ENERGY POTENTIAL OF AGRICULTURAL BIOMASS IN PUNJAB

Thesis

Submitted to the Punjab Agricultural University
in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE
in
AGRICULTURAL ECONOMICS
(Minor subject: Statistics)

By

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CERTIFICATE-I

This is to certify that the thesis entitled, **"Energy potential of agricultural biomass in Punjab"** submitted for the degree of **Master of Science**, in the subject of **Agricultural Economics** (Minor subject: **Statistics**) of Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Rajinder Kaur (L-2017-BS-230-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE-II

This is to certify that the thesis entitled, **"Energy potential of agricultural biomass in Punjab"** submitted by **Rajinder Kaur (L-2017-BS-230-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Agricultural Economics (Minor subject: Statistics**) has been approved by the Student's Advisory Committee along with Head of the Department and External Examiner after an oral examination on the same.

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ABSTRACT

The secondary data based study entitled "Energy Potential of Agricultural Biomass in Punjab" was envisioned to assess the availability of agricultural biomass in Punjab and to estimate the energy potential thereof. The district-wise analysis for all the major and minor crops has been carried out for the triennium ending (TE) 2017-18, except for cotton, wherein the average corresponds to two years i.e. 2016-17 and 2017-18 to omit the influence of the abnormal year 2015-16 with a substantial crop loss due to whitefly attack. The data on the requisite variables have been culled from various web and published sources and verified from certain research papers, wherever deemed necessary. The annual agricultural biomass potential from all the major and minor crops in the state has been estimated at 56.4 million t in TE 2017-18, the on-farm, and the processing level biomass being in the ratio of 83.6:16.4. It comprised 54.8 per cent of wheat, 38.0 per cent of paddy, 4.5 per cent of cotton, and 1.8 per cent of maize residue. The quantity of surplus biomass available for power generation has been estimated at 27.4 million t, out of which 22.9 million t (83.5%) is the quantity rendered surplus out of the field-based residue generated. The crop-wise analysis of biomass surplus highlighted the prominence of paddy with a contribution in total available biomass recorded at 63.1 per cent followed by wheat (28.2%), cotton (5.1%), and maize (2.8%), together accounting for 99.2 per cent of the biomass availability. The study of district wise spread of annual availability of biomass recorded at 27.4 million t at the state level highlighted that district Sangrur was at the top with a share of 9.6 per cent followed by Ludhiana (8.3%), Bathinda (7.4%), Patiala (6.8%) and Sri Muktsar Sahib (5.8%) collectively accounting for 37.9 per cent. A total of five districts namely, Fatehgarh Sahib, S.B.S. Nagar, Rupnagar, S.A.S. Nagar and Pathankot at the bottom ebb of the contribution scale together contributed 8.7 per cent. It was estimated that 22.9 million t of on-farm biomass available in Punjab had the energy potential of 358 PJ, out of which as high as 92 per cent is accounted for by paddy and wheat alone. Of all the districts, Sangrur had the maximum energy potential (34.8PJ) accounting for 9.7 per cent of the state total, followed by Ludhiana (8.5%), Patiala (6.9%), Bathinda (6.6%) and Moga (5.8%) together contributing 38 per cent to the energy potential of the state. The district-wise energy potential per unit of cropped area ranged from 36.9 GJ/ha in the case of district Pathankot to as high as 60.1 GJ/ha in Sangrur, with the state average recorded at 50.5 GJ/ha. The present study conclusively establishes the immense potential of Punjab agriculture in terms of conversion of agricultural biomass to energy. However, the effective use of this potential calls for a reorientation of the policy priorities to make use of this potential judiciously.

Keywords: Agricultural biomass, Energy, Crop residues, Potential, Punjab

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Signature of the Major Advisor **Signature of the Student**

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ਸੈਕੰਡਰੀ ਅੰਕੜੇ ਅਧਾਰਤ ਅਧਿਐਨ "ਪੰਜਾਬ ਵਿੱਚ ਖੇਤੀਬਾੜੀ ਬਾਇਓਮਾਸ ਤੋਂ ਊਰਜਾ ਦੀ ਯੋਗਤਾ" ਸਿਰਲੇਖ ਹੇਠ ਪੰਜਾਬ ਵਿੱਚ ਖੇਤੀ ਅਧਾਰਿਤ ਬਾਇਓਮਾਸ ਦੀ ਉਪਲਬਧਤਾ ਅਤੇ ਇਸ ਤੋਂ ਊਰਜਾ ਦੀ ਯੋਗਤਾ ਦਾ ਮੁਲਾਂਕਣ ਕੀਤਾ ਗਿਆ ਹੈ। ਸਾਰੀਆਂ ਪ੍ਰਮੁੱਖ ਅਤੇ ਅਪ੍ਰਮੁੱਖ ਫ਼ਸਲਾਂ ਲਈ ਜ਼ਿਲ੍ਹਾ ਪੱਧਰ ਦਾ ਵਿਸ਼ਲੇਸ਼ਣ ਟ੍ਰਾਈਨੇਨੀਅਮ ਐਂਡਿੰਗ (ਟੀ.ਈ.) 2017-18 ਲਈ ਕੀਤਾ ਗਿਆ ਹੈ। ਜਦਕਿ ਕਪਾਹ ਦੀ ਫ਼ਸਲ ਦਾ ਮੁਲਾਂਕਣ, 2015-16 ਵਿੱਚ ਚਿੱਟੀ ਮੱਖੀ ਕਾਰਨ ਹੋਏ ਫ਼ਸਲੀ ਨੁਕਸਾਨ ਨੂੰ ਛੱਡ ਕੇ ਸਿਰਫ ਦੋ ਸਾਲਾ 2016-17 ਅਤੇ 2017-18 ਦੀ ਔਸਤ ਤੋਂ ਕੀਤਾ ਗਿਆ ਹੈ। ਲੋੜੀਂਦੇ ਵੇਰੀਏਬਲਜ਼ ਦੇ ਅੰਕੜਿਆਂ ਨੂੰ ਵੱਖੋ-ਵੱਖਰੇ ਵੈੱਬ ਅਤੇ ਪ੍ਰਕਾਸ਼ਤ ਸਰੋਤਾਂ ਤੋਂ ਲਿਆ ਗਿਆ ਅਤੇ ਲੋੜ ਅਨੁਸਾਰ ਅੰਕੜਿਆਂ ਦੀ ਤਸਦੀਕ ਖੋਜ ਪੱਤਰਾਂ ਤੋਂ ਕੀਤੀ ਗਈ ਹੈ। ਰਾਜ ਦੀਆਂ ਸਾਰੀਆਂ ਪ੍ਰਮੁੱਖ ਅਤੇ ਅਪ੍ਰਮੁੱਖ ਫ਼ਸਲਾਂ ਤੋਂ ਸਲਾਨਾ ਖੇਤੀਬਾੜੀ ਬਾਇਓਮਾਸ ਦੀ ਸੰਭਾਵਨਾ ਦਾ ਅਨੁਮਾਨ 56.4 ਮਿਲੀਅਨ ਟਨ ਲਗਾਇਆ ਗਿਆ ਹੈ। ਟੀ.ਈ. 2017-18 ਵਿੱਚ ਖੇਤੀਬਾੜੀ ਪੱਧਰ ਅਤੇ ਪ੍ਰੋਸੈਸਿੰਗ ਪੱਧਰ ਬਾਇਓਮਾਸ ਦਾ ਅਨੁਪਾਤ 83.6:16.4 ਪਾਇਆ ਗਿਆ ਹੈ। ਇਸ ਵਿੱਚ ਕਣਕ ਦਾ 54.8 ਪ੍ਰਤੀਸ਼ਤ, ਝੋਨੇ ਦਾ 38 ਪ੍ਰਤੀਸ਼ਤ, ਕਪਾਹ ਦਾ 4.5 ਪ੍ਰਤੀਸ਼ਤ ਅਤੇ ਮੱਕੀ ਦਾ 1.8 ਪ੍ਰਤੀਸ਼ਤ ਬਾਇਓਮਾਸ ਸ਼ਾਮਲ ਹੈ। ਬਿਜਲੀ ਉਤਪਾਦਨ ਲਈ ਉਪਲੱਬਧ ਸਰਪਲੱਸ ਬਾਇਓਮਾਸ ਦੀ ਮਾਤਰਾ 27.4 ਮਿਲੀਅਨ ਟਨ ਅਨੁਮਾਨਤ ਕੀਤੀ ਗਈ। ਜਿਸ ਵਿੱਚ 22.9 ਮਿਲੀਅਨ ਟਨ (83.5%) ਖੇਤ ਅਧਾਰਤ ਬਾਇਓਮਾਸ ਤੋਂ ਬਣਿਆ ਹੈ। ਬਾਇਓਮਾਸ ਸਰਪਲਸ ਦੇ ਫ਼ਸਲੀ ਪੱਧਰ ਵਿਸ਼ਲੇਸ਼ਣ ਨੇ ਝੋਨੇ ਦੀ ਪ੍ਰਮੁੱਖਤਾ (63.1%) ਨੂੰ ਦਰਸਾਇਆ ਹੈ, ਇਸ ਦੇ ਨਾਲ-ਨਾਲ ਕਣਕ (28.2%), ਕਪਾਹ (5.1%) ਅਤੇ ਮੱਕੀ (2.8%) ਮਿਲਕੇ ਰਾਜ ਦਾ 99.2 ਪ੍ਰਤੀਸ਼ਤ ਸਰਪਲੱਸ ਬਾਇਓਮਾਸ ਬਣਾਉਂਦੇ ਹਨ। ਜ਼ਿਲ੍ਹਾ ਪੱਧਰ ਤੇ ਬਾਇਓਮਾਸ ਅਧਿਐਨ ਨੇ ਦਰਸਾਇਆ ਹੈ ਕਿ ਜ਼ਿਲ੍ਹਾ ਸੰਗਰੂਰ 9.6 ਪ੍ਰਤੀਸ਼ਤ ਦੇ ਹਿੱਸੇ ਨਾਲ ਪਹਿਲੇ ਨੰਬਰ ਤੇ ਹੈ, ਇਸ ਤੋਂ ਬਾਅਦ ਲੁਧਿਆਣਾ (8.3%), ਬਠਿੰਡਾ (7.4%), ਪਟਿਆਲਾ (6.8%) ਅਤੇ ਸ੍ਰੀ ਮੁਕਤਸਰ ਸਾਹਿਬ (5.8%) ਜੋ ਕਿ ਮਿਲਕੇ ਰਾਜ ਦਾ 37.9 ਪ੍ਰਤੀਸ਼ਤ ਯੋਗਦਾਨ ਪਾਉਂਦੇ ਹਨ। ਜਦਕਿ ਪੰਜ ਜ਼ਿਲ੍ਹੇ ਫਤਿਹਗੜ੍ਹ ਸਾਹਿਬ, ਐੱਸ.ਬੀ.ਐੱਸ. ਨਗਰ, ਰੂਪਨਗਰ, ਐੱਸ.ਏ.ਐੱਸ. ਨਗਰ ਅਤੇ ਪਠਾਨਕੋਟ ਮਿਲਕੇ ਸਭ ਤੋਂ ਘੱਟ, ਰਾਜ ਵਿੱਚ ਕੇਵਲ 8.7 ਪ੍ਰਤੀਸ਼ਤ ਯੋਗਦਾਨ ਪਾਉਂਦੇ ਹਨ। ਇਹ ਅਨੁਮਾਨ ਲਗਾਇਆ ਗਿਆ ਹੈ ਕਿ ਪੰਜਾਬ ਵਿੱਚ ਉਪਲਬਧ 22.9 ਮਿਲੀਅਨ ਟਨ ਖੇਤੀ ਅਧਾਰਿਤ ਬਾਇਓਮਾਸ ਵਿੱਚ ਊਰਜਾ ਪੈਦਾ ਕਰਨ ਦੀ ਯੋਗਤਾ 358 ਪੈਟਾਜੂਲ ਹੈ। ਜਿਸ ਵਿੱਚੋਂ 92 ਪ੍ਰਤੀਸ਼ਤ ਸਿਰਫ ਝੋਨੇ ਅਤੇ ਕਣਕ ਦੇ ਯੋਗਦਾਨ ਤੋਂ ਬਣਦਾ ਹੈ। ਸਾਰੇ ਜ਼ਿਲ੍ਹਿਆਂ ਵਿੱਚ ਸੰਗਰੂਰ ਵਿੱਚ ਬਾਇਓਮਾਸ ਤੋਂ ਊਰਜਾ ਪੈਦਾ ਕਰਨ ਦੀ ਯੋਗਤਾ ਸਭ ਤੋਂ ਵੱਧ ਪਾਈ ਗਈ (34.8 ਪੈਟਾਜੂਲ) ਜੋ ਕਿ ਰਾਜ ਦਾ 9.7% ਹੈ, ਇਸ ਤੋਂ ਬਾਅਦ ਲੁਧਿਆਣਾ (8.5%), ਪਟਿਆਲਾ (6.9%), ਬਠਿੰਡਾ (6.6%) ਅਤੇ ਮੋਗਾ (5.8%) ਮਿਲਕੇ ਰਾਜ ਦਾ 38 ਪ੍ਰਤੀਸ਼ਤ ਬਾਇਓਮਾਸ ਊਰਜਾ ਵਿੱਚ ਯੋਗਦਾਨ ਪਾਉਂਦੇ ਹਨ। ਜ਼ਿਲ੍ਹਾ ਪੱਧਰ ਦੇ ਅਧਿਐਨ ਨੇ ਦਰਸਾਇਆ ਹੈ ਕਿ ਰਾਜ ਵਿੱਚ ਪ੍ਰਤੀ ਇਕਾਈ ਖੇਤੀਬਾੜੀ ਬਾਇਓਮਾਸ ਤੋਂ ਸਭ ਤੋਂ ਘੱਟ ਪਠਾਨਕੋਟ 36.9 ਗੀਗਾਜ਼ਾਊਲ/ਹੈਕ ਤੋਂ ਸਭ ਤੋਂ ਵੱਧ ਸੰਗਰੂਰ 60.1 ਗੀਗਾਜ਼ਾਊਲ/ ਹੈਕ ਦੇ ਦਰਮਿਆਨ ਸਮਰੱਥਾ ਰੱਖਦਾ ਹੈ। ਜਿਸ ਨਾਲ ਰਾਜ ਦੀ ਔਸਤਨ ਊਰਜਾ ਯੋਗਤਾ 50.5 ਗੀਗਾਜ਼ਾਊਲ/ਹੈਕ ਪਾਈ ਗਈ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਨੇ ਦਰਸਾਇਆ ਹੈ ਕਿ ਪੰਜਾਬ ਵਿੱਚ ਖੇਤੀਬਾੜੀ ਬਾਇਓਮਾਸ ਤੋਂ ਊਰਜਾ ਪੈਦਾ ਕਰਨ ਦੀ ਅਥਾਹ ਸੰਭਾਵਨਾ ਹੈ, ਹਾਲਾਂਕਿ ਨਵੀਆਂ ਅਤੇ ਪ੍ਰਭਾਵਸ਼ਾਲੀ ਨੀਤੀਆਂ ਦੀ ਵਰਤੋਂ ਨਾਲ ਇਹਨਾਂ ਸਰੋਤਾਂ ਦੀ ਸੁਚੱਜੇ ਢੰਗ ਨਾਲ ਵਰਤੋਂ ਕਰਕੇ ਰਾਜ ਦੇ ਊਰਜਾ ਉਤਪਾਦਨ ਨੂੰ ਵਧਾਇਆ ਜਾ ਸਕਦਾ ਹੈ ।

ਮੁੱਖ ਸ਼ਬਦ: ਖੇਤੀਬਾੜੀ ਬਾਇਓਮਾਸ, ਊਰਜਾ, ਫ਼ਸਲੀ ਰਹਿੰਦ-ਖੂੰਹਦ, ਯੋਗਤਾ, ਪੰਜਾਬ ।

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ | **ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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CHAPTER - I

INTRODUCTION

Energy remains crucial for the fulfillment of India's ambitious plans for its ever-expanding economy, to provide electricity in every nook and corner of the country, to fuel the demand for increased mobility needs and to meet the infrastructure needs of the world's most populous country in the making. India is confronted with a serious challenge crisis with an ever-widening gulf between the energy supply and its demand. India faces a host of multi-faceted energy challenges (Ravindranath *et al* 2005). These are exacerbated by growing demand for energy fuelled by modern-day living, the present-day fossil fuel based energy system beset with a serious resource crunch, the imperative need for providing energy to the energy-deprived segment of the population, mounting pressures for ensuring energy security and the considerations for saving the environment along with sustainable economic development.

Under the circumstances, renewable energy has been deemed as one of the most potent alternatives. It is well documented that renewable energy resources can increase the energy supply on a sustainable basis. Apart from this, the economic advantage to the rural masses can't be overlooked (Goldemberg *et al* 1988). The environmental compulsions in their own right endorse the greater use of sustainable technologies. One of the major environmental threats entails health issues as well eventually leading to poor economic wellbeing. Agricultural biomass is a cleaner energy source in comparison to fossil fuels, which are notorious for polluting the atmosphere**.** Biomass, being a readily available carbon-neutral fuel for the power generation, stands to gain supremacy over the fossil fuels.

The serious concerns being raised world over on the use of fossil fuels, India must initiate the effective utilization of renewable energy sources in a big way. India ranks seventh in the world in terms of its geographical spread over 328 million hectares and fortunate enough to be endowed with renewable energy sources. Moreover, India is an agricultural economy characterized by varied agro-ecological regions and therefore agricultural residues are available in plenty. All the organic waste which is produced by crops, termed as agricultural residue, can be used to increase the availability of energy potential. Thus, the abundantly available agricultural waste can be transformed into high efficiency and eco-friendly fuels. The strength of locally available biomass resources can be utilized for the economic development of the region (Singh and Chauhan 2014). The efforts in this direction are underway.

In India, Uttar Pradesh has a remarkable distinction of producing the highest crop residue. Ten states namely Uttar Pradesh, Maharashtra, Punjab, Gujarat, Tamil Nadu, Haryana, Andhra Pradesh, Karnataka, Madhya Pradesh, and Rajasthan together account for 89 per cent of crop residue surplus in India. Among the crops, after rice sugarcane is the second highest surplus residue producing crops in India. Quite pronounced differentials in per capita bioenergy potential could be observed, with West Bengal at the lowest ebb having a potential of 679 MJ and Punjab at as high as 16840 MJ. Uttar Pradesh was the only state which could optimally utilize its biomass potential, which can well be attributed to the preponderance of Sugar Mills and the Co-generation Power Plants. The states of Haryana and Punjab were reportedly unfortunate to have installed capacity relatively lower than the potential (Hiloidhari *et al* 2014).

The crop residue generation in India has been portraying quite a large variability attributed primarily to the regional variations in cropping patterns, the intensity of cultivation, and productivity potential (Singh and Sidhu 2014). As much as a quarter of crop residue generated in India can be ascribed to the rice-wheat system alone. It has come to the fore that after making the allowance for domestic use of residue as animal feed, thatching, and domestic use, the substantial portion is burnt in the field itself. As per a study (Kaur 2017), the quantum of surplus crop residue in India has been pegged at somewhere between 84 and 141 million mt annually with cereal crops accounting for 58 per cent. As high as 44.5 million mt of rice straw and 24.5 million mt of wheat straw is burnt annually.

Endorsing the strategic role of biomass energy, the Union Government and some of the State Governments with huge biomass power potential have made all-out efforts to make policy prescriptions to propagate the use of the crop for power generation, but their efforts have more failures than successes. Despite concerted efforts, the power sector has not been able to optimally utilize the crop biomass potential. It is fraught with myriad challenges in transporting the agricultural biomass which is spatially scattered and bulky. The exorbitant biomass collection and transportation expenses are the chief deterrents in the effective working of Power Plants using crop biomass. The properly planned collection schedule and establishment of the biomass collection centers can go a long way in smoothening the supply to power plants.

Punjab has won accolades for its stupendous performance not only in the agriculture sector but has also made rapid strides in other sectors as well leading to a significant increase in the energy demand. The demand for power in the State has increased by leaps and bounds because of a spurt in the use of electrical power due to increasing mechanization of farm operations, growth in the number of industries, and improvement in the standard of living to name a few. Leaving apart all other sectors, the electricity consumption by the agriculture sector of Punjab alone increased from 1850 million kWh in 1980-81 to 12484 million kWh in 2016-17 (Annoymous, 2018). It can well be implied that over less than four decades, the electricity consumption in agriculture has increased by more than 6.7 times, which amounts to a point to point annual growth rate of 5.3 per cent. There are strong apprehensions that the current power supply may not be adequate to match the increasing demand.

It goes without saying that agricultural biomass has enormous potential for energy generation in Punjab, where paddy straw burning has been posing a serious threat to the environment. Prudent use of available crop biomass could go a long way in alleviating the environmental hazards of non-renewable energy sources particularly related to climate change. Punjab being an agricultural state, can count down on crop biomass resources, which can be put to more efficient use to provide sustainable energy base to the state. Against this backdrop, the present study was taken up to assess the agricultural biomass energy potential of the state, to pinpoint the potential areas of the state, from where biomass can be procured for power generation. The specific objectives of the study have been enlisted as

i. To ascertain the regional spread of agricultural biomass availability in Punjab
ii. To estimate the biomass energy potential of the state
iii. To make an inventory of viable and sustainable agricultural biomass management options

CHAPTER - II

REVIEW OF LITERATURE

The review of the literature available on a research question is a building block that ensures that the present study would be an addition to the body of existing knowledge and lends the perfect opportunity to bridge the gap left in the process of exploration of the study by the earlier researchers. Therefore, an attempt has been made to take cognizance of the work done in the past related to the present study. A few of the studies having a direct or indirect bearing on the research problem at hand have been outlined below in the chronological order under the following subheads:

2.1. Biomass Production and Related Issues

2.2. Energy Potential of Biomass

2.1. Biomass production and related issues

In a study conducted by Koopmans and Koppejan (1997) way back in 1997, it was highlighted that that very little information was available on the availability and end-use of residues. The reason behind it was marked variations amongst countries and within regions in a particular country. The methodology for the studies conducted was also different from one area to another hence leading to apprehensions about the usefulness of the studies in developing a database system for residue generation at the domestic level. Although many factors influence the database system but a customized system on a national level or better still on even a very small area may be put into place. The study affirmed that while conducting the study, one should not lose sight of the social aspects like residue usage and the interest of farmers who produce the by-products. It was considered pertinent to determine the effect of increased use of residue at the farm, as it helps conserve soil health and degradation. The study affirmed that applications like power generation will undoubtedly add value to the residues but at the same time may also lead to deprivation of cooking and heating fuel to the poorest section of the population.

Chahal and Kumar (2008) examined the status of crop biomass generation and its utilization in the agriculturally advanced state of Punjab. The authors observed that the sizeable proportion of biomass from paddy and wheat crops in Punjab is either burnt or at the best utilized for feeding the animals in Punjab. The estimated residue for 2007-08 stood at 238.47 lakh t for maize, 192.27 lakh t for cotton, 42.22 lakh t for sugarcane in Punjab. The crop residue, which was leftover post utilization, had been recorded at 519.29 lakh t in totality. The crops which generate substantial residue at the time of processing include maize, sugarcane, and paddy crops wherein the residue is in the form cobs, bagasse, and husk. As regards the residue generated per unit of crop area is concerned, it was recorded as 2.42, 10.21, and 0.78 t per hectare in case of paddy, sugarcane, and maize crop respectively. The quantum of processing/ off-farm residue was assessed as 75.58 lakh t. The total biomass generation, inclusive of on and off-farm, during the year 2007-08 in Punjab has been reported as 594.87 lakh t.

Das and Jash (2009) conducted their study in West Bengal, where crop and forest residues are abundant. Out of the total biomass residues to the tune of 37.35 million t per annum generated in the state, as high as 79 per cent are crop-based. The authors reported widespread differentials in the 19 districts of the state and identified eleven districts as biomass resource-rich districts. The state's net biomass resource can generate about 1197 MW of power, which can fulfill the needs of rural West Bengal. The authors have put forth suggestions to give priority to resource-rich districts for future planning.

