1. INTRODUCTION

The most coniferous forests in the Himalayan territories cover 1.09 million km^2 and have a high potential of pine trees (*Pinus roxiburghii*) spreading across Nepal, Bhutan, China, Pakistan, and India (Bhagat et al., 2009). The western subalpine coniferous forests in the Himalayan territory cover 39,700 km^2 on the middle and lower elevations of Nepal, Pakistan, and India. These regions have a considerable potential of forest residues in term of pine needles (Gupta, 2013). The use of pine needles for energy source is progressively gaining the attention of researchers (Nunes et al., 2016; Polphan et al., 2009). Pine needles also act as an alternative to conventional sources, can improve the energy access options, and provides many environmental benefits (Bisht and Kumar, 2014). The pine needles fall off trees from the middle of March to the onset of rain in July and lounge for a more extended period. Shed pine needles have to make a thick layer of foliage on the pinewood floor, prevent natural growth of forest flora and also have relatively poor biodegradability due to high lignin content (Lal et al., 2013). Moreover, dried pine needles are the primary cause of forest fires in the summer days. Even a small ignition of such litter on the pinewood floor damages a large economy and slaughters mature pines and forest fauna. Besides this, the heat of the wildfire that consumes dried pine needles intercept seedling growth due to prematurely opening cones which spread seeds when exposed to the fire. The wildfire also creates drastic living conditions (Zhu et al., 2019; Joseph et al., 2009; Sairorkham, 2014). Adversely, dried pine needles current usage is limited for space heating, bedding for cattle, and other residential purposes (Malik and Mohapatra, 2013). The usage quantity is measured far less than the amount of pine needles that persist on the pinewood floor every year. Some necessary information is required to ensure that the pine needles would be suitable for use as an energy feedstock (Phrommarat, 2019; Sedpho and Sampattagul, 2015). The pine needles' calorific value as an energy source of 18.64 MJ/kg is comparable to some commonly available agricultural and forestry residues. For example, the calorific value is 16.91 MJ/kg for cotton stalk (Sharma and Mohapatra, 2016), 17.10 MJ/kg for wheat straw (Jain et al., 2014), 15.40 MJ/kg for rice husk (Malik and Mohapatra, 2013), 15.70 MJ/kg for wood chips (Parikh et al., 2005), and 17.32 MJ/kg for sugarcane baggage (Bilgen and Sarikaya, 2016). Moreover, its net calorific value is in good agreement with the other parts of the pine tree. For example, the calorific value is 18.55 MJ/kg for pine cone, 20.54 MJ/kg for pine pellet, 16.64 MJ/kg for pine chip,

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21.78 MJ/kg for pine bark, and 16.64 MJ/kg for pinewood (Nhuchhen and Salam, 2012). Additional main attractive features of pine needles are analyzed by proximate analysis and ultimate analysis ensure the high energy potential. Volatile matter confirms the way of thermochemical conversion of pine needles during the combustion process. Pine needle has a low bulk density, further enhancing the benefits for use in conversion.

Many researchers have worked on harnessing pine for various applications. The influence of climate on the structural growth of pine trees has been studied by Sharma and Lekha (2013) and Mahajan et al. (2016). Particular interest has also been paid to the knowledge of medicinal properties of pine trees for the treatment of various tropical disorders and its antioxidant characteristics (Parikh et al., 2005). Tiwari et al. (2013) studied the effect of altitude on the morphological, epidermal, and anatomical structure of pine needles. Sharma and Lekha (2013) studied pine resin, one of the essential non-wood products for the production of turpentine. Bisht et al. (2014), Dhaundiyal and Tewari (2015), and Dhaundiyal and Gupta (2014) made attempts to harness pine needles energy generation using gasification. Joshi et al. (2017) and Pandey and Dhakal (2013) worked on the pine needles briquettes for use as energy feedstock for gasification. The following are the potential applications of pine needles for energy feedstock:

1) It can provide extra fuel for electricity generation by various thermochemical conversion systems to meet the heat requirements of industries.

2) It creates a good source of employment by opening small or medium scale industries that provide the tasks of collection, transportation, and storage.

3) Suitable feedstock for water heating, space heating, and cooking necessities of residential and commercial installations.

Pine needles availability estimation is a challenging task as its density, shape-size, and quantity may vary along with climate, location, and species (Sharma and Lekha, 2013; Bisht et al., 2014). Utilization of unexploited source of pine needles has become the impetus for a future energy system due to their multiple environmental benefits. Additionally, recognition of pine needle distribution among the selected site and also undertake the calculation of the grid accessibility for power generation. The pine needle estimation study in a particular location should cover the present biomass status, its environment effect, availability, and approximate energy potential. The present work is primarily focused on the assessment of dried pine needles litterfall data as energy feedstock and predicting the annual primary, thermal, and electrical energy-producing capacity from it.

