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Bio-energy potential of crop residue in Indian Punjab

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Abstract

A safe, reliable and inexpensive energy supply is at the centre of any laudable economic growth and development. Being an agriculturally dominant nation, the strength of India's bio-energy programs mostly lies in the agricultural sector generating over 500 million tons of biomass in the form of crop residues every year. In Punjab state which produces about 19% of wheat and 11% of rice of the country, the disposal of agro residue in the beneficial way along with its pollution is a very serious problem. Therefore, the study synthesized and evaluated the energy potential for the power sector from the available crop residue in the state. It was estimated that of the total crop residues generated in the state (48.2 million tons), the surplus residue about 16.9 million tons (35% of the total generation) belonged to cereals (94.1%). The highest residue generated per unit of area was from sunflower (7.88 t ha^{-1}). It was estimated that the surplus crop residue has a potential to generate about 77.3 MW of bio energy annually in which the contribution of wheat and paddy is maximum due to higher area under these crops in the state during their respective *rabi* and *kharif* seasons. The crop wastes are capable to meet about 28652 Joules capita^{-1} energy requirements per annum. Against the potential for power generation at 3472 MW, there exists an installed capacity of only 317.10 MW for total biomass forming about 23% of the total power generating capacity in the state. Majority of the installed capacity in the state comes from thermal sources (60.6%) followed by hydro (28.4%) and nuclear (1.5%) and renewable sources form only 9.5% of the total installed capacity. Thus biomass energy, from crop residues available in plenty in the state, can be used as substitute to fulfill the additional energy requirements and reduce dependency on fossil fuels.

Keywords: bio-energy, crop residue, surplus crop residue, installed capacity, renewable

1. Introduction

A safe, reliable and inexpensive energy supply is at the centre of any laudable economic growth and development. No economy in modern age has succeeded at alleviating poverty significantly without effectively increasing the provision, availability, and usage of energy to make material progress (Nnaji *et al.*, 2010). With population growth, economic and technological advancement, the demand for energy over the years have been on the increase. The reliance on fossil fuels to meet the energy needs of humanity is gradually losing popularity because of associated disadvantages like limited existence in environment, non-eco-friendly nature and non-economical. India's power sector is predominantly based on indigenous fossil fuels and growing income trends are linked to growing demand for power supply (IEA, 2015). India is responsible for nearly 6.7% of total global carbon emissions, ranked fourth next to China (26.8%), the USA (14.4%), and the European Union (9.7%) (Olivier *et al.*, 2016). Burning of residue generated from paddy in North-west India causes losses to the tune of Rs 8953 ha^{-1}, and social cost of the same is Rs 3199 crores each year (Kumar *et al.*, 2019) [17]. In order to enhance environmental sustainability, there have been efforts at identifying alternative and renewable sources of energy capable of meeting increasing global demand. Renewable energy sources play a vital role in securing sustainable energy with lower emissions (Kumar, 2016) [16]. Comparing with other renewable energy sources, biomass is much economical than others, as this require less capital investment and per unit production costs (Rao *et al.*, 2010[24]. Singh *et al.* 2017a [27]. Singh *et al.* 2017b [28]. Singh *et al.* 2017c [29]. Singh *et al.* 2018; Tiwari *et al.* 2018; Tiwari *et al.* 2019a [32]. Tiwari *et al.* 2019b [33]. Kour *et al.* 2019 [34]. Singh *et al.* 2019) [17]. The current use of biofuels in domestic devices is also associated with drudgery and adverse health impacts on women. In most rural houses in India, the fuel use efficiency in domestic devices, particularly cook stoves, is low, in the range of 10-14% (Ravindranath *et al*., 2005) [23]. Improving the efficiency would be a significant step towards improving the quality of life and environment (ibid) and this needs use of biomass through efficient conversion process other than direct combustion. One study (Junginger *et al.*, 2001) [14]. Finds that process based agricultural residues in Asia alone could contribute between 25% and 40% of the total primary commercial energy production. A study (Bhattacharya *et al*., 2005) [6, 23]. Also suggests that in South Asia, India and Sri Lanka have a significant primary energy potential from non-planted biomass, which is 45% and 33% of the total primary energy consumption in 2010 respectively. The continued existence of living organisms on this planet cannot be sustained indefinitely unless there is a change of attitude and behaviour to the current lifestyle as man constantly keep pushing the boundary of the planet resources to its limit and replacing it with wastes including various emissions (Titiloye, 2011) [37].