The study conducted by Saud *et al* (2011) brought forth that biomass is widely used in the form of fuel in rural India. The study highlighted that in the Indo-Gangetic Plains (IGP) biomass fuel is the main source of energy for close to 90 per cent of the rural households. Dung cake is the major domestic fuel (80 to 90%) in rural Punjab, Uttar Pradesh, Haryana, Bihar, and West Bengal, whereas in Uttarakhand, nearly all the rural households (99% to be exact) were found to use wood as the main energy source. The estimated consumption of crop residue for fuel has been recorded at 21.13 million t.

Sasmal *et al* (2012) conducted their study in Kamrup district of Assam and pointed towards the potential candidature of areca nut husk, moj and bonbogori as a source of lignocellulosic biomass for the production of biofuel. This material has been found to stand at par with other conventional sources (sugarcane bagasse and corn) for biofuel production. The lack of knowledge about the indigenous tree and shrub species predominantly found in the forests of the North Eastern Region hampers the task of establishing biomass power plants.

Chauhan (2012) conducted a study to assess the biomass resources of Punjab for power generation. According to the study based on primary data, the annual crop residue generated from the entire range of crops grown stood at 40.142 million t, out of which 29 per cent can be potentially used for power generation as a high proportion (71%) is utilized for other purposes in many different forms. The district-wise analysis to assess the surplus crop biomass for power generation highlighted the worth of district Sangrur, Ferozpur, Amritsar, Patiala and Ludhiana as the potential districts for accessing the surplus biomass. The study quantified the power potential of basic surplus and net surplus biomass as around 1.510 GW and 1.464 GW of power respectively. The study, apart from assessing the season-wise biomass availability, studied the prevalent usage pattern, and cost return aspects of the crop residues in each district of Punjab. It was highlighted that the power generation potential of the agricultural biomass is enormous in Punjab state. The biomass types like cotton stalks, paddy straw, arhar stalks, maize cobs, sunflower stalks, sugarcane trash, sesamum stalks, and mustard stalks were found to contribute significantly to the power generation potential in the state.

Chahal and Chhabra (2014) in their study concluded that the total production of biomass during the year 2009-10 was 48.26 million t. It was estimated that 4852 MW of electricity can be produced by these power plants. The total waste of energy by the process of burning of wheat and paddy stubbles was ascertained as 142294 and 254013 million MJ respectively during the study year.

Natarajan *et al* (2015) carried out a study to ascertain the potential of biomass resources and their present usage in Maharashtra, Madhya Pradesh, and Tamil Nadu. The study highlighted that a major portion of biomass is used as animal feed for domestic livestock followed by the application of in-situ measures of biomass management, leaving a very meager quantity for other productive purposes. The use of biomass for cooking was found to be negligible owing to the easy access to the Liquefied Petroleum Gas (LPG) cylinders available in the study districts. The study strongly reiterated the critical importance of biomass as fodder in India thereby necessitating the use of non-fodder crops (e.g., soybean husks, cotton stalks, coconut fronds) for energy generation.

Channi (2015) carried out a study to assess the power generating potential of the Patiala district of Punjab from surplus agricultural biomass. The results of the study showed that this region has great potential for power generation. The study pointed towards the concentration of surplus biomass primarily in two villages, namely Nabha and Samana of the district. The stalks of paddy, cotton, mustard and sunflower, maize cobs, and sugarcane trash were the commonly found crop residues.

Cardoen *et al* (2015) concluded that India produced 611 Mt of agricultural field residues every year, out of which one fourth can be deemed as a potential surplus for bio-energy. The study emphasized focusing on yield enhancement of maize to increase to European levels, which would lead to a five times increase in the residue generation. Annually 150 Mt of organic processing by-products were generated, of which 61 Mt/year was the surplus available. About 47 Mt of chickpea, cotton, groundnut, maize, mustard, paddy, and pigeon pea residues were utilized annually as domestic fuel. The most abundant crop residues were reported sugarcane bagasse, paddy straw, wheat straw, and cotton stalks producing annually as much as 41, 28, 21 and 19 million tons respectively.

The study conducted by Kumar *et al* (2015) highlighted various aspects of residue generation, chemical compositions of the crop biomass, pollutants emitted by residue burning, and its likely effects on humans and animals and several crop stubble management options. It was estimated that the burning of paddy straw leads to heavy nutrient losses like 3.85 million tons of organic carbon, 59,000 tons of nitrogen, 20,000 tons of phosphorus, and 34,000 t of potassium. Straw burning results in the emission of smoke, which when mixed with gases present in the air can cause severe atmospheric pollution. These gaseous emissions can create lots of health problems, deplete ozone, and reduces soil health. The on-farm impact of burning included damage to soil fertility and important chemicals on the other hand off-farm impacts were related to health and environmental issues.

Pandey (2017) suggested that biomass resources can be used efficiently when densified using appropriate densification technology. Among all the available densification technologies, pellet making provides an additional advantage of high density, easy handling, transportation, and durability as compared to others. In India, the Briquette press was more common while agglomeration and roller presses were still under development/trial stages. Briquette press can utilize larger particle size with high moisture content, whereas Screw press was proficient in producing compact carbonized biomass. Densification technology was limited by some process variables like temperature, residence time, and application of pressure, which were optimized according to end product utilization and biomass variables (moisture and particle size).

The study conducted by Kaur (2017) to study the crop residue management in Punjab had been based on primary data collected from 495 farm households of different landholding categories from three agri-economic zones viz. sub– mountainous zone, central plain zone and southwestern zone of Punjab. It was reported that all the sampled farmers were against the burning of crop residue in principle, but the majority of them could not find any solution at the individual level and were seeking government assistance to dispose it off. About 29 per cent suggested utilizing it as animal feed and 14 per cent suggested grant of subsidy on machinery used for straw management, 4 per cent of the respondents endorsed its use in the cardboard industry.

The study conducted by Devi *et al* (2017) highlighted the great economic value of crop residues. The challenges of crop residue management tend to be region-specific because of varied socio-economic needs. However, a large amount was treated as waste despite widespread attention given to agricultural waste management. Burning of crop residue at the farm level has been fraught with many negative effects to the human, animal and soil health, biodiversity, micro, and macro-environment, etc. Although awareness was created by extension machinery put in place that gives alternative options for managing agricultural residue like gasification as a fuel for the boilers, briquettes conversion, *in-situ* composting, and straw mulching practices while using disc ploughs, disc harrows, rotavators, zero tillage, and happy seeders etc, but the effect is minimal. The prospect of crop residue utilization in non-conventional ways was reported as limited.

A study conducted by Hiloidhari *et al* (2019) reiterated the role of renewable energy resources to mitigate climate change. The study was carried out in Uttar Pradesh to empirically investigate this and reported that 29 out of 75 districts of the state have the potential of more than 100MW, with the potential of the state at large pegged at 7028MW per annum. The study established that biomass power has less impact on global surface temperature rise than that of coal and natural gas and replacing fossil fuels with biomass could be a wise decision for the future to save the environment.

Mohan and Kanaujia (2019) discussed the merits of green energy in their study and asserted that it is one of the most efficient ways to achieve sustainable development. Replacing green energy sources with fossil fuel resources can reduce the challenges posed by climate change, and can ensure energy security on a global scale. The researchers highlighted the mounting commercial growth of technologies using newer resources. Some of the well-established technologies referred to in the paper were bio-electricity and bio-ethanol, which have found acceptance world over. It was highlighted that the bio-refinery concept can manage to completely utilize the sugarcane biomass, which would make the sugarcane industry sustainable.

The study undertaken by Usmani (2020) aimed at the estimation of the biomass potential of India. The peculiarity of this study is that it focused on both agroforestry and energy crops grown specifically on marginal lands. The estimation of the potential had been carried out on two different scales; one is a calculation of energy in the available biomass and the other one is the computation of the quantity of biofuels which can be presumably produced therefrom and its likely contribution in achieving energy security in the transport sector. The study highlighted that marginal land area stands estimated at 38.5 million ha, 12 per cent of 328 million ha of land area India has. The biomass potential of three energy crops namely; Miscanthus, Switchgrass and Mix crops has been worked out as 770, 260, and 230 million t respectively.

2.2. Energy potential of biomass

McKendry (2001b) in his article suggested that biomass can be converted into energy by two primary technologies i.e., thermochemical and biochemical, depending upon the form of energy required. The liquid fuels (energy) can be produced by pyrolysis, fermentation, and mechanical trans-esterification whereas, another conversion process is the one producing energy in the form of hot air/ steam or gas. However, the production of liquid fuel from fermentation has not been found economical, only gasification (commercially available), pyrolysis, and anaerobic digestion were cost-effective fuel to be used in static spark ignition gas engines. Pyrolysis, more suitable for fuel oil production, is accepted as a fast-developing technology with immense potential. The anaerobic digestion can serve both purposes i.e., to produce gaseous energy and treatment of industrial generated organic waste.

Ravindranath *et al* (2005) in their paper discussed the potential of energy from agricultural residues, animal waste, municipal solid wastes, industrial wastewater, and biomass fuels that can be conserved for other applications through efficiency improvement. In India, the total potential of energy equivalent from these sources increased from 5.14 EJ (a little more than a third of the total fossil fuel use) in 1997 to about 8.26 EJ in 2010. The authors suggested the use of Industrial and municipal wastes such as wastewater, municipal solid wastes, and crop residues such as rice husk and bagasse for energy generation.

Singh *et al* (2008) examined the energy potential of the state of Punjab through biomass and highlighted that energy to the extent of 235.14 TJ can be produced annually. The study substantiated the reduction in unit collection cost with an increase in spatial density of biomass and marginal increase with the increase in the carrying capacity of the transport unit.

The study conducted by Sukumaran (2009) highlighted the importance of biomass-based energy generation as a potential contributor to India's energy security. It was reiterated that with the advancement in technology that is being readily made available locally in conjunction with financial incentives and policy measures, the investment in this sector will get accelerated.

A study conducted in the United States by Boundy *et al* (2010) highlighted that out of 73.1 quadrillion Btu energy produced in 2009, a little over one-twentieth was contributed by biomass. Biomass energy made up for 4.1 per cent of 94.7 quadrillion Btu of energy consumed. It was highlighted that the United States needs to import energy for its requirements. The study also brought forth the three-fold increase in the contribution of biofuels since 2005 which stands at nearly 40 per cent of entire biomass consumption in the United States.

Chauhan (2010) carried out a study in the Haryana state, which has the massive crop biomass available in the form of residue. The study was conducted primarily to assess the bioenergy generation in the form of power. Haryana had a total production of residue to the tune of 24.697 million t per year, out of which 71 per cent is used as various domestic and commercial uses. The total amount of biomass generation in the state was 45.51 per cent as biomass surplus, 37.48 per cent as productive surplus, and 34.10 per cent as net surplus. So, the potential for generating power from the surplus biomass in Haryana is significant. The concentrated amount of biomass husk and stalk are the major source of surplus biomass in the state.

Hiloidhari and Baruah (2011) investigated the decentralized electricity generation potential from surplus rice straw residue in the Lakhimpur district of Assam, India. GIS integrated methodology was employed to map the spatial availability of surplus rice straw residue and estimated that annually 51.5 thousand tons of rice straw was surplus in Lakhimpur district, which has a power potential of 5 MWe at a continuous generation with 20 per cent overall conversion efficiency. There were wide spatial variations in the availability in different development blocks and villages attributed primarily to the variations in the cropped area. Estimated power potential among the development blocks hovered between 294 kWe and 927 kWe.

Hiloidhari *et al* (2014) estimated the crop residue biomass and subsequently bioenergy potential of 39 residues from 26 crops for all the 28 states of India. Rice, sugarcane, wheat and cotton were found to be the major contributor to India's crop residue biomass pool. Overall, 34 per cent of gross agricultural biomass was available as surplus. This study also revealed that crop residue potential and hence bio-energy potential in all the eight Northeastern states was much lower than that in the rest of the country. Barring Assam, the potential was almost negligible in other northeastern states. Annually, India produces 686 MT gross agricultural residues out of which 234 MT (i.e., 34 per cent of gross agricultural residue) is considered for bioenergy generation.

Singh and Chauhan (2014) estimated the supply potential of agricultural biomass during the year 2012-13. A supply potential of the order of 41890 thousand metric tons was reported for crop biomass in the state of Punjab. Under the assumptions made by them, a total of 5667 MW of electric power can be generated, by using all the biomass resources available on annual basis. Rice straw has the potential to produce 1600MW of electricity, with 40MW capacity.

Kumar *et al* (2015) carried out an analysis of the resources and potential of biomass in India. The study reinforced the existence of huge biomass potential for conversion into energy. The diversity in the waste biomass sources e.g. agricultural waste, food wastes, industrial wastewaters points towards the possibility to switch over to non-conventional energy sources. At present two major technologies are being used to convert biomass into energy; thermo-chemical and bio-chemical. The selection of conversion technologies for biomass depends upon the form in which the energy is required like combustion produce heat, mechanical, electricity energy; pyrolysis, fermentation, and mechanical extraction produce liquid fuels suitable for use as transportation fuels, etc. Gasification processed biomass to form syngas. Several power generation projects have already proved successful in India based on gasification based cogeneration rural electrification plants. These plants have not only solved the rural electrification problem for the remote villages, where infrastructural costs could have been quite high for conventional electrification but also the power generation cost has also been relatively low.

Čurovic *et al* (2016) examined the energy potential of residues from agricultural primary production and waste from livestock production in Montenegro. It has been estimated that approximately 9490 ton of dry matter of agricultural residue was available. Intensive livestock farming resulted in the generation of 108 ton of waste. The estimation of the technical energy potential of crop residues has been worked out as 143 GJ. The technical potential of total livestock waste resulted in a total of 298 GJ of energy potential. The annual energy potential of agricultural waste has been totaled to 441GJ per year. This potential is significantly lower than the theoretical potential.

Gojiya *et al* (2018) studied the economic viability of decentralized biomass power plants by computing the cost associated with capital investment for biomass power plant, operation, and maintenance cost of the plant with discounted rate method and compared to the income generated from the power generation. It was inferred that cotton stalk and groundnut shell residues were not cost-effective for electricity production. The rice and wheat residue were observed to be cost-effective for the biomass power plant. The maize stover residue has proved to be only marginally cost-effective for biomass-based power plants.

Naqvi *et al* (2018) highlighted that biomass is an emerging renewable resource for bioenergy production to meet the future energy demand in Pakistan to tackle the energy crisis. The importance of the development of infrastructure for biomass conversion to bioenergy on all scales was highlighted. It was opined that efforts should be made to identify suitable thermal or biochemical conversion techniques for different biomass producing flexible fuels like char, pyrolysis vapors, bio-oil, or synthesis gas which could be further converted to methane, dimethyl ether (DME), methanol, hydrogen, etc. The flexible fuels may then be utilized for combined heat and power production or converting them to vehicle fuels.

In the study conducted by Lohan *et al* (2018), it was brought forth that despite increasing awareness among the farmers about the adverse effects of paddy straw burning at the farm level, they are constrained by the lack of economically viable and acceptable machinery and alternatives for disposal of paddy residues. In-situ alternatives like managing crop residue by happy seeder, zero-till machine, double disc colters, straw choppers are required for practicing and adoption of conservation agriculture in the region will reduce the residue burning in rice-wheat rotation.

Singh *et al* (2019) conducted a study to estimate the power potential of biomass in district Fatehgarh Sahib of Punjab. The study highlighted that availability of unused agricultural biomass in Fatehgarh Sahib in 2018-19 recorded at 625.7 Kt, has the potential of producing power to the tune of 115.0 MW.

The review of the existing literature has given a broad perspective of the biomass potential of different regions and the related management issues. There have been a lot of studies conducted to document the potential of agricultural biomass in Punjab. However, not much of work has been done on the assessment of the geographical spread of the crop-wise biomass availability in Punjab and the energy potential thereof. The present study is a modest effort to bridge this gap.

CHAPTER - III

MATERIAL AND METHODS

The application of the scientific methodology is a pre-requisite for conducting research and getting the research questions answered. This chapter, therefore, systematically explicates the research plan and analytical tools used to achieve the objectives of the study entitled, "Energy Potential of Agricultural Biomass in Punjab". The present study called for a thorough review of the literature to converge to a systematic methodology to carry out the research to arrive at reasonable estimations. The basic outline of this chapter is as follows

3.1 Locale of the Study

3.2 Data Type and Sources

3.3 Operational Definition of Agricultural Biomass

3.4 Analytical Tools and Techniques

3.1 Locale of the study

The study was conducted in the state of Punjab, the most advanced agricultural state of India. The state covers an area of 50,362 square km accounting for 1.53 per cent of India's total geographical area.

3.2 Data type and sources

The formulations of the present study, aimed at the ascertainment of the regional spread of agricultural biomass in Punjab and to estimate the biomass energy potential of the same, are based on the secondary data. The time frame for the basic profile of Punjab agriculture as a prelude to the study at hand started with 1970-71 up to the latest available. The assessment of agricultural biomass and the energy potential thereof has been carried out for the triennium ending (TE) 2017-18 rather than for the latest year to negate the effect of year to year variations. In the case of cotton, the average corresponds to two years i.e., 2016-17 and 2017-18 so as omit the abnormal year 2015-16 with a substantial crop loss due to whitefly attack.

The data on the requisite variables have been culled from various web and published sources and verified from certain research papers, wherever deemed necessary. The data sources tapped for the present study are

i. Statistical Abstract of Punjab, various issues,

ii. Statistical Abstract of India, various issues

iii. Statistics of Punjab Agriculture

iv. Agricultural Statistics at a Glance

3.3 Operational definition of agricultural biomass

The agricultural biomass, synonymously termed as crop residues are customarily grouped into two categories i.e., on-farm residues and processing residues/ off-farm residues.

The crop residues, available at the place where the crop is harvested, such as straw, stalks, sugarcane tops and leaves are known as on-farm residues. On the other hand, the residues generated during post-harvest processing are termed as processing based residues or processing residues. In the table below is given the categorization of biomass (Table 3.1).

Table 3.1: Categorisation of agricultural biomass

Category	Type of biomass	Name of Crop
A1	Straw	Wheat, Paddy
A2	Stalk	Bajra, Maize, Moong, Groundnut, Arhar, Barley, Gram, Mustard, Sunflower, Cotton, Sesamum, Mash
A3	Bagasse[a]	Sugarcane
	Tops and leaves	Sugarcane
A4	Cobs[a]	Maize, Bajra
	Husk[a]	Paddy, Bajra, Moong, Wheat, Arhar, Cotton, Mash
	Shell[a]	Groundnut, Cotton

[a] *processing residues.*

The study has assumed that bagasse, a processing residue produced at the time of manufacturing of sugar is used for co-generation after sun drying in the sugar mills itself. Hence it has not been counted in the potential biomass.

3.4 ANALYTICAL TOOLS AND TECHNIQUES

The enumeration of the agricultural biomass potential, its availability, and further the energy potential in Punjab state, entailed a schematic procedure, the details of which are outlined below.

3.4.1 Assessment of Biomass Potential

The biomass potential (BP) connotes the gross annual production of the agricultural biomass in a region. It depends upon the annual production of the crops and the residue-to-product ratio (RPR) value. It has been evaluated by the relation given below

$$BP = \sum_{i=1}^{n} R(i) \times P(i)$$

Where,

$R(i)$ *is the RPR for* i^{th} *crop*

$P(i)$ *is the production for* i^{th} *crop*

It is pertinent to mention that *P(i)* i.e. the production of i^{th} crop is predisposed to variations in seed variety, crop management practices, biotic and abiotic factors. The study assumed usual farming practices and the same seed variety leading to uniform average production. However, it was assumed that year to year fluctuations in yield will be taken care of by taking the triennium averages.

The residue-to-product ratio i.e. *R(i)* indicates the quantum of residue produced per unit production of the i^{th} crop. These values are also region-specific depending on the cultural practices and the varietal differences (Singh 2015). The RPR values used for the present study are given below in Table 3.2.

Table 3.2: RPR value by crop biomass type

Category	Type of biomass	Name of Crop
A1	Straw	Wheat (1.5), Rice (1.5)
A2	Stalk	Bajra (2.0), Maize (2.0), Moong (1.1), Groundnut (2.0), Arhar (2.5), Barley (1.3), Gram (1.12), Mustard (1.8), Sunflower (3.0), Cotton (3.8)[@], Sesamum (1.2), Mash (1.0)
A3	Bagasse[a]	Sugarcane (0.33)
	Tops and leaves	Sugarcane (0.05)
A4	Cobs[a]	Maize (0.3), Bajra (0.33)
	Husk[a]	Rice (0.2), Bajra (0.3), Moong (0.15), Wheat (0.3), Arhar (0.3),Cotton (1.10), Mash (0.15)
	Shell[a]	Groundnut (0.3), Cotton (1.10)

[a] *processing residues.*
@t /ha
Source: Combustion Gasification & Propulsion Laboratory (CGPL), Bangalore, India

3.4.2 Assessment of Biomass Availability

The biomass potential (BP) worked out as explicated in subsection 3.4.1 above is a theoretical potential and the entire quantity can't be translated into energy potential as crop residues have alternate uses at domestic and farm level. Hence only a fraction of biomass potential can be made available for energy conversion. The biomass availability (BA) synonymously referred to as surplus residue potential has been worked out as

$$BA = \sum_{i=1}^{n} R(i) \times P(i) \times SF(i)$$

Where,

$R(i)$ *is RPR for* i^{th} *crop*

$P(i)$ *is the production for* i^{th} *crop*

$SF(i)$ *is the surplus residue fraction for* i^{th}*crop*

The surplus residue fractions (*SF*) used for the present study are given below in Table 3.2.

Table 3.3: Surplus residue fraction (SF) by crop biomass type

Category	Type of biomass	Name of Crop
A1	Straw	Wheat (0.20)[A], Rice (0.85)[A]
A2	Stalk	Bajra (0.10)[B], Maize (0.75)[A], Moong (0.10)[B], Groundnut (0.20)[B], Arhar (0.30)[B], Barley (0.80)[A], Gram (0.90)[B], Mustard (0.30)[A], Sunflower (0.20)[B], Cotton (0.687)[A], Sesamum (0.80)[A], Mash (0.10)[A]
A3	Tops and leaves	Sugarcane (0.40)[A]
A4	Cobs[a]	Maize (0.745)[A], Bajra (0.38)[B]
	Husk[a]	Rice (0.477)[A], Moong (-), Wheat (0.50)[B], Arhar (-), Cotton (0.45)[B], Mash (-)
	Shell[a]	Groundnut (0.53)[A], Cotton (0.45)[B]

[a] processing residues
-negligible
Sources: Ref. [A] Singh et al 2008,
Ref. [B] Biomass Resource Atlas of India http://lab.cgpl.iisc.ernet.in/atlas/Default.aspx

3.4.3 Energy Potential

The energy potential here connotes the energy equivalent (in units of energy) of power potential the agricultural biomass has. This has been ascertained by using the following equation:

$$EP = \sum_{i=1}^{n} BA(i) \times C(i)$$

Where,

$BA(i)$ *is the biomass of* i^{th} *crop available for power generatin*

$C(i)$ *is the calorific value of* i^{th} *crop*

The calorific value for each crop residue culled from the available literature has been given in the table that follows.