2. METHODOLOGY

2.1 Classification of conifer forest

Forest Survey of India uses remote sensing technology to generate satellite data of forests. The satellite LISS-III with a spatial resolution of 23.50 m provides statistical information of forest cover land. Table 1 shows the forest type and tree canopy relation (Gupta, 2013). According to Dasgupta et al. (2011), the state covers 15,100 km^2 of forest including particular forest, reserved forest, private forest, unclassified forest, demarcated protected forest, un-demarcated protected forest, and other forest managed by the forest department. Canopy density or crown cover is the part of the forest floor covered by vertical projections of trees as observed from top.

Table 1. Classification of pine forest basis of canopy density (Gupta, 2013).

Number	Forest type	Canopy density	Forest cover area (km^2)	
			Himachal Pradesh	Hamirpur
1	Very dense forest (VDF)	> 70%	3,224	39
2	Moderate dense forest (MDF)	40 - 70%	6,381	86
3	Open forest (OF)	10- 40%	5,074	188
4	Scrub	< 10%	300	2

2.2 Pine needles

Pine needles (*Pinus roxburghii*) were collected from conifer forest situated in the western Himalayan region were chosen for experimentation. Pine needles were collected from four different types of pinewoods, as mentioned in Table 1. These needles were dried in the box type solar cooker for 7-8 hours at 60-80 °C and were kept in an airtight poly bag before experimentations. The solar drying removed 40% of the initial moisture content. Table 2 shows some measurements of the dimensions of freshly litter dried pine needles. The Pulverizer mill helps to convert dried pine needle samples into fine powder for ultimate analysis and proximate analysis, as shown in Table 2. The table also shows the energy characteristics of pine needles and indicates their suitability as feedstock for thermochemical conversion in a specially designed fluidized bed (Sharma and Sharma, 2018).

Table 2. Pine needle properties as an energy feedstock

Properties	Values
Bulk density (kg/m^3)	92.11-112.00
Net calorific value (MJ/kg)	18.64
Lignocellulosic analysis (%)	Alcohol benzene extractive = 6.23 Holo cellulose content = 53.46 Lignin = 37.50
Proximate analysis (%)	Volatile matter = 75.75 Fixed carbon = 16.67 Ash content = 3.45 Moisture = 3.83
Ultimate analysis (%)	Carbon (C) = 48.20 Hydrogen (H) = 6.10 Oxygen (O) = 38.30 Nitrogen (N) = Not detected (eligible) Sulphur (S) = 0.12

2.3 Study site description

The study site, located at the lower outer range of the Himalayas, extends between 31°25’-31°52’ north latitudes and 70°18’-70°44’ east longitudes. The study was conducted in the Hamirpur range forest of Himachal Pradesh, with a total geographical area of 1,118 km^2. The pine trees grow naturally in abundance in 9 out of 12 districts of the state, over the altitude varying from 350-2,500 m. Out of the total area, 19.58 % area is occupied by the conifer forest along with some broad-leaved trees (Gupta, 2013). The study area overall altitude varies from 400-1,100 m above mean sea level. The climate generally remains warm (average annual temperature 21.6 °C) with an average rainfall of 157.2 cm. The study area and sampling sites are shown in Figure 1 (Gupta, 2013).

The pine needle samples were collected from 20 different forest sites, located in the Hamirpur forest range. The structural standard variables such as above-ground pine needles, number of pine trees per km^2, pine tree height, and pine tree age were measured with non-destructive methods. From each selected site, pine needles samples were collected from a 1 × 1 m area in airtight polythene bags, after removing foreign particles, from March - June 2018. The selected sites of the conifer forest are according to the working plan reported by the work plan officer (WPO) of the forest division. The pine needles samples were weighed on an Electronic balance (CT-300, Contech Instruments Ltd., India) after drying in a domestic solar cooker for 7-8 hours to remove the interstitial moisture content. Allometric and statistical sampling technique is generally used to evaluate forest statics prior to available advance applications of remote sensing satellite technology.

2.4 Pine tree age and height estimation

A study was conducted to estimate the height-age of pine trees by measuring the diameter at breast height (DBH). The total of 209 observations of pine trees were taken, to figure out the approximate age and height of trees nearby each plot. The tree calliper (Long Jaw Vernier Caliper Series 534, Roorkee Survey House Sheikhpuri Roorkee, India) was used to measure DBH of pine trees. The collected data was statically analyzed through linear regression and correlations. The height and age of pine tree were estimated based on already developed equations (Sadiq et al., 2016; Gonzalez-Benecke et al., 2014):

