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ASSESSING BIOMASS AVAILABILITY AND COMPRESSED BIOGAS (CBG) POTENTIAL IN HAPUR DISTRICT

UTTAR PRADESH

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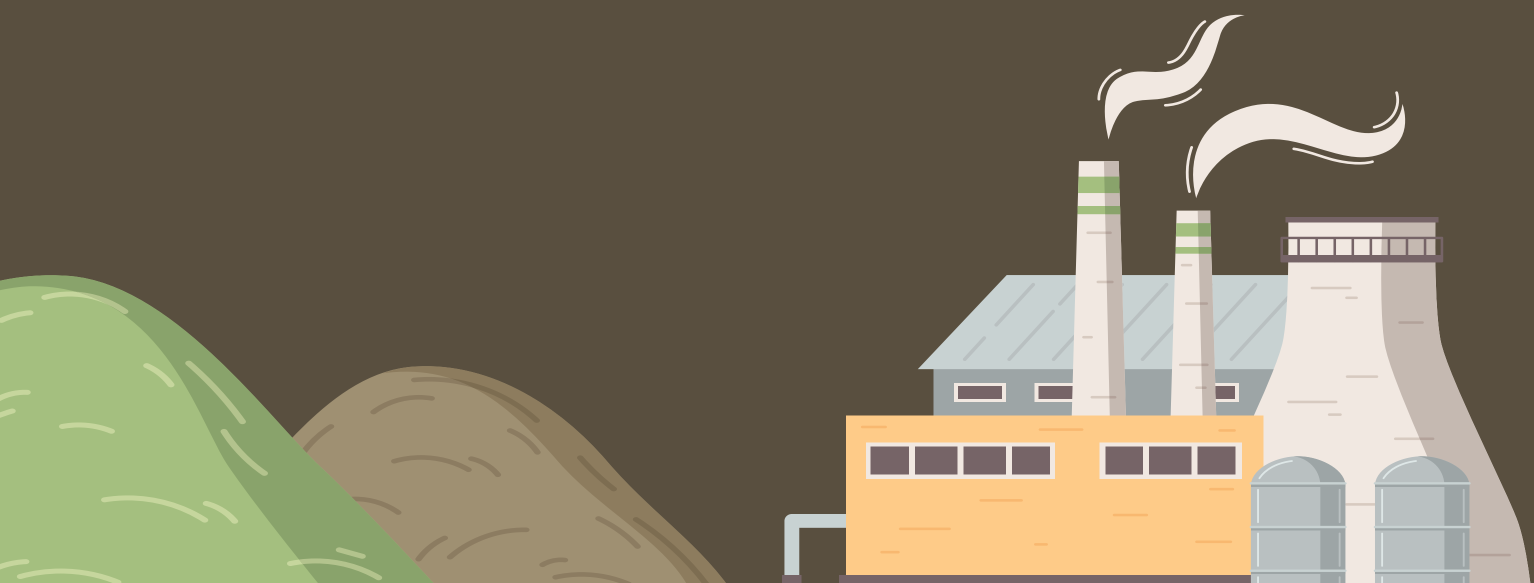
Contents



List of Tables

List of Figures:

01 Executive Summary

India's energy demand is projected to triple by 2050, making the shift to renewable energy sources essential. Biomass energy presents a sustainable solution by converting organic waste into fuel, thus mitigating environmental concerns and enhancing energy security. Uttar Pradesh, particularly Hapur district, has significant potential for biomass-based Compressed Biogas (CBG) production due to its agrarian economy and abundant biomass resources.

Biomass Availability and CBG Potential in Hapur

The study utilised Geographic Information System (GIS) tools and field data collection to assess biomass availability in Hapur. Key findings include:

- **Major Biomass Feedstocks**: SSugarcane Press Mud, Sugarcane Tops and Leaves, Paddy Straw and Cow Dung
- **High-Potential Zones**: Garhmukteshwar tehsil emerged as the top biomass source. Potential locations for CBG plants could be sited close to the sugar mills or sugar farms in these tehsils.
- **CBG Generation Potential**: The district has the potential to generate approximately 35 tonnes per day (TPD) of CBG from major feedstocks, such as sugarcane tops and leaves, press mud and cattle dung, thereby contributing to the goal envisioned under the SATAT (Sustainable Alternative

Towards Affordable Transportation) Scheme, which envisions installing 5,000 CBG plants by 2030.

Table 1: Tehsil-wise, feedstock-wise CBG potential in TPD as per NIBE factors

Tehsil	Sugarcane Tops & Leaves	Sugarcane Pressmud	Paddy Straw	Cattle Dung	Total
Dhaulana	4.44	0	1.84	0.78	7.06
Garhmukteshwar	14.56	2.53	0.83	1.42	19.34
Hapur	6.58	0	1.5	1.043	9.123
Hapur District	25.58	2.53	4.17	3.243	35.523

- **Emission Savings:** Compressed Biogas is a sustainable alternative to traditional natural gas and therefore can replace it as an automotive fuel or in city gas distribution networks. This replacement can result in reduction of natural gas consumption and save carbon emissions. To put it in figures, a total installed capacity of 35 TPD capacity CBG plants can collectively abate 35,131.25 T CO_2 emissions annually[1].
  - In other words, 35 TPD of CBG can replace 35 TPD of CNG which will correspond to daily carbon emission savings of close to 96.25 T of CO_2.
- **Supply Chain Considerations**: Efficient logistics and storage solutions are essential for sustainable biomass utilisation.

1 Assuming combustion of 1 Kg of Methane produces 2.75 Kg of CO_2 emission, Source: G, Sutheo, et.al., 2024, Comparison of Carbon-Dioxide Emissions of Diesel and LNG Heavy-Duty Trucks in Test Track Environment, Clean Technol, Vol.6, pp. 1465-1479.

Recommendations

1. **Hybrid Feedstock Utilisation**
   - Encourage blending of sugarcane leaves, pressmud mustard straw, Napier grass, and cattle dung to ensure year-round CBG production.
   - Diversified feedstocks stabilise biogas output and reduce supply fluctuations.

2. **Biomass Banks and Farmer Incentives**
   - Establish biomass banks managed by Farmer Producer Organisations (FPOs) to streamline biomass collection and distribution.
   - Introduce transparent pricing and payment mechanisms to encourage farmer participation.

3. **Strategic Siting of CBG Plants**
   - Identify barren lands near sugar mills (within 3-5 km radius) for setting up of CBG plants.
   - Locate plants close to cowsheds, poultry farms, and fuel stations to optimise feedstock procurement and CBG distribution

4. **AgriPV for Fallow Land**
   - Install Agrivoltaics (AgriPV) on fallow land to create a favourable microclimate, enabling land reclamation for cultivation.
   - AgriPV helps conserve soil moisture, reduce evaporation, and provide shade, enhancing agricultural productivity.

5. **AgriPV in Horticulture Areas**
   - Deploy AgriPV systems in horticultural zones to improve crop yield and increase biomass availability.
   - Certain crops like leafy greens benefit from AgriPV, leading to higher biomass production for CBG generation.

6. **Promotion of Bio-Slurry Utilisation**
   - Encourage farmers to use bio-slurry from CBG plants as an organic fertiliser to improve soil health and crop productivity.
   - Develop training programs to educate farmers on the benefits and application techniques of bio-slurry.

7. **Advanced Biomass Storage Solutions**
   - Implement in-house and third-party storage facilities to manage seasonal fluctuations in biomass availability.
   - Utilise separate storage solutions for short-lived residues like press mud and long-lasting residues like paddy straw.

02

Introduction

India is expected to experience the largest increase in energy demand, tripling from current levels by 2050.[2] With rising global energy demand, limited local fossil fuel reserves, and environmental concerns, renewable sources like solar, wind and biomass[3] are gaining focus. Biomass energy not only meets the rising energy demand but also effectively manages organic waste - crop residues, animal waste, and municipal solid waste - reducing environmental problems if left unaddressed. Currently, India's bioenergy accounts for 13 percent of total final energy consumption, with a projected growth rate of 45 percent between 2023 and 2030.[4] India's abundant biomass availability (*See Fig.1* which describes the potential of biomass power in India), positions it well to meet this demand.

2 The Hindu Bureau, India's energy demand to triple by 2050, 05 October, 2024, https://www.thehindu.com/business/indias-energy-demand-to-triple-by-2050/article68719527.ece

3 Singh, A., Olsen, S.I., 2011. A critical review of biochemical conversion, sustainability and life cycle assessment of algal biofuels. Appl. Energy 88, 3548-3555.

4 IEA 2025, Unlocking India's bioenergy potential, https://www.iea.org/commentaries/unlocking-indias-bioenergy-potential

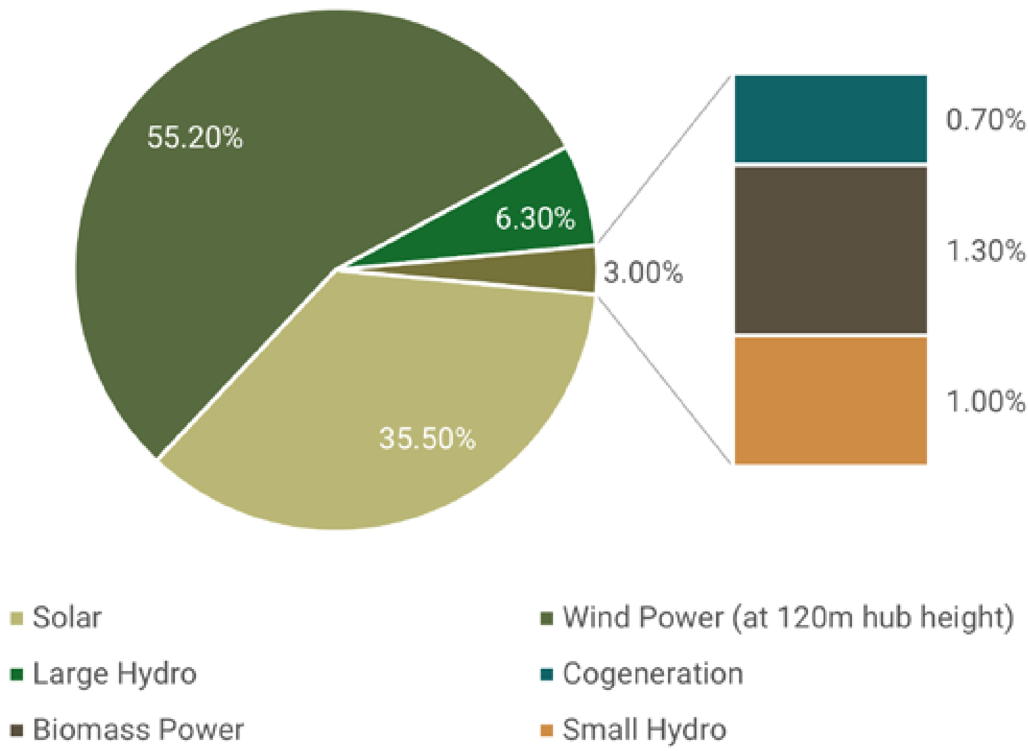


Figure 1: Source-wise renewable power potential in India, 2023[5,6]

India is the second largest agro-based economy and has 58 percent of its total land area available for agricultural purposes, with net cultivated area of around 219.16 million hectares and has about 141.6 percent cropping intensity. , Therefore, it generates a huge amount of agricultural residues which can contribute to biofuel and bioenergy production. At the national level, India generates approximately 686 Million Tonnes (MT) of gross crop residues including approximately 234.5 MT of surplus residues annually.

In India, Uttar Pradesh is a leading agrarian state (See Figure 2) and has the highest biomass power potential (See Figure 3). It is building a robust renewable biofuel economy in line with its Bio-energy Policy 2022. The main thrust of the policy is to promote the production of biofuels such as Bio-CNG and Bio-coal through waste-based enterprises.

5 Energy Statistics 2024, Ministry of Statistics, Programme and Implementation (MoSPI)

6 This share is against total estimated renewable power potential of India as on 2023, i.e., 21,09,654 MW.

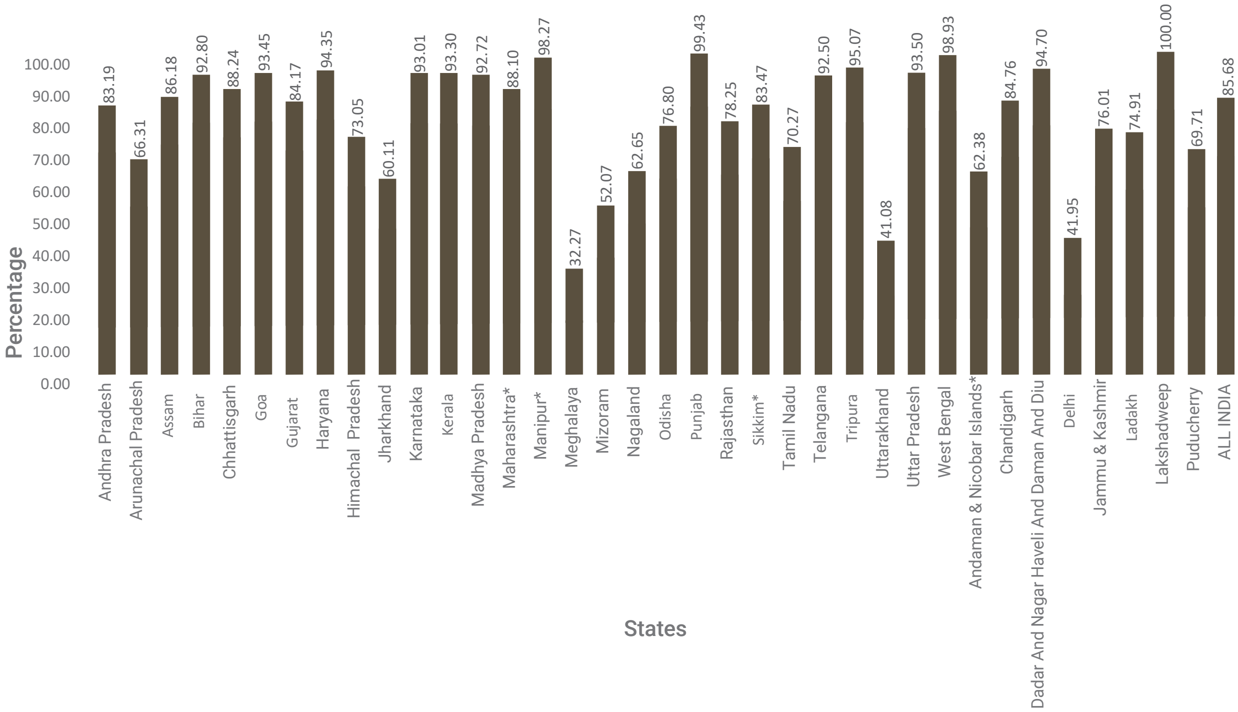


Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23[7]

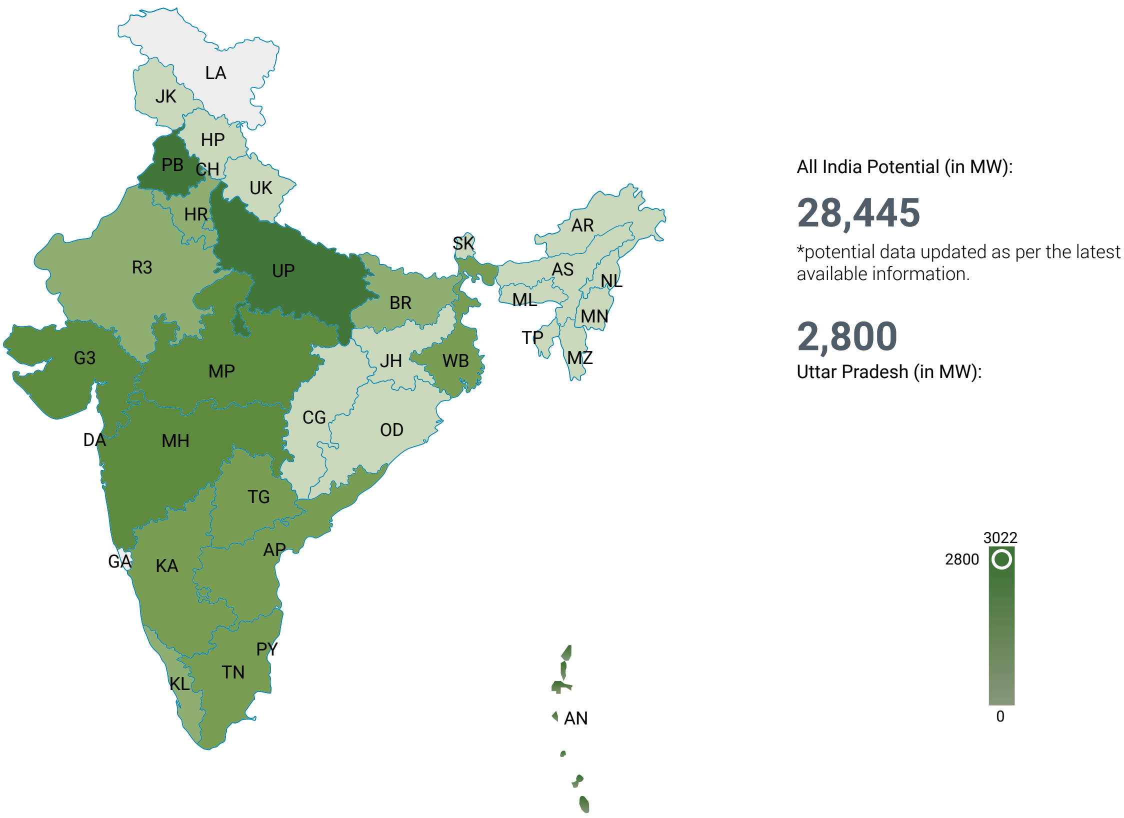


Figure 3: Biomass power potential in India[8]

7 Land Use Statistics At a Glance: 2022-23, Ministry of Agriculture & Farmers Welfare

8 India Climate and Energy Dashboard (ICED) 2025

Uttar Pradesh, among all other States, also has one of the highest total biomass and surplus biomass residue in India i.e., 124 MT and 21 MT, respectively (See Figure 4). It has abundant biomass residue available which include bagasse, press mud, paddy straw, cattle dung, etc. which are potential feedstocks for Compressed Bio-Gas (CBG) production.