Table 3.4: Calorific value by crop biomass type

Category	Type of biomass	Name of Crop
A1	Straw	Wheat (17.15)[A], Rice (15.03)[A]
A2	Stalk	Bajra (18.16)[B], Maize (16.67)[A], Moong (16.67)[C], Groundnut (14.40)[B], Arhar (18.58)[A], Barley (17.10)[A], Gram (16.02)[B], Mustard (17.00)[A], Sunflower (17.53)[B], Cotton (17.40)[A], Sesamum (14.35)[B], Mash (15.95)[C]
A3	Tops and leaves	Sugarcane (20.00)[A]
A4	Cobs[a]	Maize (17.39)[B], Bajra (17.39)[B]
	Husk[a]	Rice (15.54)[B], Bajra (17.48)[B], Wheat (17.39)[B], Cotton (16.70)[B]
	Shell[a]	Groundnut (15.56)[B], Cotton (16.70)[B]

[a] processing residues
Sources: Ref. [A] Singh et al 2013, Ref. [B] Hiloidhari et al 2014, Ref. [C] CES IISc.
http://wgbis.ces.iisc.ernet.in/energy/paper/alternative/calorific.html

3.4.4 Analysis for the Identification of Clusters

In order to ascertain the regional spread and identify the clusters with the biomass surplus available, the district wise biomass availability figures were normalized using the MIN-MAX approach. The Biomass Availability Index (BAI) for j^{th} district has been worked out as:

$$BAI(j) = \frac{BA\,(j) - Min\,BA}{Max\,BA - Min\,BA}$$

Where,

$BA(j)$ *is Biomass Availability in* j^{th} *district*

Max BA is the maximum of 22 study districts

Min BA is the minimum of 22 study districts

CHAPTER -IV

RESULTS AND DISCUSSION

The present study entitled "Energy Potential of Agricultural Biomass in Punjab" has been envisioned to assess the crop biomass potential of Punjab with the ultimate aim of estimating the biomass energy potential of agricultural biomass available in the Punjab state. The results of the present study and discussion on the inferences that may be drawn thereof have been presented in this chapter. The results have been classified under the following heads:

4.1 Status of Punjab Agriculture

4.2 Agricultural Biomass Potential in Punjab

4.3 Agricultural Biomass Availability in Punjab

4.4 Biomass Energy Potential in Punjab

4.5 Agricultural Biomass Management Options

4.1 Status of Punjab agriculture

Punjab is a state in the northwest region of India and is one of the most prosperous states. Agriculture has always been the mainstay of Punjab's economy. The state of Punjab with merely 1.53 per cent of the geographical area of the India contributed about 19 per cent wheat, 11 per cent rice, and 5 per cent of cotton to the agricultural economy of India. The state has got the remarkable distinction of having the highest irrigated area (99.9 per cent) and the highest cropping intensity (206 per cent) of all the Indian states. The state achieved the record production of rice (133.8 lakh tons) during 2017-18 and the highest wheat production (182.0 lakh tons) during 2018-19 in the country. As per the latest agricultural statistics, Punjab has attained the highest productivity of cotton (776 kg/ha) during the year 2018-19.

4.1.1 Land resources of Punjab

The land is the fundamental basis for most of the human or natural activities and is one of the major natural resources on earth. The primary production of minerals and agricultural products depends entirely on the availability and use of suitable land. Punjab has a total geographical area of 5.033 million ha. The land use pattern in the state has undergone significant changes over the years (Table 4.1). The forest wealth of the state is very poor with only 5.09 per cent of the total area under the forest cover. The area under permanent barren and unculturable land is less than one per cent of the state area for the last so many decades.

In Punjab, the land falling under the category of barren and unculturable land stood at 0.21 million ha in 1970-71 representing close to four per cent of the state's geographical area. This type of land, which cannot be brought under plough except at exorbitant cost or is covered by buildings, roads, railways and water or otherwise appropriated for non-agricultural purposes, has been recorded at 42000 ha in the year 2017-18. The land put to non-agricultural use in the year 1970-71 was 0.42 million ha constituting 8.25 per cent of the state’s geographical area. The land apportioned to non-agricultural uses has seen quite many ups and downs over the last forty-eight years period. In the year 2017-18, the land area used for non-agricultural purposes accounted for 9.8 per cent of the State’s geographical area. The culturable wasteland recorded at 83000 ha in the year 1970-71 has come down to 14000 ha by 2017-18.

Table 4.1 Shifts in land use pattern in Punjab, 1970-71 to 2017-18

’000ha

Year	1970-71	1980-81	1990-91	2000-01	2015-16	2016-17	2017-18
Geographical area	5036	5036	5036	5036	5033	5033	5033
Forests	123	216	222	280	256	256	256
Barren & unculturable land	208	96	83	28	52	52	42
Land put to non-agricultural use	416	436	343	410	475	475	494
Culturable wasteland	83	41	35	15	16	16	14
Permanent pasture & grazing land	5	4	10	4	5	5	4
Land under misc. uses	4	4	12	3	9	9	9
Current fallow	139	45	82	40	77	77	78
Net area sown	4053	4191	4218	4250	4137	4130	4125
Net area sown as % to total area	80.5	83.2	83.8	84.4	82.2	82.1	82.0
Area sown more than once	1625	2572	3284	3691	3734	3699	3700
Total cropped area	5678	6763	7502	7941	7872	7823	7825

Source: Statistical Abstract of Punjab, various issues

The land area in Punjab coming under the category of permanent pastures and other grazing lands was 5000 ha in 1970-71 which increased to 10000 ha in 1990-91 and slipped to 4000 ha by 2017-18. The cultivable land kept uncultivated during the current year called “current fallow” has been recorded at 0.14 million ha for the year 1970-71, accounting for 2.76 per of the total geographical area. This has declined to 78000 ha by 2017-18 reflecting the scenario of Punjab Agriculture, where all-out efforts have been made to bring about more and more area under the plough.

The net area sown during the year 1970-71 accounted for 80.5 per cent of 5.04 million ha of Punjab’s geographical area. As per the figures reported for 2017-18, the state area already under cultivation stands at 82 per cent, the highest in the country. The gross area sown during 2017-18 was 7.83 million hectares as against 5.68 million hectares recorded in 1970-71. The state has virtually reached the saturation point in the matter of adding to the physical area horizontally.

4.1.2 Cropping Intensity of Punjab

Apart from the impressive increase in the area cropped, the cropping intensity in Punjab has also increased from 140 per cent in 1970-71 to 190 per cent in 2017-18 (Fig 4.1) and at the same time limiting the possibility of vertical expansion as well. Since, 82 per cent of total land area in the state is already under cultivation, bringing more area under the plough is practically impossible and also damaging to our fragile agro-eco-system. However, cropping intensity can be increased from the present level of 190 per cent but it is also not an easy proposition. Therefore, sustainability in the growth of production per unit of land area has to come through raising the input use efficiency or upward shift in the use of technology.

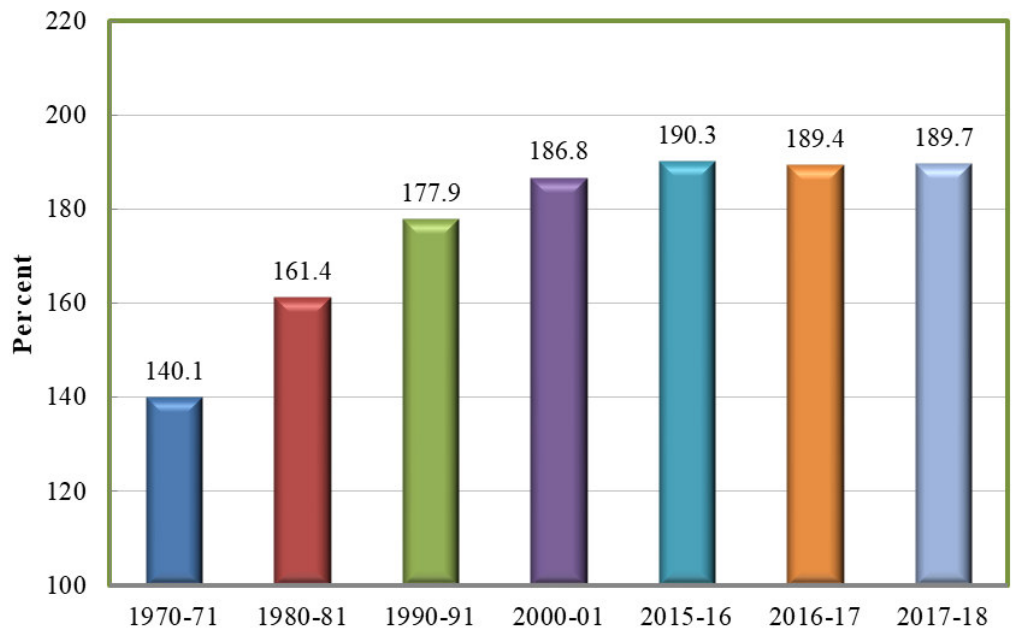


Figure 4.1 Cropping intensity in Punjab: Shifts over time

4.1.3 Productivity Profile of Crops in Punjab

Punjab is the most stunning example of the Green Revolution in India. In the 1950-60s, the country was importing food grains putting a heavy drain on its foreign reserves. Hence, the policy to adopt agricultural practices that promoted grain production for National Food Security was followed. The massive investments made by the government and with the all-out efforts made by innovative and hardworking farmers of the state, Punjab emerged as the forerunner in the adoption of the Green Revolution and making it a great success. With the advent of high yielding, input-responsive dwarf varieties of rice and wheat during the

60's, the entire agriculture production system in Punjab got revolutionized. Major shifts were witnessed in the cropping pattern, especially, in irrigated ecosystems where cereal-based multiple cropping came into prominence, relegating less productive, risk-prone legumes and oilseed crops to marginal lands. The farmers found the rice-wheat cycle the most profitable. The inherent risk in the production of oilseeds and pulses was another factor to force a shift in favour of the rice-wheat cropping system. Consequently, the farmers abandoned other crops. This was the reason that rice and wheat crops together account for 84 per cent of the state's gross cropped area in the year 2017-18 (Table 4.2). This practice has resulted in the depletion of nutrient and organic content leading to degradation of soil health.

Table 4.2: **Shifts in the cropping pattern of Punjab, 1970-71 to 2017-18**

Per cent of Gross Cropped Area

Crop	1970-71	1980-81	1990-91	2000-01	2015-16	2016-17	2017-18
Rice	6.86	17.49	26.85	32.91	37.73	38.94	39.17
Wheat	40.48	41.57	43.62	42.94	44.54	44.68	44.88
Maize	9.77	5.64	2.50	2.07	1.61	1.48	1.46
Oilseeds	5.19	3.51	1.32	1.08	0.61	0.54	0.51
Cotton	6.99	9.59	9.34	5.97	4.26	3.64	3.72
Sugarcane	2.25	1.04	1.35	1.52	1.17	1.12	1.23
Pulses	7.29	5.04	1.90	0.68	0.23	0.19	0.13

Source: Statistical Abstract of Punjab, various issues

Over the years, Punjab agriculture has seen a significant improvement in the irrigation status. The irrigated area in the state rose to 99.9 per cent of the net sown area by 2017-18 from 71 per cent in 1970-71. Besides, the number of tubewells increased from 1.92 lakhs to 14.76 lakhs, of which more than 90 per cent were electrified, while the share of tubewells in irrigated areas grew from 41 per cent to 85 per cent during this period. The extensive irrigation system has provided the impetus for the large scale adoption of high yielding varieties; indeed, the entire area of wheat and rice is now under high yielding varieties. It has simultaneously made multi-cropping systems feasible due to the short duration of crops.

Large-scale mechanization was introduced and played an important role in expanding cropped area, productivity, and production in Punjab. The use of chemical fertilizers also registered tremendous growth. The use of fertilizers rose from 0.213 million tons of nutrients in 1970-71 to 1.878 million tons in 2017-18. On a per-hectare basis, fertilizer use increased from 38 kg in 1970-71 to 240 kg of cropped area in 2017-18. The use of technical grade plant protection measures (fungicides, insecticides and pesticides) increased from 3200 tons in 1980-81 to 6970 tons in 2000-01, though it declined later to 5835 tons by the year 2017-18. Minimum support prices and assured markets for produce have further contributed to the profitability of the rice-wheat cropping system.

The trio of high yielding seeds, irrigation along with fertilizers supported by farm mechanization, institutional and infrastructural development led to tremendous growth in agricultural productivity as well as production (Dhillon *et al* 2010). The state of Punjab has always been a forerunner in terms of the productivity of rice and wheat crops. During 2017-18, Punjab marked the highest yield in rice, 6.5 t/ha as against the productivity level of 1.8 t/ha attained in 1970-71 (Table 4.3).

Table 4.3 Productivity of major crops in Punjab, 1970-71to 2017-18

(kg/ha)

Crop	1970-71	1980-81	1990-91	2000-01	2015-16	2016-17	2017-18
Rice	1765	2733	3229	3506	5933	6193	6516
Wheat	2237	2730	3715	4563	4583	5046	5077
Maize	1555	1602	1786	2793	3732	3836	3711
Sugarcane (*gur*)	4117	5526	5941	6425	6935	7670	8358
Cotton (*lint*)	350	309	463	430	196	756	750

Source: Statistical Abstract of Punjab, various issues

The productivity of wheat has also increased from 2.2 t/ha in 1970-71 to 5.1 t/ha in 2017-18; making Punjab as ‘the highest yielding state of India’. The productivity of maize, which is considered as an alternative to paddy, increased from 1.6 t/ha in 1970-71 to 3.7 t/ha in 2017-18. The productivity of sugarcane increased in recent years from 6.4 t/ha in 2000-01 to 8.4 t/ha in 2017-18. There was not much improvement in the productivity of oilseeds and pulses which needs serious attention from the researchers. At the same time, further improvements in the yield of cereals viz. wheat, rice, maize to match the global standards poses a formidable challenge to the state.

4.2 AGRICULTURAL BIOMASS POTENTIAL IN PUNJAB

Punjab, being an agriculture dominant state has huge potential for biomass production. The biomass residue is an immense storehouse of energy that can be fruitfully used for myriad purposes. Soil and climatic conditions, the state of Punjab is endowed with, support cultivation of diverse crops resulting in the production of a variety of agricultural residues such as straw, stalk, bagasse, tops, leaves, and shells, etc. These agricultural residues can be divided into two different categories i.e., on-farm residues or field-based residues and processing residues synonymously termed as off-farm residues. The crop residues, available at the place where the crop is harvested, such as straw (A1), stalks (A2), sugarcane tops, and leaves (A3) are known as the on-farm residue. On the other hand, the residues generated during post-harvest processing are termed as processing based residues or processing residues. These crop-based residues (referred to as agricultural biomass hereafter) have a massive amount of energy stored in it, which can be used for power generation, bioethanol production, or as a fertilizer, etc. For the efficient and effective utilization of agricultural residues, one needs to evaluate the quantum of biomass available in the state.

4.2.1 On-farm Agricultural Biomass Potential

This section is devoted to the quantification of the on-farm biomass potential of crops grown in Punjab to identify the crops, strategic from the point of view of residue generation and at the same time pinpointing the potential areas of the state, from where biomass can be procured.

Punjab, the state bestowed with the best agro-climatic conditions had the potential to produce 47.2 million t of on-farm crop biomass as per TE 2017-18 crop production figures (Table 4.4). Out of all the 22 districts of Punjab, the contribution of district Sangrur has been recorded as the highest with 9.33 per cent share, followed by that of Ludhiana (7.96%), Bathinda (7.09%), Patiala (6.83%) and Sri Muktsar Sahib (5.82%). These five top-ranking districts namely Sangrur, Ludhiana, Bathinda, Patiala and Sri Muktsar Sahib together add up to 37 per cent of the state's total on-farm biomass potential. The high biomass potential of these districts might be corroborated with the large availability of agricultural land coupled with high productivity. As many as thirteen districts had on-farm biomass generation of more than 2 million t each and together made up for 36.3 million tons (77% of the on-farm potential in TE 2017-18). District Pathankot with on-farm biomass generation potential of 0.43 million tons per year happened to be at the bottom contributing only 0.9 per cent to the state's on-farm biomass potential. It can be observed from Fig 4.2 that field-based biomass potential of top-producing district Sangrur happened to be a little over ten times that observed in the case of Pathankot. The five districts, starting from the lowest biomass potential district of Pathankot, S.A.S. Nagar, Rupnagar, S.B.S. Nagar and Fatehgarh Sahib together contributed only around nine per cent to the state's on-farm biomass generation potential.

Table 4.4: On-farm crop biomass potential in Punjab, TE 2017-18

'000t

District/crop	Paddy	Bajra	Maize	Moong	Sugar cane	Ground nut	Wheat	Arhar	Barley	Gram	Rapeseed & Mustard	Sunflower	Cotton	Sesamum	Mash	Total	% Share
Gurdaspur	850.50	-	5.33	-	82.25	-	1290.00	-	-	-	5.28	-	-	-	0.23	2233.60	**4.73**
Pathankot	125.50	-	39.33	-	14.70	-	249.50	-	-	0.12	2.04	-	-	0.20	0.30	431.70	**0.91**
Amritsar	882.00	-	5.33	0.44	17.85	-	1346.00	0.67	-	-	4.86	-	-	0.36	0.13	2257.64	**4.78**
Tarn Taran	938.50	-	2.67	0.29	1.58	-	1299.50	0.33	-	-	1.02	-	-	0.36	-	2244.26	**4.76**
Kapurthala	733.00	-	14.00	-	16.08	-	757.00	-	-	-	1.62	1.40	-	-	-	1523.10	**3.23**
Jalandhar	1031.50	-	64.00	-	39.80	-	1216.00	0.83	-	-	1.92	4.80	-	0.08	-	2358.93	**5.00**
S.B.S. Nagar	397.00	-	72.00	-	22.55	-	563.50	-	-	-	4.32	2.20	-	-	-	1061.57	**2.25**
Hoshiarpur	411.50	-	422.67	-	82.83	4.93	908.50	-	-	0.09	5.82	4.70	-	0.04	0.10	1841.18	**3.90**
Rupnagar	253.50	-	162.67	-	11.15	-	464.00	0.17	0.30	0.05	4.32	-	-	0.04	-	896.20	**1.90**
S.A.S. Nagar	168.00	-	50.00	0.04	3.30	-	357.50	0.50	0.35	0.05	1.08	3.10	-	-	0.13	584.05	**1.24**
Ludhiana	1826.00	-	31.33	0.99	11.38	-	1870.50	1.58	6.28	-	3.18	5.00	-	-	-	3756.25	**7.96**
Firozpur	1181.00	-	-	0.33	-	-	1399.00	0.25	-	-	0.72	2.30	-	0.28	-	2583.88	**5.48**
Fazilka	522.00	-	8.00	1.32	8.12	0.27	1484.50	2.00	7.97	1.01	15.42	-	311.60	-	-	2362.20	**5.01**
Faridkot	707.00	-	-	0.07	-	-	886.50	0.08	0.13	-	1.14	-	7.60	-	-	1602.53	**3.40**
Sri Muktsar Sahib	1026.50	-	-	0.11	-	-	1585.00	0.50	2.64	0.16	2.58	-	129.20	0.04	-	2746.73	**5.82**
Moga	1278.00	-	-	0.15	-	-	1315.50	0.50	0.91	-	1.38	-	-	-	-	2596.44	**5.50**
Bathinda	1028.50	0.13	-	0.48	-	-	1932.00	0.17	4.42	0.15	6.78	-	372.40	-	-	3345.03	**7.09**
Mansa	652.00	0.80	-	0.15	-	-	1277.50	0.08	2.99	0.20	4.56	-	233.70	-	-	2171.98	**4.60**
Sangrur	2065.50	-	4.67	0.18	14.32	-	2280.50	0.58	9.06	0.11	3.48	-	24.70	-	-	4403.10	**9.33**
Barnala	796.00	-	-	0.18	4.42	-	897.50	0.17	1.13	0.04	0.84	-	11.40	-	-	1711.68	**3.63**
Patiala	1447.50	-	8.00	0.04	9.07	-	1744.50	-	4.03	-	2.10	3.60	3.80	-	0.17	3222.80	**6.83**
Fatehgarh Sahib	592.00	-	2.67	-	12.50	-	642.00	-	0.82	-	1.86	3.00	-	-	-	1254.85	**2.66**
Punjab	**18913.0**	**0.93**	**892.67**	**4.77**	**351.90**	**5.20**	**25766.5**	**8.42**	**41.04**	**1.98**	**76.32**	**30.10**	**1094.40**	**1.40**	**1.07**	**47189.69**	**100.0**
% Share	40.079	0.002	1.892	0.010	0.746	0.011	54.602	0.018	0.087	0.004	0.162	0.064	2.319	0.003	0.002	100.00	

Among all crops, wheat has maximum biomass potential (54.60%) followed by paddy (40.08%), cotton (2.32%), maize (1.89%) and sugarcane (0.75%) to the total on-farm agricultural biomass of state. However, the least biomass potential was recorded for mash and bajra i.e. only 0.002 per cent each to the total on-farm agricultural biomass of state. The data revealed that wheat and paddy crops were the major contributors to the on-farm biomass potential of the state, which can be attributed to continuously increasing area under wheat and paddy since 1970-71 (Table 4.2).

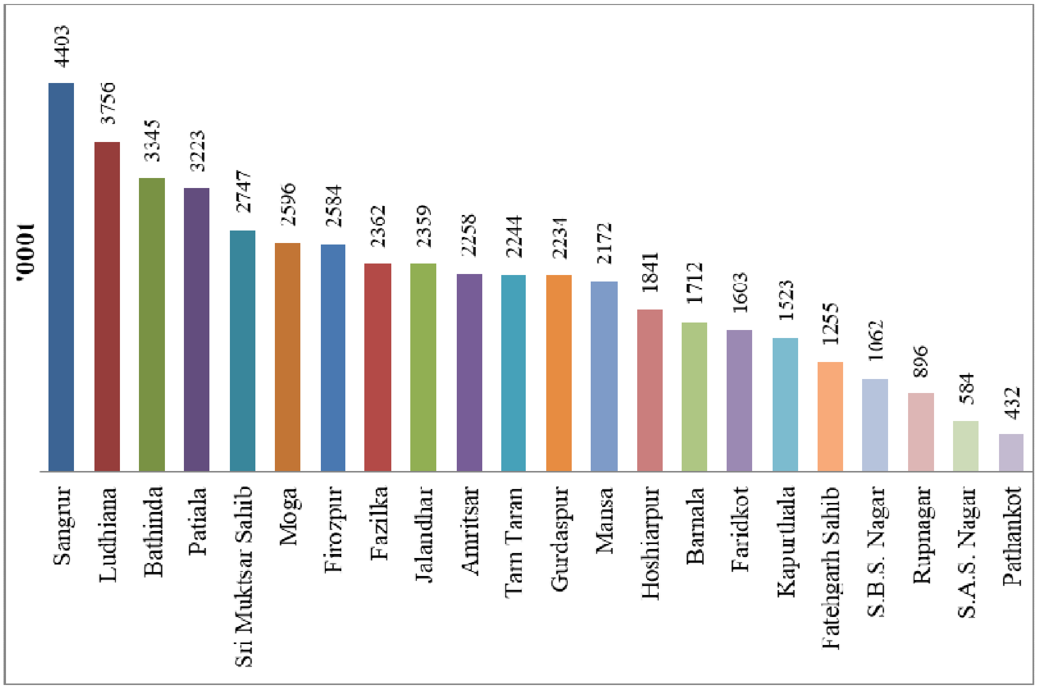


Figure 4.2: District wise on-farm biomass potential in Punjab, TE 2017-18

The increase in the area can well be attributed to the assured marketing of these crops at Minimum Support Price fixed by the union government. Oilseeds and pulses crops had a negligible contribution in the state's on-farm biomass potential which might be due to less area apportioned to these crops i.e. only 0.13 per cent of the gross cropped area of the state (Table 4.2).

The study conducted by Chauhan (2012), based on field survey for the year 2003, also brought forth that in all the districts of Punjab state, wheat and paddy were high biomass residue generating crops and that District Sangrur had the highest biomass production of all the districts of Punjab at that time also. According to another study conducted by Singh *et al* (2013), the share of wheat and paddy in the agricultural biomass potential was recorded at more than 80 per cent.