$$\text{Age} = 1.1627 \times \text{DBH} - 2.7039 \quad (1)$$

$$\text{Height} = 0.1792 \times \text{DBH} + 8.8237 \quad (2)$$

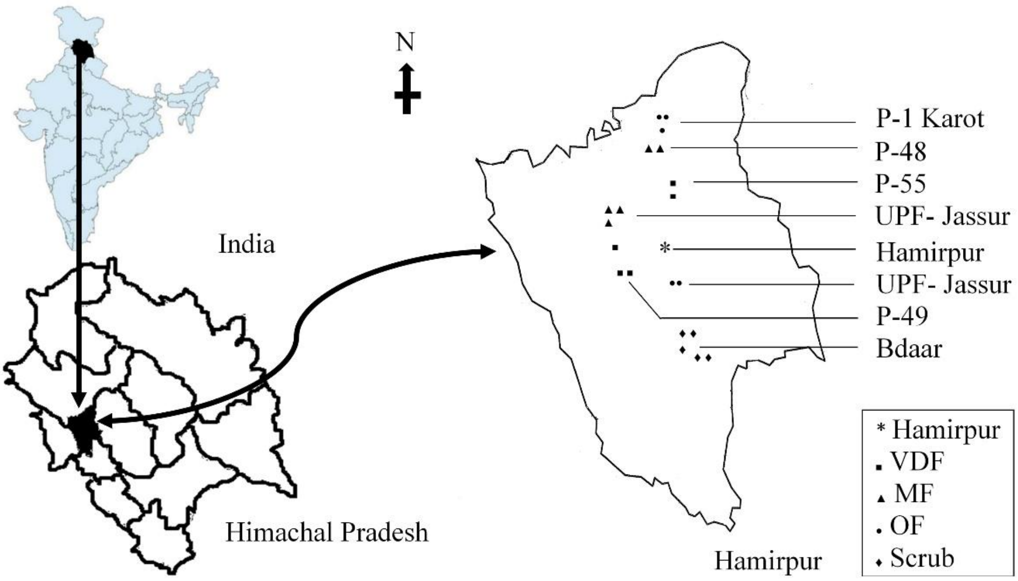

Figure 1. Pine needles collection sites surveyed in various forest range (Gupta, 2013)

2.5 Different approaches in the estimation of above ground pine needles data

2.5.1 Pine needle yield estimation per unit forest area

The pine needle litterfall generally occurs from March to the onset of the rain in July. This approach estimates the pine needle yield per square meter for different types of forest and is tabulated in Table 3. The approach is applied to the four different types of the forest canopy for potential estimation of annual pine needle yield. The collected pine needle samples varied from 2.00-2.93 kg/m^2/year for VDF, 1.12-2.20 kg/m^2/year for MDF, 0.94-1.60 kg/m^2/year for OF, and 0.18-1.10 kg/m^2/year for scrub.

Table 3. Litterfall data of pine needles in March, April, May, and June of the year 2018.

Plot number	Collection of pine needles from the forest (kg/m^2/year)			
	VDF	MDF	OF	Scrub
1	2.71	2.10	1.60	0.19
2	2.24	1.81	0.94	1.10
3	2.93	1.12	1.38	0.80
4	2.00	2.20	0.89	0.18
5	2.18	1.81	1.10	0.90
Average	2.41	1.81	1.22	0.62

The potential annual accessibility of pine needle yield along with VDF, MDF, OF, and scrub area was estimated with the average value of collected pine needles yield. Annual pine needle yield ($APNY_1$) can be estimated as (Kala and Subbarao, 2018),

$$APNY_1 = A_{VDF} \times PNY_{tree} + A_{MDF} \times PNY_{tree} + A_{OF} \times PNY_{tree} + A_{scrub} \times PNY_{tree} \quad (3)$$

Where, A_{VDF}, A_{MDF}, A_{OF}, and A_{scrub} indicate the area in km^2 under the VDF, MF, OF, and scrub, respectively, PNY_{tree} represents pine needle yield per tree.

2.5.2 Pine needle yield estimation as per canopy density based on the total number of pine tree per km^2

Canopy density characterized the percentage and helped to estimate the total number of pine tree per km^2. The forest is classified based on canopy density, as canopy density is greater for VDF as compared to MDF, OF, and Scrub. Estimating its yield per tree can predict the annual pine needle yield per km^2. Table 4 shows the pine needle yield collected from the conifer forest. The method used assumptions for calculating canopy density and the total number of trees in the known or selected area. All tree canopy densities were measured carefully for estimation. Tree canopy density of the conifer can be a help to calculate the tree density of the forest. The tree canopy density can be described as follows (Kala and Subbarao, 2018; Gill et al., 2000; Wu, 2012):

$$D_i = 2 \times (b_o + b_1 \times DBH) \quad (4)$$

$$\text{Canopy cover} = \left(\frac{\pi}{4} \times D_i^2\right) \quad (5)$$

Tree canopy density is the measurement of tree cover per unit area of the forest land and can be described as:

$$\text{Tree canopy density} = \sum_{i=0}^{n} \left(\frac{\pi}{4} \times \frac{D_i^2}{\text{Forest area}}\right) \quad (6)$$

Where, D_i is the diameter of the tree crown, b_o=1.1817±0.2627 and b_1=0.0265±0.0040 are the regression coefficient, and DBH is the diameter at the breast height.