As per the 2022 Agricultural Statistics, State-wise potential availability of agriculture-based biomass (MT) is summarised in the table 2:[9]

Table 2: Potential availability of biomass in Uttar Pradesh

State	Rice Husk	Wheat Straw	Maize Cobs	Pearl Millet Straw	Sugarcane Bagasse	Groundnut Shell	Cotton Stalks
Uttar Pradesh	7.64	45.15	N.A.	3.24	58.55	N.A.	N.A.

Despite the availability, challenges such as limited offtake, seasonal biomass supply, and inadequate logistics continue to hinder the consistent production of CBG. To ensure a steady and reliable feedstock supply for a commercial CBG plant, it is crucial to evaluate the available biomass, considering both the type of feedstock and its respective quantity. If such assessments can be conducted at a local level (say, sub-District), it can enable CBG stakeholders to plan and execute projects that are commercially viable and sustainable.

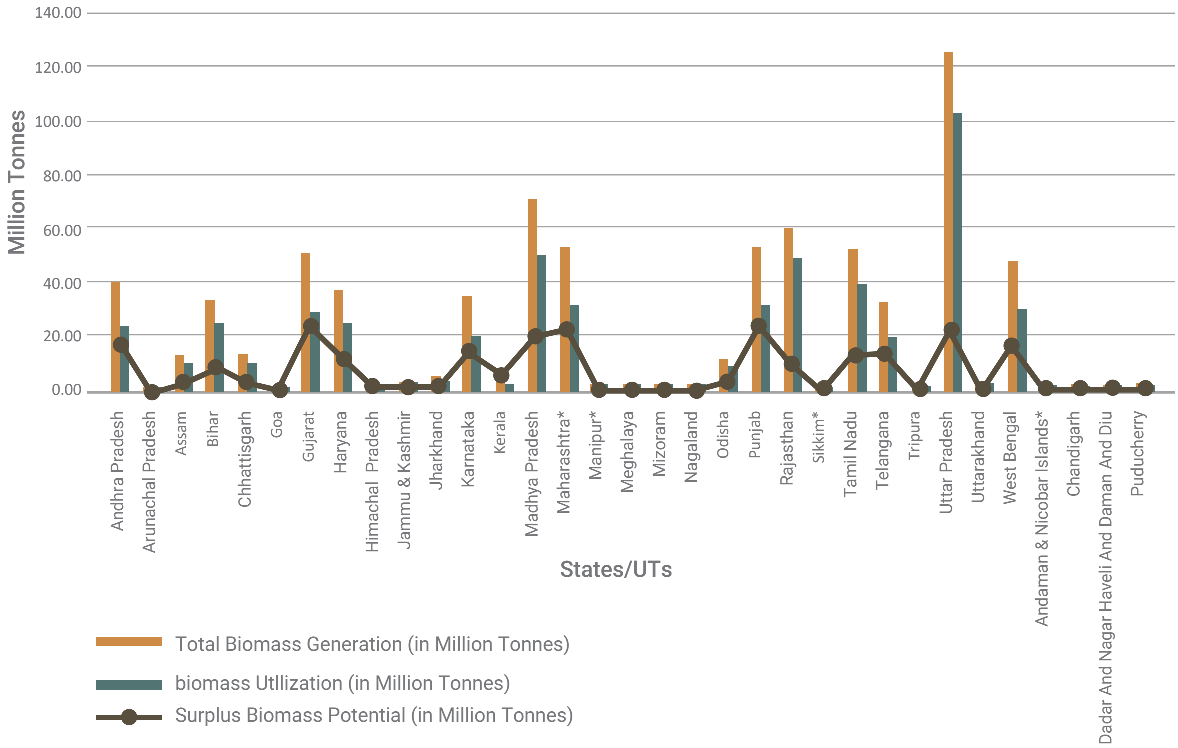


Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential[10]

9 Agricultural Statistics at a Glance 2022, Economics, Statistics and Evaluation Division, Ministry of Agriculture and Farmer's Welfare

10 Study Report of the Ministry of New and Renewable Energy (MNRE) conducted by Administrative Staff College of India (ASCI), Centre for Energy Studies (CES), Hyderabad in 2021, Evaluation Study for the Assessment of Biomass Power and Bagasse Power Potential in in India, All India – Crop Production, Surplus biomass availability and Biomass Power Potential during 2015-18

Biofuels can be broadly classified as food-based (biodiesel, ethanol from feedstocks like sugar, maize, and vegetable oils, etc.) and Non-Grain-Based (NGB) which are produced from lignocellulose materials such as:

- Agriculture and forestry residues that include – livestock residue and crop residue (includes non-edible plant parts that are left in the field after the crop is harvested, thrashed or left after pastures graze including stalk, stubbles, straws, bagasse, seed pods, and roots)[11]
- Industrial waste

In comparison to food-based, NGB biofuels do not compete with food and also not necessarily require land to cultivate for energy purposes, making it the most promising feedstock for energy generation[12]. Further, the contribution of NGB biofuels in reduction of GHG emissions is 30-35 percent greater compared to food-based biofuels.[13]

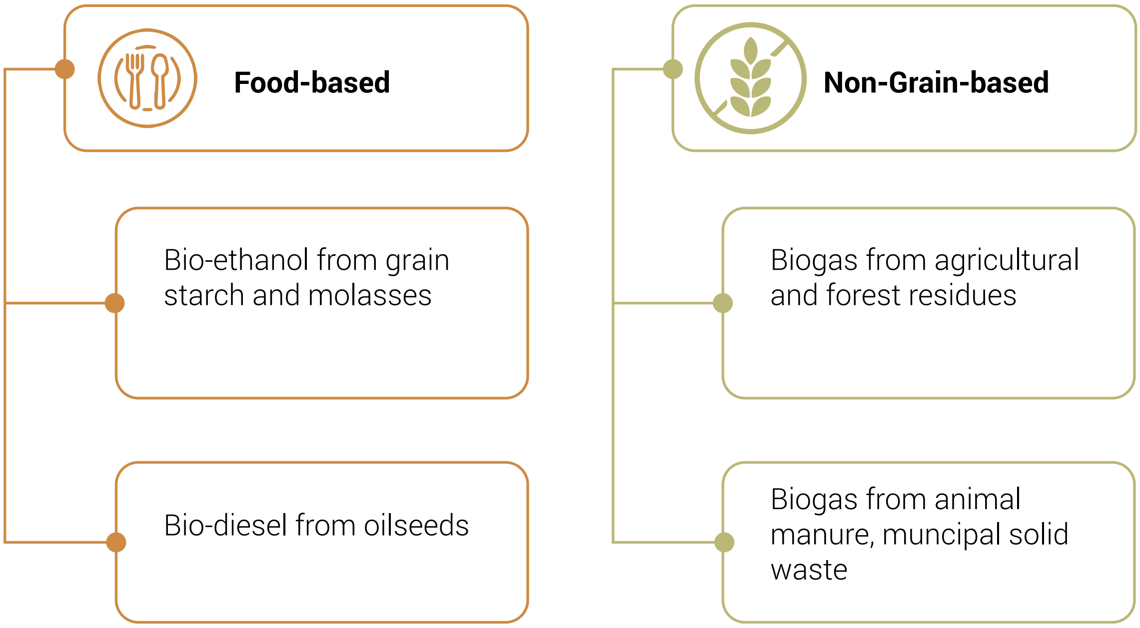


Figure 5: Classification of biofuels

2.1 Scope of the Study

This study aims to measure the net biomass residue production during 2023-24 across all seven tehsils (administrative subdivisions) of Hapur district in Uttar Pradesh. The resulting data will help determine the appropriate capacity and number of CBG plants that can be sustainably established and operated district-wide at sub-district levels. This approach ensures that planned facilities align with the available biomass supply, thereby protecting investor profitability while preventing unsustainable practices in biomass procurement. The assessment includes various agricultural and organic waste feedstocks and their respective residues.

11 Sharma, I.P, Kanta, C., Gusain, Y.S., 2018. Crop residues utilization: wheat, paddy, cotton, sugarcane, and groundnut. Int. J. Botany Stud. 3(3), 11-15.

12 Prasad, S., Singh, A., et. al., 2020 Sustainable utilization of crop residues for energy generation: A life cycle assessment (LCA) perspective, Bioresource Technology 303

13 Global Biofuel Alliance 2025, Role of Non-grain-based Biofuels in India's Energy Transition

Table 3: Different feedstock and their biomass residues

Feedstock	Scope of the Study
Agricultural Residue	Stalks, Leaves, Cobs, Tops, Straw, and other organic residues from Cereals, Millets, Perennial Grass (Sugar Crops), Oilseeds, Pulses, Horticulture Crops, Agri-plantations
Livestock	Dung/Litter from Cattle, Goat, Sheep, Swine, Poultry
Municipal Solid Waste	Dry, Wet, Home Composting, and Sanitary Waste from Municipalities and Municipal Councils

The study excludes the following feedstocks which include forestry residues, municipal solid wastes, effluents and other wastes from industries such as paper and pulp, food processing, etc. It provides an 'as-is' condition and excludes, the potential of biomass residues that can be generated by utilising barren and uncultured land or fallow lands, etc. It takes into consideration of the current biomass residue management practices and decrease in the available feedstock due to its usage in the existing or under way bioenergy projects at each tehsil.

The study quantifies the net residue across two major cropping seasons (kharif and rabi) across all the tehsils. The crops were selected based on their acreage and production across the district. The selected crops for the spatio-temporal mapping include mustard, potato, jowar, sugarcane, vegetables, wheat, bajra, maize, pulses, paddy and other crops (e.g., barley).

2.2 Importance of Biomass Quantification

Agro-residues are geographically distributed with variation in spatio-temporal availability. Agricultural statistics are fundamental datasets for assessing the general conditions of agricultural production and rural economy in India and are proven to be reliable and useful by various applications. For viable utilisation of biomass residue for energy generation, prior and precise database of residue distribution, seasonal fluctuation (peak and lean period of availability) is a pre-requisite. Logistics such as residue harvest, collection, storage, transportation are spatially interlinked and need meticulous planning. In this study, adequacy, precision, reliability of data collected through traditional methods (secondary data collection or survey) is integrated with high-resolution spatial maps of crop production (one of the major agro residues) at the sub-district level that can inform the potential plant capacity, annual feedstock availability for CBG production (both, in terms of quantity and location from where it can be procured).

Government agencies and industry developers/investors can utilise these biomass quantification findings to evaluate crop residue availability across the district. By providing detailed information on both quantity and type of crop residues (such as paddy straw and wheat husk) available in each area, the research supports the design and implementation of CBG plants tailored to local feedstock conditions.

2.3 Overview of Compressed Biogas (CBG) Industry

India has a diverse range of feedstocks available for biogas generation. The optimal feedstock for biogas production is determined by its methanogenic potential—the maximum methane yield per tonne of raw material. This potential is primarily influenced by two factors: the organic matter content and its composition. Higher organic matter concentrations directly correlate to greater biogas production volumes. Additionally, the specific composition of this organic matter significantly affects yield, with lipids exhibiting methanogenic capabilities compared to proteins or carbohydrates. The most common feedstocks utilised in existing CBG plants include animal waste, agricultural residue, organic fraction of municipal solid waste (MSW), and sewage sludge.

Biogas production constitutes an intricate biological process unfolding in four distinct phases. The process begins with hydrolysis (Phase 1), where fermentative bacteria break down complex biopolymers such as proteins, polysaccharides, and fats/oils into simpler monomers and oligomers like sugars, amino acids, and peptides. In the acidogenesis phase (Phase 2), these simplified compounds are further transformed by fermentative bacteria into short-chain volatile organic acids, including propionate and butyrate. During acetogenesis (Phase 3), these intermediate products are transformed by acetogenic bacteria into acetate, hydrogen (H), and carbon dioxide (CO). Finally, in the methanogenesis phase (Phase 4), methanogenic microorganisms follow two pathways: acetolactic methanogens convert acetate into methane (CH) and CO , while CO -reducing methanogens utilise hydrogen to reduce carbon dioxide to methane. Figure 6 shows this sequential breakdown of organic matter under anaerobic conditions, ultimately producing biogas.

Figure 6: Bio-chemical process flow for biogas production

Biogas is mostly composed of methane (40-60%) and carbon dioxide (30-35%), with small amounts of impurities such as Hydrogen Sulphide (H_2S), ammonia and moisture. This biogas can be used directly as cooking fuel or undergo additional processing. An important secondary benefit of biogas production is the digestate byproduct, which contains high concentrations of carbon and nitrogen compounds. Once dewatered, this digestate can be marketed as premium fertiliser. This dual-product approach creates two distinct revenue streams from a single CBG plant operation.

Additional processing of biogas is carried out by removing Carbon dioxide (CO_2), H_2S, and moisture content, resulting in a fuel of higher calorific value. If the methane content of the upgraded product is above 90 percent, it can be used directly as the transportation fuel to replace Compressed Natural Gas (CNG) or injected into gas grids as CBG, which should meet IS 16087:2016 specifications of Bureau of Indian Standards (BIS). Table: 4 and 5 summarise the characteristics of raw biogas and Bio-CNG/CBG.