4.2.1.1 ***On-farm biomass potential by category of biomass***

The district-wise information about on-farm biomass potential as characterized by different kinds of biomass in TE 2017-18 has been presented in Table 4.5. The perusal of the table revealed that out of the total annual on-farm biomass potential of 47.2 million t in the state estimated for TE 2017-18, 44.7 million t was contributed by Category A1 accounting for 94.7 per cent, followed by Category A2 (4.6%) and Category A3 (0.7%). It can be readily observed that there wasn't much of a variation in the potential of on-farm biomass in all the districts of Punjab so far as the contribution of different categories of biomass was concerned. There were 13 out of 22 districts wherein the contribution of on-farm biomass Category A1 stood at more than 95 per cent. In the rest of the districts, the said contribution varied from 80

Table 4.5: District-wise on-farm biomass potential in Punjab, TE 2017-18

District	Category A1		Category A2		Category A3		Total
	'000t	% to district total	'000t	% to district total	'000t	% to district total	
Gurdaspur	2140.5	95.8	10.8	0.5	82.3	3.7	2233.6
Pathankot	375.0	86.9	42.0	9.7	14.7	3.4	431.7
Amritsar	2228.0	98.7	11.8	0.5	17.9	0.8	2257.6
Tarn Taran	2238.0	99.7	4.7	0.2	1.6	0.1	2244.3
Kapurthala	1490.0	97.8	17.0	1.1	16.1	1.1	1523.1
Jalandhar	2247.5	95.3	71.6	3.0	39.8	1.7	2358.9
S.B.S Nagar	960.5	90.5	78.5	7.4	22.6	2.1	1061.6
Hoshiarpur	1320.0	71.7	438.3	23.8	82.8	4.5	1841.2
Rupnagar	717.5	80.1	167.5	18.7	11.2	1.2	896.2
S.A.S Nagar	525.5	90.0	55.2	9.5	3.3	0.6	584.0
Ludhiana	3696.5	98.4	48.4	1.3	11.4	0.3	3756.3
Firozpur	2580.0	99.8	3.9	0.2	-	0.0	2583.9
Fazilka	2006.5	84.9	347.6	14.7	8.1	0.3	2362.2
Faridkot	1593.5	99.4	9.0	0.6	-	0.0	1602.5
Sri Muktsar Sahib	2611.5	95.1	135.2	4.9	-	0.0	2746.7
Moga	2593.5	99.9	2.9	0.1	-	0.0	2596.4
Bathinda	2960.5	88.5	384.5	11.5	-	0.0	3345.0
Mansa	1929.5	88.8	242.5	11.2	-	0.0	2172.0
Sangrur	4346.0	98.7	42.8	1.0	14.3	0.3	4403.1
Barnala	1693.5	98.9	13.8	0.8	4.4	0.3	1711.7
Patiala	3192.0	99.0	21.7	0.7	9.1	0.3	3222.8
Fatehgarh Sahib	1234.0	98.3	8.4	0.7	12.5	1.0	1254.9
Total	**44679.5**	**94.7**	**2158.3**	**4.6**	**351.9**	**0.7**	**47189.7**

to 85 per cent, except for district Hoshiarpur wherein Category A1contributed 71.7 per cent to on-farm biomass potential of the district. The contribution of Category A2 and A3 towards the total on-farm biomass potential in the case of district Hoshiarpur stood at 23.8 and 4.5 per cent respectively, which can be attributed to the cultivation of maize and sugarcane at a substantial area after wheat crop.

As regards the absolute value of Category A1 on-farm biomass potential in Punjab, Sangrur district ranks at the top producing 4.3 million tons i.e. a little less than 10 per cent of total A1 On-farm biomass. The top seven districts in descending order of the magnitude of A1 on-farm biomass, namely Sangrur, Ludhiana, Patiala, Bathinda, Sri Muktsar Sahib, Moga and Firozpur together accounted for 49.2 per cent of the state potential.

Switching over to Category A2 of on-farm biomass potential in Punjab, the district Hoshiarpur happened to be the frontrunner accounting for close to one fifth (20.3% to be precise) of the respective state total. It needs a special mention that as high as 83 per cent of the state's A2 on-farm biomass potential is contributed by the top seven districts namely Hoshiarpur, Bathinda, Fazilka, Mansa, Rupnagar, Sri Muktsar Sahib and S.B.S. Nagar. The results were in line with the findings of Singh *et al* (2013) which revealed that the share of agricultural biomass potential had registered an increase for districts namely Sangrur, Fatehgarh Sahib, Rupnagar, S.B.S Nagar, Hoshiarpur, Ludhiana, Barnala and Moga during the period of TE 2010-11 with a total potential of 14.5 million t per annum.

4.2.2. Processing Agricultural Biomass Potential

The focus of this sub-section is the potential of Category A4 biomass synonymously named as processing biomass or off-farm biomass potential in Punjab. As is evident from Chapter III, at the time of processing, biomass is generated from nine out of the 15 crops, which were amenable to the estimation of crop biomass in the case of Punjab. The perusal of Table 4.6, which has pertinent crop-wise and district wise information on processing biomass, highlights that out of the 9.2 million t of processing biomass, the highest contributing crop happened to be wheat accounting for 55.75 per cent, distantly followed by paddy (27.28%) and cotton (15.49%). These three crops viz. wheat, paddy, and cotton together accounted for 98.5 per cent of processing biomass potential of the state, with other crops individually having a negligible contribution. The district Bathinda with 1.1 million t of processing biomass topped the list with close to one-ninth of the state biomass potential. The thorough perusal of the processing potential figures highlights that Bathinda ranked first in the case of the cotton crop, second in wheat and seventh in the case of paddy. The contribution of top seven districts namely, Bathinda (11.55%), Sangrur (8.25%), Fazilka (8.17%), Ludhiana (6.74%), Sri Muktsar Sahib (6.73%), Mansa (6.68%) and Patiala (5.93%) together add up to 54 per cent of the state's off-farm biomass potential.

Table 4.6: Processing biomass potential in Punjab, TE 2017-18

'000t

District/crop	Paddy	Bajra	Maize	Moong	Groun d nut	Wheat	Arhar	Cotton	Mash	Total	% Share
Gurdaspur	113.40	-	0.80	-	-	258.00	-	-	0.04	372.24	4.03
Pathankot	16.73	-	5.90	-	-	49.90	-	-	0.05	72.58	0.79
Amritsar	117.60	-	0.80	0.06	-	269.20	0.08	-	0.02	387.76	4.19
Tarn Taran	125.13	-	0.40	0.04	-	259.90	0.04	-	-	385.51	4.17
Kapurthala	97.73	-	2.10	-	-	151.40	-	-	-	251.23	2.72
Jalandhar	137.53	-	9.60	-	-	243.20	0.10	-	-	390.43	4.22
S.B.S. Nagar	52.93	-	10.80	-	-	112.70	-	-	-	176.43	1.91
Hoshiarpur	54.87	-	63.40	-	0.74	181.70	-	-	0.02	300.72	3.25
Rupnagar	33.80	-	24.40	-	-	92.80	0.02	-	-	151.02	1.63
S.A.S. Nagar	22.40	-	7.50	0.01	-	71.50	0.06	-	0.02	101.49	1.10
Ludhiana	243.47	-	4.70	0.14	-	374.10	0.19	-	-	622.59	6.74
Firozpur	157.47	-	-	0.05	-	279.80	0.03	-	-	437.34	4.73
Fazilka	69.60	-	1.20	0.18	0.04	296.90	0.24	387.02	-	755.18	8.17
Faridkot	94.27	-	-	0.01	-	177.30	0.01	8.55	-	280.13	3.03
Sri Muktsar Sahib	136.87	-	-	0.02	-	317.00	0.06	168.37	-	622.31	6.73
Moga	170.40	-	-	0.02	-	263.10	0.06	0.00	-	433.58	4.69
Bathinda	137.13	0.04	-	0.07	-	386.40	0.02	543.71	-	1067.37	11.55
Mansa	86.93	0.25	-	0.02	-	255.50	0.01	274.49	-	617.21	6.68
Sangrur	275.40	-	0.70	0.03	-	456.10	0.07	30.13	-	762.42	8.25
Barnala	106.13	-	-	0.03	-	179.50	0.02	14.45	-	300.13	3.25
Patiala	193.00	-	1.20	0.01	-	348.90	-	4.88	0.03	548.01	5.93
Fatehgarh Sahib	78.93	-	0.40	-	-	128.40	-	-	-	207.73	2.25
Punjab	**2521.73**	**0.29**	**133.90**	**0.65**	**0.78**	**5153.30**	**1.01**	**1431.61**	**0.16**	**9243.43**	100.00
% Share	**27.28**	**0.003**	**1.45**	**0.007**	**0.008**	**55.75**	**0.011**	**15.49**	**0.002**	**100.00**	

The graphical representation of processing biomass in different districts of Punjab highlighted the huge dispersal with the potential varying from only 73 thousand t in Pathankot district (primarily the wheat husk) to as high as 1.1 million t in Bathinda (Fig 4.3).

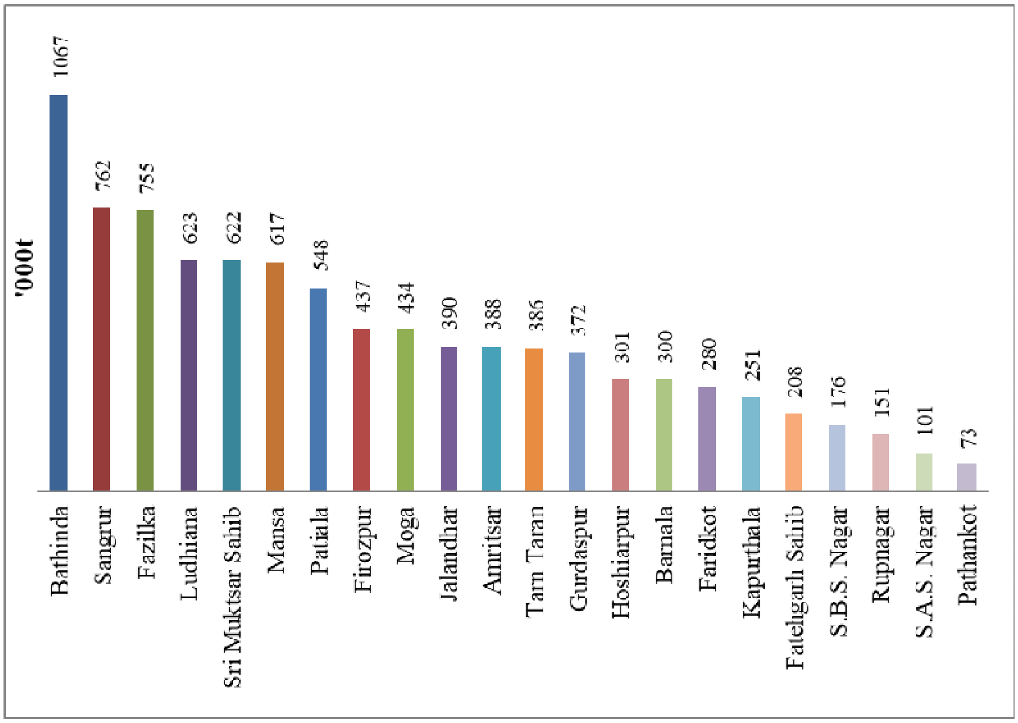


Figure 4.3: District wise Processing biomass potential in Punjab, TE 2017-18

The extent of concentration of processing biomass over a limited area can be gauged by the fact that top seven districts (Bathinda, Sangrur, Fazilka, Ludhiana, Sri Muktsar Sahib, Mansa and Patiala) together accounted for 54 per cent and bottom seven (Pathankot, S.A.S. Nagar, Rupnagar, S.B.S. Nagar, Fatehgarh Sahib, Kapurthala and Faridkot) only 13.4 per cent.

4.2.3. Total Biomass Potential in Punjab

The present subsection is devoted to the total biomass potential of the state, which is the amalgam of field-based and processing biomass. This analysis has been carried out crop-wise as well as district wise and the results have been presented hereunder.

4.2.3.1 *Crop-wise Biomass Potential*

The figures in Table 4.7 elicit the information on crop-wise total biomass potential and the respective share of on-farm and processing biomass in Punjab. It can be readily observed that the annual crop biomass potential totaled to 56.4 million t in TE 2017-18, the on-farm residue and the residue generated at the processing level being in the ratio of 83.6:16.4. The crop-wise analysis revealed that total biomass potential of state comprised of 54.8 per cent of wheat, 38.0 per cent of paddy, 4.5 per cent of cotton and 1.8 per cent of maize residue. These four crops together accounted for 99.1 per cent of the state's total biomass potential. The share of on-farm residue in total biomass potential stood at 83.3 per cent in the case of wheat, 88.2 per cent in paddy, 43.3 per cent in cotton and 87 per cent in the case of the maize crop. The proportion of processing residue for pulses viz. arhar, moong, and mash has been recorded as 10.7, 12.0, and 13.0 per cent respectively. As noted earlier in Chapter III, the enumeration of processing residue of sugarcane crop has not been attempted on the premise that it is not going to be available for power generation as the leftover (at the time of sugar manufacturing from sugarcane i.e. Bagasse) is consumed in the sugar mill itself.

Table 4.7: Crop wise agricultural biomass potential in Punjab. TE 2017-18

District	On-Farm		Processing		Total Potential	
	'000t	% of crop total	'000t	% of crop total	'000t	% of State total
Wheat	25766.50	83.3	5153.30	16.7	30919.80	54.79
Paddy	18913.00	88.2	2521.73	11.8	21434.73	37.98
Cotton	1094.40	43.3	1431.61	56.7	2526.01	4.48
Maize	892.67	87.0	133.90	13.0	1026.57	1.82
Sugar cane	351.90	100.0	-	-	351.90	0.62
Mustard	76.32	100.0	-	-	76.32	0.14
Barley	41.04	100.0	-	-	41.04	0.07
Sunflower	30.10	100.0	-	-	30.10	0.05
Arhar	8.42	89.3	1.01	10.7	9.43	0.017
Ground nut	5.20	87.0	0.78	13.0	5.98	0.011
Moong	4.77	88.0	0.65	12.0	5.42	0.010
Gram	1.98	100.0	-	-	1.98	0.004
Sesamum	1.40	100.0	-	-	1.40	0.002
Bajra	0.93	76.0	0.29	24.0	1.22	0.002
Mash	1.07	87.0	0.16	13.0	1.23	0.002
Total	**47189.69**	**83.6**	**9243.43**	**16.4**	**56433.12**	**100**

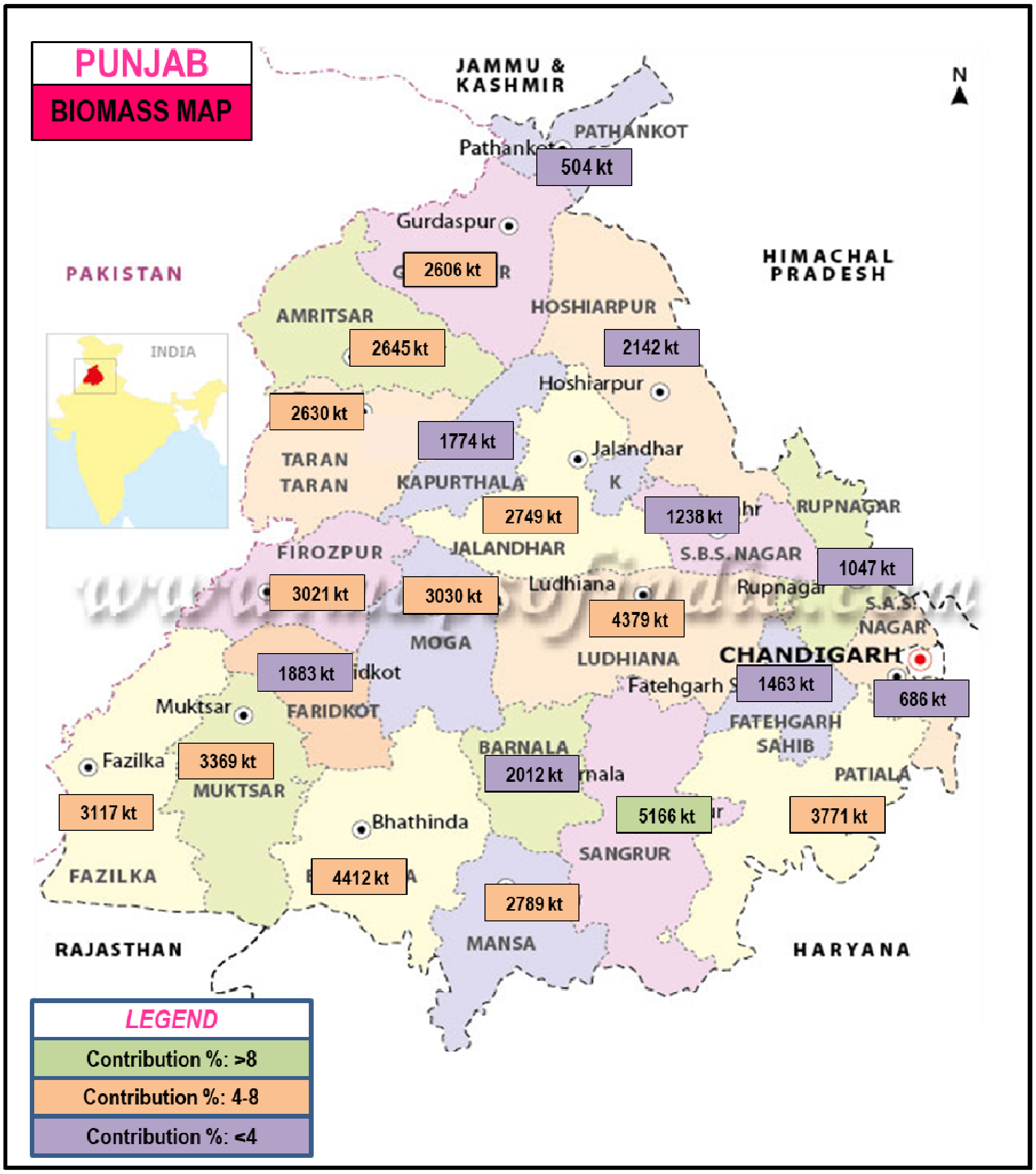
4.2.3.2 ***District-wise Biomass Potential***

The crop biomass potential from all the major and minor crops in the state has been estimated at 56.4 million t. Out of all the 22 districts of Punjab, the contribution of district Sangrur to the state's annual biomass potential has been recorded as the highest with 9.2 per cent share (Table 4.8). In terms of per cent contribution to total biomass potential of the state, Sangrur has been followed by Bathinda and Ludhiana (7.8% each), Patiala (6.7%) and Sri Muktsar sahib (6.0%). The five top crop biomass generating districts of Punjab i.e. Sangrur, Ludhiana, Bathinda, Patiala and Sri Muktsar Sahib together produced 21.1 million t of biomass, accounting for 37.5 per cent of the state potential.

Table 4.8: District wise agricultural biomass potential in Punjab, TE 2017-18

District	On-Farm		Processing		Total	
	'000t	% of District total	'000t	% of District total	'000t	% of State total
Sangrur	4403	85.2	762	14.8	5166	9.2
Bathinda	3345	75.8	1067	24.2	4412	7.8
Ludhiana	3756	85.8	623	14.2	4379	7.8
Patiala	3223	85.5	548	14.5	3771	6.7
Sri Muktsar Sahib	2747	81.5	622	18.5	3369	6.0
Fazilka	2362	75.8	755	24.2	3117	5.5
Moga	2596	85.7	434	14.3	3030	5.4
Firozpur	2584	85.5	437	14.5	3021	5.4
Mansa	2172	77.9	617	22.1	2789	4.9
Jalandhar	2359	85.8	390	14.2	2749	4.9
Amritsar	2258	85.3	388	14.7	2645	4.7
Tarn Taran	2244	85.3	386	14.7	2630	4.7
Gurdaspur	2234	85.7	372	14.3	2606	4.6
Hoshiarpur	1841	86.0	301	14.0	2142	3.8
Barnala	1712	85.1	300	14.9	2012	3.6
Faridkot	1603	85.1	280	14.9	1883	3.3
Kapurthala	1523	85.8	251	14.2	1774	3.1
Fatehgarh Sahib	1255	85.8	208	14.2	1463	2.6
S.B.S Nagar	1062	85.7	176	14.3	1238	2.2
Rupnagar	896	85.6	151	14.4	1047	1.9
S.A.S Nagar	584	85.2	101	14.8	686	1.2
Pathankot	432	85.6	73	14.4	504	0.9
Punjab	**47190**	**83.6**	**9243**	**16.4**	**56433**	**100.0**

The category of districts contributing less than four per cent to state biomass potential in descending order included Hoshiarpur, Barnala, Faridkot, Kapurthala, Fatehgarh Sahib, S.B.S. Nagar, Rupnagar, S.A.S. Nagar and Pathankot (Map 4.1), which together contributed 22.6 per cent. Out of 56.4 million t of crop biomass generated annually in the state, as much as 83.6 per cent is potentially generated at farm level. The districts with the said proportion being less than the state average of 83.6 per cent happened to be Sri Muktsar Sahib, Fazilka and Mansa, the observed proportion being 81.5, 75.8 and 77.9 per cent respectively. Bathinda, Fazilka, and Mansa are the three districts, where processing biomass is well above one-fifth of the total biomass, the plausible reason can be the cropping pattern favoring cotton crop. The dispersal within the districts was also quite pronounced in terms of total biomass potential (varying from 504 Kt for Pathankot to 5166 Kt for Sangrur) as was in the case of on-farm biomass potential.



Map 4.1: District wise biomass potential in Punjab

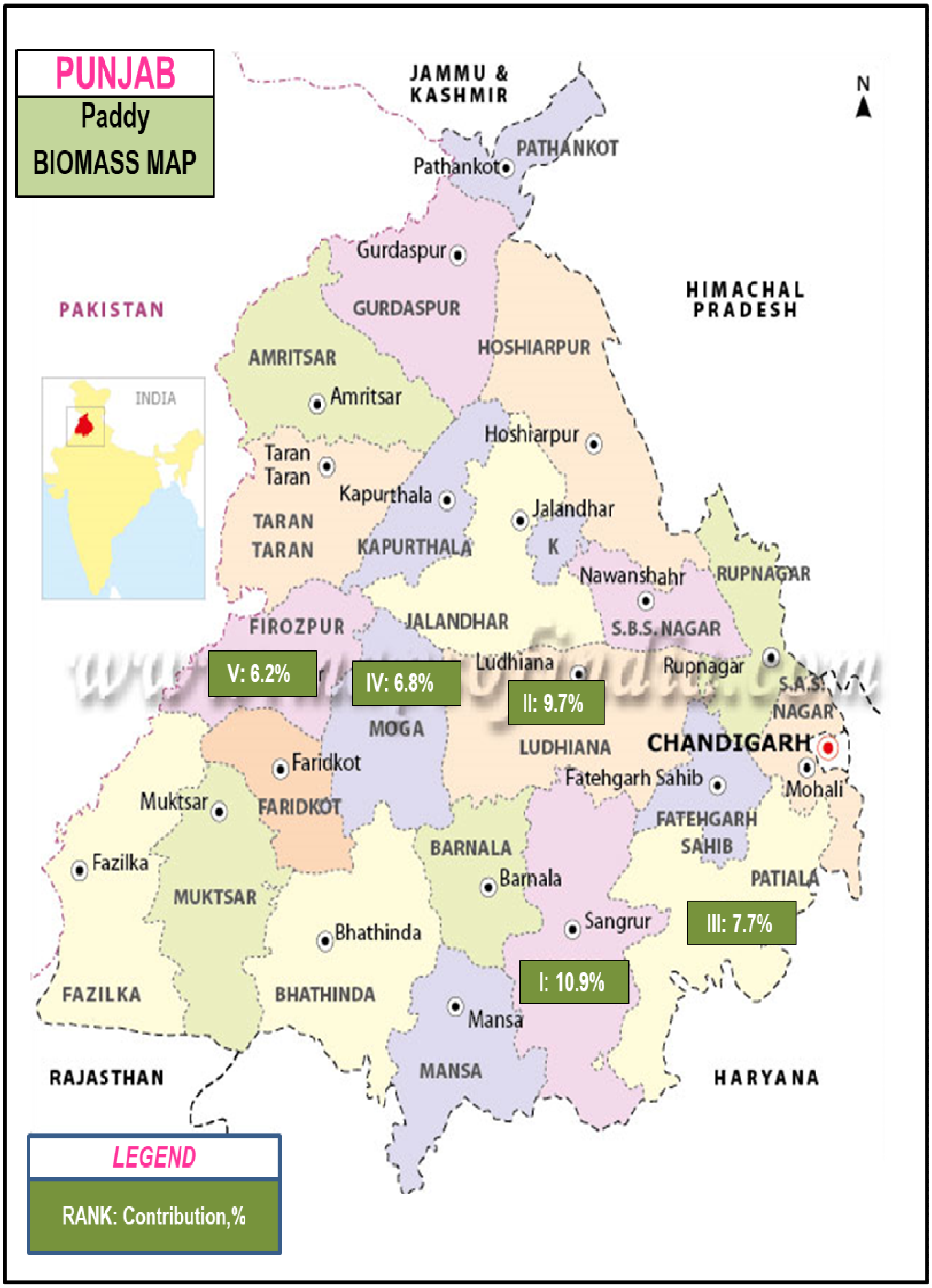
4.2.4. District-wise Spread of Biomass Potential of Major Crops

The status of different districts in the generation of total biomass across top biomass producing crops has been presented in Table 4.9. This table can provide useful insights into the regional spread of biomass which in its own right can help in identifying the areas with a high concentration of biomass. The perusal of the table highlights that out of paddy biomass potential of 21.4 million tons; a little over 90 per cent of the potential is concentrated in 16 districts. The top ten districts in descending order of their contribution to paddy biomass potential viz. Sangrur, Ludhiana, Patiala, Moga, Firozpur, Jalandhar, Bathinda, Sri Muktsar Sahib, Tarn Taran and Amritsar together account for 67.3 per cent . The district-wise analysis of wheat biomass potential assessed as 30.9 million t revealed that top ten wheat biomass producing districts namely Sangrur, Bathinda, Ludhiana, Patiala, Sri Muktsar Sahib, Fazilka, Firozpur, Amritsar, Moga and Tarn Taran produced 63.2 per cent of wheat biomass potential.

