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# Biomass resources assessment for power generation: A case study from Haryana state, India

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ABSTRACT

India generates over 370 million tonnes of biomass every year. In addition to the direct harvesting from plants, biomass is also produced as a by product in many agro based industries such as rice husk from rice mill, saw dust from saw mill, bagasse from sugar mills etc. It has been estimated that about 17 GW of power can be generated through cogeneration, combustion and gasification routes from the available biomass. However, for this potential to be realized, data on production, present usage patterns, prices and seasonal fluctuation on biomass is essentially required. The present article is based on the resource assessment of non-plantation surplus biomass with a view to using it for energy production and its utilization in the state of Haryana, India.

Being an agricultural state, Haryana has a huge potential of biomass availability in the form of crop residue and saw dust. In the agricultural sector, a total 24.697 Mt $y^{-1}$ of residue is generated, of which 71% is consumed in various domestic and commercial activities within the state. While in agro based industrial sector, a total of 646 kt $y^{-1}$ of sawdust is generated, of which only 6.65% is consumed in the state. Of the total generated biomass in the state, 45.51% is calculated as basic surplus, 37.48% as productive surplus and 34.10% as net surplus. The power generation potential from all these three categories of surplus biomass is 1.499 GW, 1.227 GW and 1.120 GW respectively.



## 1. Introduction

Today the world thrives on power. Power in its various forms permeates the modern society; urban and rural alike. On the other hand conventional sources of energy are finite. Therefore, there is a crying need to explore alternate and renewable sources of energy that are more sustainable and would complement or even supplement the existing sources. One of the non-conventional sources of energy is bioresidue or biomass that is available mainly as a by-product of crop production, and from forest wastes as agro processing or wood based industry.

According to Rai and Chakrabarti [1], historically, biomass has been a major source of household energy in India. It meets the cooking energy needs of the most rural households and half of the urban households [2]. As per the report of the National Council for Applied Economic Research [3], biomass fuel contributed 90% energy in the rural areas and over 40% in the cities and over two third of the households in the country use biomass as the only source of energy.

India, being a tropical country, the renewable energy is seen as an effective option for ensuring access to modern energy services [4]. Sinha et al. [5] also indicated that the biomass energy consumption trend is considerably on the rise, especially during the last couple of decades. This is mainly because of increasing demand in both rural and urban sectors and absence of alternative fuels.

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According to the 2001 census [6], about 13.32% of the total 0.587 million villages are still un-electrified, and at the household level only 43.5% are electrified in India. It has been estimated that at the end of the Xth five year plan, of the total un-electrified villages, 77% will be electrified through conventional sources. For remaining 23% villages, which are remote and hence cannot be connected to the grid, the only viable option is non-conventional resources of energy. The MNERS (Ministry of New and Renewable Energy Sources) [7] proposes to electrify 5750 such remote villages through SPV (Solar Photovoltaic) power, biomass generated power and hydropower.

The present paper draws from a larger project titled "District Level Biomass Assessment Studies" launched by MNERS, Government of India in various biomass potential states of India in the year 2003 to 05. The article focuses on the availability of surplus biomass and its potential for power generation from two major sectors: Agriculture and Agro based industrial sector in the state of Haryana, northern India.

### 1.1. *Profile of Haryana state*

The state of Haryana is located between 27′37″ N to 30′35″ N latitude and 74′28 E to 77′36 E longitude, spreading over 44,200 $km^2$ (which is about 1.4% of the total geographical area of the country). Administratively, the state is divided into 19 districts with 67 Talukas (Taluka or Tehsil is the administrative and revenue unit below the district with in the state). The total human population of the state is around 21.08 million, which is about 2% of total population of the country, with 76% residing in rural areas. The total livestock population is around 9.89 million, of which 45% is of buffaloes only in the state.

The forest cover in the state is limited to 1553 $km^2$, which is constitutes only 3.52% of the total geographical area of the state further the forest are mainly distributed in North Shivalik and South Aravali hills ranges.

The southeast part of the state is characterized by dry semi-arid to arid climate. The temperature reaches up to 50 °C during summer and falls below 1 °C in winters. May and June are the hottest months, while December and January are the coldest ones. The rainfall varies significantly in the state. The Shivalik ranges in the north remains the wettest, while Aravali hill region in south is the driest. About 80% of the rainfall occurs during the monsoon season (July to September) and some times causes local flooding in various parts of the state.

### 1.2. *Agriculture scenario*

Agriculture is the major economic activity of the state, sustaining nearly 70% of the total population. Haryana together with adjoining state Punjab is referred as the "Grain Bowl of India". Wheat, Paddy, Cotton, Jowar (*Sorghum bicolor*), Bajra (*Pennisetum glaucum*), Pulses, Sugarcane, Oil seeds, and Potato are the major crops grown in the state. About 85% of the total geographical area of the state is cultivable, of which 96% has already been brought under plough. Of about 75% of the cultivated area, 50% is irrigated through groundwater, while rest is from the surface water such as canals, drains and rivers. In view of good irrigation sources, the cropping intensity in the state is averaged at 170% [8]. There are two major agricultural seasons in the state "Rabi" (winter crop) and "Kharif" (summer crop). The major crops grown during the Rabi season are Wheat, Barley, Gram, Mustard, Cotton and Sugarcane, while during Kharif season Paddy, Jowar, Bajra and Maize are major crops. The residues generated from these crops consists of Wheat stalk and pod, Barley stalk, Gram stalk, Mustard stalk and husk, Cotton stalk, Sugarcane top and trash, Paddy husk and straw, Jowar stalk, Bajra stalk and Cobs and Maize stalk and cobs. Apart from these major and minor crops, there are various other crops such as Chilies, Vegetables, Pulses, and Green manure etc., which are categorized as 'Insignificant crops' as defined under methodology section.