The availability of affordable energy supply is an important component in improving the quality of life, but there is huge scarcity of energy supply in all the sectors of rural as well as urban economy of the country. Non-renewable resources have been used frequently in India due to lack of awareness and acceptability of renewable energy sources. Although the country is recognized as one of fastest growing economies of the world, basic energy needs of thousands of millions of its citizens are yet to be fulfilled. It is reported that by 2031–32, power generation capacity must increase to nearly 800 GW from the current capacity of around 183 GW, inclusive of all captive plants to meet the basic energy needs of its citizens (Titiloye, 2011) [37]. The electricity supply constraint has forced almost all the sectors; industrial, commercial, institutional or residential to rely on diesel or furnace oil. At the same time, due to the increasing population and environmental deterioration, the country faces the challenge of sustainable development. In 2018, the energy demand was 1,212,134 GWh, and the availability was 1,203,567 GWh, i.e., a deficit of −0.7% (Anonymous, 2019c) [4]. Growing energy demand coupled with limited conventional fuel options, geo-politics of oil and environmental concern has compelled India to search for renewable and sustainable energy options. It has been fundamental now to provide energy by biomass for the development of civilization. In present scenario, global warming, decrement of resources and other international issues have led to the decision of sustainable development. And in power sector use of renewable energy like biomass is the need one of the major green source (Pachauri and Jiang, 2008) [22]. India would be the third largest country consuming renewable energy, accounting for 9% of the global total by 2030. So engaging India – together with the other largest users such as Brazil, China, the European Union and the United States is essential if the goal of doubling renewable energy's global share is to be achieved (Gielen *et al*., 2017) [12].

Being an agriculturally dominant nation, the strength of India's bio-energy programs mostly lies in the agricultural sector. It is estimated that India generates over 500 million tons of biomass in the form of crop residues every year, but unfortunately at present this biomass resource is used inefficiently. In Indo-Gangetic basin of India, area under rice–wheat double cropping is 10 million hectare (m ha), of which 2.6 mha falls in Indian Punjab (Jalota *et al.*, 2018) [13]. Intensive agriculture is being practised in these areas and burning of rice and wheat straw and stubbles is widespread (Singh *et al*., 2018) [30 31 36]. Presently around 70–90% of the rice in North West India is being harvested (Gajri *et al*., 2002) [9]. by using combine harvesters which results in the retention of paddy stalk of 6–10 cm on the fields and windrows of loose and uneven line of around 7–9 tonnes of straw per hectare (Erenstein, 2011 [11]. Sidhu, *et al*., 2007) [25]. The collection and management of such scattered and loose paddy stalk is very labour intensive and costly considering the shortage of labour (Kaur, 2017) [15]. Punjab is a small Indian state with 5033 thousand hectare geographical area of which about 83% of the total land is under agricultural activities. With only 1.53% of the total geographical area of the country, Punjab produces approximately, 19% of wheat, 11% of rice and 5% of cotton of the country. According to estimates from various researchers, farmers burn 30-90% of paddy residue in Punjab albeit with a strong regional variation (Lohan *et al*., 2017) [18]. The disposal of agro residue in the beneficial way along with its pollution is very serious problem of Punjab. The cereal residues are not waste until we waste it (Shahane and Shivay, 2016) [22]. The present study was carried out focusing on the availability of agricultural residue and its inherent energy potential for power generation in Punjab.