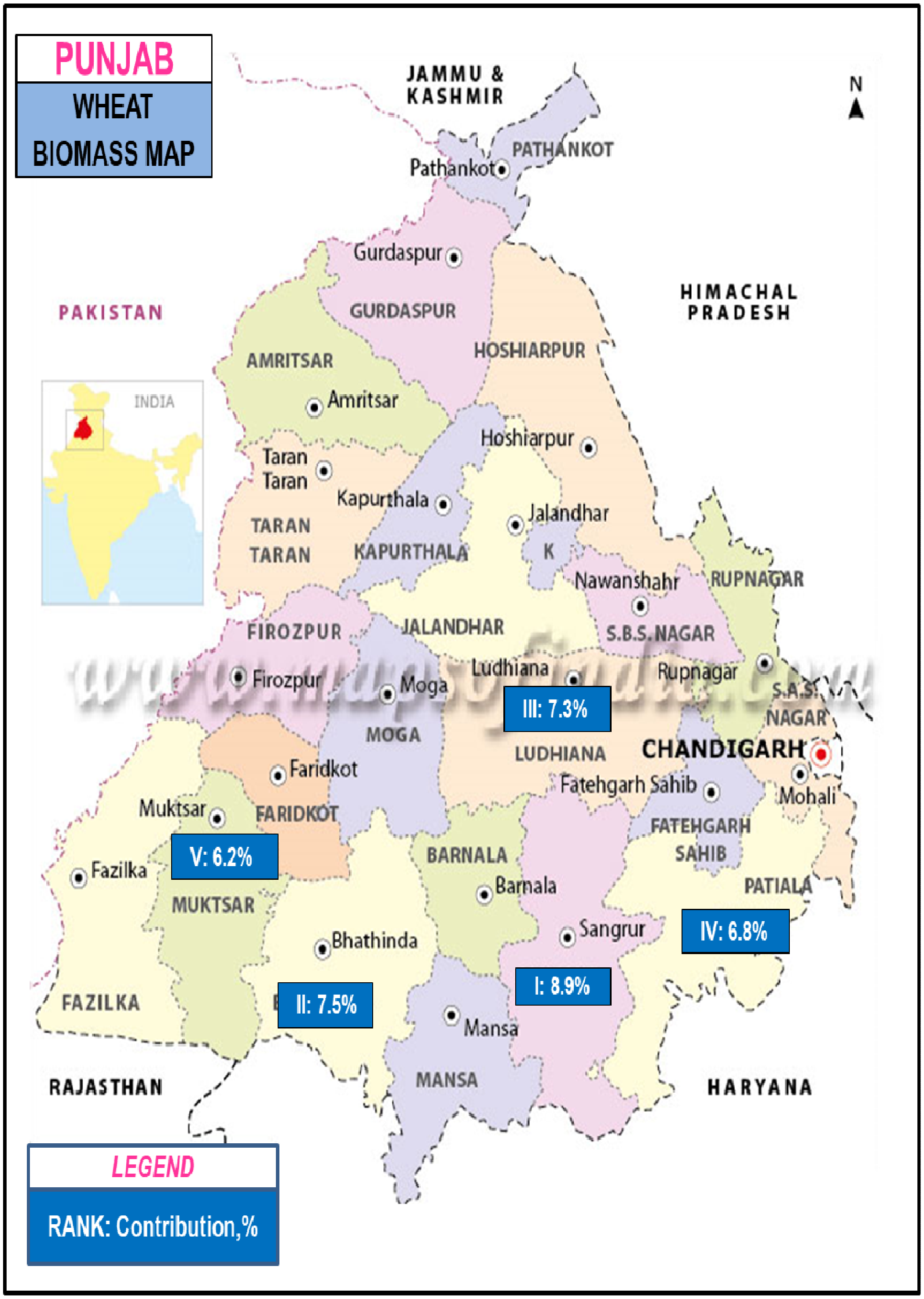
Table 4.9: District wise biomass potential of major crops, TE 2017-18

Paddy		Wheat		Cotton		Maize	
District	**% of Punjab**	**District**	**% of Punjab**	**District**	**% of Punjab**	**District**	**% of Punjab**
Sangrur	10.9	Sangrur	8.9	Bathinda	36.3	Hoshiarpur	47.3
Ludhiana	9.7	Bathinda	7.5	Fazilka	27.7	Rupnagar	18.2
Patiala	7.7	Ludhiana	7.3	Mansa	20.1	S.B.S. Nagar	8.1
Moga	6.8	Patiala	6.8	Sri Muktsar Sahib	11.8	Jalandhar	7.2
Firozpur	6.2	Sri Muktsar Sahib	6.2	Sangrur	2.2	S.A.S. Nagar	5.6
Jalandhar	5.5	Fazilka	5.8	Barnala	1.0	Pathankot	4.4
Bathinda	5.4	Firozpur	5.4	Faridkot	0.6	Ludhiana	3.5
Sri Muktsar Sahib	5.4	Amritsar	5.2	Patiala	0.3	Kapurthala	1.6
Tarn Taran	5.0	Moga	5.1	Gurdaspur	-	Fazilka	0.9
Amritsar	4.7	Tarn Taran	5.0	Pathankot	-	Patiala	0.9
Gurdaspur	4.5	Gurdaspur	5.0	Amritsar	-	Gurdaspur	0.6
Barnala	4.2	Mansa	5.0	Tarn Taran	-	Amritsar	0.6
Kapurthala	3.9	Jalandhar	4.7	Kapurthala	-	Sangrur	0.5
Faridkot	3.7	Hoshiarpur	3.5	Jalandhar	-	Tarn Taran	0.3
Mansa	3.4	Barnala	3.5	S.B.S. Nagar	-	Fatehgarh Sahib	0.3
Fatehgarh Sahib	3.1	Faridkot	3.4	Hoshiarpur	-	Firozpur	-
Fazilka	2.8	Kapurthala	2.9	Rupnagar	-	Faridkot	-
Hoshiarpur	2.2	Fatehgarh Sahib	2.5	S.A.S. Nagar	-	Sri Muktsar Sahib	-
S.B.S. Nagar	2.1	S.B.S. Nagar	2.2	Ludhiana	-	Moga	-
Rupnagar	1.3	Rupnagar	1.8	Firozpur	-	Bathinda	-
S.A.S. Nagar	0.9	S.A.S. Nagar	1.4	Moga	-	Mansa	-
Pathankot	0.7	Pathankot	1.0	Fatehgarh Sahib	-	Barnala	-
Punjab Biomass, '000t	**21435**		**30920**		**2526**		**1027**

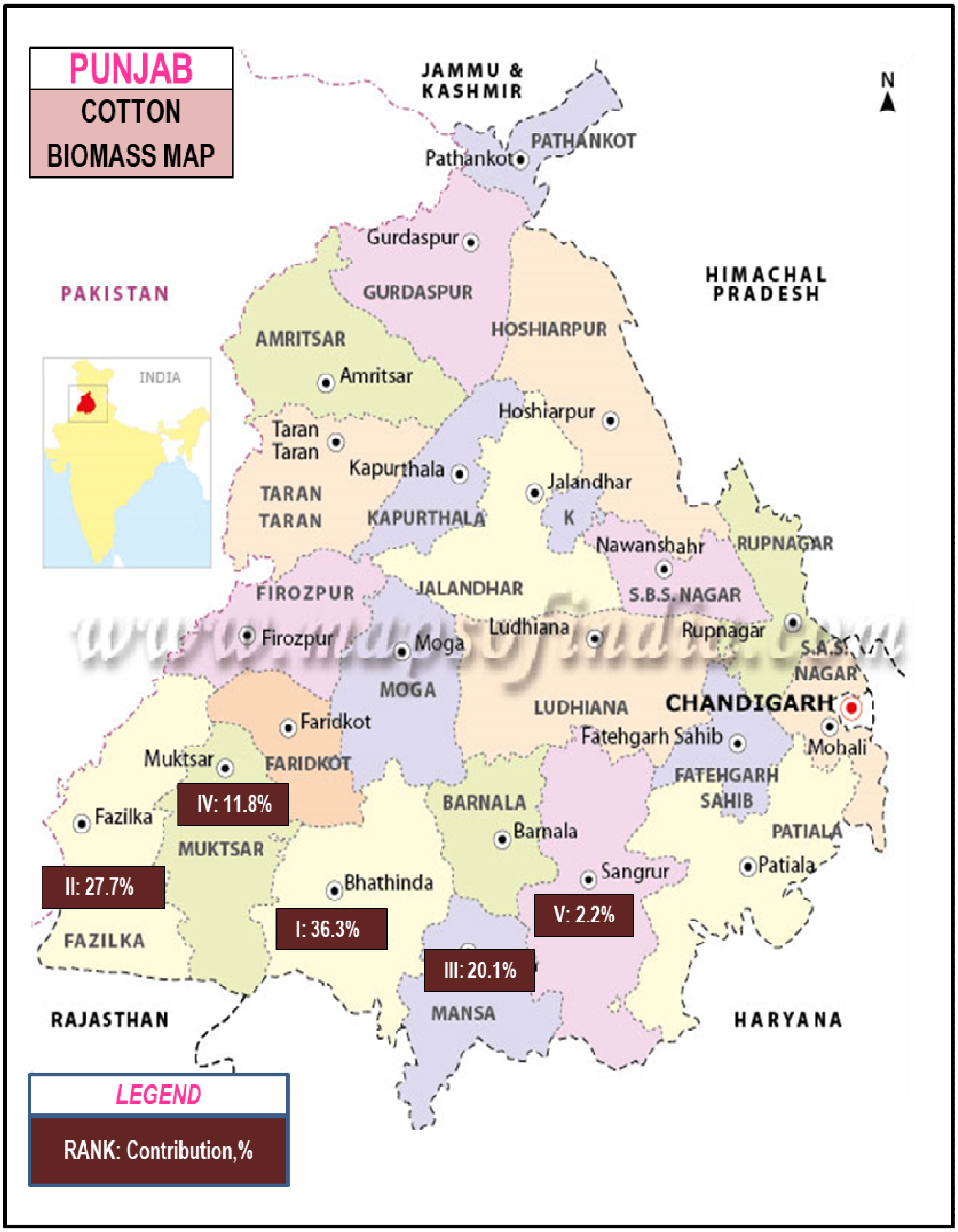
In the maps that follow, the top districts in terms of their contribution to the state potential of paddy, wheat, cotton and maize biomass have been presented for at-a-glance preview.



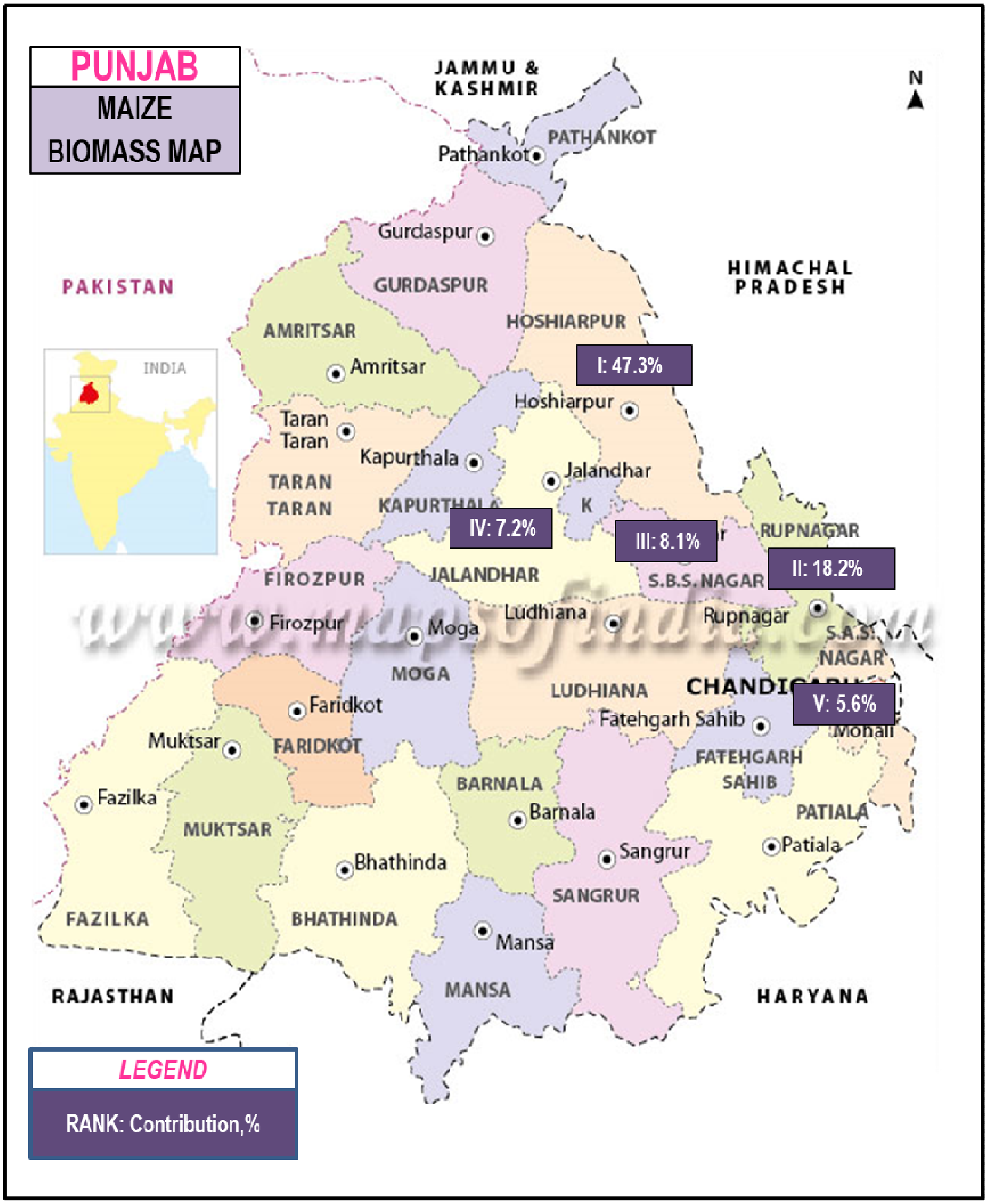
Map 4.2: Top five paddy biomass resource rich districts in Punjab



Map 4.3: Top five wheat biomass resource rich in districts in Punjab



Map 4.4: Top five cotton biomass resource rich districts in Punjab



Map 4.5: Top five maize biomass resource rich districts in Punjab

The entire cotton biomass potential of 2.5 million t has been found to concentrate in eight districts namely Bathinda, Fazilka, Mansa, Sri Muktsar Sahib, Sangrur, Barnala, Faridkot and Patiala (Map 4.4). As can be observed from the table that maize biomass is concentrated in 15 districts for the obvious reason that preference for paddy weighs very heavy on the rest of the districts to have completely relegated the maize crop. It can be readily observed that as much as 91 per cent of the 1 million t of maize biomass potential is concentrated in six districts (Hoshiarpur, Rupnagar, S.B.S. Nagar, Jalandhar, S.A.S. Nagar, and Pathankot) with district Hoshiarpur alone accounting for 47.3 per cent of the state's maize biomass potential (Map 4.5).

4.2.5. Crop-wise Spread of Biomass Potential in Major Producing Districts

The information about major contributing crops and the contribution in biomass generation thereof for selected districts of Punjab has been presented in Table 4.10. Only the top ranking districts with their contribution in total crop biomass generation of the state being more than five per cent have been presented in the said table.

Table 4.10: Top three contributing crops in major biomass rich districts, TE 2017-18

District@		Crop Biomass, '000t	Crop ranked			% of District Total
			I	II	III	
Sangrur	Crop		Wheat	Paddy	Cotton	
	'000t	5165.52	2736.6	2340.9	54.83	
	% share		53.0	45.3	1.1	99.4
Bathinda	Crop		Wheat	Paddy	Cotton	
	'000t	4412.39	2318.4	1165.63	916.11	
	% share		52.3	26.4	20.8	99.7
Ludhiana	Crop		Wheat	Paddy	Maize	
	'000t	4378.85	2244.60	2069.47	36.03	
	% share		51.3	47.3	0.8	99.4
Patiala	Crop		Wheat	Paddy	Maize	
	'000t	3770.81	2093.4	1640.5	9.2	
	% share		55.5	43.5	0.2	99.2
Sri Muktsar Sahib	Crop		Wheat	Paddy	Cotton	
	'000t	3369.04	1902.00	1163.37	297.57	
	% share		56.5	34.5	8.8	99.8
Fazilka	Crop		Wheat	Cotton	Paddy	
	'000t	3117.39	1781.40	698.62	591.60	
	% share		57.1	22.4	19.0	98.5
Moga	Crop		Wheat	Paddy	Mustard	
	'000t	3030.02	1578.6	1448.4	1.38	
	% share		52.1	47.8	0.05	99.9
Firozpur	Crop		Wheat	Paddy	Sunflower	
	'000t	3021.22	1678.8	1338.47	2.3	
	% share		55.6	44.3	0.1	99.9

@ accounting for ≥ 5 per cent of Punjab's biomass potential

The selected districts arranged in descending order of their contribution are Sangrur, Bathinda, Ludhiana, Patiala, Sri Muktsar Sahib, Fazilka, Moga and Firozpur. Wheat has been the top-ranking crop, its share in the respective district's total biomass generation being the lowest in Ludhiana district (51.3%) and the highest for Fazilka district (57.1%). Paddy has been observed as the second-highest contributing crop in the case of seven out of eight selected districts except for Fazilka. The cotton crop secured the second rank in the case of district Fazilka (with 22.4% share) and third rank in the case of Sangrur, Bathinda, Sri Muktsar Sahib, and Moga, contributing the highest (20.8%) in the district Bathinda's biomass potential of 4.4 million t. In the case of Sangrur, the most strategic district in terms of crop biomass potential, wheat, paddy, and cotton together account for 99.4 per cent of the potential, the share of three crops being, 53.0, 45.3 and 1.1 per cent respectively. In the case of Ludhiana, 51.3 per cent of potential is attributed to the wheat crop, 47.3 per cent to paddy, and a paltry 0.8 per cent to cotton. This type of analysis can be beneficial in making the necessary arrangements for the procurement of biomass by those who intend to make use of this resource for any of the diverse purposes.

4.3 AGRICULTURAL BIOMASS AVAILABILITY IN PUNJAB

As enunciated earlier, the biomass potential worked out for the state of Punjab for the period TE 2017-18 can't be translated into the energy potential because of certain restrictions imposed by the alternative uses of the agricultural residues at domestic and farm level. Thus the competitive uses of the agricultural biomass, which are specific to the crop and residue, need to be taken in to account to arrive at the quantity of biomass available for power conversion. The task of assessment of biomass available has been carried out by making use of surplus residue fraction (SF), the values for which have been culled from the available literature and given in Table 3.3 in Chapter III.

4.3.1 Crop-wise Surplus Agricultural Biomass Availability

It needs to be recapitulated that the agricultural biomass potential of Punjab for the TE 2017-18, the reference period of the study has been estimated at 56.4 million t. The availability of surplus agricultural biomass, which can be put to use for power generation has been estimated at 27.4 million t, out of which 22.9 million t (83.5%) is the quantity rendered surplus out of the field based residue generated (Table 4.11). The crop wise analysis of biomass surplus highlighted the prominence of paddy as the major contributor with 63 per cent share in total biomass available. It is contrary to that witnessed in case of biomass potential, wherein the contribution of wheat stood at 54.8 per cent (Table 4.7) attributable primarily to more competitive uses (animal feed, packing material, animal bedding, fuel etc.) of wheat residue than those of paddy residues. In terms of share in agricultural biomass available in Punjab, the paddy crop has been followed by wheat (28%), cotton (5%) and maize (3%) together accounting for 99.2 per cent of the biomass ascertained as surplus after accounting for the competitive usage. It underlines the insignificant role of the rest of the crops, which doesn't come as a surprise in the case of Punjab agriculture, which has over the years become synonymous with rice-wheat system. Narrowing down to paddy and wheat crop, it comes to the fore that these two crops made up for 91.3 per cent of the surplus biomass, out of which 85 per cent is field based. In other words, on-farm paddy and wheat residues (21.2 million t) account for 77.5 per cent of the biomass available for power generation.

Table 4.11: Crop wise surplus biomass availability in Punjab, TE 2017-18

District	On-Farm		Processing		Total	
	'000t	% of District total	'000t	% of District total	'000t	% of State total
Paddy	16076.05	93.0	1202.87	7.0	17278.92	63.10
Wheat	5153.30	66.7	2576.65	33.3	7729.95	28.23
Cotton	751.85	53.9	644.22	46.1	1396.08	5.10
Maize	669.50	87.0	99.76	13.0	769.26	2.81
Sugarcane	140.76	100.0	-	-	140.76	0.51
Barley	32.83	100.0	-	-	32.83	0.12
Mustard	22.90	100.0	-	-	22.90	0.084
Sunflower	6.02	100.0	-	-	6.02	0.022
Arhar	2.53	100.0	neg	-	2.53	0.009
Gram	1.78	100.0	-	-	1.78	0.007
Ground nut	1.04	71.4	0.42	28.6	1.46	0.005
Sesamum	1.12	100.0	-	-	1.12	0.004
Moong	0.48	100.0	neg	-	0.48	0.002
Bajra	0.09	45.5	0.11	54.5	0.21	0.001
Mash	0.11	100.0	neg	-	0.11	0.0004
Total	**22860.35**	**83.5**	**4524.02**	**16.5**	**27384.37**	**100.00**

Neg : negligible

The literature is replete with the studies resonating with the foregoing discussion on the importance of paddy straw for the purpose of conversion to bio-energy in the case of Punjab. According to the study conducted by Singh *et al* (2003), the residue straw of wheat and rice was available in abundance in the Punjab state with a contribution of 74.81% to the total crop residue production, which could be used to fulfill as much as 15 per cent of the total energy requirements of the state. Singh *et al* (2008) found that 83.5% of the rice straw was surplus in the state of Punjab. It was also revealed by the researchers that the wheat straw was commonly used as animal feed in almost all the parts of the state, while the farmers did not prefer rice straw as dry fodder due to its high silica content, which was unsuitable for animal consumption (Hiloidhari *et al* 2011).

4.3.2 District wise surplus biomass availability

As highlighted earlier in the previous section, the annual availability of biomass after accounting for the possible usage has been recorded 27.4 million t at the state level, out of which 83.5 per cent is accessible at the field and the remaining (16.5%) constitutes the processing level residues (Table 4.12).