Table 4: Chemical composition of raw biogas vs. CBG

Composition	Raw Biogas	Bio-CNG/CBG
Methane	55-65%	>90%
Carbon dioxide	30-40%	<4%
Hydrogen sulphide	0.1-4%	<16 ppm
Nitrogen	3%	<0.5%
Oxygen	0.1-2%	<0.5%
Moisture	1-2%	0%
Calorific Value	19.5 MJ/kg	47-52 MJ/kg

Table 5: Composition of CBG as per IS 16087:2016

Characteristic	Requirement
Methane (min)	90%
Carbon dioxide (max)	4%
Oxygen (max)	0.5%
Total sulphur (including H_2S) (max)	20mg/m^3
Moisture (max)	5mg/m^3

The wide variability in biogas substrates and raw materials often necessitates pretreatment processes, which can substantially enhance biogas yields. Figure 7 illustrates significant advantages that can be achieved through appropriate feedstock pretreatment. A single feedstock or a combination of feedstocks is fed into shredders (mechanical pretreatment) that make the substrate smaller or break open their cellular structure, increasing the specific surface area of the biomass (See Figure 8). This gives greater possibility for enzymatic attack and increase biogas yields. The substrate is then dewatered to remove excess moisture from biomass material thereby improving their thermal efficiency and storage stability. After the substrate is homogenised and dewatered, it is preheated in a preparation tank before it is actually fed into a digestor.[14]

14 K.K., Ashin, et.al., 2022, Numerical Analysis of bio-digester substrate heating methods, Vol. 66, pp. 1563-1570

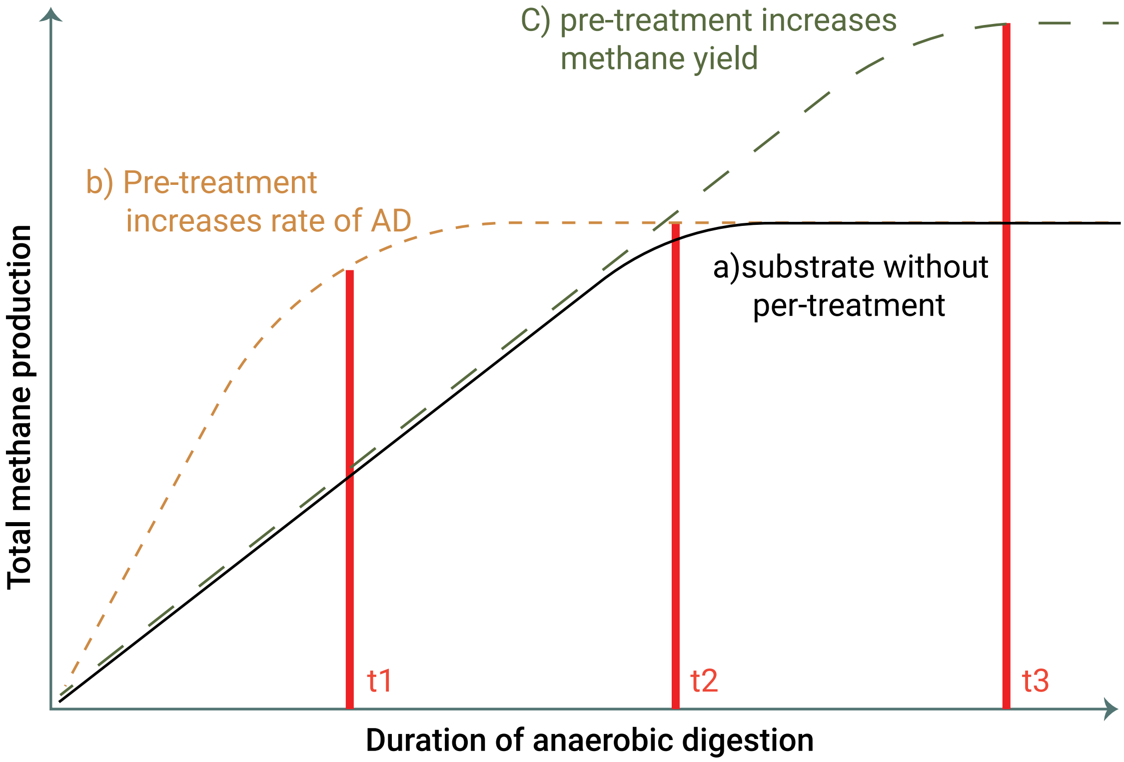


Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[15]

After the raw biogas exits digester, the moisture is removed using a dehumidifier or dryer as water vapour can not only decrease the heat value of the gas but also form condensates and accumulates in the downstream unit thereby forming plugs or hydraulic seals obstructing the transport of biogas. This is followed by removal of hydrogen sulphide which not only contaminates the environment, but also minimizes the useful life of downstream equipment by corrosion. Carbon dioxide is removed from the biogas stream using a Pressure Swing Adsorption technique which separates the two gases through selective adsorption. Purified gas is then compressed in a high-pressure compressor before getting deposited in a high-pressure compartment or cylindrical vessel.

15 IEA Bioenergy 2014

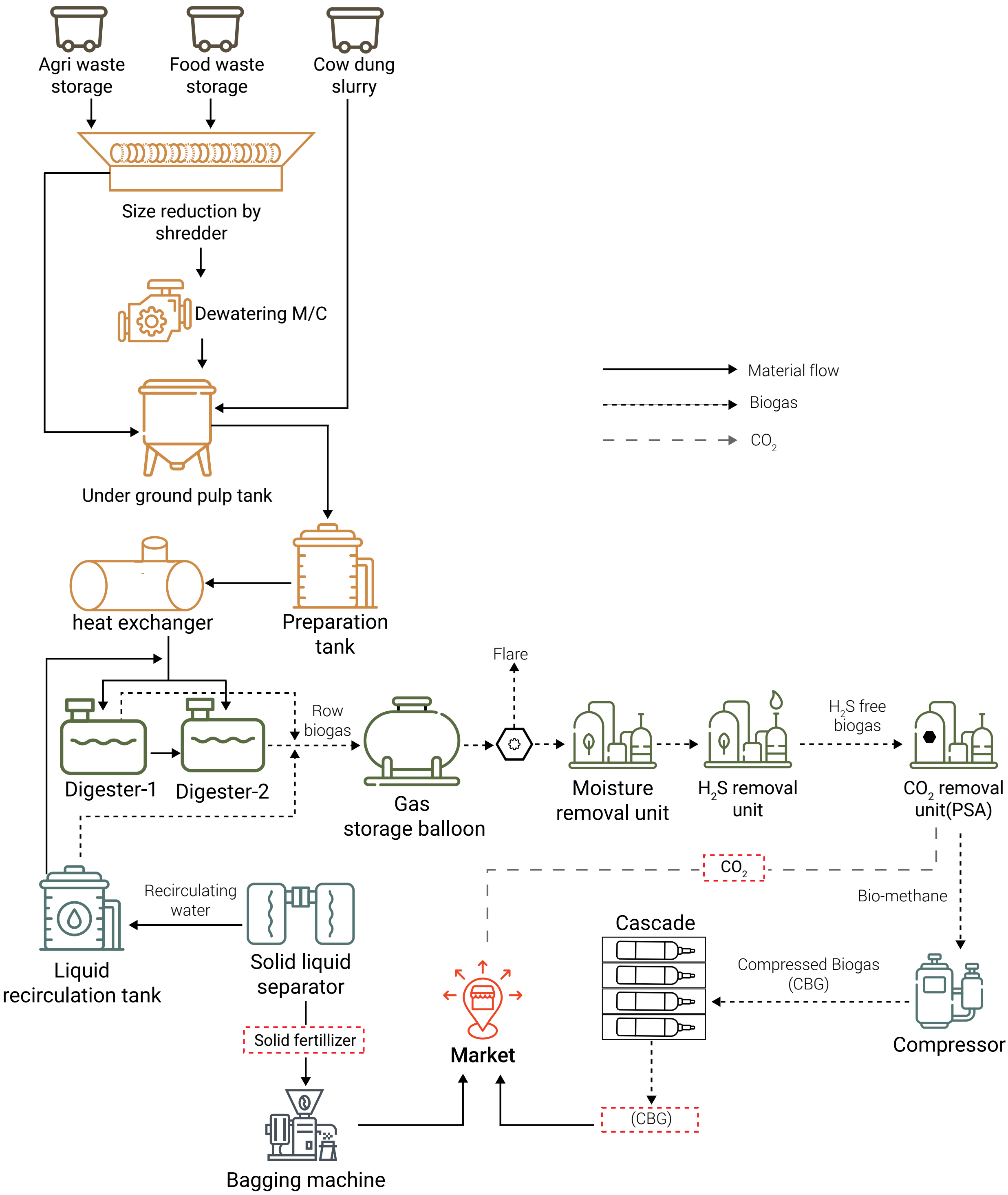


Figure 8: Processflow diagram for a Compressed Biogas Plant[16]

India's CBG potential is estimated at approximately 87 bcm/yr[17], while the installed capacity currently represents less than 1 percent of this potential. As of September 2024, approximately 90 CBG plants were operational with an additional 508 plants under various stages of development. By 2030, CBG production could reach 0.8 bcm/yr. Realising this potential, Government of India through various measures have been promoting the production and use of CBG, which include:

16 B, Gami. B, Patel. P, Patel. V, Parmar., 2022 Cost benefit and environmental impact assessment of CBG production from industrial, agricultural, and community organic waste from India, Biomass Conversion and Biorefinery, Vol. 14

17 Metric 'bcm' refers to billion cubic meters of natural gas

- GOBARdhan (Galvanising Organic Bio-Agro Resources Dhan) which promotes converting cattle dung, agricultural residue and other organic waste into CBG and organic manure. The initiative has resulted in the installation of 110 community biogas plants and 21 CBG plants in Uttar Pradesh alone.[18]
- Under the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative, Government has introduced the phase-wise mandatory blending of CBG in CNG in transport and PNG (Petroleum Natural Gas) in City Gas Distribution network[19]
- Under the National Bioenergy Programme, government has been promoting energy generation from urban/industrial/agricultural residues.
- Market Development Assistance under GOBARdhan and amendments in the Fertiliser (Control) Order of 1985 , providing financial assistance to CBG developers, primarily for promotion of organic fertilisers i.e., manure produced at CBG plants. This further enables farmers to get access to organic fertilisers namely, Fermented Organic Manure (FOM), Liquid FOM, Phosphate Rich Organic Manure (PROM) at reasonable prices, addressing the organic carbon and micronutrients deficiency in Indian soil.
- Facilitating CBG offtake by financially supporting cost-effective pipeline transportation of CBG from production facilities to consumption centres (Scheme for Development of Pipeline Infrasturcture) and price support for CBG gas under CBG-CGD Synchronisation scheme.

Among all States, Uttar Pradesh accounts for 24 percent of the total CBG generation potential in India due to abundant organic feedstock availability.

18 Status of GOBARdhan Scheme for Waste-to-Wealth Plants, Official Reply to Rajya Sabha Unstarred Question No. 718, 10.02.2025, Ministry of Jal Shakti

19 Under the Petroleum and Natural Gas Regulatory Board (PNGRB) Act 2006, CGD in a specified geographical area includes the following distinct segments:
i. Compressed Natural Gas predominantly used as auto-fuel
ii. Piped Natural Gas used in domestic, commercial, and industrial segments

03 District Profile

3.1 Geographic Overview

Hapur is located at 280 72’ 770 78’ E. It has an average elevation of 213 meters (699 feet). It is bound on the north by Meerut, in the south by Bulandshahr, while Ghaziabad forms the southern and western limits. Amroha District lies to the east. It is a relatively newer district carved out from Ghaziabad district with a population of 1,338,310 as per the 2011 Census. The river Ganges forms the eastern boundary. Hapur has a big grain mandi with Food Corporation of India having its godowns as well as processing unit in the district.

Hapur is a major industrial town in the National Capital Region area of western Uttar Pradesh. There are approximately 25 factories of paper cone in Hapur. The district is also a manufacturing hub of making stainless steel pipes and tubes.

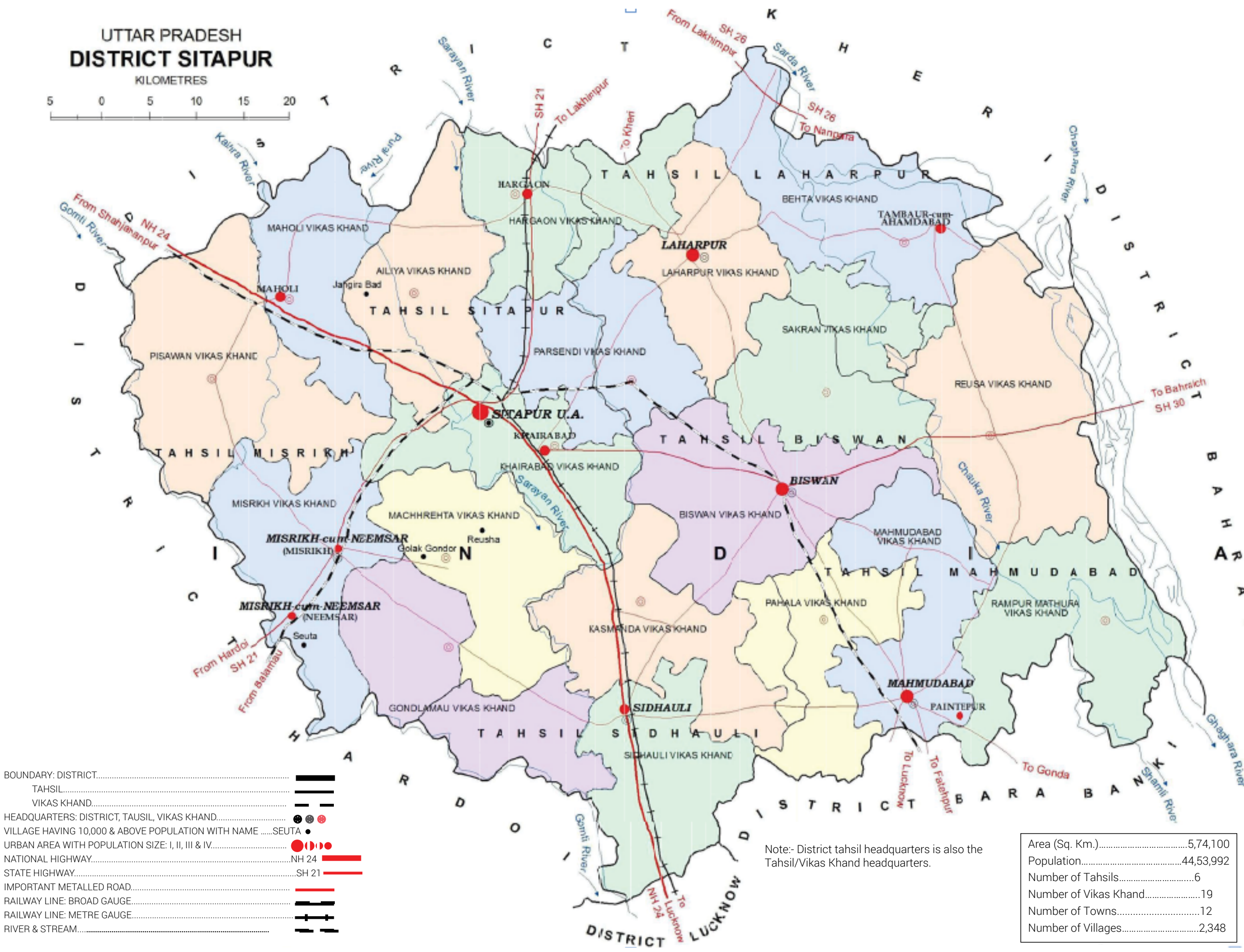


Figure 9: District map of Hapur as per the 2011 Census[20]

3.2 Administrative Units (Tehsils/Blocks)

For administrative convenience, the district is divided into 3 Tehsils which are: Dhaulana, Garhmukteshwar, and Hapur. There are 4 blocks in the district which are: Hapur, Garhmukteshwar, Simbhauli and Dhaulana. Further, there are 4 Nagar Palikas and one Nagar Panchayat.

20 District Census Handbook, Hapur, Census of India 2011 Part XII-B

Table 6: Tehsil-wise revenue village count in Hapur District

Block/Division	Inhabited Village
Hapur	82
Dhaulana	44
Garhmukteshwar	54
Simbhauli	54
Total	**243**

3.3 Climatic Conditions

Typical humid subtropical climate of North India prevails in Hapur, with high variation between summer and winter temperatures and precipitation. There are three distinct seasons – first of which is the monsoon season – hot and humid season from mid-June to September. Second season, winter, is the cool and dry season from October to March. The third phase, summer, is characterized by hot and dry weather which prevails from April to mid-June. The average temperature ranges from 1.80C to 470C. Predominant winds are from north, northwest and west. Annual average rainfall is 732 mm.

Table 7: District agricultural and climate profile of Hapur

District Agricultural and Climate Profile				
Agro-Climatic Zone (State Agricultural Profile)	Northern Plain, Hot Sub-humid (Dry) Eco-Region and Mid-Western Plain Zone			
Rainfall[21]				
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Southwest Monsoon (June-September)	598.7	47	4th Week of June	3rd Week of September
Post-monsoon (October-December)	31.5	12	-	-
Winter (January-March)	66.2	13	-	-
Pre-monsoon (April-May)	23.8	7	-	-
Annual	720.2	79	-	-

21 Agriculture Contingency Plan for District: Hapur, 2019, Department of Agriculture and Farmers' Welfare

District Agricultural and Climate Profile			
Temperature (in degree Celsius)[22]	**Maximum** 1.8	**Minimum** 44.9	
Soil	Loam soils with pockets of sandy loam and clay loam		
Major Climate Contingency and Frequency	**Regular**	**Occasional**	**None**
Drought		√	
Flood			
Cyclone		√	
Hailstorm			√
Heat wave	√		
Cold wave	√		
Frost		√	

A report which measured district-level climate vulnerabilities in India highlighted that Hapur district in Uttar Pradesh fall is placed under relatively high vulnerable category and the major drivers of vulnerability include high percent of marginal and small operational holders, low percent area covered under centrally funded crop insurance, lack of forest area per 1000 rural population, etc.