2. Materials and Methods

The study is based on secondary information collected from different published sources Statistical Abstract of Punjab, Agricultural Statistics at a Glance, reports of Indian Agricultural Research Institute (IARI), etc. and various websites during the year 2017-18. The data were analyzed using simple tabular analysis, percentages, averages, etc. to estimate the crop residue production, its surplus and bio-energy potential in the state.

2.1. *Estimation of total crop residue*

The total production of the crop residue in Punjab has been estimated by using crop-to-residue ratios (CRR). The CRR values for different crops were taken from an earlier study conducted by Chauhan (2012) [7]. The residue/biomass generated from a particular crop depends upon three parameters viz. area covered by the crop, yield of the crop and CRR of the crop. Using these parameters, the total crop residue generated in the state by different crops has been estimated as follows.

$$CR = \sum_{i=1}^{n} (A_i) * (Y_i) * (CRR_i)$$

Where,

CR = Total crop residue generation in the state

A_i = Area under 'ith' crop

Y_i = Average yield of 'ith' crop

CRR_i = Crop-to-residue ratio of 'ith' crop

2.2. *Estimation of surplus crop residue*

However, crop residues have competing uses and therefore, the portion which remains unused is termed as surplus and estimated as follows

$$SR = \sum_{i=1}^{n} (CR_i * SF_i)$$

Where,
SR = Total crop residue surplus in the state
CR_i = Crop residue potential of 'i^th' crop
SF_i = Surplus residue fraction of 'i^th' crop

Surplus residue fractions for different crops for Punjab state calculated by Hiloidhari *et al.*, 2014 [10]. Using data available from Biomass Resource Atlas of India (BRAI) were used to estimate the crop residue surplus in the state

2.3. *Estimation of bio-energy potential*

Bio energy potential from crop residue biomass is estimated using the following expression.

$$E = \sum_{i=1}^{n} (SR_i * HVi)$$

Where,
E = Bio-energy potential from surplus crop residue in the state
SR_i = Surplus residue of 'i^th' crop
HV_i = Heating value of 'i^th' crop

Heating values for different crops were taken from the study conducted by Hiloidhari *et al.*, 2014 [10].
Further, the crops have been categorized in five different groups of crops i.e. cereals (paddy, maize, bajra, wheat and barley), fibre (cotton), plantation crop (sugarcane), pulses (arhar, moong, gram and lentil) and oilseeds (rapeseed & mustard, sunflower, groundnut and sesamum).

3. Results and Discussion

3.1. Crop Residue Generation In Punjab State

Biomass is a renewable energy source from plant and animal materials which can be used as fuel. Crop residue can be the residue generated at farmers' fields (like stalk, stubble, leaves, etc.) and the residue generated at processing stage (like rice husk). The total residue generation from all crops in Punjab state was estimated to be about 48241 thousand ton (tt) during 2017-18 (Table 1). Of the total crop residues generated in the state, the surplus residue that remained unused was estimated to be about 16868 tt (35% of the total generation).

Table 1: Crop residue components and its generation in Punjab, 2017-18

Crop category	Crop	Residue Component	CR (000 ton)	SR (000 ton)
Cereals	Paddy	Straw & husk	22985	15870.4 (94.1)
	Maize	Stalks & cobs	554.6	
	Wheat	Straw & husk	23082	
	Barley	Stalks & husk	55.20	
	Bajra	Stalks & husk	0.8	
	Sub-total (a)	-	46677.6 (96.8)	
Fibre (b)	Cotton	Sticks	762.00 (1.6)	685.8 (4.1)
Plantation crop (c)	Sugarcane	Trash and bagasse	668.00 (1.4)	267.2 (1.6)
Pulses	Arhar	Stalks & husk	6.8	6.815 (0.04)
	Moong	Stalks & husk	4.1	
	Gram	Stalks	2.6	
	Lentil/Masur	Stalks	1	
	Sub-total (d)	-	14.5 (0.03)	
Oilseeds	Rapeseed & mustard	Stalks	67.4	35.76 (0.21)
	Sunflower	Stalks	44.9	
	Ground nut	Stalks & shell	4.8	
	Sesamum	Stalks	2.1	
	Sub-total (e)	-	119.2 (0.3)	
Grand Total (a+b+c+d+e)		-	48241.3 (100.0)	16867.99 (100.00)