### 1.3. *Agro based industries*

Sugar, Rice and Saw mills are the major agro based industries in the state. Presently, there are 15 Sugar mills operating in the state and few of them are working as cogeneration. It was revealed that most of the Sawmills in the state were small and process firewood only. These Sawmills process timber, procured either from farmers or purchase auctioned wood from the Forest Department. These mills operate for about 15–20 days a month with an average of 6–8 hours per day for the whole year except during the monsoon period. The average wood processed in one mill is about 1500 t $y^{-1}$.

### 1.4. *Power scenario*

The state of Haryana is ranked fourth in terms of proportion of electrified households with 80.5%, after Himachal Pradesh (94.5%), Goa (92%) and Punjab (90.5%) in the country [9]. Today, Haryana has total available installed generation capacity of around 4.0333 GW. The State Government has proposed to add over 3.0GW power generation capacity during the 10th & 11th Five Year Plan, which includes Yamunanagar and Hissar Thermal Projects of 600 MW and 500 MW respectively.

## 2. Materials and methods

The study consisted of intensive field surveys, interviews and secondary data collection from all 67 Talukas of the state and covering both, agriculture and agro-industrial sectors.

### 2.1. *Sample size and categories*

Field surveys based on household and direct interview methods were carried out during June – November 2003 in all the 19 districts of the state. In all, a total of 1134 respondents, averaging at 60 respondents in each district, were interviewed. These respondents spread across different user categories such as Households, Sawmills, Brick kilns, Sugar mills, Biomass traders, Rice mills and other industries, and geographical extent. At the household level, the sources of biomass production, patterns of consumption, types and efficiency of improved devices, if any were assessed. Within Taluka, villages selected for the study were located at minimum of 5 km from the main road.

**Table 1 – Survey details in Haryana state.**

| Sr. no. | Category of respondent | Total in state | Average per district |
|---|---|---|---|
| 1 | Households | 763 | 40 |
| 2 | Saw mill owners | 91 | 5 |
| 3 | Brick kiln owners | 96 | 5 |
| 4 | Rice mills | 93 | 5 |
| 5 | Biomass traders | 44 | 2 |
| 6 | Other industries | 32 | 2 |
| 7 | Sugar factory | 15 | 1 |
| | Total | 1134 | 60 |

Field survey June–November 2003.

Besides primary data collection through direct interviews, secondary data were also collected from various sources. Information on proportion of area under different crops and crop wise per unit area productivity were collected from Statistical Abstract of Haryana, 2001–02. CRR (Crop Residue Ratios) for all the major and minor crops have been measured and compared with the data of MoA (Ministry of Agriculture), Government of India. However, no major difference was found between the field data and MoA data, except for the Wheat in few districts, where high yielding varieties were grown.

From Agro-industrial sector, a sample of about 3–5 industrial units was drawn from each biomass producing or consuming industries in each district of the state. The sources of information included DICs (District Industries Center), DoI (Department of Industries) and DFCS (Department of Food and Civil Supplies). In all, a total about 15 to 20 industrial units covering all types of biomass based industries was drawn a sample in each district. Besides this, in-depth interviews with biomass traders were conducted to assess the quantum, collection timing, source, destination and pricing of the biomass. These sets of interviews helped in crosschecking the information gathered from the industry owners. Various meetings and discussions were also held with the officials of Revenue, Agriculture, Horticulture, Forests and Industrial Departments of the Sate Government during the field survey for cross checking the data. Before starting the field survey, a pilot survey was conducted to pre test the questionnaire for its refinement, wherever necessary. In order to collect information from various stakeholders, seven different sets of questionnaires were prepared for conducting the surveys, covering Households, Sawmill owners, Brick kiln owners, Sugar mill representative, Biomass traders, Rice mill owners and other Industries representatives (Table 1). It is important to mention here that paddy husk has been considered as agriculture by a product, rather than a by product of agro industrial sector.

## 3. Data reporting and analysis

### 3.1. *Significant and insignificant crops*

A crop was considered major if its crop area fraction was 10% or above of the total cultivated area or one or more of its residues had the residue fraction of 10% or above of the total residue production of the district. A crop was considered minor if it was not covered under the major crop and had either crop area fraction of 2.5% or above or one or more of its residues had the residue fraction of 2.5% or above. Crops that do not qualify either as major or minor was considered 'Insignificant crop'. Data for the insignificant crops were not calculated in the present resource assessment study due to miniscule contribution by such crops in the total biomass production. The total biological residue generation was expressed in kt per season at 10% moisture content and RRG (Ratio of Residue Generation) to CP (Crop Production) measured in terms of their weight and averaged (Table 2).