Table 4. Estimation of pine needle yield per tree

Forest Canopy	Pine needle yield (kg/2,500 m^2/year)	Number of Pine tree per 2,500 m^2	Pine needle per tree (kg/year)
VDF	6,023	307	19.62
MDF	4,519	268	16.86
OF	2,949	202	14.6
Scrub	1,548	195	7.94

Further trees packing in the forest are acknowledged by the green covering. For VDF the trees are packed more closely as compared to MDF, OF, and scrub. Gill et al. (2000) mentioned the average minimum crown radius for conifer trees is 2.21 m. It might be taken note that the effective diameter is smaller than the actual diameter of the canopy of the tree crown. By using this method, the total number of pine trees per 50 m × 50 m is achieved as 307 trees for VDF, 268 for MDF, 202 for OF, and 195 for the scrub area (by neglecting damaged trees and other species).

With this approach the annual pine needle yield is calculated in the following manner (Kala and Subbarao, 2018):

$$APNY_2 = A_{VDF} \times PNY_{tree} \times N_{tree,VDF} + A_{MDF} \times PNY_{tree} \times N_{tree,MDF} + A_{OF} \times PNY_{tree} \times N_{tree,OF} + A_{scrub} \times PNY_{tree} \times N_{tree,scrub} \quad (7)$$

These two simple methodologies have been considered to predict pine needle potential for all types of conifer forest canopy (VDF, MDF, OF, and scrub). Equation 3 and Equation 7 help to find the expected annual pine needle yield value in the year 2018. The first approach provides the single point estimates and the second approach gives the data based on tree canopy density of all types of conifer forest.

2.6 The annual energy potential of pine needle yield

The calorific value and the net annual pine needle yield are taken into account for available annual primary energy (APE). Electric and thermal energy from pine needles is estimated. These are the primary form of energy. The energy estimation has been carried out by using the following equation (Nhuchhen and Salam, 2012):

$$HHV_{PA} = 19.2880 - 0.2135 \times \frac{\%VM}{\%FC} - 1.958 \times \frac{\%Ash}{\%VM} + 0.0234 \times \frac{\%FC}{\%Ash} \quad (8)$$

$$HHV_{UA} = 32.7934 + 0.0053 \times (\%C)^2 - 0.5321 \times \%C - 2.87 \times \%H + 0.0608 \times \%C \times \%H - 0.2401 \times N \quad (9)$$

$$LHV_{moist\ basis} = HHV_{PA/UA} - 24.44 \times (9 \times \%H + \%M) \quad (10)$$

$$LHV_{dry\ basis} = \frac{LHV_{moist\ basis} \times 100}{100 - \%H} \quad (11)$$

Where, NCV = Net calorific value (MJ/kg) wet basis, GCV = Gross calorific value (MJ/kg) dry basis, w = Water content of the fuel as % of weight, and h = Hydrogen concentration as % of weight.

The thermal energy potential of pine needles (Given et al., 1986):

$$Q = 328.4 \times \%C + 1422 \times \%H + 92.7 \times \%S - 138 \times \%O + 636 \quad (12)$$

Where, Q = heat combustion per unit weight kJ/kg.

3. RESULTS AND DISCUSSION

3.1 Pine tree age and height

The growth rate among individual trees in the four study areas varied with diameter. The estimated DBH of pine trees range from 56.97-117.65 cm. The present work found that there was a strong relationship between diameter and age of the tree; the diameter has a direct proportion to the age of the pine tree.

From Equation 1, the age of the VDF, MDF, OF, and scrub has been calculated as 134.09 (±10.33) years, 97.7 (±6.50) years, 81.52 (±6.67) years, and 63.53 (±7.99) years respectively. The average age of pine trees lies between 30 years to 47 years for VDF, 30 years to 45 years for MF, 25 years to 35 years for OF, and 20 years to 33 years for a scrub as shown in Figure 2. A similar study revealed that growth rates changing among individual trees at study sites (Shackleton, 2002). In the comparison of the present study, it was found that the tree diameter and tree age relation have significant correlation.

The study also reported that the height of the pine trees varied from 7.9-10.6 m. The results found that the maximum height was 12.6 m with a 133.5 cm diameter and the minimum height was 7.6 m with a 56 cm diameter. The average height of all conifer forest trees was 9.6 (±1.59) m, 8.9 (±1.00) m, 8.9 (±1.02) m, and 8.9 (±1.23) m for VDF, MF, OF, and scrub, respectively as shown in Figure 2. In all types of forest canopy, the height and age increased with an increase in diameter. There is a strong direct relationship between diameter, age, and height. The pine tree environmental conditions have a significant role in regulating forest growth. A similar study by Ferguson and Carlson (2010) reported that the estimation of height and age relation was adopted to predict ages for the future. It has been concluded from the present study that forest growing stock parameters have a significant role in balancing forest growth. Thus, diameter increment has a substantial relationship with the height and age of the conifer forest and it directly affected the estimates of production in a forest area when statistically analysed (Khan et al., 2016).