Note: CR and SR indicate total crop residue and surplus crop residue, respectively

Among different crop categories/groups, maximum residue (96.80%) was generated by cereals followed by category fibres (1.58%), plantation crop (1.38%), oilseeds (0.25%) and pulses (0.03%). The cereals alone contributed about 94% to the total surplus residue in the state. Paddy straw, which has high silica content, is considered to be inferior feed for animals and it has no other use. The contribution of fibre crops, sugarcane, oilseeds and pulses to the surplus crop residue was 4.1, 1.6, 0.21 and 0.06%, respectively.

Per unit analysis further revealed that on an average about 6.77 ton ha^{-1} (t ha^{-1}) residue is being produced from all the crops in the state. Crop wise analysis shows that highest residue per unit area was produced in the case of sunflower crop (7.88 t ha^{-1}) followed by paddy (7.50 t ha^{-1}), barley (7.36 t ha^{-1}) sugarcane (6.96 t ha^{-1}) and wheat (6.58 t ha^{-1}). The crop wise productivity of residue is presented in Figure1.

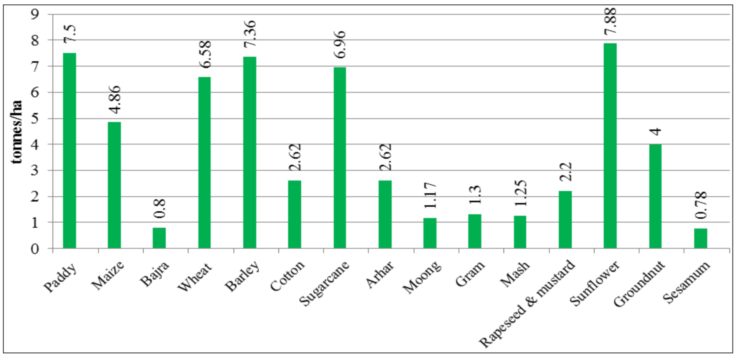
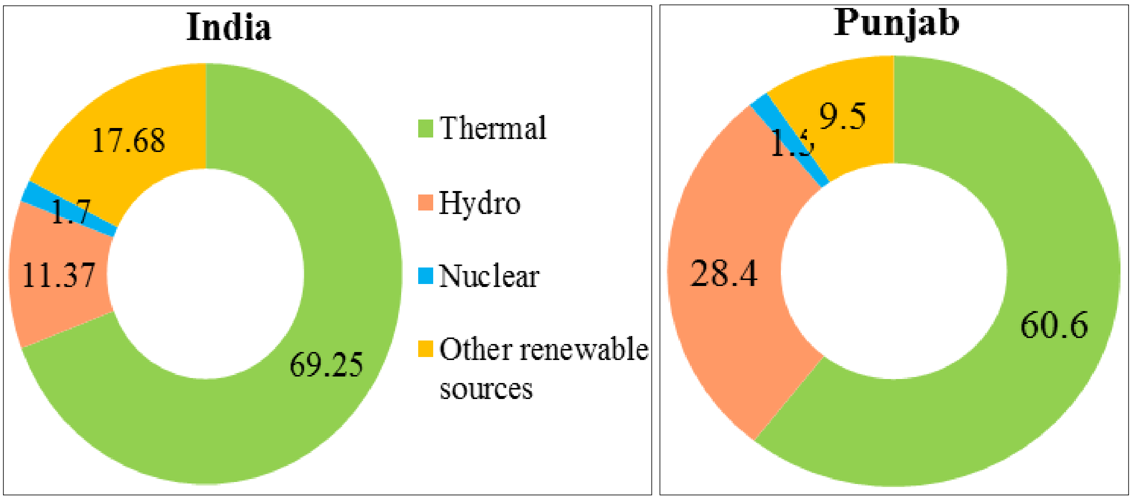