Table 4.12: District wise surplus biomass availability in Punjab, TE 2017-18

District	On-Farm		Processing		Total	
	'000t	% of District total	'000t	% of District total	'000t	% of State total
Sangrur	2246.55	85.7	373.50	14.3	2620.05	9.6
Ludhiana	1961.81	86.5	306.69	13.5	2268.49	8.3
Bathinda	1522.28	75.2	503.30	24.8	2025.58	7.4
Patiala	1596.11	85.5	269.60	14.5	1865.71	6.8
Sri Muktsar Sahib	1281.51	81.1	299.55	18.9	1581.06	5.8
Moga	1350.71	86.4	212.83	13.6	1563.54	5.7
Firozpur	1284.66	85.7	215.01	14.3	1499.67	5.5
Jalandhar	1185.75	85.9	194.36	14.1	1380.10	5.0
Fazilka	976.61	73.2	356.73	26.8	1333.34	4.9
Mansa	974.31	76.9	292.84	23.1	1267.15	4.6
Tarn Taran	1060.98	84.8	189.94	15.2	1250.92	4.6
Amritsar	1032.04	84.4	191.29	15.6	1223.33	4.5
Gurdaspur	1019.43	84.7	183.69	15.3	1203.12	4.4
Hoshiarpur	885.40	84.3	164.65	15.7	1050.05	3.8
Barnala	866.96	85.5	146.88	14.5	1013.84	3.7
Faridkot	783.95	85.1	137.46	14.9	921.41	3.4
Kapurthala	792.15	86.5	123.88	13.5	916.03	3.3
Fatehgarh Sahib	640.42	86.2	102.15	13.8	742.57	2.7
S.B.S Nagar	514.91	85.2	89.65	14.8	604.55	2.2
Rupnagar	436.40	84.4	80.70	15.6	517.10	1.9
S.A.S Nagar	254.55	83.0	52.02	17.0	306.57	1.1
Pathankot	192.87	83.8	37.33	16.2	230.20	0.8
Punjab	**22860.35**	**83.5**	**4524.02**	**16.5**	**27384.37**	**100.0**

As per the TE 2017-18 figures, the district Sangrur was at the top with the highest surplus agricultural biomass (2.6 million t) translating to a little less than one-tenth (9.6% to be precise) of the availability at the state level. As regards the regional spread of surplus biomass is concerned, there were as many as eight districts, accounting for five or more than five per cent of biomass availability at the state level.

These districts in descending order of their contribution to state's surplus crop biomass have been Sangrur with 9.6 per cent followed by Ludhiana (8.3%), Bathinda (7.4%), Patiala (6.8%), Sri Muktsar Sahib (5.8%), Moga (5.7%), Firozpur (5.5%) and Jalandhar with five per cent. These eight districts collectively accounted for 54 per cent of the biomass available at the state level attributed to the larger net sown area and higher productive potential of these districts compared to the rest of the districts. There were as many as five districts namely, Fatehgarh Sahib, S.B.S. Nagar, Rupnagar, S.A.S. Nagar and Pathankot at the bottom ebb of the contribution scale together contributing 8.7 per cent and individually contributing 2.7, 2.2, 1.9, 1.1 and 0.8 per cent respectively to the biomass available for power generation.

The contribution of the processing based residue estimated at 4.5 million t per annum during TE 2017-18 in the state, stood at 16.5 per cent to the total biomass available. The corresponding contribution has been recorded as the highest in the case of district Fazilka (26.8%), followed by Bathinda (24.8%) and Mansa (23.1%) and in the rest of the districts, it ranged between 13 to 18 per cent.

The findings of the study were in line with the findings of Chauhan (2012), which also brought forth that among all the districts of Punjab state, Sangrur district had the highest availability of agricultural biomass (13.14 per cent) due to large agricultural land followed by that in Firozpur (11.49%) and Ludhiana districts (10%). The district Rupnagar has been reported as the one with the least surplus potential of 1.73 per cent.

4.3.3 Narratives of On-farm Biomass Availability

The use of biomass in the energy sector is being increasingly propagated but the efforts to use it to its utmost potential have seen more failures than successes due to several challenges. The issue of logistics of biomass collection because of its bulkiness and being scattered is the major barrier in this regard. The present study in this context hypothesizes that the true potential of biomass for its effective use in the energy sector lies in focusing only on the on-farm biomass available. The present section, therefore, attempts to delve into the narratives of the crop biomass available on the farm in detail.

Table 4.13: District wise biomass potential-availability-connect TE 2017-18

District	Biomass production ’000t	Biomass surplus availability		
		’000t	as % of production	t/ha
Gurdaspur	2234	1019	45.6	2.65
Pathankot	432	193	44.7	2.31
Amritsar	2258	1032	45.7	2.73
Tarn Taran	2244	1061	47.3	2.86
Kapurthala	1523	792	52.0	3.40
Jalandhar	2359	1186	50.3	3.31
S.B.S. Nagar	1062	515	48.5	3.35
Hoshiarpur	1841	885	48.1	2.91
Rupnagar	896	436	48.7	3.33
S.A.S. Nagar	584	255	43.7	2.84
Ludhiana	3756	1962	52.2	3.77
Firozpur	2584	1285	49.7	3.42
Fazilka	2362	977	41.4	2.37
Faridkot	1603	784	48.9	3.38
Sri Muktsar Sahib	2747	1282	46.7	3.09
Moga	2596	1351	52.0	3.79
Bathinda	3345	1522	45.5	3.01
Mansa	2172	974	44.8	2.89
Sangrur	4403	2247	51.0	3.88
Barnala	1712	867	50.6	3.76
Patiala	3223	1596	49.5	3.39
Fatehgarh Sahib	1255	640	51.0	3.66
Punjab	47190	22860	48.5	3.22

The perusal of Table 4.13, which portrays the crucial facets of district wise biomass potential-availability-connect, bring forth that the proportion of crop biomass available on the farm for energy purposes (22.8 million t) stands at a little less than half (48.5%) of the corresponding theoretical biomass potential (47.2 million t) of the state. This particular proportion varied from 41.4 per cent in the case of district Fazilka to 52.2 per cent in Ludhiana.

It is pertinent to mention here that this proportion, is a catch-all factor encompassing the effect of differentials in cropped area, cropping pattern and crop management practices translating into the productive performance differentials as reflected in the variations observed over the districts. The justification for this lies in the use of uniform RPRs and the SFs for the state-wide assessment of biomass potential and its availability for energy purposes. The availability of surplus biomass per unit of the cropped area stood at 3.22 t/ha at the state level. It was observed that district Sangrur, lying at the top in terms of both potential and available agricultural biomass (4.40 and 2.25 million t respectively) had 3.88 t of biomass available per hectare.

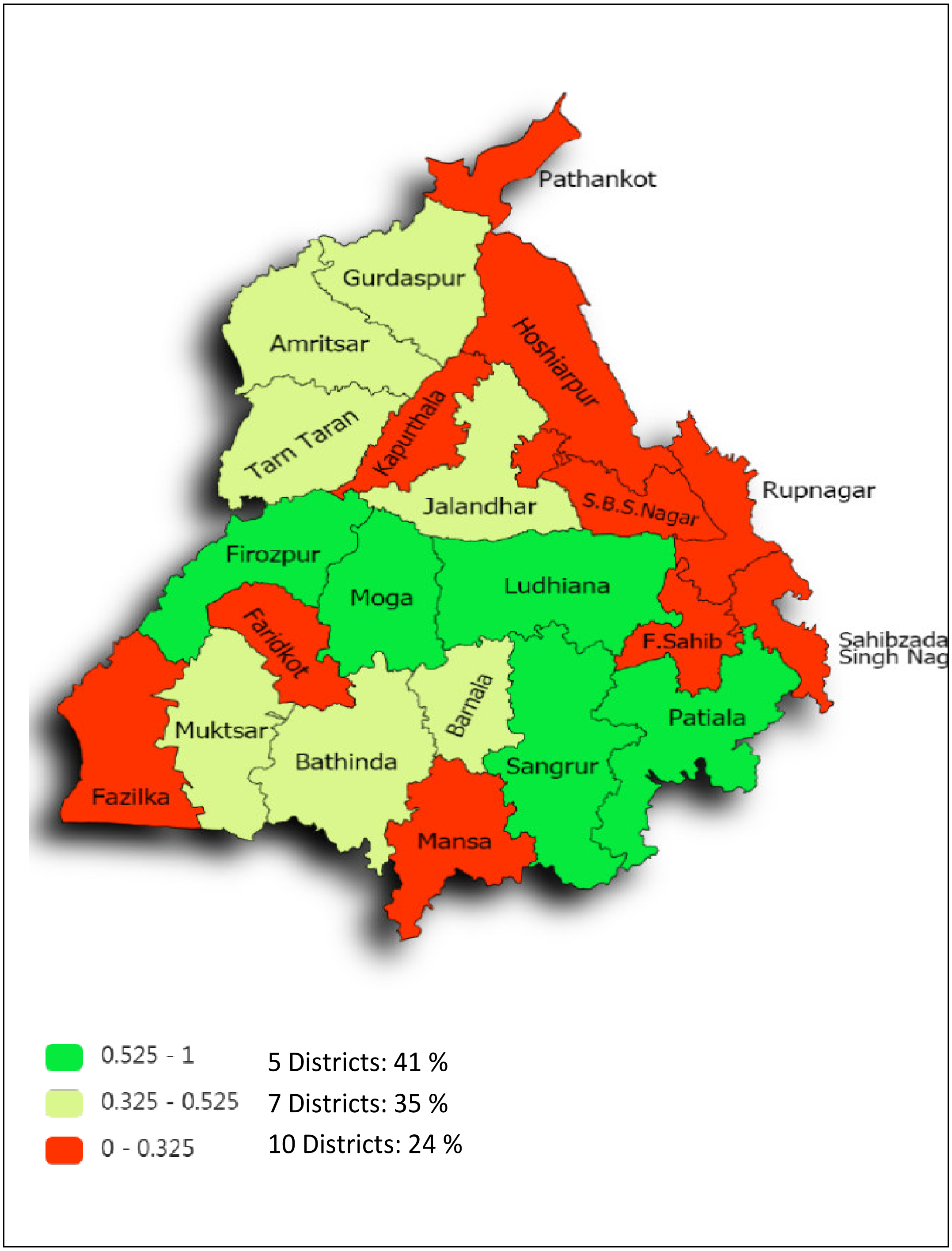
The district Sangrur was followed by Moga with 3.79 t/ha, Ludhiana with 3.77 t/ha, Barnala with 3.76 t/ha and Fatehgarh Sahib with 3.66 t/ha. The other districts with biomass available per unit of land area higher than the state average of 3.22 t/ha have been identified as Firozpur, Kapurthala, Patiala, Faridkot, S.B.S. Nagar, Rupnagar and Jalandhar with available biomass tonnage per hectare being more or less being the same, the absolute values lying between 3.31 to 3.42 t/ha. In the case of district Pathankot, having the lowest biomass potential and availability, the per hectare availability of surplus biomass has been recorded at 2.31t. Apart from Pathankot, the districts having per unit surplus biomass availability of less than 3 per cent were observed to be Fazilka (2.37 t/ha), Gurdaspur (2.65 t/ha), Amritsar (2.73 t/ha), S.A.S. Nagar (2.84 t/ha), Tarn Taran (2.86 t/ha), Mansa (2.89 t/ha) and Hoshiarpur (2.91 t/ha). It is envisaged that this analysis can go a long way in easing out the biomass collection issues.

The foregoing discussion boils down to a crucial narrative of on-farm biomass availability in Punjab that two major crops of Punjab i.e. paddy and wheat together account for 92.9 per cent of the state's surplus biomass available and addition of cotton and maize biomass increases the percentage to 99.1 per cent. It was therefore considered imperative to have an in-depth analysis of the regional spread of the surplus biomass originating from these four crops. The information on this aspect has been presented in Table 4.14 with the districts arrayed in descending order of magnitude of crop biomass available.

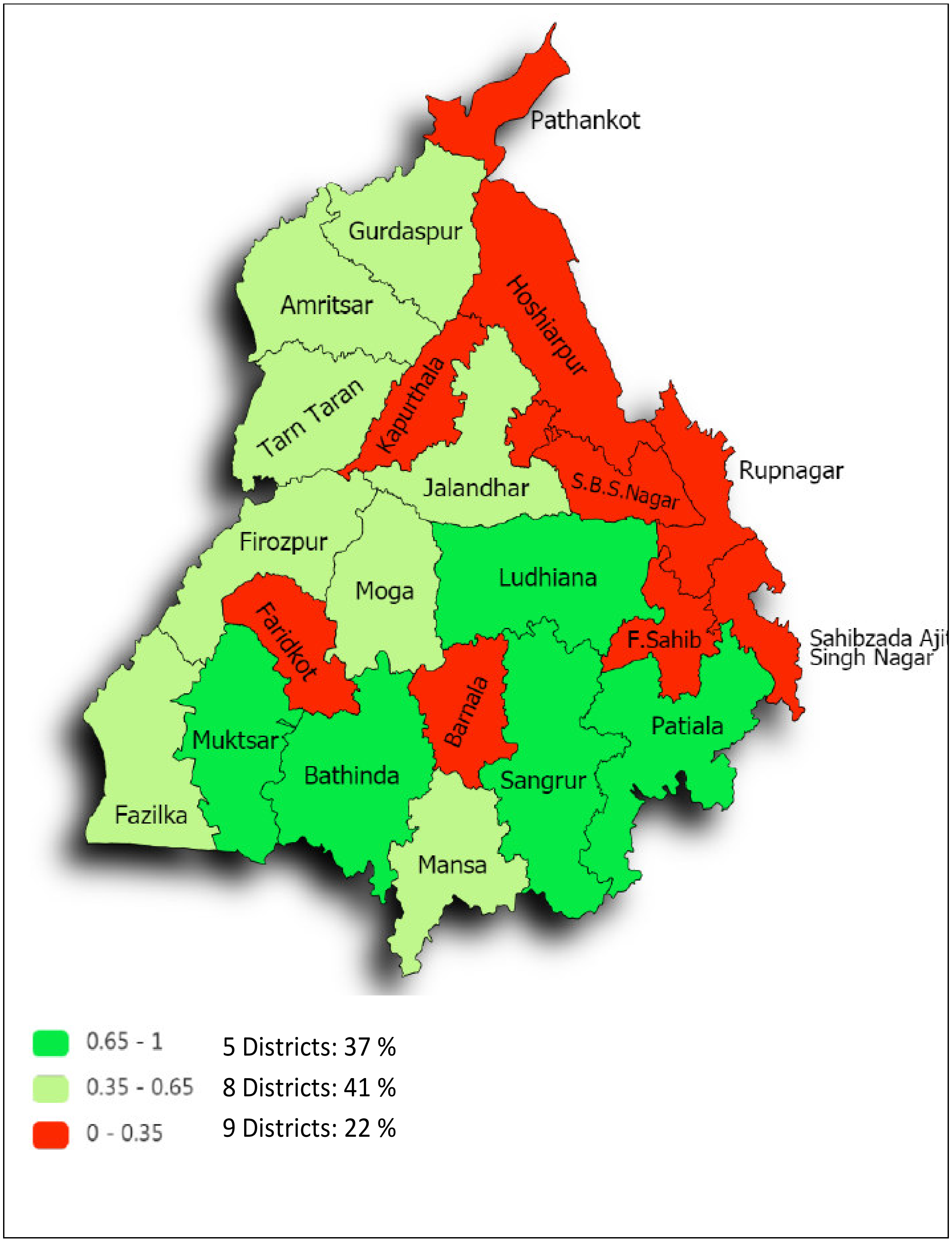
Table 4.14: District wise on-farm biomass surplus for major crops, TE 2017-18

District	On-farm Biomass Surplus, '000t					P+W % of T	P+W+C+M % of T
	Total T	Paddy P	Wheat W	Cotton C	Maize M		
Sangrur	2247	1756	456	17	4	98.5	99.4
Ludhiana	1962	1552	374		24	98.2	99.4
Patiala	1596	1230	349	3	6	98.9	99.5
Bathinda	1522	874	386	256	-	82.8	99.6
Moga	1351	1086	263	-	-	99.9	99.9
Firozpur	1285	1004	280	-	-	99.9	99.9
Sri Muktsar sahib	1282	873	317	89	-	92.8	99.7
Jalandhar	1186	877	243	-	48	94.5	98.5
Tarn Taran	1061	798	260	-	2	99.7	99.9
Amritsar	1032	750	269	-	4	98.7	99.1
Gurdaspur	1019	723	258	-	4	96.2	96.6
Fazilka	977	444	297	214	6	75.8	98.4
Mansa	974	554	256	161	-	83.1	99.6
Hoshiarpur	885	350	182	-	317	60.0	95.8
Barnala	867	677	180	8	-	98.7	99.7
Kapurthala	792	623	151	-	11	97.8	99.1
Faridkot	784	601	177	5	-	99.3	99.9
Fatehgarh Sahib	640	503	128	-	2	98.6	98.9
S.B.S Nagar	515	337	113	-	54	87.4	97.9
Rupnagar	436	215	93	-	122	70.6	98.6
S.A.S Nagar	255	143	72	-	38	84.2	98.9
Pathankot	193	107	50	-	30	81.2	96.5
Punjab	**22860**	**16076**	**5153**	**752**	**670**	**92.9**	**99.1**

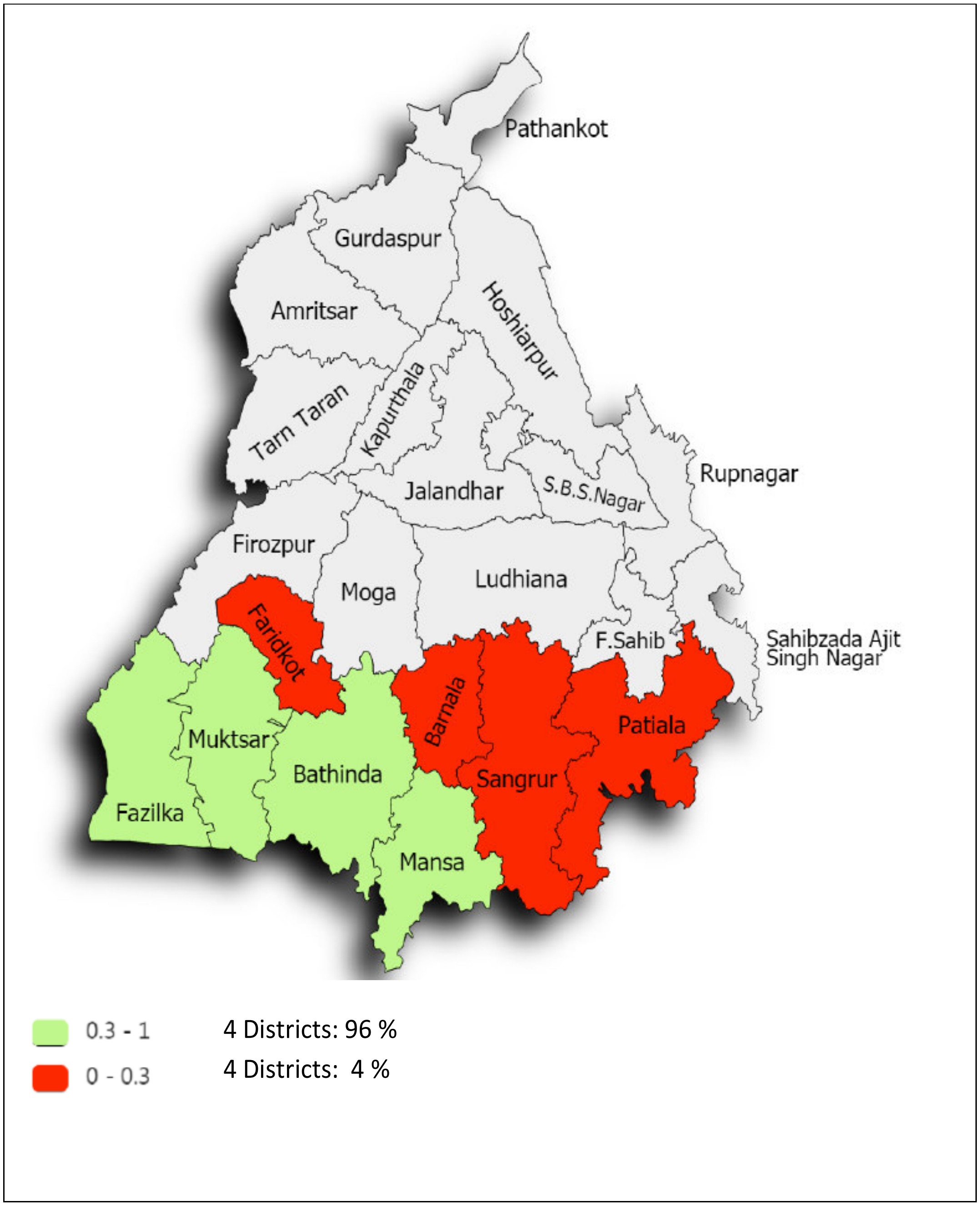
It is reiterated that in 22.9 million t of field-based crop biomass available to harness the energy, the maximum contribution was that of paddy crop (70.3%), followed by wheat (22.5%), cotton (3.3%) and maize (2.9%). The information presented in the table highlights the typicality of districts due primarily to the cropping pattern adopted therein. The districts can be categorized into three groups based on the number of crops, which will have to be focused upon to harness the power for available biomass to exploit its power potential. The maps that follow highlight the spatial spread of paddy, wheat, cotton and maize crop in a self-explanatory manner. In these maps, the district-specific biomass availability indices (details in Chapter III) have been plotted to pinpoint the districts with a high concentration of biomass.



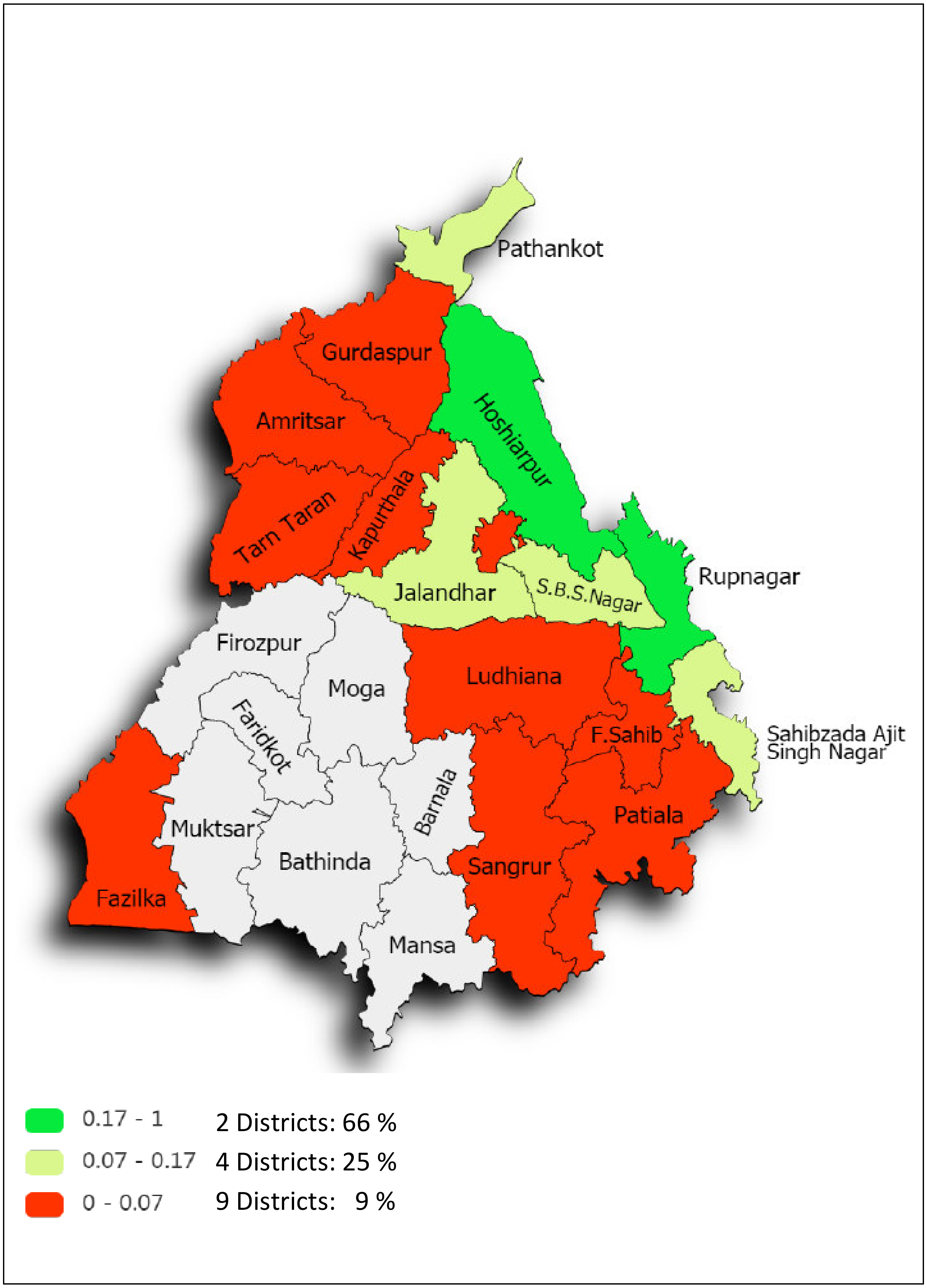
Map 4.6: District wise spread of on-farm biomass availability of paddy in Punjab



Map 4.7: District wise spread of on-farm biomass availability of wheat in Punjab



Map 4.8: District wise spread of on-farm biomass availability of cotton in Punjab



Map 4.9: District wise spread of on-farm biomass availability of maize in Punjab

The first category includes the districts of Moga and Firozpur in it, whereby only two crops i.e. paddy and wheat together account for 99.9 per cent of the biomass available in the respective districts. Another category includes the districts; Sangrur, Patiala and Fazilka, that warrant focus on all the four crops to exploit the maximum biomass available. The four crops together accounted for 99.4 per cent of crop biomass available in district Sangrur, 99.5 per cent in district Patiala and 98.4 per cent in district Fazilka. The rest of the 17 districts were marked by the prominence of three crops i.e. paddy, wheat and cotton in the case of five districts and paddy, wheat and maize in another 12 districts. The share of three crops; paddy, wheat and cotton/maize, in on-farm biomass availability in the above said districts ranged from 95.8 per cent in district Hoshiarpur to as high as 99.9 per cent in case of Tarn Taran and Faridkot district. The districts, wherein the contribution of paddy and wheat crops to the available biomass has been conspicuously low were Fazilka (75.8%), Rupnagar (70.6%) and Hoshiarpur (60%), the reason being the cultivation of cotton in Fazilka district and maize in Rupnagar and Hoshiarpur districts.