**Table 2 – Significant and insignificant crops grown in Haryana state.**

| District/Crops | Wheat | Paddy | Sugarcane | Bajra | Cotton | Gram | Mustard | Barley |
|---|---|---|---|---|---|---|---|---|
| Hissar | ✓✓ | ✓✓ | X | ✓✓ | ✓✓ | X | ✓ | X |
| Sirsa | ✓✓ | ✓✓ | X | X | ✓✓ | X | ✓✓ | ✓ |
| Fatehabad | ✓✓ | ✓✓ | X | ✓ | ✓✓ | X | ✓ | X |
| Jind | ✓✓ | ✓✓ | X | ✓✓ | ✓✓ | X | X | X |
| Kaithal | ✓✓ | ✓✓ | X | ✓ | X | X | X | X |
| Karnal | ✓✓ | ✓✓ | ✓ | X | X | X | X | X |
| Kurukshetra | ✓✓ | ✓✓ | ✓ | X | X | X | X | X |
| Bhiwani | ✓✓ | ✓ | X | ✓✓ | ✓✓ | X | ✓✓ | X |
| Faridabad | ✓✓ | ✓✓ | ✓ | ✓ | X | X | X | X |
| Ambala | ✓✓ | ✓✓ | ✓ | X | X | X | X | X |
| Panipat | ✓✓ | ✓✓ | ✓ | X | X | X | X | X |
| Sonipat | ✓✓ | ✓✓ | ✓ | ✓ | X | X | ✓ | X |
| Yamunanagar | ✓✓ | ✓✓ | ✓ | X | X | X | X | X |
| Jhajjar | ✓✓ | ✓ | X | ✓ | X | X | ✓ | ✓ |
| Rewari | ✓✓ | X | X | ✓✓ | X | X | ✓✓ | ✓ |
| Gurgaon | ✓✓ | ✓ | X | ✓✓ | X | X | ✓✓ | X |
| Mahendragarh | ✓✓ | X | X | ✓✓ | X | ✓ | ✓✓ | X |
| Rohtak | ✓✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | X |
| Panchkulla | ✓ | ✓ | ✓ | X | X | ✓ | ✓ | X |

✓✓: Major crop, ✓: Minor crop, X: Insignificant crop.

### 3.2. Biomass classification

Primary and secondary data was compiled and analyzed to calculate the surplus biomass and power generation potential from all the districts of the state. In estimating the surplus biomass, the following classification of biomass by utilization was used:

- Basic Biomass Generation ($Q_{BG}$) [kt $y^{-1}$] = Kharif or Rabi or other season residue generation estimated based on the total biological growth expressed in kt $y^{-1}$. The estimate can be made either using the CRR (Crop to Residue Ratio) or using the production (growth) rate of the residue (kt $ha^{-1}$) as the case may be; residue has been reported differently for all the seasons of the year.
- Total Biomass Generation ($Q_{TG}$) [kt $y^{-1}$] = Sum of the Biomass Residue ($Q_G$) generated from all the seasons in the year.
- Industrial Usage = Industries that contribute more than 2.5% of the net production ($Q_{NP}$) and the biomass residues in which industry can technically operate with.
- Basic Surplus Biomass ($Q_{BS}$) [kt $y^{-1}$]) = Basic Biomass Generation ($Q_{BS}$) [kt $y^{-1}$] – (Fodder + Thatching and Other non fuel domestic usages).
- Productive Surplus Biomass ($Q_{PS}$) [kt $y^{-1}$] = Basic Surplus Biomass ($Q_{PS}$) [kt $y^{-1}$] – (Domestic fuel use * K + Manure and similar usage) [kt $y^{-1}$]. Where K is a judgemental factor to be applied to present total domestic fuel use to indicate the potential for improvement in efficiency. As per the present technologies, this factor is expected to be around 25%, which indicates the potential for having the biomass consumption for domestic fuels, by efficiency improvement [10].
- Net surplus Biomass ($Q_{NS}$) [kt $y^{-1}$] = Productive Surplus Biomass ($Q_{PS}$) [kt $y^{-1}$] – usage in industry [kt $y^{-1}$].

### 3.3. Import and export of biomass

The residue generated biologically can be transported either with the crop product such as Rice husk or even traded in the raw form, like fuel wood, to fetch better prices (these are termed as exported biomass residues). Some districts, due to their location and other advantages, have large number of industries such as rice mills, where paddy processed is also exported. In such districts, there is a large-scale import of paddy from other districts and even from nearby states such as Punjab. As such the total Paddy husk generated in these districts exceeds the husk that would have been generated biologically in the district. Moreover, several of these mills also consume paddy husk for their own operations like para-boiling of Rice or drying of Paddy. Further, in some of the districts the consumption also exceeds the biological generation. In such cases, the net surplus of paddy husk has been reported as a negative suggesting larger industrial activity in the district. This negative net surplus has not been used to compute power generation potential in that district and the potential from such "Negative Net Surplus" has been reported as "Zero". Some of the other residues, like Mustard husk (locally called Padadi) being used in brick kilns and woody biomass for households and commercial establishments has also been treated in a similar fashion.

### 3.4. Reporting on bagasse from sugar mills

Sugarcane is grown in most of the districts of the state. The residues from sugarcane in these districts (trash/tops and leaves) have been treated as any other biomass residue and have been reported as such in the present study. But for Bagasse, it is assumed that it would be used for co generation after sun drying in the sugar mills itself. At present, there are total 15 Sugar mills in the state. Some of these have the co-generation facilities. In the present situation, these sugar industries do not dry the Bagasse and use it with up to 50% moisture. The possible Bagasse generated from the sugar mills in the state has been calculated, but is not considered in the present study, since as per the government industrial policy, it is assumed that all the Bagasse generated from the sugar mills would be consumed itself in the mills for co generation in near future. Thus, the total Bagasse generated has been considered as "Zero" while accounting net surplus.