22 Krishi Vigyan Kendra, Hapur, Agriculture Department, Government of Uttar Pradesh

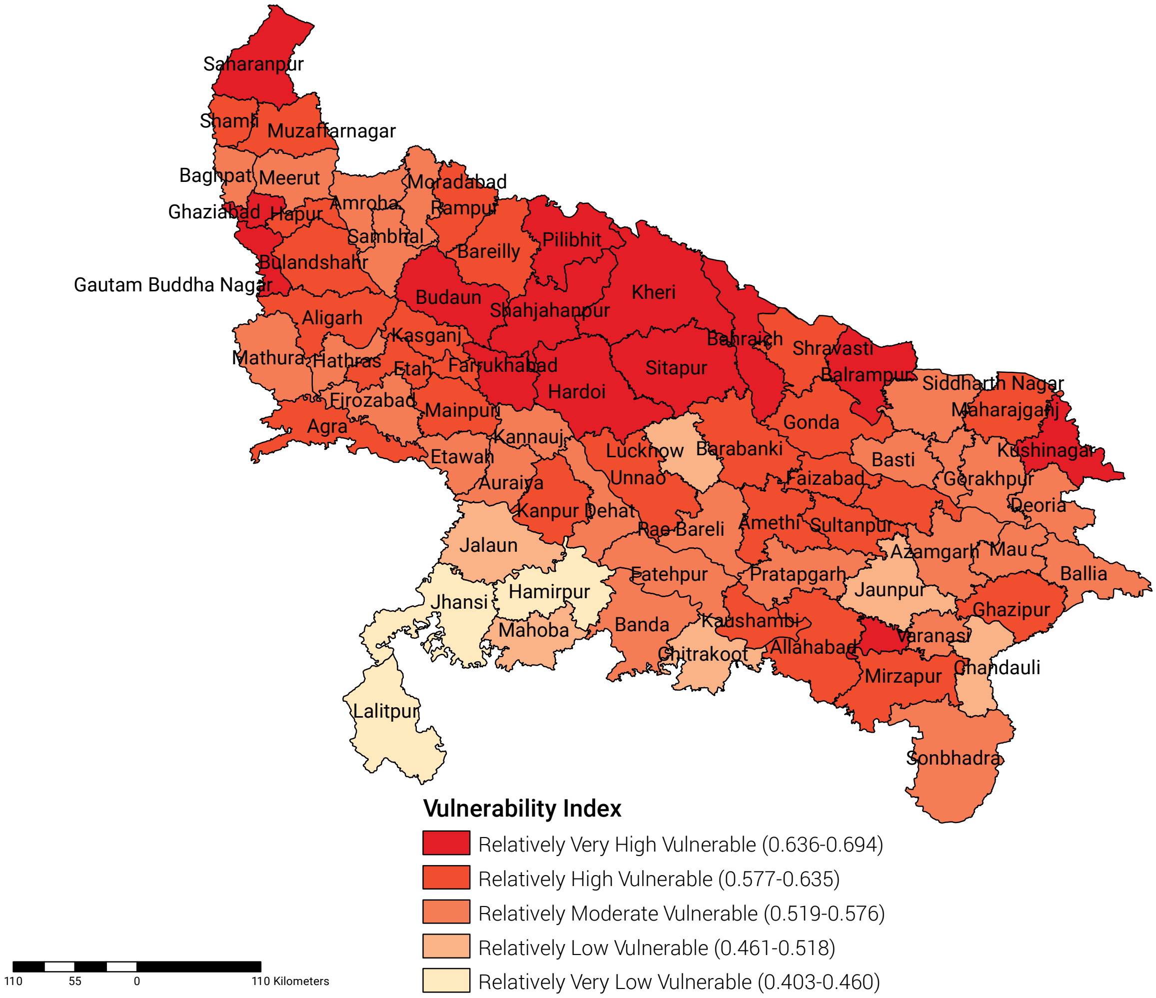


Figure 10: District-wise climate vulnerability index

On the basis of soil, climate, topography, vegetation, and crops, Uttar Pradesh has been divided into nine agro-climatic zones. Hapur is located in the Western Plain Zone (as described in Figure 11) and records high productivity of food grains as seen in the Table 8:

Table 8: Productivity of food grains in different agro-climatic zones of Uttar Pradesh

Zones	Productivity of Food Grains (Q/ha)	Category
Tarai & Bhabhar	25.07	High
Western Plain	31.53	High
Mid-Western	25.17	High
South Western Semi-dry	27.51	High
Mid-Plain/Central	24.68	Medium
Bundelkhand	14.58	Low
North Eastern	23.24	Medium
Vindhyan	17.62	Low
Eastern Plain	23.43	Medium
Uttar Pradesh	23.66	

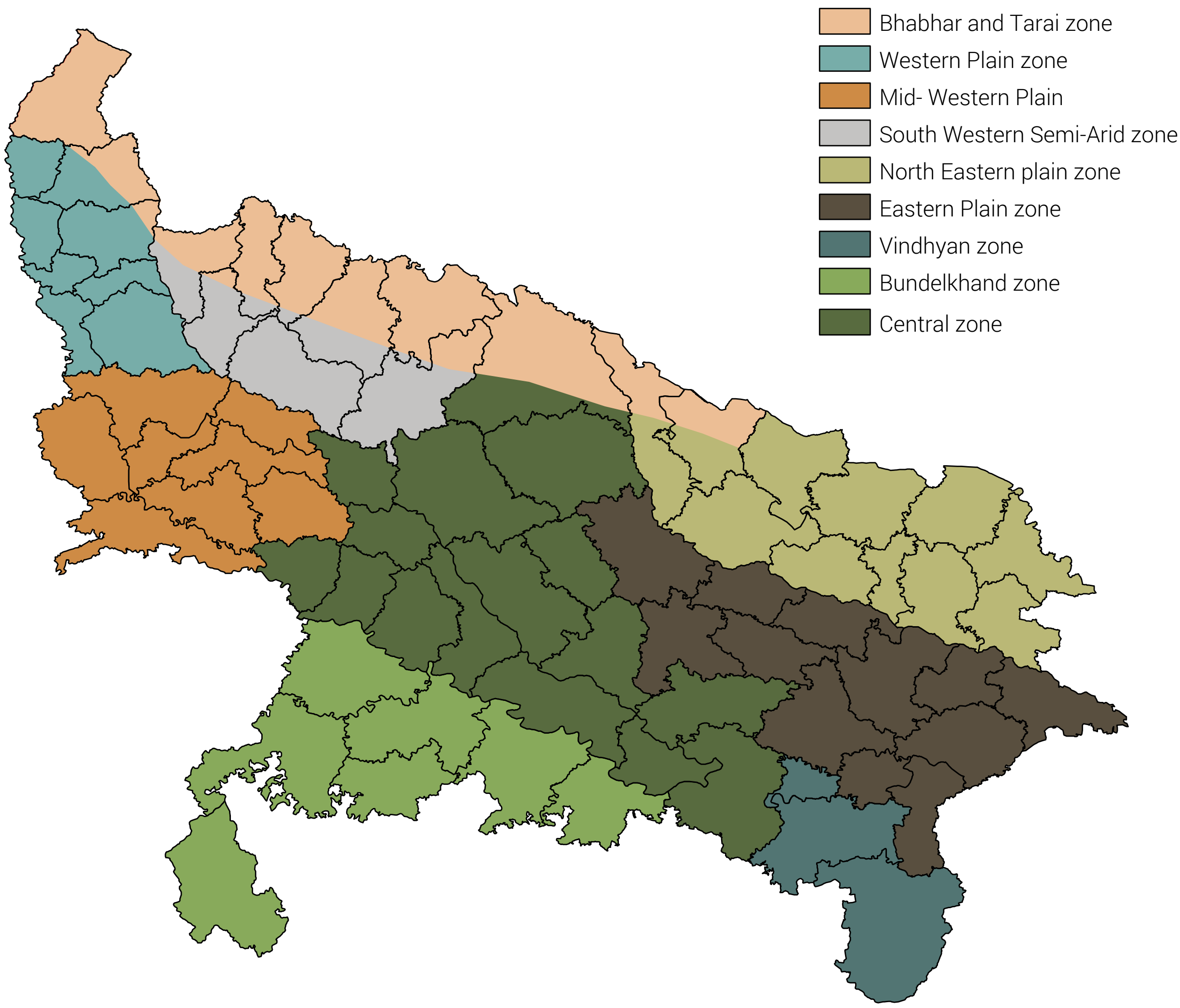


Figure 11: Agro-climatic zones in Uttar Pradesh[23]

3.4 Demographics (Urban/Rural)

Over 32 percent of the total workers in the district were involved either as cultivators or agriculture labourers as per 2011 Census.

In terms of agricultural landholdings, 35.23 percent of the holdings in the district were less than 1 hectare (ha.) while 28.51 percent of the holdings were 1-2 ha, 24.68 percent of the holdings lie between 2-4 ha and 11.58 percent of the holdings were 4 ha or more during 2015-16. In terms of agricultural income, during 2022-23, the gross value of agricultural produce per ha. of net area sown was INR 3,15,974.

23 S, Misra, et.al., Exploitation of agro-climatic environment for selection of 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase producing salt tolerant indigenous plant growth promoting rhizobacteria, Microbiological Research, Vol. 205, December 2017, pp. 25-34

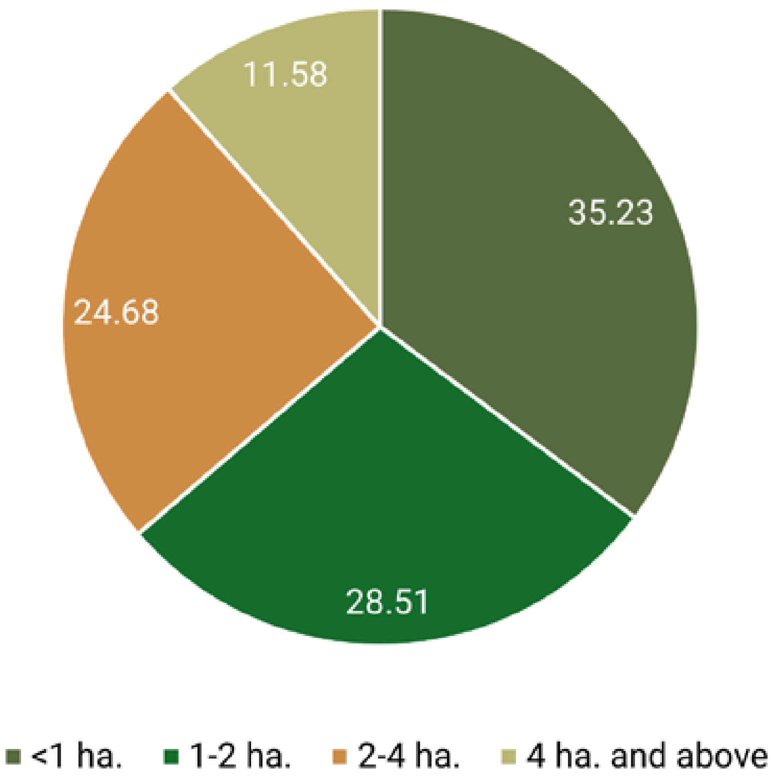


Figure 12: Agricultural land holdings in Hapur[24]

3.5 Agricultural Overview

Hapur is majorly an agricultural district. At the district-level, it has a cultivable area of around 0.949 lakh hectares (ha.) with a cropping intensity of 164.9 per cent.49 Gross cropped area is approximately 4.23 lakh ha. with over 0.565 lakh ha. area sown more than once. The net irrigation area is around 0.87 lakh ha. out of which merely 10 ha. is rainfed. Other major sources of irrigation include canals and bore wells.

3.5.1 Total Agricultural Area[25]

Table 9: Agricultural land area and cropping intensity in Hapur District

Agricultural Land Use	Area ('000 ha)	Cropping Intensity (%)
Net sown area	87	164.9
Area sown more than once	56.5	
Gross cropped area	143.6	

24 Uttar Pradesh Statistical Diary, Economics and Statistics Division, Planning Department, Government of Uttar Pradesh

25 District Profile, Krishi Vigyan Kendra, Hapur

3.5.2 Major Crops and Cropping Patterns (*Kharif*, *Rabi* and *Zaid*)

Major agricultural crops by production in the district include mustard, sugarcane, wheat and vegetable crops during Rabi season and maize, paddy, sugarcane, bajra, etc. during Kharif season. Zaid are intermediate harvest and is of little significance. Cash crops that are popularly sown in the district include sugarcane, etc. At times, double cropping is practised in the district to obtain more yield. Fig. 13 describes the extent of land use in terms of gross area sown for Kharif and Rabi crops in Hapur district during 2021-22.

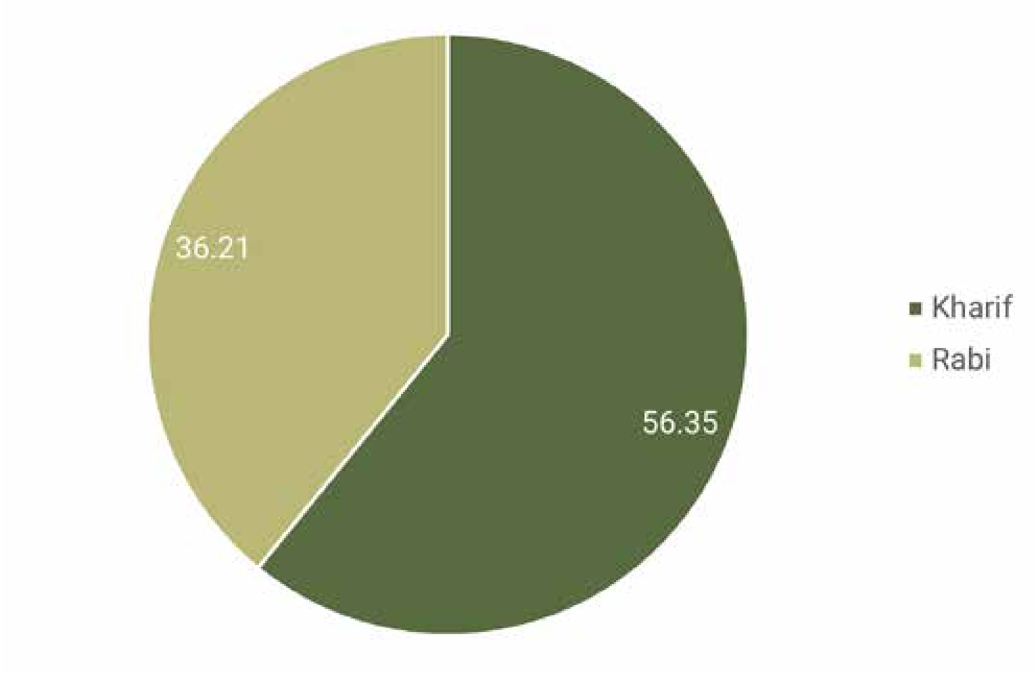


Figure 13: Gross area sown during both the cropping seasons in Hapur[26]

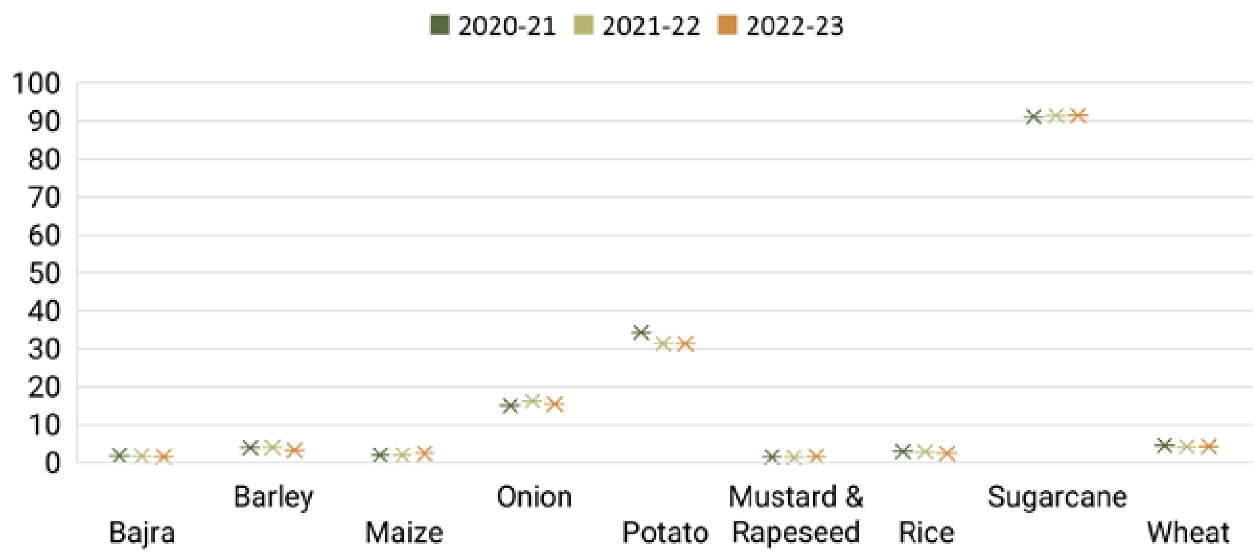


Figure 14: Crop yield during 2020-23 for major crops sown in Hapur during *Kharif* and *Rabi*

26 District Profile, Krishi Vigyan Kendra, Hapur

Rabi are sown around mid-November and harvested during spring (April to June) while Kharif crops are sown during the first week of June to mid-July and are harvested during September to October. During 2023-24, the prominent rabi crops were wheat and bajra where wheat alone occupied close to 55 percent of the total cropped area. Other major rabi crops include vegetables, barley, etc.