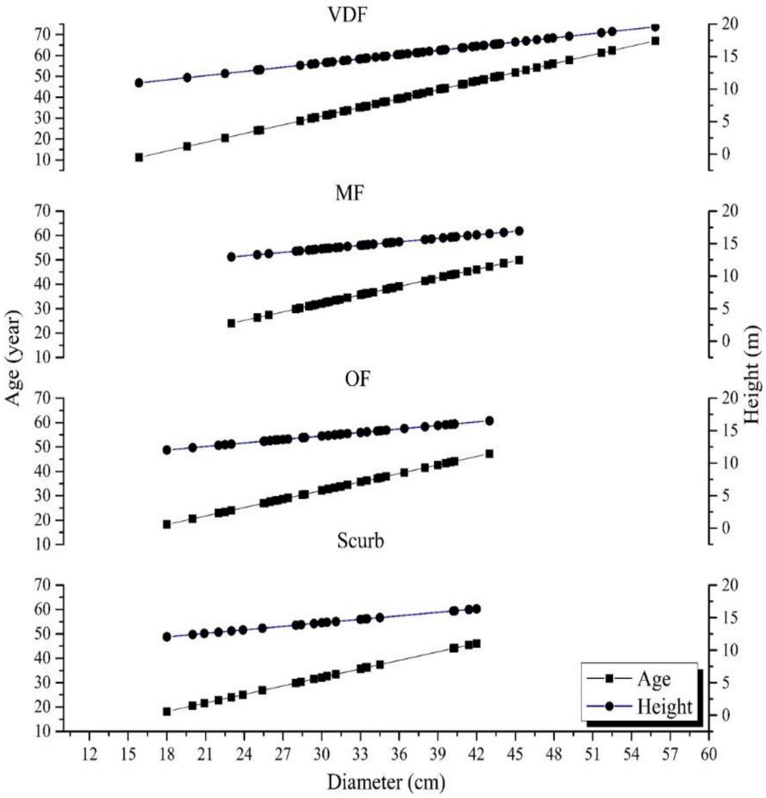

Figure 2. Relationship between the diameter, tree age, and height.

3.2 Pine needle litterfall data

The samples were collected four times at the end of each month from March - June 2018 from 20 randomly selected plots of 1 × 1 m for VDF, MF, OF, and scrub. The litterfall was lower for plot 4 in March to June as compared to all other forest canopy densities. From Figure 3, it reveals that all the forest canopies followed the same trend in terms of litterfall of pine needles in all fall-out months. The variation in the litterfall data of pine needles was due to some environmental factors like temperature, light intensity, location etc. (Lal et al., 2013). The litterfall of pine needles has shown enormous potential in VDF as compared to MF, OF, and scrub. From Figure 4, the litterfall in March showed lower potential, which tends to increase in April and May then decrease in June although this value for MF in May showed significantly different results. The maximum and minimum litterfall recorded was 1.45 kg in May of VDF (plot 3) and 0.02 kg in March of scrub (plot 4). The total observation period of litterfall was four months which is applicable for the year. The mean annual standard-litterfall rate of VDF, MF, OF, and scrub was estimated to be 3.41, 2.40, 1.22, and 0.14 (dry weight kg/m^2/year) respectively. The mainly seasonal trend for litterfall was followed in which needle fall was more significant during May. Some other environmental conditions also affect litterfall rates (Rawat et al., 2011). The proportion of each set of pine needle litterfall data is shown in Figure 4. The pine needles have the massive potential in VDF plots as compared with the MF, OF, and scrub plots in all fall-out months. The litterfall data has shown a significant variation ranging from 0.02 kg from the scrub in March (plot 4) to 1.45 kg from VDF in May (plot 3).