4.4 Assessment of biomass energy potential in Punjab

In the present study, an attempt was made to assess the energy potential of agricultural biomass available in Punjab for the reference period TE 2017-18. As discussed in the previous section the quantity of field-based biomass that the agriculture sector of Punjab can offer for power generation stands at 22.9 million t, which is 83.5 per cent of the 27.4 million t of total biomass rendered surplus after accounting for the other competitive uses the crop biomass has. The biomass energy potential has been ascertained crop-wise as well as district wise and presented in the following sub-sections.

4.4.1 Crop wise energy potential

The information about the energy equivalent of the power potential of agricultural biomass in Punjab has been presented crop-wise in Table 4.15. It can be readily observed from the table that 22.9 million t of on-farm biomass available in TE 2017-18 had the potential to produce energy to the tune of 358234 TJ out of which as high as 92 per cent is accounted for by paddy and wheat and 98.9 per cent by four major crops i.e., paddy, wheat, cotton and maize taken together. The simultaneous perusal of Table 4.11 and 4.15 highlighted that paddy accounting for 70.3 per cent of the on-farm biomass available at the state level can potentially produce 67.4 per cent of energy as against 24.6 per cent from the wheat residue, which made up for a comparatively smaller proportion (22.5%) in biomass available in the state. This can be attributed to the higher calorific value of wheat straw compared to that of rice straw. The rest of the crops together accounted for a meager 1.1 per cent of the energy pointing towards the futility of arranging for their collection to be used as feedstock for the biomass-based power plants. The analysis has brought forth the potential of paddy and wheat straw, which is quite significant to be ignored.

Table 4.15: Crop wise energy potential in Punjab, TE 2017-18

District	Energy, TJ	% of total
Paddy	241623.03	67.448
Wheat	88379.10	24.671
Cotton	13082.24	3.652
Maize	11160.57	3.115
Sub Total	**354244.93**	98.886
Sugar cane	2815.20	0.786
Barley	561.38	0.157
Mustard	389.23	0.109
Sunflower	105.53	0.029
Arhar	46.91	0.013
Gram	28.53	0.008
Ground nut	14.98	0.004
Sesamum	16.07	0.004
Moong	7.95	0.002
Bajra	1.69	0.000
Mash	1.70	0.000
Total	**358234.11**	100.000

The findings of the study were in agreement with the findings of Singh (2015) which showed that cereal crops (rice, wheat, maize and barley) were having a maximum contribution to the available bioenergy potential (2.6×10^{11} MJ) of the Punjab state.

4.4.2 District wise energy potential

This section provides an insight into the district wise energy potential of the available agri-biomass. It can be readily observed that out of the energy potential enumerated at 358234 TJ at the state level, Sangrur district had the maximum energy potential (34825 TJ) accounting for 9.7 per cent of the state total, followed by Ludhiana (8.5%), Patiala (6.9%), Bathinda (6.6%) and Moga (5.8%) (Table 4.16).

Table 4.16: District wise energy potential in Punjab, TE 2017-18

District	Energy, TJ	% of State total
Sangrur	34825	9.7
Ludhiana	30357	8.5
Patiala	24773	6.9
Bathinda	24317	6.8
Moga	20862	5.8
Sri Muktsar sahib	20150	5.6
Firozpur	19903	5.6
Jalandhar	18500	5.2
Tarn Taran	16505	4.6
Amritsar	16128	4.5
Gurdaspur	16042	4.5
Fazilka	15867	4.4
Mansa	15574	4.3
Hoshiarpur	14383	4.0
Barnala	13441	3.8
Kapurthala	12278	3.4
Faridkot	12172	3.4
Fatehgarh Sahib	9930	2.8
S.B.S Nagar	8115	2.3
Rupnagar	6981	1.9
S.A.S Nagar	4049	1.1
Pathankot	3083	0.9
Punjab	358234	100.0

These top five districts together contributed 38 per cent to the energy potential of the state. The top ten districts collectively made up for 63 per cent of the state's biomass energy potential. The thorough perusal of the figures highlighted that as high as 84 per cent of the energy potential of the state could be harnessed by the use of biomass available with top 15 districts, which included Sangrur, Ludhiana, Patiala, Bathinda, Moga, Sri Muktsar Sahib, Firozpur, Jalandhar, Tarn Taran, Amritsar, Gurdaspur, Fazilka, Mansa, Hoshiarpur and Barnala (Figure 4.4). The districts lying at the lower ebb in terms of their contribution were Kapurthala and Faridkot both accounting for 3.4 per cent each, followed by Fatehgarh Sahib (2.8%), S.B.S. Nagar (2.3%), Rupnagar (1.9%), S.A.S. Nagar (1.1%) and Pathankot with a meager 0.9 per cent contribution lying at the bottom. Similar studies were conducted by Chauhan (2012) and Singh *et al* (2008) which also showed that Sangrur and Firozpur districts were at the top in terms of energy potential.

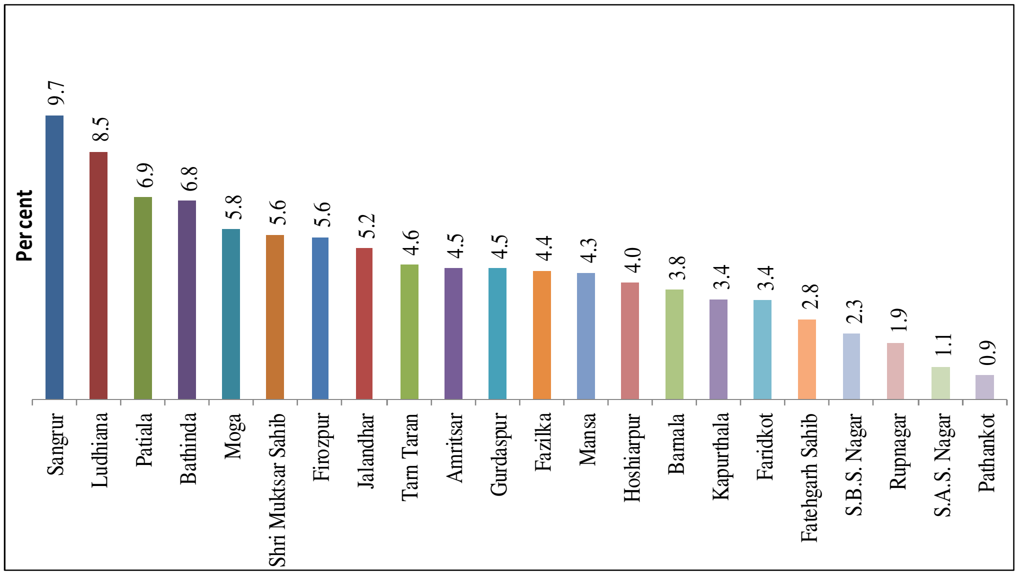


Figure 4.4: District wise share (%) in the energy potential of on-farm surplus biomass

As regards the district wise energy potential per unit of cropped area, quite pronounced variations were observed within the districts. It ranged from 36.9 GJ/ha in the case of district Pathankot to as high as 60.1 GJ/ha in Sangrur.

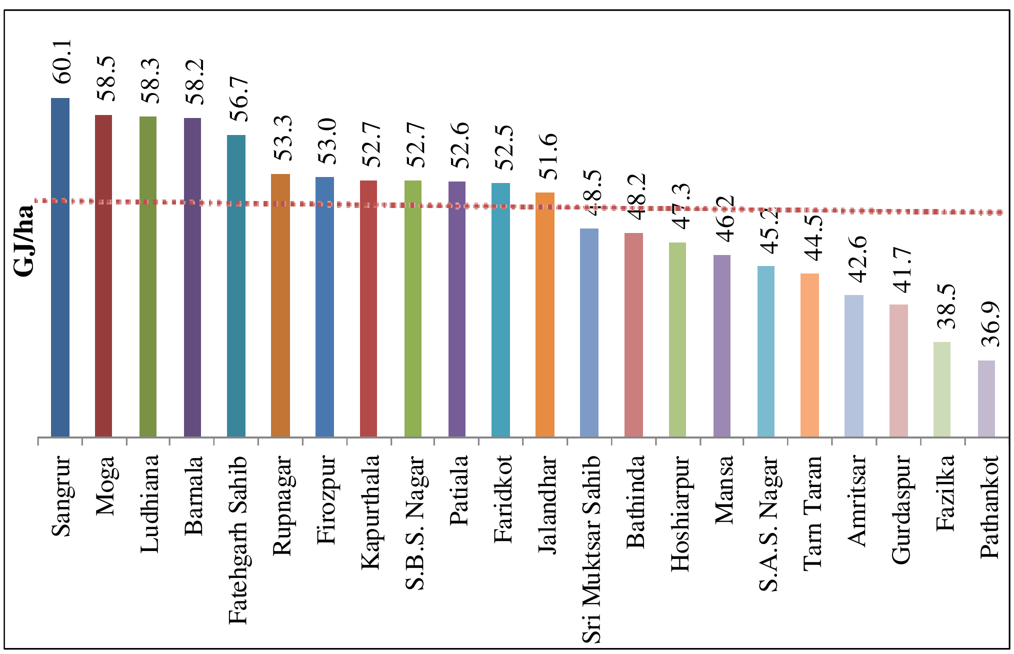
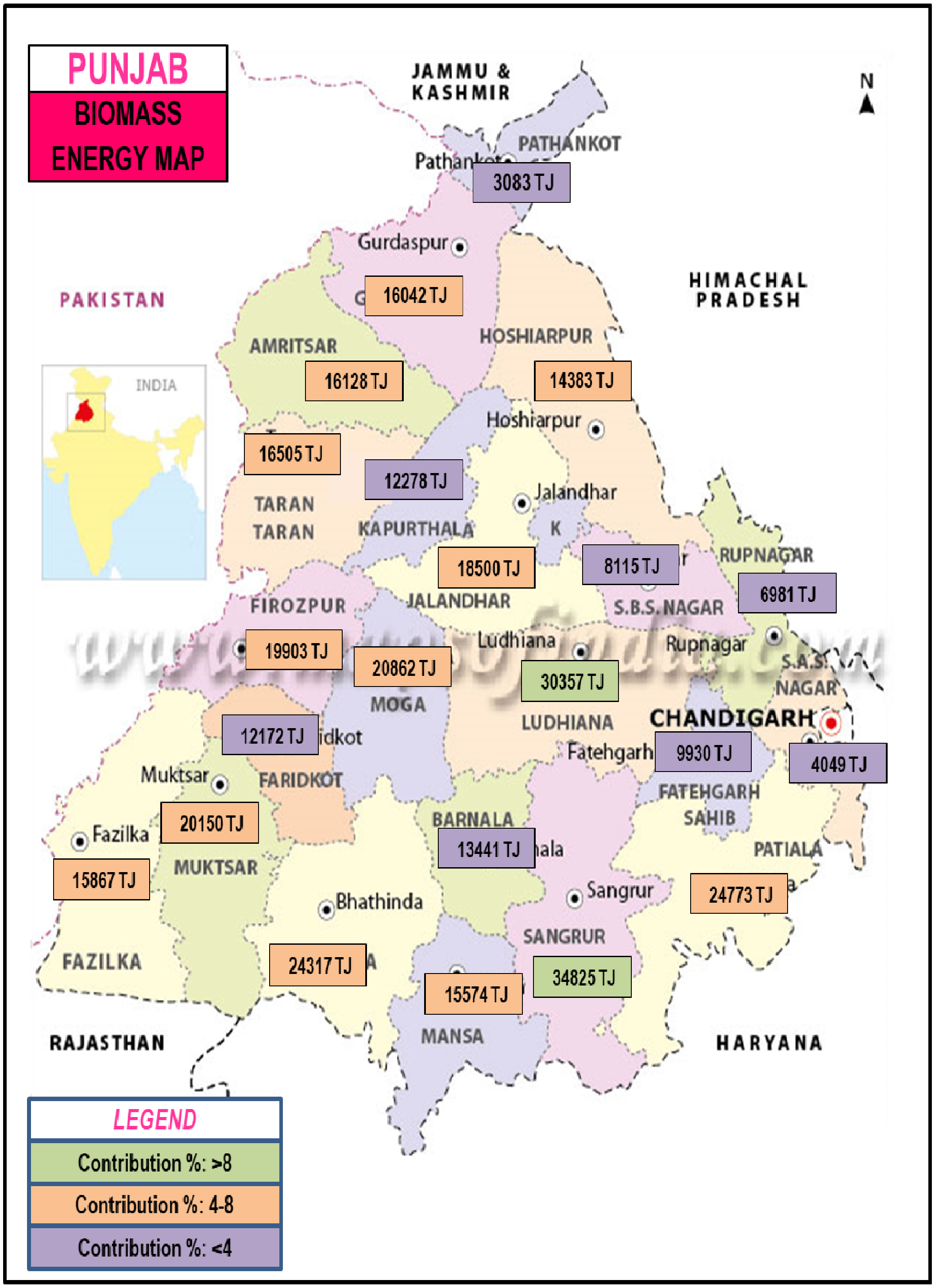


Figure 4.5 District wise energy potential of on-farm crop biomass, GJ/ha of GCA

There were as many as ten districts that had energy potential per ha of the cropped area being even less than the state average of 50.5 GJ/ha (Figure 4.5).



Map 4.10: District wise on-farm biomass energy potential in Punjab

4.4.3 Harnessing the Biomass Energy Potential of Punjab

As highlighted in the foregoing discussion, the energy potential of the available biomass of paddy (P), wheat (W), cotton (C) and maize (M) has been estimated as 241.6 PJ, 88.4 PJ, 13.1PJ and 11.2PJ, with paddy as the highest contributor to the state's biomass energy potential accounting for as high as 67.4 per cent. The paddy and wheat crops together account for 92.1 per cent of the total energy potential of Punjab. Only 6.8 per cent of the energy potential was contributed by maize and cotton crops taken together. In other words, 92.1 per cent of the state's biomass energy potential can be harnessed by focusing only on two major crops i.e. paddy and wheat and inclusion of cotton and maize can increase the proportion of potential harnessed to 98.9 per cent. The figure that follows is the outcome of the district-wise analysis, which brings forth that given the concentration of biomass spread in the state, 37.5 per cent of the energy potential can be harnessed by focusing only on the top biomass resource-rich districts of Sangrur, Ludhiana, Patiala, Bathinda and Moga.

Focus on paddy, wheat, cotton, and maize	Focus on paddy and wheat

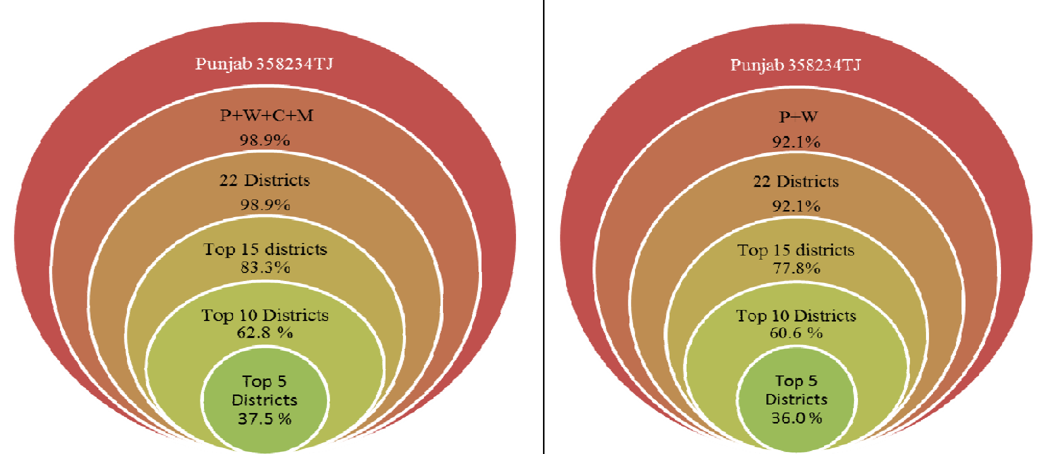


Fig 4.6: Plan for harnessing the energy potential of on-farm biomass available in Punjab

It is further highlighted that as much as 36 per cent of the potential can still be tapped if the focus is restricted to the collection of paddy and wheat residue alone. Going a step further schematically, it was ascertained that increasing the focus to top ten districts (details of the districts in Table 4.16) and that too to paddy and wheat alone, can help the bio-energy conversion units tap 61 per cent of the potential. The top 15 districts can serve the purpose of fulfilling the requirement of biomass for harnessing as high as 77.8 per cent of state's energy potential, which can increase to 83.3 per cent if the necessary arrangements are put in place for the collection of cotton and maize biomass as well from these 15 districts only. It is envisaged that this analysis would go a long way in giving a concrete shape to the state's energy policy.

4.5 Inventory of agricultural biomass management options

The biomass generated at the farm level can be managed by two approaches i.e.

i. In- situ management

ii. ex-situ management

The discussion that follows focuses on these two management approaches and gives an overview of the options available for the management of biomass under these two approaches (Fig 4.7).

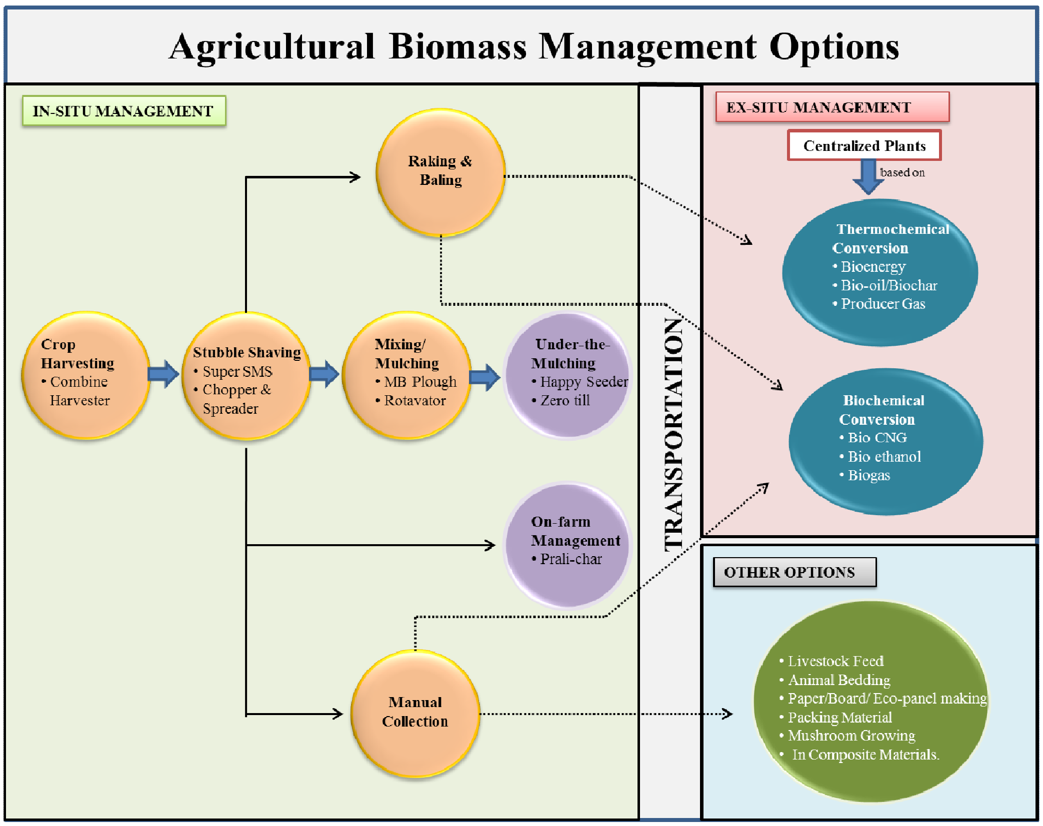


Figure 4.7: The flow of crop residues management options

4.5.1 In-situ Management

In-situ means "in the natural or original position or place" (Merriam-Webster, 2020). In-situ management of biomass implies that the biomass generated on-farm will be managed at the farm itself in a sustainable form. The in-situ management options have been detailed as under:

4.5.1.1 Incorporation and mulching of biomass

The agricultural biomass is a rich source of various nutrients and organic carbon, which makes them a fascinating option for their use as fertilizers. However, the quantum, form, and bulky nature of biomass restrict the use of such options. Of late, various machinery and techniques have been developed, which if deployed can overcome this problem. The agricultural biomass can thereby be directly incorporated, mulched, or used to prepare biochar that can serve as fertilizers and soil health boosters.

Agricultural equipment such as straw chopper, super straw management system, mulcher cum spreader, rotavators, reversible MB plough, etc. can be used for incorporating or mulching agricultural residues while Happy seeder and zero-till seed drill, etc. are to be used for efficient sowing of next crop. Continuous incorporation of crop residues (usually rich in the organic nutrient) over the 3-4 years increases the soil fertility, productivity, and crop yield while tackling the issue of post-harvest residue management (CII-NITI Aayog 2018). In mulching, "A layer of biomass is added to the surface of the soil that suppresses weeds and prevents water loss through evaporation from the soil. The organic biomass such as paddy straw can be used as organic mulches instead of fabric sheet or inorganic mulches (CITE, 2008) that results in reduced usage of fertilizers, irrigation, and higher yield. In Punjab, happy seeder with CH-SMS (combine harvester along with super straw management system) is recommended to cut the paddy straw into small pieces and spread the same in the field (*Kharif* 2019). The use of agricultural equipment (such as Happy Seeder) for biomass incorporation was also emphasized to state farmers for enhancing soil quality and yield as reported in The Tribune (Nov 11, 2019). During the year 2005-2008, PAU has conducted 17 different experiments at different locations in the state to evaluate the effect of Happy Seeder technology. The study revealed yield enhancement to the tune of 7 to10 per cent in happy seeder sown fields as compared to no-tillage conventional system (Singh *et al* 2009). A study was conducted and reported in CII Foundation Project Report (2019), which included 60 farmers and 522 acres agricultural land of district Ludhiana, out of which 16 farmers and 154.5 acres of land was subjected to burning of paddy straw followed by the sowing of wheat while rest of the land was subjected to the incorporation of paddy followed by wheat sowing. The economic analysis of both land-use practices showed that the total expenditure on paddy harvest and wheat sowing was approximately equal, with the reduced land fallow period between paddy harvest and wheat sowing in residue incorporated fields (2-3 days instead of 7 days in case of burning) as well as reduced weedicide consumption. Twenty-two farmers, out of 60 were convinced with the results of residue incorporation and wished to try the practice in upcoming years (CIIFR, 2019). The findings of this study can be strengthened with the success story of Mansa district farmer, who had continuously incorporated paddy residue (CR212, heavy subtle producing variety) for seven years in his fields and was bestowed with the National Award by Indian Council of Agricultural Research (ICAR), New Delhi. The farmer highlighted that the addition of straw with super SMS not only strengthened the soil health and hence required fewer agrochemicals (fertilizer/pesticides) with a cleaner environment (Tribune, September 11, 2019). Many other progressive farmers of state were adopting these techniques, two farmers of Hoshiarpur district had successfully sown wheat crop after incorporating paddy straw using Happy Seeder and had improved the soil fertility, health and crop productivity (Changi Kheti, 2018). In 2017, another farmer from Hoshiarpur district used chopped paddy straw for the mulching of the sweet pea field, which enhanced its economic benefit from the crop (Changi Kheti, Sept 2018, PAU).