Table 10: Tehsil-wise cropped area of *Rabi* crops (in ha.) during 2023-24[27]

Tehsil	Mustard	Other Crop[28]	Potato	Sugarcane	Vegetable	Wheat
DHAULANA	1150.09	1603.57	197.74	1914.99	202.38	10890.32
GARHMUK-TESHWAR	2408.71	2360.22	1677.22	2220.95	-	9998.33
HAPUR	2580.69	3904.31	2344.93	2781.47	1124.23	11141.33

27 Analysis by Vasudha Foundation, 2025

28 Other Crop here means majorly Bajra

During 2023-24, the prominent Kharif crops in the district were paddy and sugarcane where together they comprised 87 percent of the total cropped area. Other major kharif crops vegetables, maize and bajra that were sown and cultivated during the same period. Among all tehsils, Garhmukteshwar had the highest share of cropped area for sugarcane, while Dhaulana dominated in the cultivation of paddy, followed by Hapur.

Table 11: Tehsil-wise production of *Kharif* crops (in ha.) during 2023-24

Tehsil	Agri Plantation	Maize	Paddy	Sugarcane	Vegetables
DHAULANA	600.59	66.97	11722.83	4328.83	329.20
GARHMUKTESH-WAR	4079.62	97.38	5298.07	15574.35	1070.56
HAPUR	928.34	224.72	9536.58	11802.10	1122.47

3.5.3 Land Use Categories (Irrigated, Rainfed, etc.)

In Hapur, the percent of gross irrigated area to the gross area sown was 97.98 percent during 2022-23 .

Table 12: Sowing pattern for major *Kharif* and *Rabi* crops which are both irrigated and rainfed

Sowing window for major field crops	Rice	Wheat	Sugarcane	Pigeon pea	Mustard
Kharif – Rainfed	-	-	-	June-July	-
Kharif – Irrigated	June-July	-	March-May	March-May	-
Rabi – Rainfed	-	-	-	-	-
Rabi – Irrigated	-	Novem-ber-Decem-ber	October-No-vember	-	October-No-vember

3.6 Forest Resources

3.6.1 Total Forest Area[29]

Table 13: Total forest area (by classification) in Hapur

District	Calculated Area (km^2)	Very Dense Forest (km^2)	Moderate Dense Forest (km^2)	Open Forest[30] (km^2)	Total (km^2)	Scrub[31] (km^2)
Hapur	1106.67	0	6.72	21.09	27.81	1.17

3.6.2 Types of Forests and Residue Generated

Forestry residue consists of small trees, branches, leaves, bark, tops, and un-merchantable wood left in the forest after cleaning, thinning, or final felling. Woody biomass actually requires thermal gasification at high temperature in a low-oxygen environment to convert them into a mixture of gases, mainly, carbon monoxide, hydrogen and methane (syngas) . To produce a stream of biomethane of high purity, this syngas is cleaned to remove any acidic and corrosive components. Therefore, woody biomass which consist of residues from forest management and wood processing has to follow the gasification route unlike other feedstocks like agriculture residue or Municipal Solid Wastes (MSW). Biomass such as paper, wood, dried leaves, wooden shavings, etc are generally high in lignin and cellulose. These substances are not suitable for the commercial biogas generation.[32]

29 Forest Survey of India, India State of Forest Report 2023 Vol. II p.301

30 Open Forest denotes all lands with a forest cover of trees with a canopy density of over 40% (Source: Forest Survey of India)

31 Scrub denotes lands having bushes and/or poor tree with canopy density less than 10%. Such lands are delineated largely within or around continuous forest areas (Source: Forest Survey of India)

32 Central Pollution Control Board (CPCB) 2022, Environmental Guidelines for Compressed Biogas Plant (CBG)/Bio-CNG Plants

3.7 Livestock Population

Uttar Pradesh is one of the top five milk producing states, contributing approximately 14.93 percent of the total milk production in the country during 2021-22. The continuous rise in the population of animals has also led to significant increase in livestock residues. Uttar Pradesh also has one of the highest number of livestock among all states.

3.7.1 Cattle, Poultry, and Other Livestock Statistics

Table 14: Tehsil-wise livestock statistics have been collected, and their manure and waste generation potential[33]

Tehsil	Cattle	Goat/Sheep	Swine	Poultry (Chicken)	Total Govansh
Dhaulana	19883	6483	735	5,522	933
Garhmuktesh-war	36112	13188	2688	3,908	1265
Hapur	41242	12192	1961	3,721	1497
Hapur District	97237	31863	5384	13151	3695

33 Animal Husbandry Department, Government of Uttar Pradesh

3.7.2 Manure and Waste Generation Potential

The high population of cattle and other livestock has resulted in higher quantities of cattle dung and poultry litter. Common practices for managing dung and litter include composting for manure production, forming cattle dung cakes to be used as fuel, and as feedstock for small biogas plants. Based on the existing literature , , , around dung/litter yield from the respective livestock, the following figures are derived:

Table 15: Animal categories and their dung/litter generation potential

Category	Animal	Dung	Assumption
Large	Cows, Buffalos	10-20 kg/day (5-6% of their body weight)	15 kg/day
Small	Sheep, Goat	2 kg/day (4-5% of their body weight)	1.6 kg/day
Small	Swine (Pigs)	4 kg/day (5-7% of their body weight)	2.7 kg/day
Poultry	Broiler, Layer and Other	0.1 kg/day (3-4% of their body weight)	0.045 kg/day

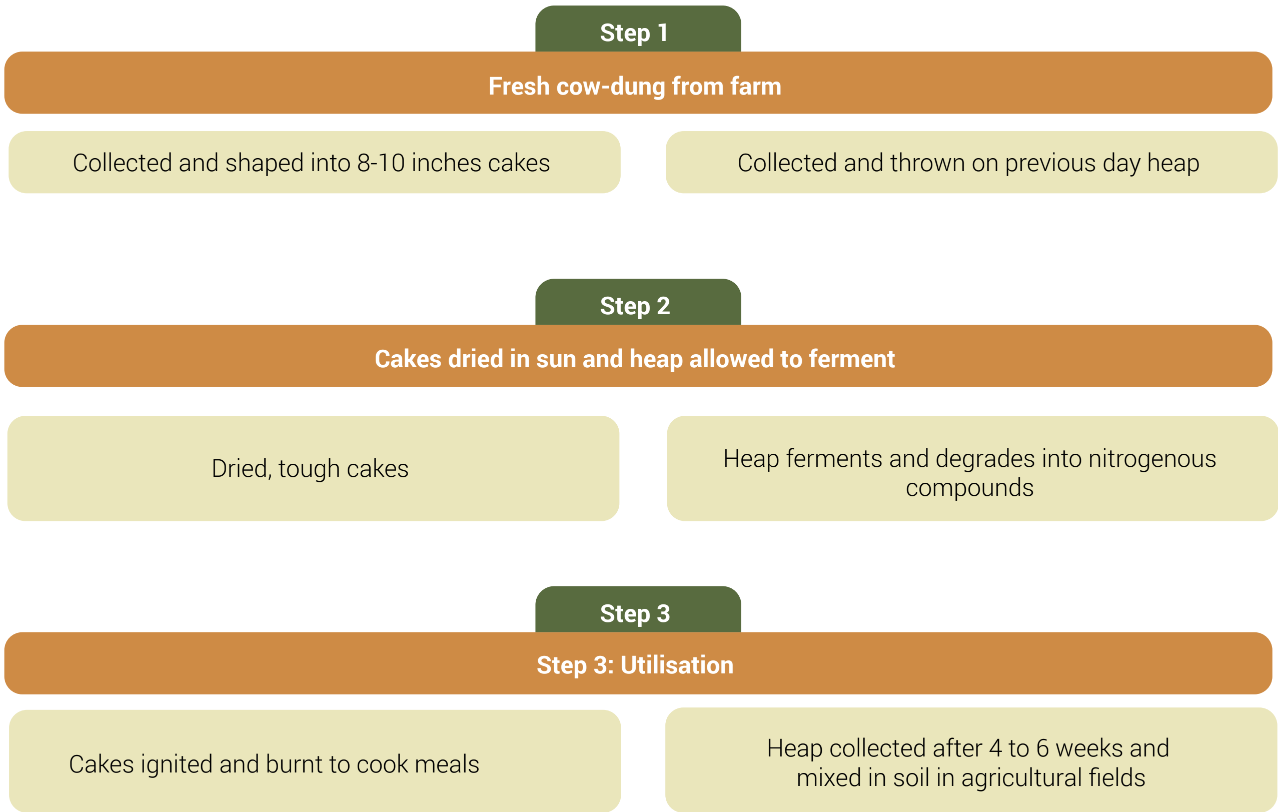


Figure 15: Traditional use of cow-dung as kitchen fuel and manure[34]

34 G, Kaur., et. al., Potenti al of Livestock Generated Biomass: Untapped Energy Sources in India, Energies 2017, 10, 847

3.8 Industry and Processing Units

3.8.1 Existing Biomass-based Industries

There are two CBG plants in the district and one large biogas plant whose details have been tabulated as under:

Table 16: Details of existing biomass-based industries in Hapur

Plant Capacity	Feedstock/Raw Material	By-Products	Procurement Plan
22.5 (TPD) in Hapur Tehsil	Sugarcane Pressmud, Sugarcane Tops and Leaves and Napier Grass	CBG, Bio-Fertiliser	Combination feedstock comprising of 288% of Sugarcane pressmud, 26% of Sugarcane Tops and Leaves, and 44% of Napier Grass. 75% of the Pressmud and Trash required are procured from Hapur Tehsil while 25% of it is procured from Garhmukteshwar and Dhaulana. Napier Grass is cultivated close to the plant and the plant will be commissioned during November 2025
9.6 (TPD) plant in Hapur Tehsil	Sugarcane Pressmud, Cattle Dung	CBG, Bio-Fertiliser	Combination feedstock comprising of 45% of Sugarcane Pressmud and 55% of Cattle Dung. 80% of Sugarcane Pressmud required will be procured from Hapur Tehsil itself while the remaining quantity will be procured from other Tehsils. The plant will also explore using Napier Grass
45 cu. m. per day biogas plant in Hapur Tehsil	Cattle Dung	Biogas	Large biogas plant producing cooking fuel

04 Data Collection

4.1 Primary Data Collection

Primary data sets of land cover, usage, and cropping pattern of specified timeframe in each tehsil were studied. Crop mapping was done using high-resolution seasonal time series data and by extracting unique temporal signatures of different crop. Land cover map primarily describes the annual land use pattern in the district and in all the tehsils by differentiating, built-up, agricultural, fallow, barren, scrub, plantation and water bodies. Crop maps provide acreage estimations of seasonal crops.

In addition, field visits were held to understand the biomass residue supply chain, usage and management (for example, visiting the sugar mills to understand the bagasse and press mud, value chain, etc.). Through our survey at sugar mills, we derived the following factors.

Table 17: Operating parameters and conversion factors for sugar mills

Parameter	Value
Conversion Factor (Sugarcane to Bagasse)	40% TCD[35]
Conversion Factor (Sugarcane to Press mud)	3.5% TCD
Number of Operating Days (Large Sugar Mill)	170 days
Number of Operating Days (Small Sugar Mill[36])	150 days
Number of Operating Days (Medium Sugar Mill[37])	150 days

Through our meetings with the District Cane Officer and Sugar Mill Operators, we understood the value chain for estimating the net available press mud or bagasse for CBG generation described below:

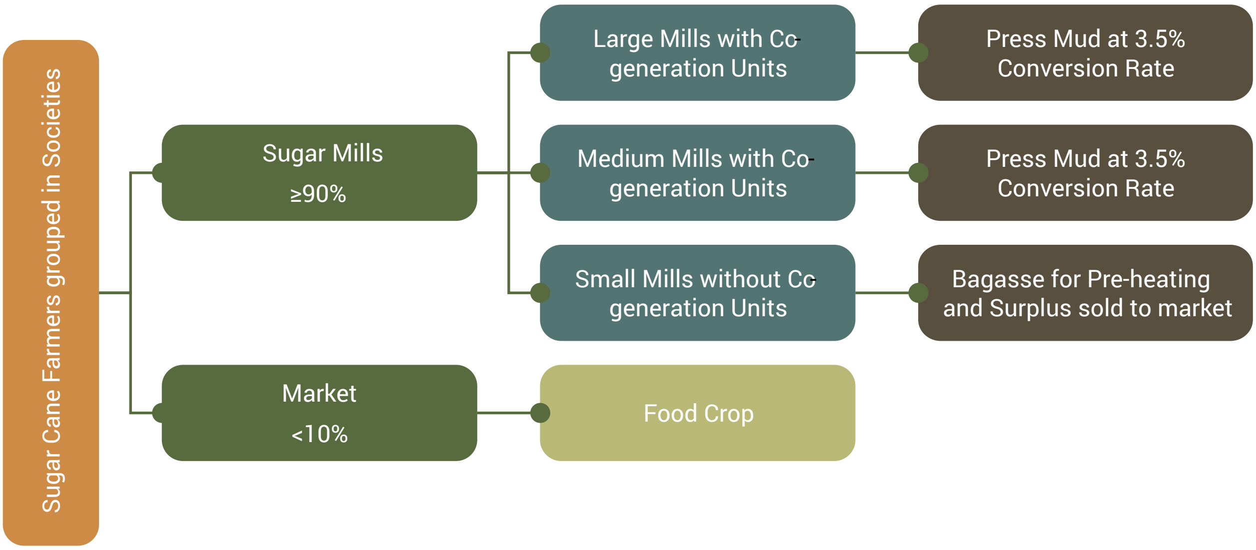


Figure 16: Mapping the value chain of sugar industries

35 TCD stands for Total Cane Crushed in a Day at a Sugar Mill

36 Small Sugar Mills (around 400 units in total) are informal small-scale mills which use Vertical Crushers to crush Sugarcane