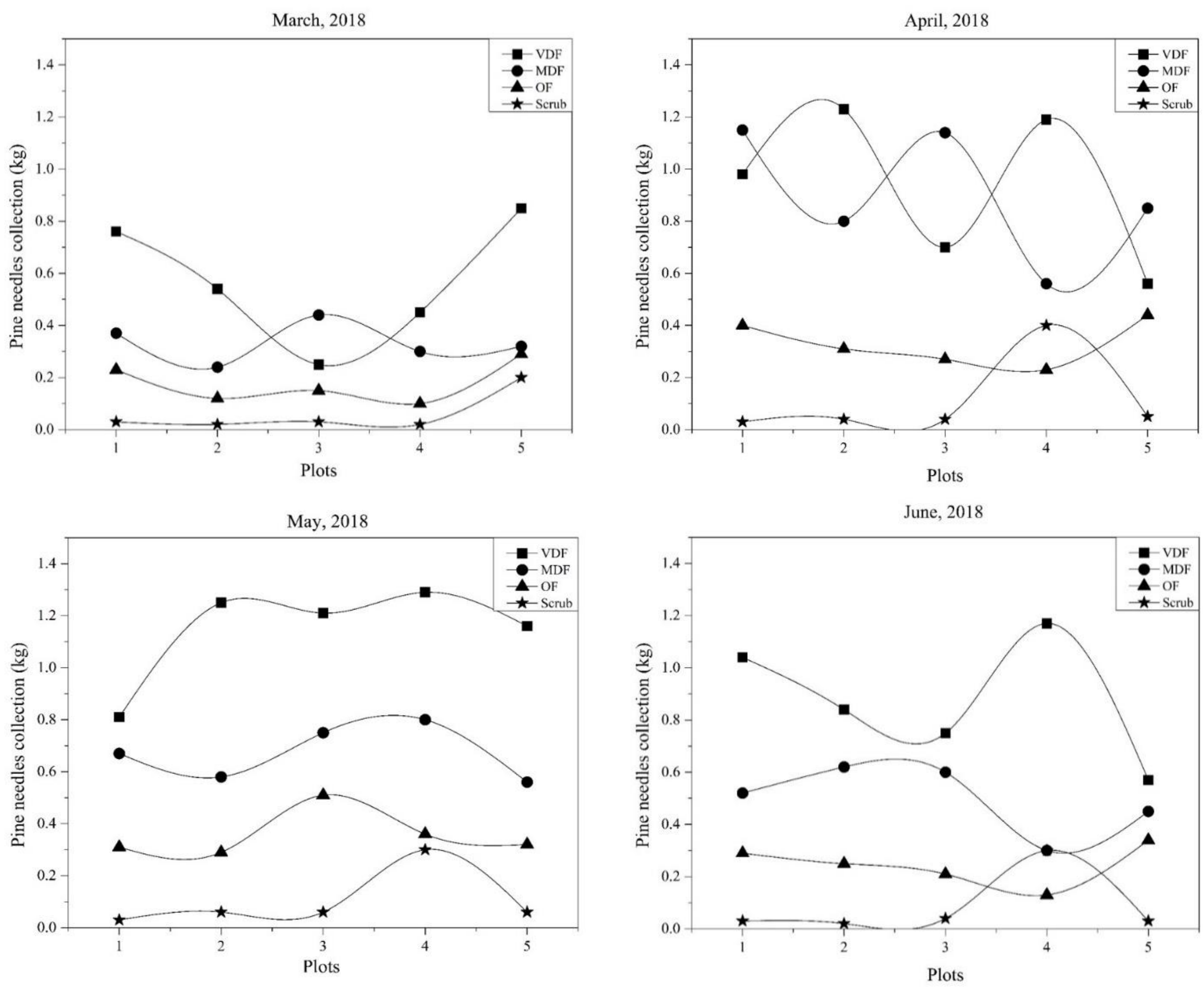

Figure 3. Litterfall data of pine needles in the month of March, April, May, and June 2018