Fig 1: Crop-wise residue generated per unit of area in Punjab (t ha^{-1})

3.2. Energy Scenario in Punjab

The major sources of energy such as coalmines, natural gas, tidal power and oil are not available in Punjab. The scope for wind energy and tidal energy is also limited due to low velocity of winds and the distant location of the state from the sea. Despite wide scope of solar energy, the commercial exploitation of this source is negligible as yet. For many years there has been a demand for nuclear power station in the state but it has not yet materialized. Thus, the main source of power in the state is thermal electricity. The installed capacity for power generation in Punjab was 13960.97 MW and generated 41387.3 Million KWH of electricity during 2017-18 (Anonymous, 2018d). The highest consumer of electricity is the industrial sector (34% of total electricity consumed in the state in 2017-18). The per capita electricity consumption was 449 KWH by domestic sector, 128 KWH by commercial sector, 528 KWH by the industry, 37 KWH by public lighting and 411 KWH by agriculture during 2017-18. The total per capita consumption being at 2046 KWH during 2018-19 is almost 1.7 times the national average of 1181 KWH (*www.indiastat.com).*

In terms of installed capacity for power generation, thermal power plants accounted for an overwhelming 69.25% of the total installed capacity in the country. Other renewable sources (excluding hydro) come next with about 18% of the total installed capacity whereas the share of hydro and nuclear energy was only 11.37% and 1.70%, respectively (Anonymous, 2019a). Majority of the installed capacity in the state also comes from thermal sources (60.6%) followed by hydro (28.4%) and nuclear (1.5%). However, renewable sources form only 9.5% of the total installed capacity (Figure 2). Further this could be increased if Punjab were to leverage the power of biomass, highly abundant in the state due to its large agricultural sector.



Source: Anonymous (b), 2019

Fig 2: Share of different components in installed power generation capacity, 2017-18

Of the total installed capacity in the state, about 49% is privately owned while 35% is owned by the state government and rest 16% is centrally owned (Anonymous, 2019c) [4]. The over dependence on private sector for power generation in Punjab may lead to tariff hike for monetary gains of private companies and resultantly may make the power costlier for the consumers. Biomass energy, from crop residues available in plenty in the state, can be used as substitute for these fossil fuels in the production of energy.

3.3 Power Generation from Crop Residue

The use of crop residue as energy source is a worldwide concern. It is not only renewable but can be used without essential damage to the environment (Nendel *et al.*, 1998) [19].The total potential for renewable power generation in the country on October 31, 2018 was estimated at 1096081MW (Table 2). This includes the potential of solar power (68.33%) followed by wind power (27.58%), small-hydro power (1.80%) and total biomass power (2.06%). For Punjab, the potential for renewable power generation was 6768 MW which formed only about 0.62% of the total potential at the national level. In Punjab, the potential for power generation from total biomass generated was estimated to be 3472 MW.

The estimated distribution of biomass power in the state was estimated to be about 51% in total energy potential followed by solar energy 41.5%, small hydro power (6.52%) and waste to energy (0.66%). Against this the installed capacity was only about 317.10 MW for total biomass forming about 23% of the total power generating capacity in the state. Thus against the potential of biomass power at 3472 MW, much higher than the installed capacity, the state may take advantage of this opportunity.