37 Medium Sugar Mills use Horizontal Crushers to crush Sugarcane

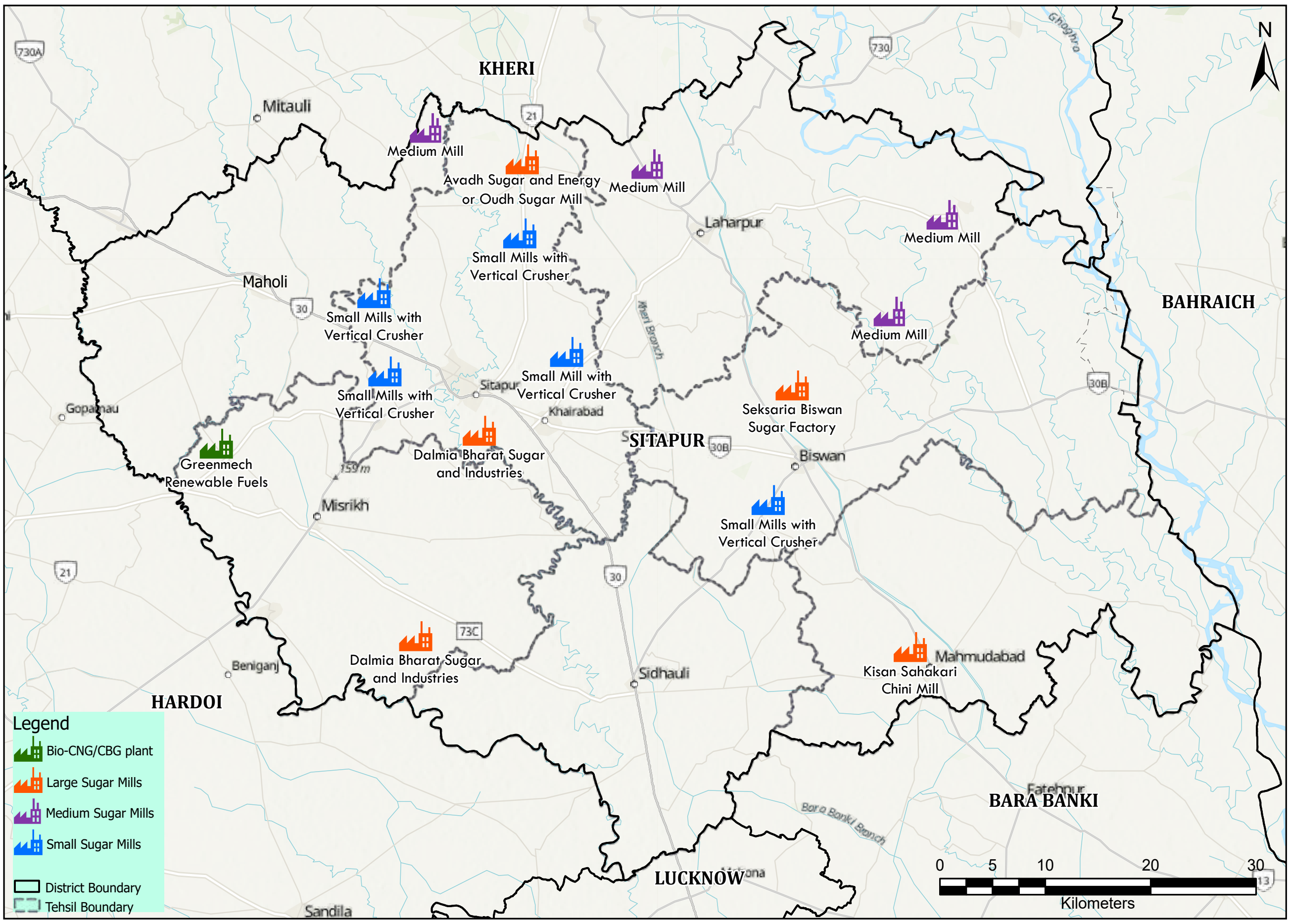


Figure 17: Location of sugar mills in Hapur District[38]

Table 18: Tehsil-wise sugar mills and their annual crushing capacity

Tehsil	Cane Crushing Capacity in TCD		
	Large Mills	**Medium Mills**	**Small Mills (Vertical Crushers)**
Garhmukteshwar	10,000x1	200x2, 100x2	96x80 TCD per plant
Dhaulana	x	x	x
Hapur	4000x1	400x1, 100x1	55x8.5 TCD per plant

38 Analysis by Vasudha Foundation, 2025

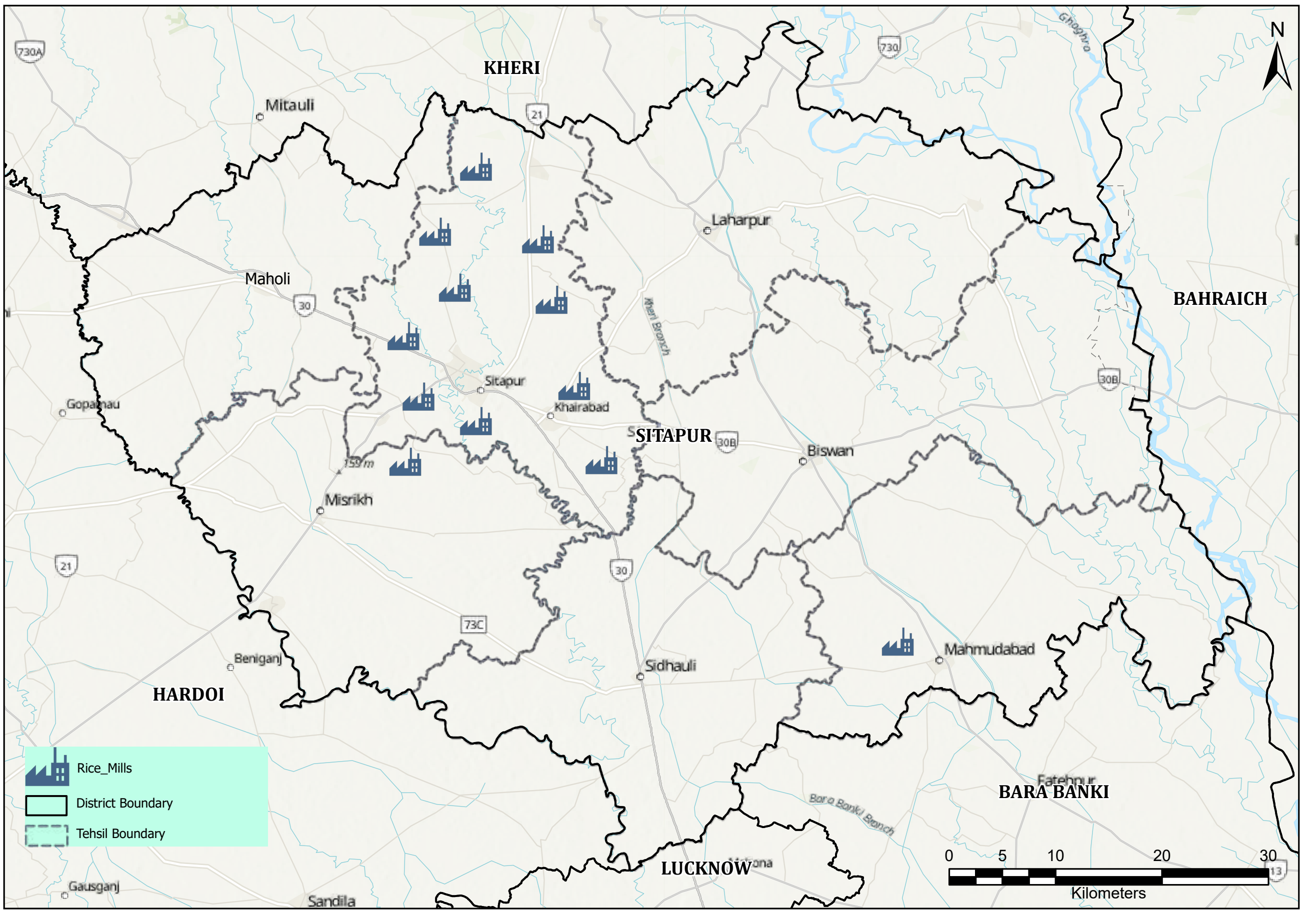


Figure 18: Location of rice mills in Hapur District

4.2 Secondary Data Collection

Major reliance was placed on secondary data that was shared by the Government at the Central, State, District, and sub-District level. Crop Yield data was collected from the Crop Production Statistics published by the Ministry of Agriculture and Farmer's Welfare for three-year period (2021-24) to arrive at an average. Further, the Crop-to-Residue Ratio (on dry weight basis) was borrowed from the latest National Biomass Atlas which is described as under:

Table 19: Residue-to-crop ratio and surplus fraction for various agricultural residue

Crop	Residue	Residue to Crop Ratio	Surplus Fraction
Wheat	Straw	1.5	0.2
	Husk	0.3	0.2
Paddy	Straw	1.5	0.17
		0.2	0.17
Sugarcane	Tops and leaves	0.05	1
Maize	Stalks	2	0.01

	Cobs	0.3	0.01
	Leaves	0.12	0.01
Mustard	Stalks	1.8	1
Pulses	Stalks	2.5	1
Potato	Stalks	0.1	1
Vegetable	Stalks	0.1	1
Barley	Straw	1.3	1
Bajra	Stalks	2	1
	Husk	0.3	1
	Cobs	0.33	1

Biogas Yield for different crops/raw materials was shared by National Institute of Bioenergy (NIBE). For crops with unavailable crop-specific conversion factors, a standardised average conversion ratio (calculated on a dry weight basis) was applied to estimate biogas yield potential. This approach accounts for moisture content variations and ensures consistency in quantifying energy generation capacity from residual biomass.[39]

Table 20: Biogas yield for various feedstocks as per NIBE estimates

Feedstock/Raw Material	Biogas Yield in m^3/T
Paddy Straw	250
Wheat Husk	200
Bagasse	85.5
Press Mud	110
MSW	250
Napier Grass	120

For animal waste, we derived the collectable dung, total solids, estimated theoretical biomass, availability coefficients for different animal groups (Large/Small/Medium/Swine/Poultry) summarised in the table below:

Table 21: Conversion factor for surplus biomass residue calculation of animals

39 As per the NIBE's approximations

Category	Animal	Collectable Dung (Kg/day)	Total Solids	Availability Coefficient	Biogas in m^3	Multiplication Factor[40]
Large	Cows, Buffalo	15	25%	70%	0.6	4.76086
Small	Sheep, Goat	1.6	29%	20%	0.4	4
Swine	Pigs	2.7	29%	60%	0.4	4
Poultry	Broiler, Layer, and Other	0.045	29%	60%	0.8	4.71428

Alternatively, we also know from various studies that 0.04 m3 of biogas can be generated from 1 kg of cattle dung.

Table 22: Calorific values[41,42] for animal residue

Animal Residue	Calorific Value	Animal Residue	Calorific Value
Cattle Dung	3900 Kcal/Kg	Swine Dung	17.9 MJ/Kg
Sheep/Goat Dung	3000 Kcal/Kg	Poultry Litter	16 MJ/Kg

To understand which feedstock is best for CBG production, we used SATAT data published by the Ministry of Petroleum and Natural Gas (MoPNG) . The tentative yield of various feedstocks is tabulated as under:

40 United Nations Industrial Development Organization (UNIDO) & GEF 2022, District Wise Assessment of Waste Availability and Energy Generation Potential (Power, Bio-CNG) in Four Priority Industrial Sectors (Fruit and Vegetable Processing, Poultry, Cattle and Press Mud) Across India.

41 J.R. Backhurst, et.al., Evaluation of physical properties of pig manure, Journal of Agricultural Engineering Research, Vol. 19, Issue 2, 1974, pp. 199-207

42 O, Larina, et.al., Influence of different temperature regimes at torrefaction of chicken litter on yield and properties of products, Energy Systems Research 2019

Table 23: Tentative CBG yield from various feedstocks[80]

Feedstock	CBG Production (T)	Feedstock requirement
Agriculture Residue	1	10 T
Press Mud	1	25 T
Spent Wash	1	10 KL
Bagasse	1	10 T
Municipal Solid Waste	1	20 T
Cow Dung	1	50 T
Chicken Litter	1	25 T
Forest Residue	1	15 T
Napier Grass	1	10 T
Sewage Waste	1	15 MLD

05

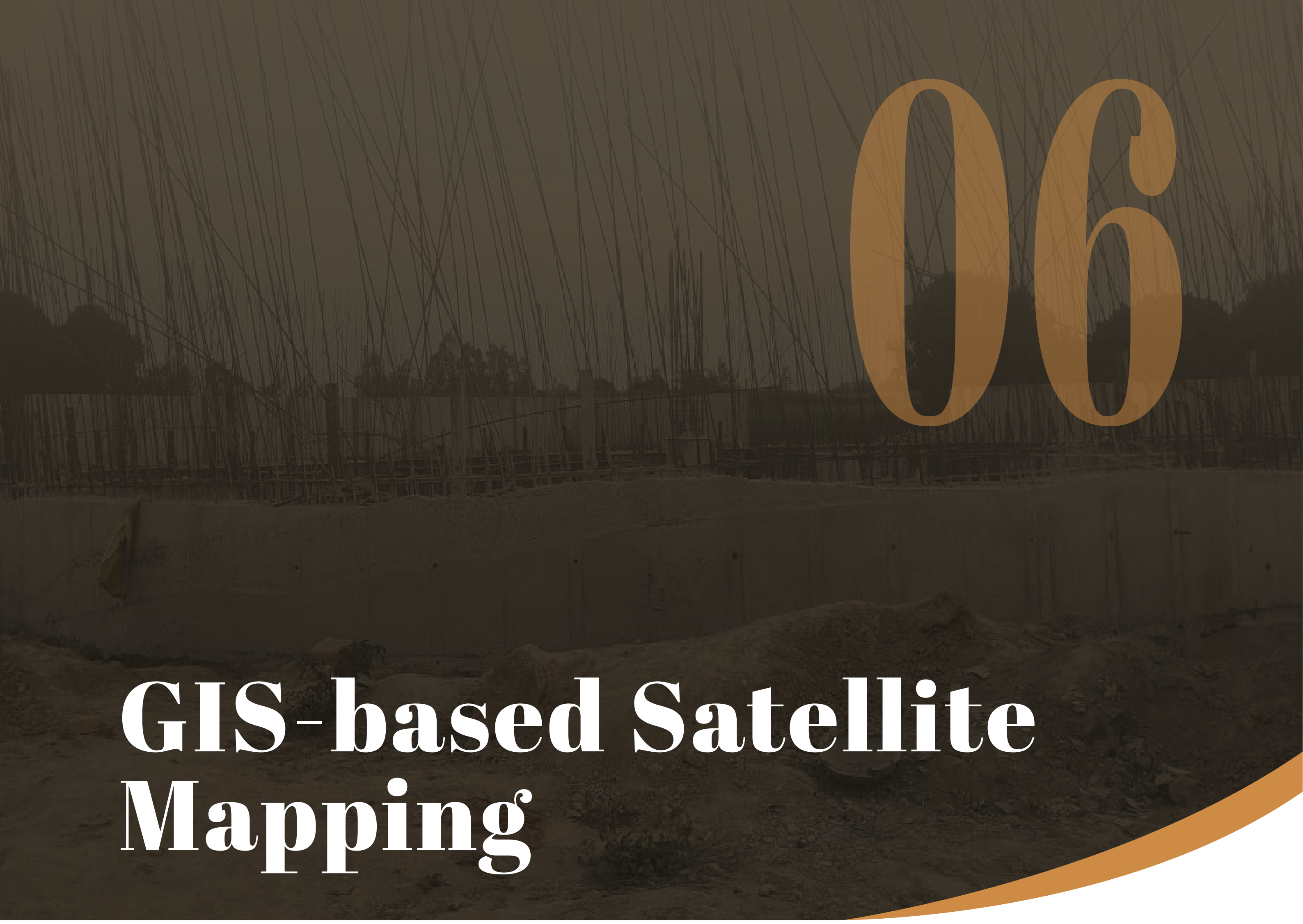
Stakeholder Mapping

5.1 Identification of Relevant Stakeholders

Multiple stakeholders were identified for data collection and to conduct surveys. This study involved engagement with stakeholders from government at the centre, state, district and sub-district level, and a few private players to primarily collect data on biomass production, yield, livestock population, biomass supply chain, etc.

Table 24: **Stakeholders in bio-energy value chain**

Sector	Stakeholder	Data
Central Government	National Institute of Bioenergy	Clarification on surplus factors (the proportion of agricultural/industrial residues available beyond existing uses) and the conversion factor used to translate surplus biomass residues (in tonnes, T) into potential CBG capacity (tonnes per day, TPD). Additionally, the support was provided to identify priority biomass residues (e.g., crop stubble, livestock manure, agro-processing waste) with the highest biogas potential, alongside assessing the suitability of industrial organic waste as feedstock.
State Government	Animal Husbandry and Dairying Department	Livestock Census 2019 data (Tehsil-wise), List of cowsheds in the district
	Agriculture Department	Tehsil-wise and block-wise crop production and yield statistics
	Sugar Industry and Cane Development Department	Society-wise cane production and yield across the district
	Horticulture and Food Processing Department	List of Food Processing, Paper and Pulp Industries located in Hapur and their effluent capacity/management
	Directorate of Economics and Statistics	Tehsil-wise land use, irrigation, crop production statistics for Hapur District
Private	Sugar Mills – Large, Medium and Small	Annual cane crushing capacity, press mud market and management, Conversion factor for bagasse and press mud in a sugar mill, Bagasse generating capacity for small-sized informal sugar mills
	Under-construction CBG Plant	Plant Capacity, Feedstock mix, raw material procurement plan, stocking and reserves, land area, contingency planning



06

GIS-based Satellite Mapping

6.1 Cropping Pattern and Analysis

It can be observed from the Kharif crop map that sugarcane is widely cultivated across all tehsils with Garhmukteshwar having the highest cultivation. Dhaulana tehsil have the highest paddy cultivation. Garhmukteshwar tehsil also has significant cultivation of bajra and maize.