### 3.5. Power conversion factor

The energy content of the biomass residue is measured at a moisture content of 10% and expressed in term of Mt $y^{-1}$ required for generation of electrical power with 6500 hours of operation and 75% PLF (Plant Load Factor). This term is also referred as FPG (Factor for Power Generation). Electrical power is computed by multiplying biomass for power and FPG. This projection does not indicate that the biomass residue is restricted for electrical output in its end use and could have other thermal applications as well. Power generation potential from surplus biomass is calculated as follows:

- Power potential from Basic Surplus ($P_{BS}$) [MW] = Basic Surplus * Factor for Power (FP).
- Power potential from Productive Surplus ($P_{PS}$) [MW] = Productive Surplus * Factor for Power (FP).
- Power potential from Basic Surplus ($P_{NS}$) [MW] = Net Surplus * Factor for Power (FP).

## 4. Results

### 4.1. Agriculture sector

#### 4.1.1. Residue generation in agriculture sector

The total residue generation from all the major and minor crops was reported to be 24.697 Mt $y^{-1}$ in the state. Of this, Wheat and Paddy in the form of stalk, pod and husk alone contributed more than 80%, while remaining was contributed by residues of Cotton (7.78%) and Mustard (3.66%) among other crops. Sirsa (10.21%), Hissar (9.21%), Jind (8.62%) and Fatehabad (8.04%) are reported as major crop residue potential districts within the state, which is due to the large agricultural area, higher crop yield, better irrigation facilities, more irrigated area, higher cropping intensity and introduction of high yielding varieties of crop seeds in these districts. Among least crop residues generation districts are Panchkulla, Yamunanagar,

**Table 3 – Crop residue generation in Haryana state. (Unit in kt $y^{-1}$).**

| District/crop residues | Paddy straw | Paddy husk | Maize stalk | Maize cob | Wheat stalk | Wheat pod | Sugar cane top | Sugar cane trash | Bajra stalk | Bajra cob | Cotton stalk | Gram stalk | Mustard stalk | Mustard husk | Barley stalk | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ambala | 325.50 | 43.40 | 18.30 | 3.50 | 294.00 | 140.30 | 14.60 | 14.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 854.20 |
| Bhiwani | 30.00 | 4.00 | 0.00 | 0.00 | 568.80 | 232.30 | 0.00 | 0.00 | 312.00 | 25.00 | 166.30 | 54.60 | 158.40 | 105.40 | 0.00 | 1656.80 |
| Faridabad | 116.00 | 16.00 | 0.00 | 0.00 | 646.80 | 242.60 | 4.70 | 4.70 | 34.60 | 3.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1068.40 |
| Fatehabad | 318.40 | 39.80 | 0.00 | 0.00 | 797.00 | 386.10 | 0.00 | 0.00 | 26.60 | 2.20 | 377.00 | 0.00 | 23.40 | 16.20 | 0.00 | 1986.70 |
| Gurgaon | 28.70 | 4.00 | 0.00 | 0.00 | 596.40 | 216.50 | 0.00 | 0.00 | 148.60 | 12.50 | 0.00 | 0.00 | 74.40 | 42.20 | 0.00 | 1123.30 |
| Hisar | 88.20 | 12.60 | 0.00 | 0.00 | 1020.10 | 416.90 | 0.00 | 0.00 | 139.90 | 11.80 | 496.70 | 0.00 | 87.40 | 0.00 | 0.00 | 2273.60 |
| Jhajjar | 38.10 | 5.00 | 0.00 | 0.00 | 482.40 | 188.90 | 0.00 | 0.00 | 64.70 | 5.00 | 0.00 | 0.00 | 49.80 | 34.20 | 16.80 | 884.90 |
| Jind | 288.60 | 44.40 | 0.00 | 0.00 | 1113.60 | 401.00 | 0.00 | 0.00 | 134.20 | 10.20 | 136.20 | 0.00 | 0.00 | 0.00 | 0.00 | 2128.20 |
| Kaithal | 488.80 | 78.20 | 0.00 | 0.00 | 791.20 | 337.10 | 0.00 | 0.00 | 9.00 | 0.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1705.10 |
| Karnal | 599.40 | 88.80 | 0.00 | 0.00 | 884.20 | 346.10 | 6.20 | 6.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1930.90 |
| Kurukshetra | 520.20 | 71.40 | 0.00 | 0.00 | 607.20 | 227.70 | 9.40 | 9.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1445.30 |
| Mahendergarh | 0.00 | 0.00 | 0.00 | 0.00 | 241.70 | 76.40 | 0.00 | 0.00 | 228.10 | 17.60 | 0.00 | 10.90 | 118.40 | 79.00 | 0.00 | 772.10 |
| Panchkula | 24.30 | 3.60 | 28.80 | 5.60 | 55.40 | 19.80 | 0.50 | 0.50 | 0.00 | 0.00 | 0.00 | 1.20 | 1.40 | 0.90 | 0.00 | 142.00 |
| Panipat | 259.90 | 37.40 | 0.00 | 0.00 | 410.60 | 191.60 | 2.90 | 2.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 905.30 |
| Rewari | 0.00 | 0.00 | 0.00 | 0.00 | 262.20 | 102.60 | 0.00 | 0.00 | 118.00 | 9.40 | 0.00 | 0.00 | 131.00 | 77.60 | 22.50 | 723.30 |
| Rohtak | 50.40 | 7.20 | 0.00 | 0.00 | 383.70 | 172.50 | 6.80 | 6.80 | 56.70 | 4.30 | 44.80 | 0.00 | 18.90 | 11.20 | 0.00 | 763.30 |
| Sirsa | 155.40 | 22.20 | 0.00 | 0.00 | 1053.80 | 456.70 | 0.00 | 0.00 | 0.00 | 0.00 | 699.70 | 0.00 | 68.90 | 43.40 | 21.60 | 2521.70 |
| Sonepat | 190.40 | 27.60 | 0.00 | 0.00 | 613.80 | 251.10 | 3.80 | 3.80 | 21.60 | 1.90 | 0.00 | 0.00 | 5.40 | 3.10 | 0.00 | 1122.50 |
| Yamunanagar | 223.60 | 32.80 | 0.00 | 0.00 | 276.00 | 103.50 | 27.00 | 27.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 689.90 |
| Total | 3745.90 | 538.40 | 47.10 | 9.10 | 11098.90 | 4509.70 | 75.90 | 75.90 | 1294.00 | 103.70 | 1920.70 | 66.70 | 737.40 | 413.20 | 60.90 | 24697.50 |
| | (15.17) | (2.18) | (0.19) | (0.04) | (44.94) | (18.26) | (0.31) | (0.31) | (5.24) | (0.42) | (7.78) | (0.27) | (2.99) | (1.67) | (0.25) | (100.00) |