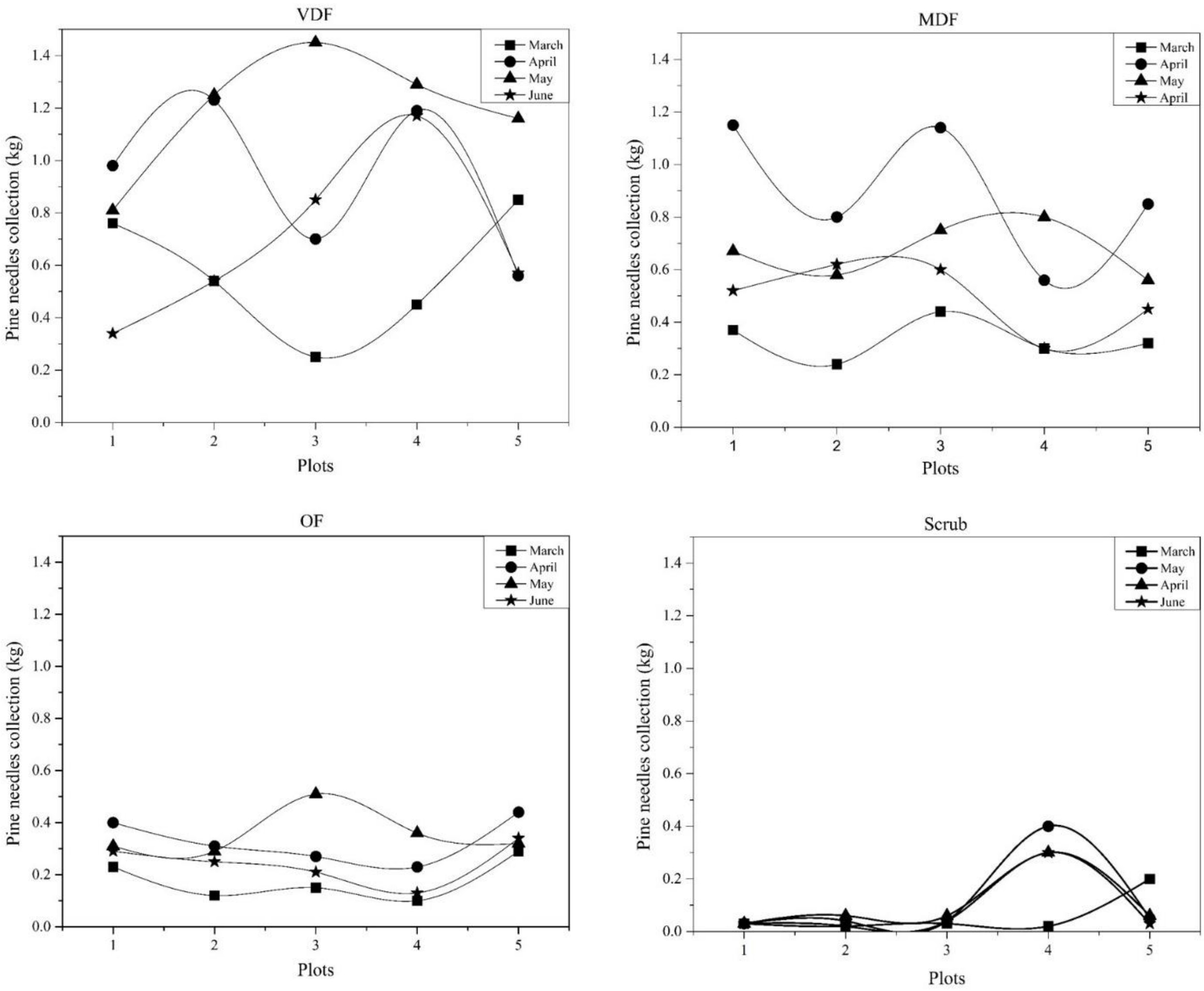

Figure 4. Litterfall data of pine needles according to forest canopy (VDF, MF, OF, and scrub).

3.3 Above ground pine needle estimation

3.3.1. Determine above ground pine needle

The estimation of gross pine needles yield has been carried out with two approaches based on the pine needle samples collection. The total annual above ground litterfall of pine needles collection can also be affected by almost 30 % due to poor accessibility, some domestic usage, rains, forest fires, various other losses, etc. (Kala and Subbarao, 2018; Gupta, 2013; Runyan et al., 2015). Table 5 presents a summary of the pine needle yield within the state.

The two different approaches for estimation of gross annual pine needle availability in the state are given in Table 5 and Table 6. The estimated results of gross annual pine needle yield is 25.5 million tonnes and net pine needle yield is 17.85 million tonnes with a single-point estimation approach (Table 5). The annual gross and net pine needle is 22.3 million tonnes and 15.61 million tonnes respectively when calculated using the tree-canopy density approach (Table 6). The most probable values of gross annual pine needle yield, 25.5 million tonnes and 22.3 million tonnes using the Approach I and Approach II, respectively. Thus Approach I shows the high value of the pine needles potential in the state. Kala and Subbarao (2018) revealed similar results by using the Approach I for Uttrahhund. Equation 8-11 help to calculate the APE, thermal energy and annual electrical energy as shown in Table 7 (Kala and Subbarao, 2018; Klass, 2004; Mckendry, 2002). The annual primary energy from dried pine needle yield is 0.44-0.50 pJ, which would provide 37.22-42.77 million kWh annual energy back up in the state.

Table 5. Gross pine needle yield estimation

Number	Parameters	Value
1	Area $_{VDF}$ (km^2)	3,224
2	Area $_{MF}$ (km^2)	6,381
3	Area $_{OF}$ (km^2)	5,074
4	Area $_{scrub}$ (km^2)	300
5	Pine needle collected from VDF (kg/2,500 m^2)	6,023
6	Pine needle collected from MF (kg/2,500 m^2)	4,519
7	Pine needle collected from OF (kg/2,500 m^2)	2,949
8	Pine needle collected from scrub (kg/2,500 m^2)	1,548
9	Gross pine needle yield per year (million tonne)	25.50
10	Net pine needle yield per year (million tonne)	17.85

Table 6. Estimated annual pine needle evaluated through the number of the pine trees

Number	Parameters	Value
1	Number of pine trees, $N_{tree\ VDF}$ (Tree/2,500 m^2)	307
2	Number of pine trees, $N_{tree\ MF}$ (Tree/2,500 m^2)	268
3	Number of pine trees, $N_{tree\ OF}$ (Tree/2,500 m^2)	202
4	Number of pine trees, $N_{tree\ scrub}$ (Tree/2,500 m^2)	195
5	Pine needle yield per tree, PNY_{tree} (kg/tree)	14.75
6	Gross pine needle yield per year (million tonnes)	22.30
7	Net pine needle yield per year (million tonnes)	15.61

Table 7. Annual pine needle energy potential.