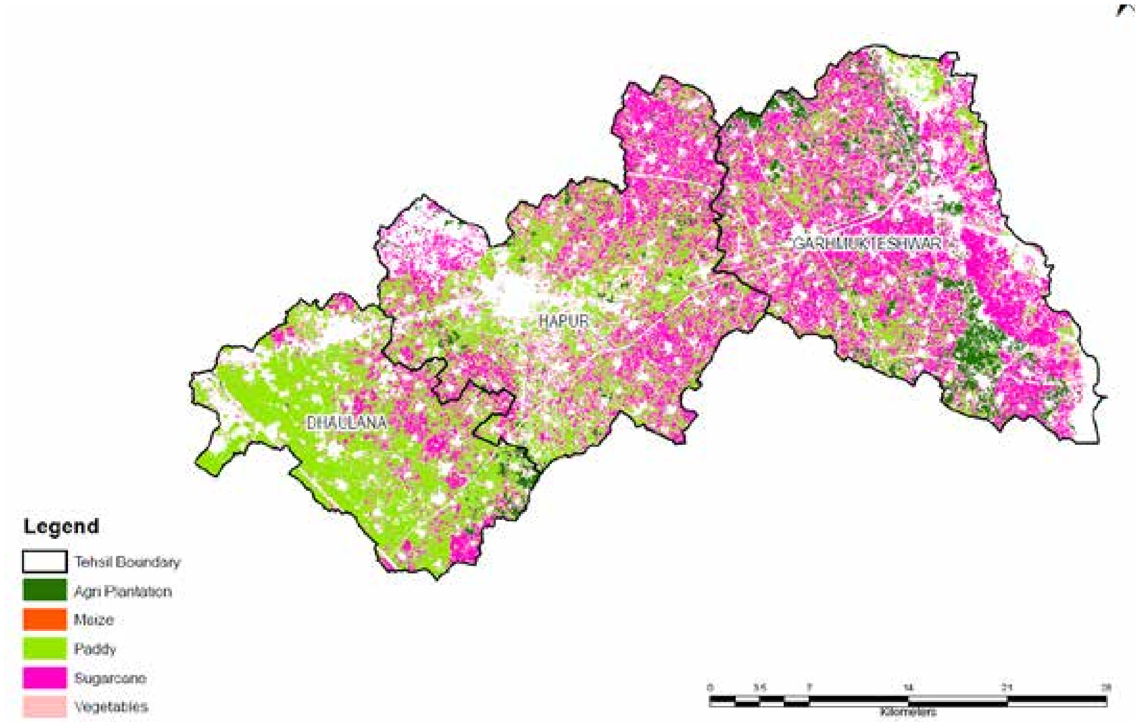


Figure 19: **Geographical spread of *Kharif* crops in tehsils of Hapur District during 2023-24**[43]

During the *Rabi* season, wheat is predominantly grown across all the tehsils with traces of mustard, potato, vegetables, etc in other tehsils.

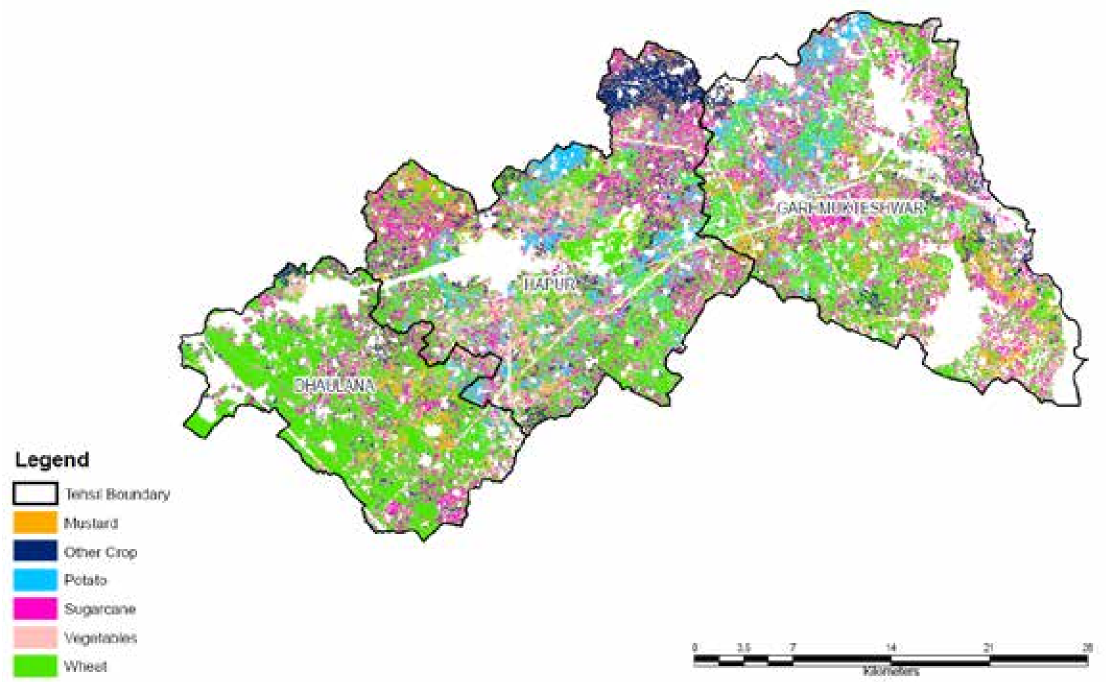


Figure 20: **Geographical spread of *Rabi* crops in tehsils of Hapur District during 2023-24**[44]

43 Analysis by Vasudha Foundation, 2025

44 Analysis by Vasudha Foundation, 2025

6.2 Land Use and Biomass Distribution Mapping

The statistics of land use are important for studying the changes in land use patterns, cropping patterns, impact of development programmes, as well as the efficient utilisation of most valuable natural resource. Land Use was analysed for Hapur during the year 2023-24, and the results are summarised below:

Table 25: Tehsil-wise land-use analysis for Hapur[45]

Tehsil	Barren/ Waste land	Built-Up	Crop land	Grassland	Scrub land	Waterbodies
DHAULANA	535.74	2916.65	22497.63	-	152.72	125.99
GARHMUKTESH-WAR	506.17	2271.52	41131.35	0.07	711.35	596.39
HAPUR	467.93	3701.59	36980.65	54.70	443.41	102.09

It can be observed from the Land Use analysis that nearly 88 percent of the total geographical area of the district was under cultivation during 2023-24.

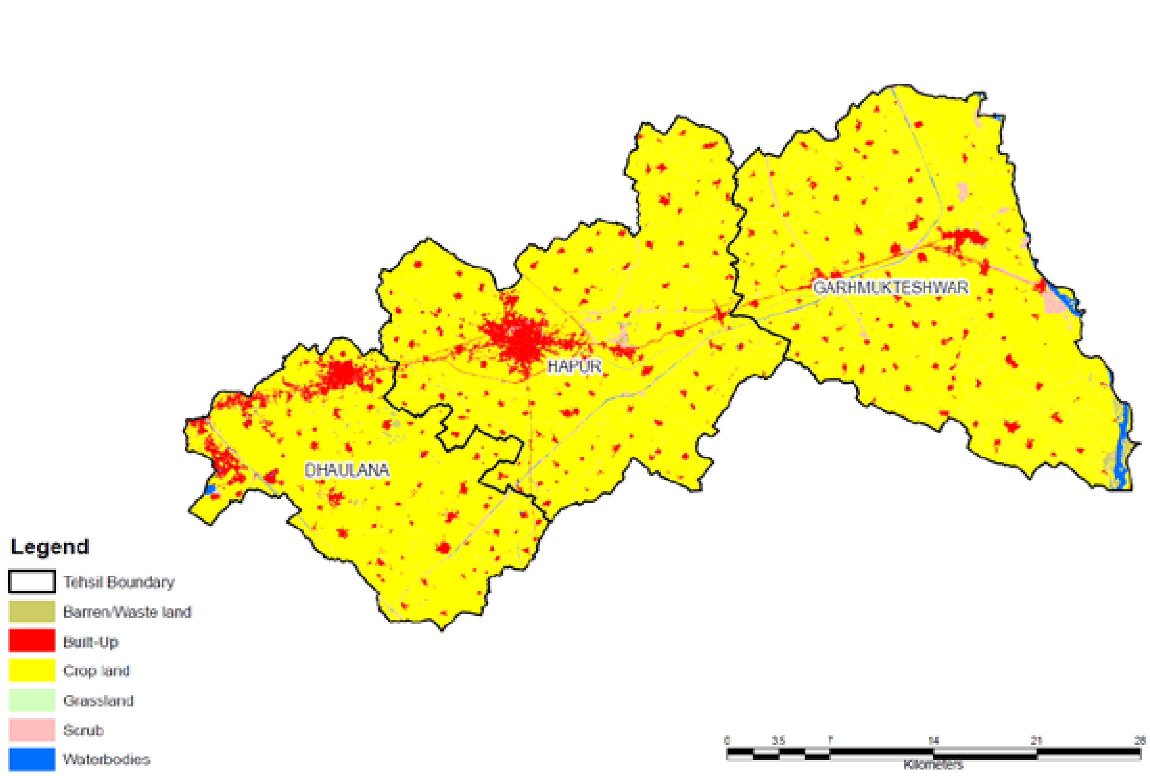


Figure 21: Land cover analysis for tehsils of Hapur District during 2023-24[46]

45 Analysis by Vasudha Foundation, 2025

46 Analysis by Vasudha Foundation, 2025

07 Methodology

This sstudy estimates annual net biomass residue availability in all the three Tehsils of Hapur district in Uttar Pradesh. It takes into account the competing uses of the biomass in the respective tehsil and generates a net value of the residue and corresponding theoretical value of Compressed Biogas (TPD) that can be generated out of it. The following approach was adopted for various feedstocks in consideration:

7.1 Agricultural Residue

The study integrated Geographic Information System (GIS) tools and seasonal satellite imagery to analyse spatial and temporal trends in crop residues. Sentinel-2 satellite data was processed to estimate the cultivated area of kharif and rabi crops. The workflow began with layer stacking and mosaicking of satellite images, followed by spatial sub setting to focus on Hapur district and its seven tehsils using administrative boundaries. A district-level land use/landcover map was then generated, and non-agricultural regions such as forests, water bodies, and urban areas were masked to isolate farmland.

Crop acreage estimation was conducted using the Support Vector Machine (SVM) , a supervised machine learning algorithm trained on ground-truth data to classify satellite imagery into distinct crop categories. This approach enabled precise mapping of kharif and rabi cultivation zones by assigning pixel-level classifications. After determining crop-specific acreage, the study incorporated existing district- and tehsil-level agricultural statistics—such as yield per hectare—to calculate total production. By merging remote sensing data with regional agricultural records, the analysis provided granular insights into crop productivity patterns across administrative scales, enhancing understanding of spatial variations in agricultural output.

Figure 22: Flow diagram of the methodology used

Once we have the crop-wise acreage and yield estimates, we can calculate the corresponding biomass residue that is generated and that is in surplus for energy generation. The following terminologies and equations would be used in estimating annual biomass residue that would be generated.

Gross crop residue can be defined as the sum total of crop residues produced for a particular crop. In general, there is a 1:1 grain-to-residue relationship between the dry matter of crop grain and the dry matter of crop residues. , It is determined based on three important parameters such as: area occupied by the particular crop, crop yield and Residue Production Ratio value for that crop.

$$CRg(j) = \sum_{i=1}^{n} A(i,j) \times Y(i,j) \times RPR(i,j)$$

Equation 1: ***Gross Crop Residue Calculation***

Here, CRg(j) denotes the gross crop residue for n number of crops at j^{th} state, in tonnes; and A(i,j) denotes the area covered by i^{th} crop at jth state, in hectares; Y(i,j) denotes the yield of the i^{th} crop at j^{th} state, in tonnes/hectare, and RPR(i,j) denotes the residue to product ratio for the given i^{th} crop at j^{th} state.

The surplus crop residue of particular crop represents the amount of crop residues that are available for energy production after all the other competing uses such as cooking fuel, cattle feed, roof thatching, composting, animal bedding, and others are taken into consideration (as described in *Fig.18*).[47]

$$CRs(j) = \sum_{i=1}^{n} CRg(i,j) \times SF\,(i,j)$$

Equation 2: ***Surplus Crop Residue Calculation***

CRs denotes the surplus crop residue for n number of crops, in tonnes which is estimated based on the surplus factor developed depending on different uses of the crop residue. Surplus factor varies widely among the crops and also shows variations in the cropping seasons.[48][49]

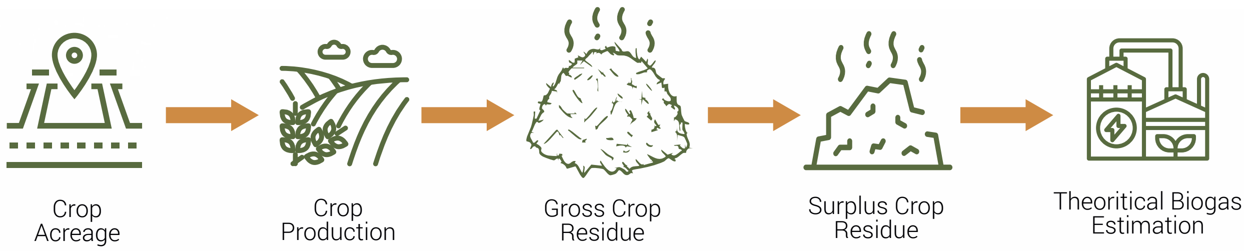


Figure 23: Flow diagram for crop residue estimation

47 V, Venkatraman., et. al., 2021 Assessment of Bioenergy Generation Potential of Agricultural Crop Residues in India, Circular Economy and Sustainability, 1(4) pp. 1335-1348

48 M, Hiloidhari and D.C., Baruah., 2011, Crop residue biomass for decentralized electrical power generation in rural areas (part I): Investigation of spatial availability, Renewable and Sustainable Energy Review, 15, pp. 1885-92

49 Technology Information, Forecasting and Assessment Council (TIFAC) & Indian Agricultural Research Institute (IARI), Estimation of Surplus Crop Residues in India for Biofuel Production, October 2018

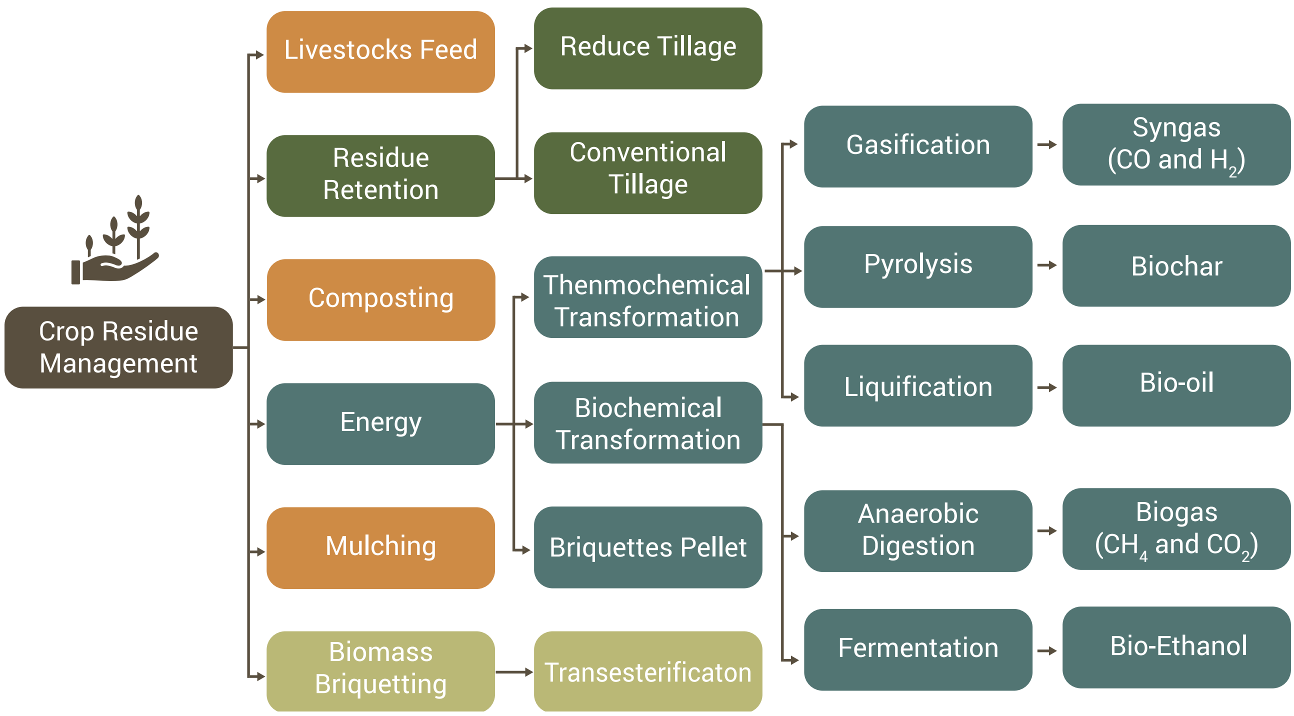


Figure 24: Crop residue management practices[50]