Values in parentheses refer to the percent of total biomass production.
Field survey June–November, 2003.

**Table 4 – Biomass consumption pattern in Agriculture sector in Haryana state (unit in %).**

| District | Domestic fuel | Fodder | Thatching | Manuring | Industrial | Total consumption in |
|---|---|---|---|---|---|---|
| Ambala | 0.00 | 38.98 | 0.48 | 4.57 | 1.39 | 45.42 |
| Bhiwani | 19.07 | 59.73 | 0.50 | 3.37 | 2.36 | 85.03 |
| Faridabad | 0.00 | 41.59 | 0.43 | 0.99 | 17.14 | 60.15 |
| Fatehabad | 13.28 | 52.64 | 0.00 | 3.39 | 1.75 | 71.07 |
| Gurgaon | 6.64 | 71.77 | 0.26 | 4.13 | 5.84 | 88.64 |
| Hisar | 15.76 | 47.38 | 0.48 | 0.02 | 2.24 | 65.88 |
| Jhajjar | 7.53 | 62.69 | 0.86 | 1.05 | 1.24 | 73.37 |
| Jind | 5.12 | 59.98 | 0.00 | 4.08 | 0.59 | 69.77 |
| Kaithal | 0.00 | 54.36 | 0.00 | 0.00 | 11.42 | 65.78 |
| Karnal | 0.00 | 59.37 | 0.00 | 0.32 | 7.94 | 67.63 |
| Kurukshetra | 0.00 | 49.00 | 0.90 | 0.94 | 6.30 | 57.15 |
| Mahendergarh | 16.75 | 58.75 | 0.00 | 1.61 | 4.38 | 81.49 |
| Panchkula | 1.83 | 63.50 | 0.00 | 5.98 | 0.00 | 71.32 |
| Panipat | 0.00 | 57.86 | 0.00 | 0.40 | 8.06 | 66.33 |
| Rewari | 18.11 | 55.37 | 0.00 | 0.97 | 0.11 | 74.56 |
| Rohtak | 6.93 | 62.17 | 1.32 | 2.20 | 5.07 | 77.69 |
| Sirsa | 19.47 | 55.70 | 0.18 | 1.59 | 2.53 | 79.47 |
| Sonepat | 0.49 | 66.18 | 0.48 | 0.34 | 26.28 | 93.77 |
| Yamunanagar | 0.00 | 48.84 | 0.00 | 15.39 | 3.16 | 67.39 |
| Total | 8.10 | 55.62 | 0.29 | 2.16 | 5.57 | 71.74 |

Field survey June–November, 2003.

Rewari, Rohtak and Mahendragarh, producing 0.58%, 2.78%, 2.93%, 3.09% and 3.13% respectively of the total crop residue generation in the State (Table 3).

#### 4.1.2. *Residue consumption from agriculture sector*

The agricultural residue consumption has been categorized into five categories such as domestic fuel, fodder, thatching, manuring and industrial usage in the state. The total residue consumption from the agriculture sector in the state is 17.716 Mt $y^{-1}$. Of this, domestic fuel and fodder together consume more than 88%, while rest is used in thatching, manuring and industrial usage form. Corresponding to the higher production potential, agricultural residues consumption is also reported high in districts Sirsa, Hissar, Jind, Fatehabad, Bhiwani and Karnal with 11.31%, 8.45%, 8.38%, 7.97%, 7.95% and 7.37% respectively. This is because of the large number of rural human and domestic cattle population and small scale agro residue consuming industries such as Brick kilns and Rice mills etc. Districts Sirsa, Jind and Fatehabad together have about 0.314 million rural households, as against a total of 0.193 million in Panchkulla, Ambala and Yamuna Nagar districts. Most of the residue generated from Wheat, Barley and Bajra is used for fodder, while Paddy husk besides being used as fodder, is also consumed in making dung cakes (*dung cakes are used mainly in open cook stoves called 'hara', which are used for cooking feed for cattle and also for slow boiling of milk in the rural areas*) and sold within the neighboring areas. While Cotton and Gram stalks are used as firewood at domestic level, major portion of Mustard husk is traded or sold as fuel to the Brick kiln owners by farmers. The least biomass consuming districts are Panchkulla, Ambala, Yamunanagar and Rewari in the state (Table 4).