Table 2: Power potential and installed capacity for renewable (as on 31-10- 2018)

Category	Power potential (MW)		Installed capacity (MW)	
	Punjab	India	Punjab	India
Wind power @ 100m	-	302251 (27.58)	-	34986.35 (47.70)
Small hydro power	441 (6.52)	19749 (1.80)	173.55 (12.35)	4506.95 (6.14)
Biomass power &cogeneration bagasse	3472 (51.30)	22536 (2.06)	317.10 (22.56)	9407.61 (12.83)
Waste to energy	45 (0.66)	2554 (0.23)	9.25 (0.66)	138.3 (0.19)
Solar energy	2810 (41.52)	748990 (68.33)	905.62 (64.43)	24312.6 (33.15)
Total estimated reserves	6768 (100.0)	1096081 (100.0)	1405.52 (100.0)	73351.81 (100.0)

Figures in parentheses are percentages to their respective totals.
Source: Anonymous, 2019b

It has been estimated that in Punjab there exists a potential to generate about 278282 MJ of bio energy annually from the surplus crop residue (Table 3). Among different crop categories, cereals alone are capable of producing 260533 MJ of energy followed by fibre (11679 MJ), plantation crop sugarcane (5344 MJ), oilseeds (610 MJ) and pulses (115 MJ).
The surplus crop residue may provide energy to the extent of 28652 J per capita per annum. This bio-energy potential can be efficiently utilized for saving scarce resources like fossil fuels to some extent. The energy usage trend shows that the consumption rate of biomass energy is considerably on the rise, especially during the last couple of decades (Anonymous, 2019c) [4]. This is mainly because of increasing demand in both rural and urban areas and shortage of alternative fuels, thus the most important and viable option is extraction of energy from biomass resources.

Table 3: Estimated energy potential from surplus crop residue in Punjab, 2017-18

Crop category	Crop	Estimated energy potential from surplus crop residue (per annum)		Per capita annual energy potential (Joules)
		MJ	MW	
1. Cereals	Paddy, maize, wheat, barley and Bajra	260533	72.37	27620
2. Fibre	Cotton	11679	3.24	468
3. Plantation crop	Sugarcane	5344	1.48	482
4. Pulses	Arhar, moong, gram and lentil/masur	115	0.03	9
5. Oilseeds	Rapeseed & mustard, sunflower, groundnut and sesamum	610	0.17	73
Total		278282	77.30	28652

4. Research, development and policy interventions required

An important constraint to the leveraging of biomass power is the fragmented nature of land holdings, due to which plants need to collect the straw from farm to farm. Also, the fuel value of the stored straw decreases with time. To overcome this issue, projects could potentially establish stronger linkages by entering into partnership with farmers to deposit their farm residue in designated collection centres. Alternatively, efforts should be made to develop commercially viable small biomass power projects that collect waste from smaller catchment areas. The renewable resources based plants are clean but not viable on a commercial scale due to several financial and technological constraints. This challenging situation can be transformed into an opportunity by the partial replacement of coal with biomass as a fuel which will require the installation of biomass-only power plants close to agricultural centers of the country. The overall carbon-dioxide emissions of the coal-fired power plant can also be reduced by replacing a small percentage of coal with biomass in a co-fired steam power plant. Therefore, there is a need to revise and tune Punjab's energy policy to incorporate the utilization of greener and local resources. Organizing training of farmers for awareness generation through mass and print media which can help the agricultural based societies like ours in achieving energy security without causing environmental degradation. Demonstration of crop residue management technologies e.g. use of straw management system attached to harvester combines, Among various efforts made by Punjab government to protect environment from pollution, one of the major steps is to stop crop residue burning as still Punjab is not free from this menace. It needs to be stopped through government policies in order to ensure healthy fertile soil and pollution free environment. Monitoring and discouraging burning of crop residue through new punitive laws should be implemented.

5. Conclusion

Cereal residue has a potential to emerge as a one of important source of energy in the state owing to availability in huge amount. Use of surplus crop residue for energy generation instead of on-farm burning is a better option to cope up with increased air pollution. If the residue from the crops is managed scientifically and used as a source of energy it will go a long way to save the fossil fuels, protect the environment, precious foreign exchange expended on import of petroleum products, create additional employment and will add to the income of farmers.

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