4.5.1.2 Incorporation of bio-char

The burning of straw residue through slow pyrolysis (heating in absence of oxygen) to produce bio-char is another very efficient way to utilize residue. The bio-char is enriched in organic carbon, potassium, phosphorous and other nutrients and is equivalent to activated carbon having fine-grained charcoal texture with the potential to store carbon in the soil for a longer duration. The process of production of biochar requires a small area (10 ft diameter and 14 ft height) for brick and clay *Prali* kiln, which can accommodate 12 q of rice straw (CII-NITI Aayog 2018). The slow-burning of this residue results in 6.5 quintal bio-char in 10-12 hours. Incorporation of two tons of biochar can replace one-third consumption of urea and renders the benefit of ten per cent more green yield and significantly enhanced soil health in three years (The Tribune, September 2019).

4.5.2 Ex situ Management

"The conservation/management of components of biological diversity outside their natural habitats" is known as ex-situ management of biomass (Convention on Biological Diversity (CBD), 1992). The agricultural residue generated on the farm is bulky hence difficult to store and transport for its efficient utilization. However, various agricultural equipment such as baling, briquetting and pelletizing machines have been made available nowadays to efficiently collect, package into a compact mass and transport crop residue to ex-situ management sites viz. paper/ cardboard manufacturing units, power plants or briquetting units (CII-NITI Aayog 2018). In briquetting, the crop residue is compressed in 6:1 ratio through hydraulic machines and press, which results in the production of 2-4 inch cylinders shaped briquettes. The briquettes can be used in various thermal applications such as industrial boilers, furnaces as well as in power plants. There were 3000 brick kilns spread all over the State, which consume 20 lakh tons of coal per annum (high calorific value) as fuel which can be supplemented with rice straw briquettes (CII-NITI Aayog 2018). The effectively collected and packaged agricultural biomass can be utilized by way of various ex-situ management options, as discussed below-

4.5.2.1 Re**sidue to fuel production**

India being an agriculture-led country produces a huge quantity of crop residues, which necessitates efficient management systems for transforming these residues treated as a waste to energy. Conversion of biomass to fuel energy is all the more beneficial to a developing country like India, that has always been facing a fuel crisis due to its dependence on Gulf countries to meet the energy demands of the progressive nation (Masera *et al* 2015). The agricultural residues can be converted into energy majorly via two approaches i.e. thermochemical conversion and biochemical conversion, the details of which are as follows.

4.5.2.1.1 ***Thermochemical conversion***

Thermochemical processes convert chemical energy store in biomass to heat electricity or mechanical power. The thermochemical conversion processes include conversion of biomass to energy via

a. Direct combustion
b. Pyrolysis/liquefaction, and
c. Gasification

Direct combustion method is the most widely used method worldwide. As high as 97 per cent of bioenergy all over the world is produced by direct combustion. Indirect combustion methods intended to use biomass in a boiler, contributing to the production of steam, which can be used to produce heat electricity concurrently to run the turbine. Thermochemical processes include extreme conditions such as supercritical temperature and pressure that can be used to generate important bio-based products.

Pyrolysis/liquefaction entails thermal degradation of agricultural residues at a very high temperature of 350-550°C, under high pressure and no oxygen (Simonyan and Fasina 2013), resulting into formation of three fractions: liquid fraction (known as ***bio-oil***), solid (ash known as ***biochar***) and gaseous fractions. In fast pyrolysis, two-third of the fraction, which is liquid in nature, can be used in engines, machinery, and multitudes of other applications (IRENA, 2013). A study conducted by Nixon *et al* (2014) emphasized that the pyrolysis process can be used for producing biofuels (pyrolysis oil, bio-char, bio-gas) by utilizing rice and wheat straw available in plenty in Punjab, India. The deployment of a small scale mobile pyrolysis plant had been suggested, which can generate biochar (to be used as a fertilizer) and pyrolysis oil (can act as an alternative to diesel in small generators) and at the same time would engage rural communities of the state. It was stated that the processing of rice straw yields approximately biochar, bio-oil, and bio-gas in the proportion of 32:35:33. The small diesel engines used by farmers can efficiently run on 20:80 bio-oil and diesel blend. The mobile pyrolysis plant can produce oil costing only 0.32-0.50 $/kg.

Gasification is a thermo-chemical process, wherein the partial combustion of crop residues forms gas. The main issue hampering in biomass gasification for power generation is the issue of purification of gas. The 'producer gas' generation is the outcome of feeding crop biomass into the gasifiers. The 'producer gas' thus generated is fed into the engines coupled with alternators for electricity generation In some of the states, the task of the generation of

‘Producer Gas’ is already underway by installing gasifiers of more than 1 MW capacity. A total of 300 kWh of electricity can be obtained by a ton of biomass. The gasification technology can fruitfully utilize the pellets and briquettes of crop biomass. The ‘producer gas’ thus generated needs to be cleaned using bio-filters and can be effectively utilized in specially designed gas engines for electricity generation. A power plant running on ‘producer gas’ generated from biomass has already been developed by The Central Institute of Agricultural Engineering (CIAE), Bhopal, India.

4.5.2.1.2 ***Biochemical conversion***

Agricultural biomass is usually composed of cellulose, hemicellulose, and lignin. The biochemical processes primarily target hemicellulose to access cellulose; however, lignin fractions are converted into important fuel source via thermochemical transformation (above discussed). Anaerobic digestion and fermentation are the two biochemical methods available to convert agricultural biomass into a valuable substance.

Biogas production is the outcome of the anaerobic digestion of biomass by microorganisms in absence of oxygen. The biogas thus produced can be a good source of fuel for the generation of heat and energy. Although the anaerobic digestion of rice straw has been attempted earlier also, its renewable energy potential is yet to be analyzed. In India, under the Swachh Bharat Yojna, Agro Gas (2G Bio CNG), Pune, Maharashtra, produced anaerobic digestion based bio-CNG from the agricultural residue (10% moisture level). The plant had a maximum capacity of 35 t/year (100kg/day) from principal feedstocks producing 12000m^3/day 2G bio CNG along with digestate (250t/day), which can be used as fertilizer. In Punjab Agricultural University, Ludhiana a dry fermentation anaerobic digestion biogas plant based on rice straw and cow dung in 80: 20 ratio has been successfully producing bio-gas in the range of 4-5m^3/day for 3-4 months (equivalent to 2-4 cylinders of LPG/month). This technology has been recommended by the Research Evaluation Committee (REC) of the university and five such plants were successfully running in the state in rural areas (NITI AAYAG, 2018). The by-product slurry is a rich source of nitrogen that can be used as fertilizer in farmer’s fields.

Bioethanol production can be produced by microbial fermentation of lignocellulose biomass by following three steps, i.e. pretreatment, enzymatic hydrolysis, and finally fermentation. The first step entails involves sieving and pelletization of biomass for the ease in transportation and reduction in expenses and handling fees. The second step involves the transformation of cellulose and hemicellulose biomass into glucose, pentoses, and hexoses. In the final step, glucose is fermented into ethanol by a suitable microorganism.

The DBT-ICT 2G-Ethanol Technology has been validated and demonstrated at a scale of 10 tons of biomass per day at India Glycols Ltd. site at Kashipur, Uttrakhand, India. The technology and plant design are feedstock flexible i.e. any biomass feedstock from hardwood chips and cotton stalk to soft bagasse and rice straw can be processed. The technology employs continuous processing from biomass size reduction to fermentation; and converts biomass feed to alcohol within 24 hours compared to other technologies that take anywhere from 3 to 5 days. The plant design with a low footprint also has unique features such as advanced reactor design and separation technologies with slurry-flow rapid reaction regime operations. The technology is Zero-Liquid Discharge where >95% of water is recycled. The plant has a capacity of 450 tons of biomass per day. Continuous flow plant operated up to 7 days non-stop with feedstocks including bagasse, rice straw, cotton stalk, and wheat straw, with alcohol yield in the range of 240-300 L/ton biomass (success stories). A similar set up based on rice straw biomass was set up in Punjab, in district Bathinda with a capacity of 100KL/ day by Hindustan Petroleum Corporation Ltd (HPCL), which was slated to get operational in 2020 (IEA 2020).

4.5.3 Other management options

Some of the other options for crop biomass management are there, which have been used over the years. These are outlined below

4.5.3.1 Livestock feed

It is a very common method to utilize agricultural residues effectively as fodder to animals. Wheat straw has been generally used as fodder for animals. High selenium content in paddy residue and low degradability by ruminal microorganisms limits its consumption as a fodder. High selenium causes selenosis and causes degnala disease within eight weeks of consumption of rice straw (Wadwa and Bakshi, 2017). Moreover, it contains high oxalates, which also reduce the absorption of calcium in the body. However, Rajasthan University of Veterinary & Animal Sciences, Bikaner, has shown that addition of urea and open fermentation of rice straw (3.5:96.5::urea: straw) for nine days can enhance its nutritive value and digestibility for cattle. GADVASU, Ludhiana also suggested that urea treated paddy straw can be utilized as basal ration which can cause an average increase of 500gm weight of buffaloes, thus benefitting in buffalo fattening protocol for higher meat production (The Tribune 2019). A 270-day growth study conducted by GADVASU on male Murrah buffalo calves revealed that feeding of treated rice straw led to 50 per cent more weight gain per day in an animal (Wadhwa *et al* 2010).

4.5.3.2 Animal bedding

The use of paddy straw as a bedding material for cattle is another effective way to utilize it. In a 60 days study conducted by state veterinary university GADVASU, Ludhiana, bedding of 30 cm during winter season increased approximately 17.1 per cent milk yield and 0.75 per cent weight gain while cattle without bedding had a weight loss of 1.27 per cent (The Tribune 2019). A study conducted by GADVASU in collaboration with PAU revealed that rice straw used as bedding of animal (10-15 kg straw/animal/day) can trap the urine and feces of animals. This bedding can be composted in open by maintaining 70-80% moisture and regular turning, the compost resulting from this process is relatively more enriched in nutrients as compared to farmyard manure (Singh *et al* 2009).

4.5.3.3 Paper/Board/Eco-panel making

The use of crop biomass in paper and board making units in the state of Punjab is very common. It has been reported that these units are already using around 0.1 million tons of paddy straw per annum. The process of conversion of paddy straw into paper involves resizing the straw followed by preparation of straw pulp by the soda pulping process in batch rotary digesters for delignification and cooking with sodium hydroxide. The straw after digestion is washed in a multi-stage washer with a counter-current system. Paddy straw pulps are blended with high strength material such as waste cloth and used gunny bag pulps for paper making. From one ton of stubble, 500 kg of the pulp can be produced. The pulp that is made from the paddy waste can be sold for Rs. 45 per kg. Another good option is to use paddy straw for making eco-panels which can be used as panels and partitions in place of wood/plyboard. The technology has already been established abroad but its cost-effectiveness in the country is yet to be assessed. The technology developed by Central Pulp and Paper Research Institute, Uttar Pradesh, India can successfully remove more than 90 per cent of silica from rice straw black liquor. Using one ton of rice straw, the paper production saves approximately 0.7 tons of wood (Dixit *et al* 2009)

4.5.3.4 Packing Material

Use of paddy straw as packing and filling material as an alternative to thermocol (having adverse environmental implications) and other materials such as plastic or paper needs can be advocated, wherever feasible. Wheat straw can be used to enhance the shelf life of apples and for giving them shiny look. Mohali based National Agri-Food Biotechnology Institute (NABI) has developed edible coating materials from wheat straw and oat bran. This technology increases the shelf life of apple by 35-40 days and peaches by 8-10 days (The Tribune, Jul17, 2018).

4.5.3.5 Mushroom growing

There is some potential to use paddy straw as a medium for growing mushrooms. At present, it is not being used in the State for this purpose. PAU has recommended the use of paddy straw (with/without wheat straw) for the cultivation of button mushrooms *(Agaricus bisporus)* and oyster mushrooms *(Pleurotus* spp.) in winters and paddy-straw mushroom *(Volvariella volvacea, V. diplasia)* in summers. The leftover of paddy straw after harvesting mushroom can be used as manure (after composting) in other crops which would save expenses on chemical fertilizers (The Tribune 2019)

4.5.3.6 Building of composite materials

Resistance to bacterial decomposition, high tensile modulus, and high silica content of rice straw makes it a favorable substrate to use as filler in building composite material, with an additional potential benefit of flame retardant in building industry. The rice straw composite materials are having good thermal insulation, intended for improvement of the energy efficiency in eco-buildings (Wadhwa and Bakshi 2017).

The use of biomass in the energy sector is being increasingly propagated but the efforts to use it to its utmost potential have seen more failures than successes due to several challenges. The present study conclusively establishes the immense potential of Punjab agriculture in terms of conversion of agricultural biomass to energy. The analysis boils down to a crucial narrative of on-farm biomass availability in Punjab that two major crops of Punjab i.e. paddy and wheat together account for 92.1 per cent of the state's energy potential. However, the effective use of this potential calls for a reorientation of the policy priorities to make use of this biomass potential judiciously by targeted technology deployment right from the field to the conversion facility. There is a critical need for a bioenergy roadmap with an integrated approach, where the efforts of all the stakeholders from the field of agriculture, infrastructure, environment, technology and innovation, energy are directed towards sustainable action.

CHAPTER-V

SUMMARY

The state of Punjab has won accolades for its stupendous performance not only in the agriculture sector but has made rapid strides in other sectors as well leading to a significant increase in the energy demand. The demand for power in the State has increased by leaps and bounds because of a spurt in the use of electrical power due to increasing mechanization of farm operations, growth in the number of industries, and improvement in the standard of living. Agricultural biomass has an enormous potential for energy generation in Punjab. Prudent use of available crop biomass could go a long way in alleviating the environmental hazards of non-renewable energy sources particularly related to climate change. Punjab being an agricultural state, can count down on crop biomass resources, which can be put to more efficient use to provide sustainable energy base to the state. Against this backdrop, the present study was taken up to assess the agricultural biomass energy potential of the state with the following specific objectives:

i. To ascertain the regional spread of agricultural biomass availability in Punjab
ii. To estimate the biomass energy potential of the state
iii. To make an inventory of viable and sustainable agricultural biomass management options

The formulations of the present study have been based on secondary data. The assessment of agricultural biomass and its energy potential has been carried out for the triennium ending (TE) 2017-18 to negate the effect of year to year variations. In the case of cotton, the average corresponds to two years i.e. 2016-17 and 2017-18 so as omit the influence of the abnormal year 2015-16 with a substantial crop loss due to whitefly attack. The data on the requisite variables have been culled from various web and published sources and verified from certain research papers, wherever deemed necessary. For the exposition of the findings of the study, the distinction between biomass potential and biomass availability has been drawn out. The biomass potential (BP) connotes the gross annual production of the agricultural biomass in a region. The biomass availability (BA) synonymously referred to as surplus residue potential that can be made available for energy conversion is therefore only a fraction of biomass potential. The annual production of agricultural biomass was estimated by the residue-to-product ratio (RPR), biomass availability by surplus residue fraction (SF), and energy potential by calorific values (CV) conversion route.

The soil and climatic conditions, the state of Punjab is endowed with, support cultivation of diverse crops resulting in the production of a variety of agricultural residues such as straw, stalk, bagasse, tops, leaves, and shells, etc. These agricultural residues can be divided into two different categories i.e., on-farm residues or field-based residues and processing residues synonymously termed as off-farm residues. The crop residues, available at the place where the crop is harvested, such as straw (A1), stalks (A2), sugarcane tops, and leaves (A3) are known as the on-farm residue. On the other hand, the residues generated during post-harvest processing are termed as processing based residues or processing residues.

The annual on-farm crop biomass potential from all the major and minor crops in Punjab has been recorded at 47.2 million t as per TE 2017-18 crop production figures. It comprised of 94.7 per cent of Category A1, 4.6 per cent of Category A2 and only 0.7 per cent of Category A3 biomass. Out of all the 22 districts of Punjab, the contribution of Sangrur to state's on-farm potential has been recorded as the highest with 9.33 per cent share, followed by that of Ludhiana (7.96%), Bathinda (7.09%), Patiala (6.83%) and Sri Muktsar Sahib (5.82%) together adding up to 37 per cent of the state's total on-farm biomass potential. The wheat and paddy crops together accounted for 94.7 per cent of the on-farm biomass potential of the state, with other crops particularly Oilseeds and pulses crops had a negligible contribution. The processing biomass synonymously named as off-farm biomass potential for TE 2017-18 has been estimated at 9.2 million t out of which the district Bathinda with 1.1 million t of processing biomass accounted for one-ninth of the state biomass potential. The contribution of the top five districts viz. Bathinda (11.55%), Sangrur (8.25%), Fazilka (8.17%), Ludhiana (6.74%) and Sri Muktsar Sahib (6.73%) has been recorded at 41.4 per cent of the state's off-farm biomass potential.

The annual crop biomass potential totaled to 56.4 million t in TE 2017-18, the on-farm and the processing level biomass being in the ratio of 83.6:16.4. The crop-wise analysis revealed that total biomass potential of state comprised of 54.8 per cent of wheat, 38.0 per cent of paddy, 4.5 per cent of cotton and 1.8 per cent of maize residue. These four crops together accounted for 99.1 per cent of the state's total biomass potential. The five top crop biomass generating districts of Punjab i.e. Sangrur, Ludhiana, Bathinda, Patiala and Sri Muktsar Sahib together produced 21.1 million t of biomass, accounting for 37.5 per cent of the state potential. The study further highlighted that out of paddy biomass potential of 21.4 million tons; a little over 90 per cent of the potential is concentrated in 16 districts. The top ten wheat biomass producing districts namely Sangrur, Bathinda, Ludhiana, Patiala, Muktsar Sahib, Fazilka, Firozpur, Amritsar, Moga and Tarn Taran produced 63.2 per cent of the state's wheat biomass potential of 30.9 million t. The entire cotton biomass potential of 2.5 million tons has been found to concentrate in eight districts namely Bathinda, Fazilka, Mansa, Sri Muktsar Sahib, Sangrur, Barnala, Faridkot and Patiala. The maize biomass is concentrated in 15 districts for the obvious reason that preference for paddy weighs very heavy on the rest of the districts to have completely relegated the maize crop.

The competitive uses of the agricultural biomass, which are specific to the crop and residue, were taken in to account to arrive at the quantity of biomass available for power conversion. Out of the agricultural biomass potential of Punjab estimated at 56.4 million t in TE 2017-18, the quantity of surplus biomass available for power generation after accounting for the possible usage has been estimated at 27.4 million t, out of which 22.9 million t (83.5%) is the quantity rendered surplus out of the field-based residue generated. The crop-wise analysis of biomass surplus highlighted the prominence of paddy with a contribution in total biomass available recorded at 63.1 per cent followed by wheat (28.2%), cotton (5.1%), and maize (2.83%), together accounting for 99.2 per cent of the biomass availability. It underlines the insignificant role of the rest of the crops, which doesn't come as a surprise in the case of Punjab agriculture, which has over the years become synonymous with the rice-wheat system. Narrowing down to paddy and wheat crop, it comes to the fore that these two crops made up for 91.3 per cent of the surplus biomass, out of which 85 per cent is field-based. In other words, on-farm paddy and wheat residues (21.2 million t) account for 77.5 per cent of the biomass available for power generation.

The perusal of district wise spread of annual availability of biomass recorded at 27.4 million t at the state level highlighted that the district Sangrur was at the top with a share of 9.6 per cent followed by Ludhiana (8.3%), Bathinda (7.4%), Patiala (6.8%) and Sri Muktsar Sahib (5.8%) collectively accounting for 37.9 per cent of the biomass available at the state level attributed to the larger net sown area and higher productive potential of these districts compared to the rest of the districts. A total of five districts namely, Fatehgarh Sahib, S.B.S. Nagar, Rupnagar, S.A.S. Nagar, and Pathankot at the bottom ebb of the contribution scale together contributed 8.7 per cent and individually 2.7, 2.2, 1.9, 1.1 and 0.8 per cent respectively to the biomass available for power generation. The contribution of the processing based residue estimated at 4.5 million t per annum during TE 2017-18 in the state, stood at 16.5 per cent to the total biomass available. The corresponding contribution has been recorded as the highest in the case of district Fazilka (26.8%), followed by Bathinda (24.8%) and Mansa (23.1%) and in the rest of the districts, it ranged between 13 to 18 per cent. The availability of surplus biomass per unit of the cropped area ranged from 2.31t/ha in the case of district Pathankot to 3.88 t/ha in district Sangrur, with state average recorded at 3.22 t/ha. It is reiterated that in 22.9 million t of field-based crop biomass available to harness the energy, the maximum contribution was that of paddy crop (70.3%) followed by wheat (22.5%), cotton (3.3%) and maize (2.9%).

In the present study, an attempt was made to assess the energy potential of agricultural biomass available in Punjab for the reference period TE 2017-18. It was estimated that 22.9 million t of on-farm biomass available in Punjab had the potential to produce energy to the tune of 358 PJ, out of which as high as 92 per cent is accounted for by paddy and wheat and 98.9 per cent by four major crops i.e. paddy, wheat, cotton and maize taken together. The Sangrur district had the maximum energy potential (34825 TJ) accounting for 9.7 per cent of the state total, followed by Ludhiana (8.5%), Patiala (6.9%), Bathinda (6.6%) and Moga (5.8%). These top five districts together contributed 38 per cent to the energy potential of the state. The top ten districts collectively made up for 63 per cent and the top 15 accounted for as high as 84 per cent of the state's biomass energy potential. The district-wise energy potential per unit of cropped area ranged from 36.9 GJ/ha in the case of district Pathankot to as high as 60.1 GJ/ha in Sangrur with the state average of 50.5 GJ/ha.

One of the objectives of the study was to make an inventory of various biomass management options. This has been accomplished with theoretical underpinning. The details of in-situ and ex-situ management have been divulged on. The in-situ management options have been detailed as; incorporation/ mulching of biomass and incorporation of biochar. The conversion of agricultural residues into energy comes under ex-situ management options. An overview of thermochemical and biochemical conversion has been given. The thermochemical conversion processes include conversion of biomass to energy via direct combustion, pyrolysis/liquefaction, and gasification. The biochemical process, that includes anaerobic digestion and fermentation, converts the agricultural biomass into valuable substances. Biogas production is the outcome of anaerobic digestion of biomass and bioethanol can be produced by microbial fermentation. Some of the other options, which have been used over the years, i.e. the use of crop residues as livestock feed, animal bedding, packing material and for mushroom cultivation have also been highlighted.

The use of biomass in the energy sector is being increasingly propagated but the efforts to use it to its utmost potential have seen more failures than successes due to several challenges. The present study conclusively establishes the immense potential of Punjab agriculture in terms of conversion of agricultural biomass to energy. The analysis boils down to a crucial narrative of on-farm biomass availability in Punjab that two major crops of Punjab i.e. paddy and wheat together account for 92.1 per cent of the state's energy potential. However, the effective use of this potential calls for a reorientation of the policy priorities to make use of this biomass potential judiciously by targeted technology deployment right from the field to the conversion facility. There is a critical need for a bioenergy roadmap with an integrated approach, where the efforts of all the stakeholders from the field of agriculture, infrastructure, environment, technology and innovation, energy are directed towards sustainable action.

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