Together, it was calculated that 88.8% of total crop residue is consumed within the state as fodder and fuel. Besides, about 564 kt $y^{-1}$ of crop residue is imported from the neighboring areas. Of this, maximum was reported from Sirsa (46.8%) and Kaithal (20.7%) districts. This was perhaps due to the higher fodder demand in these districts for Paddy husk and Mustard husk in view of large number of live stock population (Table 5).

#### 4.1.3. *Surplus crop residue available in agriculture sector*

Of the total 24.697 Mt $y^{-1}$ of generated crop residue, the basic, productive and net surplus residue is calculated as 44%, 36% and 33% respectively. Hissar (10.76%), Kaithal (8.70%), Karnal (8.57%), Jind (8.34%) and Sirsa (8.01) are the major biomass potential districts, which contribute maximum to net surplus biomass in the state. On the other hand, Panchkulla (0.51%), Gurgaon (2.06%), Mahendragarh (2.18%), Rohtak (2.62%),

**Table 5 – Crop residues imported in Haryana state (unit kt $y^{-1}$).**

| District | Crop residue source | Quantity imported |
|---|---|---|
| Faridabad | Paddy husk | 22.70 (4.02) |
| Fatehabad | Mustard husk | 3.50 (0.62) |
| Gurgaon | Paddy husk # 6.2<br>Mustard husk # 13.3 | 19.50 (3.46) |
| Kaithal | Paddy husk | 116.60 (20.66) |
| Karnal | Paddy husk | 64.70 (11.47) |
| Kurukshatra | Paddy husk | 19.68 (3.49) |
| Panipat | Paddy husk | 21.50 (3.81) |
| Rohtak | Mustard husk | 27.50 (4.87) |
| Sirsa | Paddy husk # 2.3<br>Mustard # 2.0 | 4.30 (0.76) |
| Sonipat | Paddy husk # 224<br>Mustard husk # 40.1 | 264.30 (46.84) |
| Total | | 564.28 |

Values in parentheses refer to the percentage of total biomass imported in the state.

**Table 6 – Surplus crop residue from Agriculture sector in Haryana state (unit in kt $y^{-1}$).**

| District | Total generation | Basic surplus | Productive surplus | Net surplus |
|---|---|---|---|---|
| Ambala | 854.22 | 517.11 | 478.10 | 466.24 (5.8) |
| Bhiwani | 1656.87 | 658.82 | 366.04 | 326.99 (4.06) |
| Faridabad | 1068.33 | 619.34 | 608.77 | 448.26 (5.57) |
| Fatehabad | 1986.77 | 940.88 | 675.71 | 644.39 (8.01) |
| Gurgaon | 1123.39 | 314.26 | 211.93 | 165.77 (2.06) |
| Hissar | 2273.49 | 1185.28 | 916.25 | 865.38 (10.76) |
| Jhajjhar | 884.87 | 322.55 | 263.33 | 252.29 (3.14) |
| Jind | 2128.27 | 851.72 | 683.14 | 670.66 (8.34) |
| Kaithal | 1705.07 | 778.23 | 778.23 | 700.03 (8.70) |
| Karnal | 1931.00 | 784.64 | 778.44 | 689.64 (8.57) |
| Kurukshatra | 1445.23 | 723.98 | 710.40 | 639.00 (7.94) |
| Mahendragarh | 772.03 | 318.42 | 209.04 | 175.20 (2.18) |
| Panchkulla | 142.04 | 51.82 | 41.36 | 41.36 (0.51) |
| Panipat | 905.23 | 381.43 | 377.88 | 326.31 (4.06) |
| Rewari | 723.29 | 322.83 | 217.59 | 216.78 (2.69) |
| Rohtak | 763.28 | 278.73 | 222.26 | 211.06 (2.62) |
| Sirsa | 2521.69 | 1112.43 | 704.17 | 644.69 (8.01) |
| Sonipat | 1122.57 | 374.26 | 366.34 | 335.62 (4.17) |
| Yamunanagar | 689.84 | 352.89 | 246.72 | 224.93 (2.80) |
| Total | 24697.48 | 10889.62 | 8855.70 | 8044.60 |

Values in parentheses refer to the percentage of total biomass generation.