Number	Approach	Annual thermal energy (pJ)	Annual Primary Energy (APE)		Annual electrical energy	
			pJ	Ktoe	pJ	million kWh
1	Approach I	0.506	0.77	18.39	0.154	42.77
2	Approach II	0.443	0.67	16.12	0.134	37.22

By neglecting the scrub forest densities, Figure 5 shows the district-wise distribution of pine needles in Himachal Pradesh. In this distribution, Chamba and Kangra have huge pine needle potential in VDF and MF, respectively. Shimla and Kullu has an old forest with very old-age trees and therefore has a little difference between the pine needle potential of VDF and MF within the district. Bilaspur, Hamirpur, and Lahul-Spiti have little pine needle contribution among all regions.

Pine needles estimation by using two approaches are considered to better account for biofuels in the subtropical pine forest of western Himalayan territories. From the results, the gross annual pine needles yield (APNY) as an energy feedstock in western Himalayan was concluded. The minimum and maximum values of the estimated gross yearly pine needle yield are 59.02-67.99 million tonnes. The annual pine needle yield as an energy feedstock ranges between 41.31-47.59 million tonnes. This work has achieved ranges of values for both the gross and net annual pine needle yield availability in the western Himalayan regions. The APE has a minimum value of 1.76 pJ and a maximum value of 2.03 pJ obtained from the thermochemical conversion processes. It amounts to 42.05-48.48 ktoe in term of tonnes of oil. The annual thermal energy ranges from 1.16-1.34 pJ. The annual electrical energy available has a minimum value of 0.09 billion tonnes and the maximum value of 0.1 billion kWh. This is a considerable amount of electricity left after technical and commercial losses.

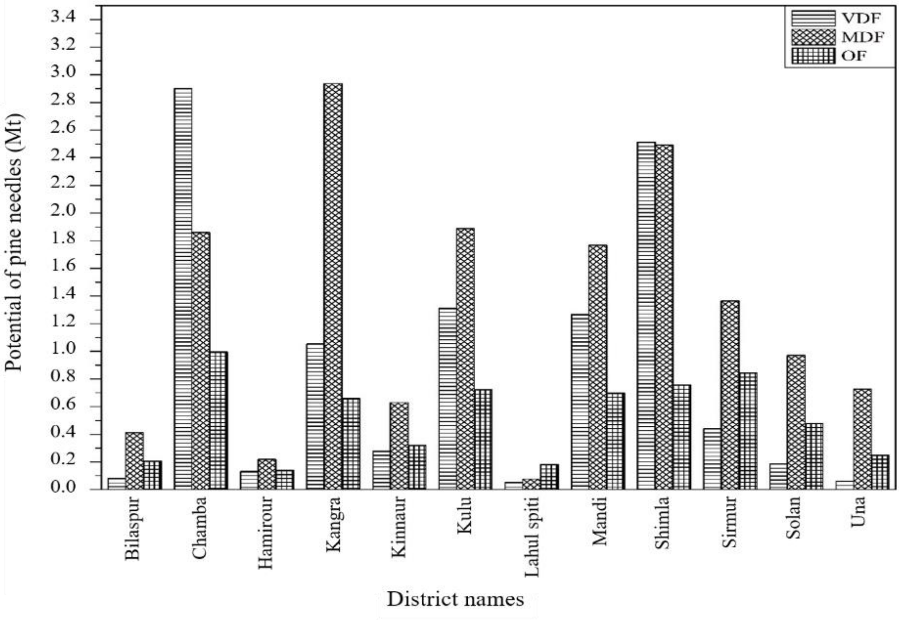

Figure 5. District-wise distribution of pine needles in the state.

4. CONCLUSION

Himalayan territories generate a tremendous amount of conifer forest waste, in terms of pine needles, that lounge on the forest floor every year for a more extended period. Some conclusions on the annual estimation of pine needle in the western Himalayan region have been discussed in the present study. The gross annual pine needle yield attained in this study using two different approaches has a minimum value of 59.02 million tonnes and a maximum value of 67.99 million tonnes. The annual pine needles yield use as an energy feedstock has also been estimated by reducing the yield by 30% due to various type of difficulties and issues in its availability. The estimations as energy feedstock of pine needles varies from 41.31 million tonnes to 47.59 million tonnes with the mean value of 44.45 million tonnes. The estimated annual primary energy 1.91 pJ as a most feasible value. Further, the estimation of annual thermal energy ranged from 1.76-2.03 pJ. It offers yearly electrical power back up of 0.09-0.10 billion kWh. This energy will be further supporting the regional commercial grid sector of Himalayan territories in the future.

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