**Table 7 – Residue generation, consumption and surplus availability from sawmills in Haryana state (unit in kt $y^{-1}$).**

| District | Total biomass generation | Total biomass consumption | Surplus biomass |
|---|---|---|---|
| Ambala | 52.33 (8.10) | 0.00 (0.00) | 52.33 (8.67) |
| Bhiwani | 11.86 (1.84) | 2.80 (6.50) | 9.06 (1.50) |
| Faridabad | 24.09 (3.73) | 1.60 (3.70) | 22.49 (3.73) |
| Fatehabad | 13.71 (2.12) | 0.90 (2.10) | 12.81 (2.12) |
| Gurgaon | 28.00 (4.33) | 0.00 (0.00) | 28.00 (4.64) |
| Hisar | 27.90 (4.32) | 6.20 (14.40) | 21.70 (3.60) |
| Jhajjar | 27.84 (4.31) | 0.00 (0.00) | 27.84 (4.61) |
| Jind | 42.93 (6.64) | 0.00 (0.00) | 42.93 (7.12) |
| Kaithal | 27.40 (4.24) | 0.00 (0.00) | 27.40 (4.54) |
| Karnal | 20.43 (3.16) | 0.80 (1.90) | 19.63 (3.25) |
| Kurukshetra | 75.00 (11.61) | 2.40 (5.60) | 72.60 (12.03) |
| Mahendergarh | 20.59 (3.19) | 2.63 (6.10) | 17.96 (2.98) |
| Panchkula | 75.90 (11.75) | 2.00 (4.70) | 73.90 (12.25) |
| Panipat | 58.40 (9.04) | 1.90 (4.40) | 56.50 (9.37) |
| Rewari | 22.62 (3.50) | 0.00 (0.00) | 22.62 (3.75) |
| Rohtak | 19.64 (3.04) | 5.30 (12.30) | 14.34 (2.38) |
| Sirsa | 44.00 (6.81) | 0.00 (0.00) | 44.00 (7.29) |
| Sonepat | 30.24 (4.68) | 12.10 (28.20) | 18.14 (3.01) |
| Yamunanagar | 23.33 (3.61) | 4.30 (10.00) | 19.03 (3.15) |
| Total | 646.21 | 42.93 | 603.28 |

Values in parentheses refer to the percentage of total biomass generation, consumption and surplus availability.

Rewari (2.69%) and Yamunanagar (2.80%) were reported as the least surplus biomass producing districts in the state (Table 6).

#### 4.1.4. *Residue generation from agro based industries*

Residue generated from the sawmills in the form of sawdust has been considered as major biomass production from agro based industries, calculated at 646 kt $y^{-1}$. Of this, major contribution is from Kurukshtra, Panchkulla, Panipat and Ambala districts, owing to the existence of large number of sawmills in these districts, estimated at around 150 to 200.

#### 4.1.5. *Residue consumption from agro based industries*

The sawdust is mixed with cow dung to make dung cake as a source of domestic fuel and also consumed in brick kilns. The total sawdust consumption in the state is estimated at about 42.93 kt $y^{-1}$. Major sawdust consuming districts are Sonipat, Hissar, Rohtak and Yamunanagar, reporting, 28.19%, 14.44%, 12.35% and 10.02% respectively of the total residue consumption in the state.

#### 4.1.6. *Surplus residue available in agro based industries*

The total surplus residue in the industrial sector is estimated about 603 kt $y^{-1}$ in the state. Of this, Panchkulla (12.25%), Kurukshetra (12.05%), Panipat (9.37%) and Ambala (8.67%) contribute maximum to the surplus biomass. On the other hand, districts such as Bhiwani (1.5%), Fatehabad (2.12%), and Rohtak (2.38%) contribute minimal to the Agro industries sector (Table 7).

### 4.2. *Total surplus biomass availability*

Various surplus biomass categories have been already defined in the biomass classification section. Of the total surplus biomass generation of 25.343 Mt $y^{-1}$, basic, productive and net surplus biomass is estimated at 45.52%, 37.49% and 34.12% respectively in the state. Hissar and Sirsa districts alone contribute more than 20% to the total basic surplus biomass generation in the state. In productive surplus category, Hissar (9.94%), Kaithal (8.48%), Karnal (8.41%) and Kurukshetra (8.27%) districts contributed maximum. Finally, in the net surplus category, which is considered as the actual surplus available for power generation Hissar (10.26%), Kaithal (8.41%), Jind (8.25%), Kurukshetra (8.23%), Karnal (8.20%) and Sirsa (7.86%) are the districts that contributed maximum net surplus biomass.

### 4.3. *Power generation potential from the surplus biomass*

To convert the various biomass residues types into power generation potential, IISc (Indian Institute of Science), Bangalore has analyzed the calorific values and calculated the conversion factor of all the crop residues. The same conversion factor for all the crop residues is applied in the present article.

Power generation from the basic, productive and net surplus was calculated as 1.499GW, 1.227GW and 1.120GW per year respectively. Districts Hissar (10.62%), Jind (8.30%), Sirsa (8.28%) and Kaithal (8.23%) contributed maximum percent of power generation from net surplus biomass in the state. However, Panchkulla (1.39%), Mahendragarh (2.21%), Gurgaon (2.29%), Rohtak (2.67%), Rewari (2.69), and Yamunanagar (2.74%) are the districts that contributed least percentage of power from the net surplus biomass in the State (Table 8).

**Table 8 – Biomass generation and surplus availability in Haryana state (unit in kt $y^{-1}$).**

| District | Total generation | Basic surplus | Productive surplus | Net surplus |
|---|---|---|---|---|
| Ambala | 906.60 | 569.50 (71.50) | 530.50 (66.50) | 518.60 (65.20) |
| Bhiwani | 1668.80 | 670.70 (87.20) | 377.90 (48.30) | 336.10 (43.50) |
| Faridabad | 1092.50 | 643.50 (84.50) | 632.90 (83.10) | 470.70 (62.30) |
| Fatehabad | 2000.50 | 954.60 (125.60) | 689.50 (89.70) | 657.20 (86.20) |
| Gurgaon | 1151.40 | 342.30 (44.10) | 239.90 (30.80) | 193.80 (25.80) |
| Hissar | 2301.30 | 1213.10 (164.10) | 944.20 (126.50) | 887.10 (119.10) |
| Jhajjar | 912.70 | 350.40 (45.50) | 291.20 (37.90) | 280.20 (36.80) |
| Jind | 2171.20 | 894.60 (116.30) | 726.00 (94.30) | 713.60 (93.10) |
| Kaithal | 1732.40 | 805.60 (100.90) | 805.60 (100.90) | 727.50 (92.30) |
| Karnal | 1951.40 | 805.10 (99.50) | 798.80 (98.60) | 709.30 (88.70) |
| Kurukshetra | 1520.20 | 798.90 (99.70) | 785.40 (97.80) | 711.60 (89.60) |
| Mahendragarh | 792.60 | 339.10 (42.90) | 229.60 (28.90) | 193.10 (24.90) |
| Panchkulla | 217.90 | 127.70 (17.20) | 117.20 (15.90) | 115.30 (15.70) |
| Panipat | 963.60 | 439.80 (55.70) | 436.20 (55.20) | 382.80 (48.90) |
| Rewari | 745.90 | 345.40 (43.90) | 240.20 (30.20) | 239.40 (30.10) |
| Rohtak | 782.90 | 298.30 (39.70) | 241.90 (31.90) | 225.40 (29.90) |
| Sirsa | 2565.70 | 1156.40 (155.80) | 748.20 (99.40) | 688.70 (92.90) |
| Sonipat | 1152.80 | 404.50 (51.90) | 396.60 (50.80) | 353.80 (45.70) |
| Yamunanagar | 713.20 | 376.20 (54.50) | 270.10 (40.90) | 243.90 (30.70) |
| Total | 25343.70 | 11535.90 (1499.50) | 9501.90 (1227.30) | 8647.90 (1120.70) |

Values in the parenthesis refer to the power generation potential in MW $y^{-1}$.

## 5. Discussions

During 2002–03 it was assessed that, of the total peak power demand of 2.871GW, only 2.721GW is met, recording a deficit of about 5.2% [11]. In view of significant gap in supply and demand of power in the state, the surplus biomass can be put use to generate power and bridge the supply-demand deficit to some extent. Agriculture sector understandably can contribute significantly to meet this deficit. The trends in the agriculture sector indicate that the cropping intensity is at its maximum and has remained constant in majority of the districts during last few years, a general scenario all over the country [12]. Therefore, an assessment presented in this article indicates the maximum potential of biomass generation from the agriculture sector in the state. During primary survey we have observed that farmers burn the surplus biomass in the agriculture fields itself, particularly the remains of the Paddy straw. Moreover, the fact remains that the collection of the generated biomass is not to the maximum within the state.

With the improved technology, the biomass can provide sufficient energy, especially to the rural areas in an environmental friendly way [13]. Of late, the modern biomass technologies are achieving performance standards [14], which make them competitive vis-à-vis conventional energy forms, especially if the social and environmental benefits of biomass are internalized. A recent assessment done for UNCED (United Nation Conference on Environment and Development) found that sustainable biomass energy system could be the largest single contributor to global energy supply [15].

## 6. Concluding remarks

Summing up all the aspects, following conclusions are drawn from the research assessment work

- The potential for generating power from the surplus biomass in Haryana State is significant.
- The surplus biomass is concentrated mainly in the old Hisar district comprising Hisar, Sirsa, Jind and Kaithal.
- Apart from Paddy husk and stalk, Mustard husk and stalk are the major sources of surplus biomass in the state. Therefore, prices for both these residues are showing rising trend day by day.
- Trading of biomass is currently occurring through formal and informal channels. Fodder based Agri residues are traded formally, while other Agri residues such as Cotton stalks, Mustard husk etc are traded through informal channels with in the State.
- Saw mills can become the hubs for biomass procurement and supply in the state.
- Biomass briquetting units based on Mustards husk are coming up in few districts of the state. Farmers are fetching good prices for Agri-residues especially Mustard husk with in the state.
- Rice mill owners are interested in cogeneration using the Paddy husk. However, they are unaware about the available technology and financial support schemes from MNERS, Government of India. A quick round of meeting with Rice mill owners, technology providers, MNERS, Govt. of India and HAREDA (Haryana Renewable Energy Development Agency) would be useful in this regard.
- Finally, during the survey it was assessed that introducing improved cooking devices e.g. improved cooking chullas, about 25% of domestic fuel wood would be saved through out the state.

The present article focused on the key issues of converting the agro wastes into power generation, which would be useful for various biomass stalk holders such as farmers, agro industry owners, NGOs, policy formulators and decision makers. The article is also expected to provide some lead to MNERS, GoI and HAREDA, to plan for the future prospects for

utilizing surplus biomass for energy generation in more sustainable and environment friendly manner, particularly to meet the deficit in the state and also to set an example for rest of the world for efficient utilization of surplus biomass.

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