After taking into consideration of the competing uses for the specific crop residue, the net crop residue, CRn(j), is estimated for n number of crops at jth state, in tonnes.

$$CRn(j) = \sum_{i=1}^{n} CRs\,(i,j) - CRc(i,j)$$

Equation 3: Net Crop Residue Calculation

Here, CRc denotes the competing usage of ith crop residue at jth state and CRn is the net crop residue available for energy generation at jth state.

$$TBEn(j) = \sum_{i=1}^{n} CRn\,(i,j) \times 0.55 \times BY(i,j) \times 0.657 \times \frac{1}{365 \times 1000}$$

Equation 4: Theoretical Estimation of CBG from Agricultural Residues

Here, TBEn denotes the Theoretical Biogas Estimation (CBG) in TPD for nth crop at jth state, 0.55 indicates the percent composition of methane, BY denotes the Biogas Yield for the ith crop at jth state, 0.657 is the density of methane in Kg/m^3

50 N.R, Gatkal., et.al., Present trends, sustainable strategies and energy potentials of crop residue management in India: A review, Heliyon, Vol. 10, Issue 21 2024

7.2 Livestock Residue

The data on livestock population at the district level and tehsil level are used to estimate the total dung/ litter that could be generated.

$$TBEn(j) = \sum_{i=1}^{n} D(i,j) \times Y(i,j) \times TS(i,j) \times AC(i,j) \times MF(i,j) \times \frac{1}{365}$$

Equation 5: Theoretical CBG Estimation from Livestock Residues

Here, TBEn(j) is the Theoretical Biogas Estimation (CBG) in TPD for nth livestock at jth state, D denotes the dung generation from ith livestock at jth state, Y denotes the annual dung yield, TS denotes the Total Solids in the dung/litter, AC denotes the Availability Coefficient (considering the competing uses of cattle dung/poultry litter) and MF is the multiplication factor for the respective organic matter. Any bulk usage of dung in, say for example, existing CBG plants, should be considered for calculating the Net Available Residue.

08

Biomass Category, Sources and Availability

The results for the Biomass Assessment are tabulated in *Table 27*. It describes for each Tehsil, the feedstock-wise annual biomass production during 2023-24 and corresponding gross residue and surplus residue that is available for CBG production. For agricultural crops, Residue-to-Crop Ratios and corresponding Surplus Fractions for various are listed in *Table 19*. Similarly, the surplus animal dung/litter and biogas yield for various biomass residues are described in Table 21 and *Table 23*, respectively. *Equations 1-6* were applied to arrive at the biogas yield results. We have two distinct results for CBG potential for the majority of the feedstocks because of the difference in Residue-to-Crop Ratio as is the case for Paddy straw, and different biogas yield ratios prescribed by NIBE and SATAT Scheme.

8.1 Agricultural Residues

Table 27: Tehsil-wise surplus biomass and potential CBG generation for various agricultural residue

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ ha)	Total Production (T)							
Dhaulana	Wheat	10890.32	4.34	47263.99	Straw	70895.98	14179.20	14179.20	1024.73	2.81	3.88
					Husk	14179.20	2835.84	2835.84	204.95	0.56	0.78
	Paddy	11722.83	2.77	32472.24	Straw	48708.36	8280.42	8280.42	673.23	1.84	7.12
					Husk	6494.45	1104.06	1104.06	89.76	0.25	
	Sugar-cane	6243.82	91.38	570560.27	Bagasse (Small)		0.00		0.00	0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00	0.00
					Tops and Leaves	28528.01	28528.01	23144.26	1620.10	4.44	4.44
	Mustard	1150.09	1.52	1748.14	Stalks	3146.65	3146.65	3146.65	314.66	0.86	0.86
	Potato	197.74	32.37	6400.84	Stalks	640.08	640.08	640.08	64.01	0.18	0.18
	Vegeta-bles	531.58	15.55	8266.07	Stalks	826.61	826.61	826.61	82.66	0.23	0.23

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ ha)	Total Production (T)							
	Maize	66.97	2.13	142.65	Stalks	285.29	285.29	285.29	28.53	0.08	0.09
						Cobs	42.79	42.79	42.79	4.28	0.01
						Leaves	17.12	17.12	17.12	1.71	0.00
	Barley	1603.57	3.73	5981.32	Straw	7775.71	7775.71	7775.71	777.57	2.13	0.00
	Bajra	600.59	1.74	1045.03	Stalks	2090.05	2090.05	2090.05	209.01	0.57	0.57
						Husk	313.51	313.51	313.51	31.35	0.09
						Cobs	344.86	344.86	344.86	34.49	0.09
Garhmuk-teshwar	Wheat	9998.3	4.34	43392.62	Straw	65088.93	13017.79	13017.79	940.80	2.58	3.57
					Husk	13017.79	2603.56	2603.56	188.16	0.52	0.71
	Paddy	5298.07	2.77	14675.65	Straw	22013.48	3742.29	3742.29	304.26	0.83	3.22
					Husk	2935.13	498.97	498.97	40.57	0.11	

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ ha)	Total Production (T)							
	Sugar-cane	17795.3	91.38	1626134.51	Bagasse (Small)		14745.60		455.57	1.25	1.25
					Press Mud (Large)		18397.50		731.27	2.00	2.02
					Press Mud (Medium)		4795.00		190.59	0.52	0.53
					Tops and Leaves	81306.73	81306.73	75922.98	5314.61	14.56	14.56
	Mustard	1150.09	1.52	1748.14	Stalks	3146.65	3146.65	3146.65	314.66	0.86	0.86
	Potato	197.74	32.37	6400.84	Stalks	640.08	640.08	640.08	64.01	0.18	0.18
	Vegeta-bles	1070.56	15.55	16647.21	Stalks	1664.72	1664.72	1664.72	166.47	0.46	0.46
	Maize	2360.22	3.73	8803.62	Stalks	11444.71	11444.71	11444.71	1144.47	3.14	3.14
					Cobs	414.84	414.84	414.84	41.48	0.11	0.11
					Leaves	62.23	62.23	62.23	6.22	0.02	0.02
	Barley	97.38	2.13	207.42	Straw	24.89	24.89	24.89	2.49	0.01	0.01

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ ha)	Total Production (T)							
	Bajra	4079.62	1.74	7098.54	Stalks	14197.08	14197.08	14197.08	1419.71	3.89	3.89
					Husk	2129.56	2129.56	2129.56	212.96	0.58	0.58
					Cobs	2342.52	2342.52	2342.52	234.25	0.64	0.64
Hapur	Wheat	11141.33	4.34	48353.37	Straw	72530.06	14506.01	14506.01	1048.35	2.87	3.97
					Husk	14506.01	2901.20	2901.20	209.67	0.57	0.79
	Paddy	9536.58	2.77	26416.33	Straw	39624.49	6736.16	6736.16	547.68	1.50	4.56
					Husk	5283.27	898.16	898.16	73.02	0.20	
	Sugar-cane	14583.57	91.38	1332646.63	Bagasse		8976.00		277.32	0.76	0.76
					Press Mud (Large)		0.00		0.00	0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00	0.00
						66632.33	66632.33	34329.83	2403.09	6.58	6.58
	Mustard	2580.69	1.52	3922.65	Stalks	470.72	470.72	470.72	47.07	0.13	0.13
	Potato	2344.93	32.37	75905.38	Stalks	7590.54	7590.54	7590.54	759.05	2.08	2.08

Tehsil	Name	Production Area (ha)	Yield (T/ha)	Total Production (T)	Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
	Vegeta-bles	2246.7	15.55	34936.19	Stalks	3493.62	3493.62	3493.62	349.36	0.96	0.96
	Maize	3904.31	3.73	14563.08	Stalks	18932.00	18932.00	18932.00	1893.20	5.19	5.19
					Cobs	957.31	957.31	957.31	95.73	0.26	0.26
					Leaves	143.60	143.60	143.60	14.36	0.04	0.04
	Barley	224.72	2.13	478.65	Straw	57.44	57.44	57.44	5.74	0.02	0.02
	Bajra	928.34	1.74	1615.31	Stalks	3230.62	3230.62	3230.62	323.06	0.89	0.89
						484.59	484.59	484.59	48.46	0.13	0.13
						533.05	533.05	533.05	53.31	0.15	0.15

8.2 Animal Waste

The cumulative biogas produced from livestock waste is influenced by several critical factors, including the animal type and breed, average body weight, diet composition, and total solids content in excrement. To accurately quantify biogas yield per unit, a standardized method for collecting dung is essential. Only through such standardized collection techniques can a reliable cumulative biogas volume be determined, which is necessary for calculating the availability coefficient factor. This factor is crucial for predicting the expected and likely biogas yield from livestock waste.

8.3 Energy Crops

Poplar Trees, Willow, Jatropha

These crops were not identified in our GIS crop maps.

8.4 Other Types of Biomasses

8.4.1 Napier Grass

Napier Grass, also known as Elephant Grass or Uganda Grass is a species native to the tropical grasslands of Africa. It has a very high productivity, both as a forage grass for livestock and as a biofuel crop. It is most susceptible to frost and grows best in high-rainfall areas (in excess of 1500 mm/year), but its deep root system allows it to survive in drought times. Pusa Giant Napier, developed by IARI provides high yield (250-300 t/ha/year) of green matter under irrigated condition.[51]

Napier Grass can be used as a combination feedstock with paddy straw and animal dung when sugarcane press mud is unavailable (after sugar season).

8.4.2 Groundnut Shell

Groundnut is sown and harvested during the kharif season and yields groundnut shells as residue. During 2022-23, as per the Crop Production Statistics, groundnut was cultivated in 3245 ha. of land accounting for a total annual production of 7217 T of the crop. Using SATAT's CBG conversion factor, the following results are observed

8.4.3 Sugarcane Bagasse

There are small sugar mills (without a bagasse co-generation unit) that operate with vertical crushers. These are located in five different clusters in tehsils of Hapur and Biswan (See *Fig.24*). They have a cumulative cane crushing capacity of 3610 TCD and based on the survey, it was noted that the conversion ratio of cane to bagasse in these mills is 40%. Further, 40% of the bagasse that is generated is captively consumed for sugar processing and the remainder is sold to bio-plastics industry and bagasse-based particleboards at around INR 700 per quintal.

51 Pandey K.C. and Roy A.K., 2011. p.23, Forage Crops Varieties, Indian Grassland and Fodder Research Institute (IGFRI)

Table 28: Tehsil-wise surplus biomass residue and potential CBG generation from various animal residues

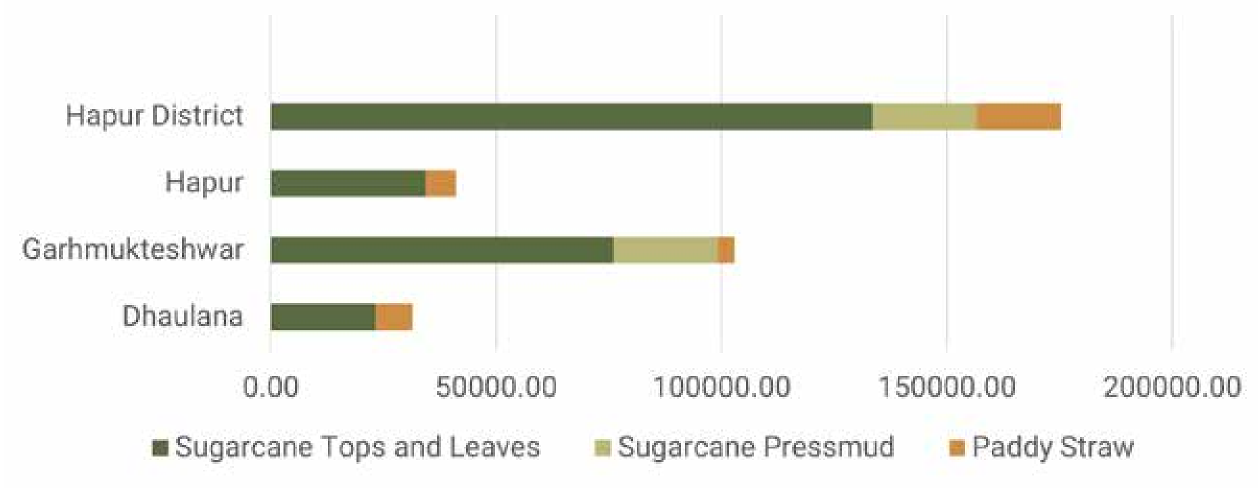
Tehsil	Animal	Population	Collectable Dung/ Litter (Kg)	Total Solids	Availability Coefficient	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG Potential (TPD)	CBG Potential (SATAT)
Dhaulana	Cattle	36112	197713200	49428300	34599810	34599.81	564585859.66	0.29827	1.420	1.044
	Goat/ Sheep	13188	7701792	2233519.68	446703.93	446.70	5607027.80	0.00596	0.02	0.017
	Swine	2688	2649024	768216.96	460930.17	460.93	8250650.15	0.00576	0.0230	0.010
	Poultry	3,908	64188.9	18614.781	11168.86	11.17	178701.90	0.0002	0.0008	0.002
Garhmuk-teshwar	Cattle	36112	1.98E+08	49428300	34599810	34599.81	564585859.7	0.2983	1.4200	1.896
	Goat/ Sheep	13188	7701792	2233519.68	446703.93	446.70	5607027.80	0.0060	0.0238	0.035
	Swine	2688	2649024	768216.96	460930.17	460.93	8250650.15	0.0058	0.0230	0.036
	Poultry	3908	64188.9	18614.781	11168.86	11.168	178701.89	0.0002	0.0008	0.001
Hapur	Cattle	41242	1.45E+08	36309287.5	25416501.2	25416.50	414736300.8	0.22	1.04	1.393
	Goat/ Sheep	12192	7120128	2064837.12	412967.42	412.96	5183567.10	0.01	0.02	0.032
	Swine	1961	1932566	560443.995	336266.39	336.26	6019168.50	0.00	0.02	0.026
	Poultry (Chick-en)	3721	61117.43	17724.0533	10634.43	10.63	170150.9112	0.00	0.00	0.001

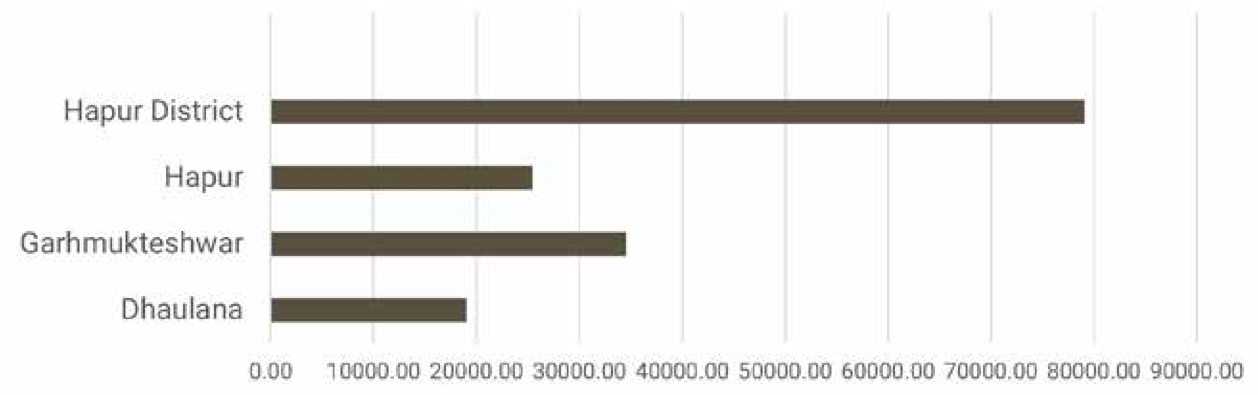
09

Biomass Quantification Results

9.1 Total Biomass Availability by Category

Major feedstocks that are taken into account for this categorisation are: paddy straw, sugarcane press mud, and cattle dung. Accordingly, the following results are observed for each Tehsil in Hapur District.





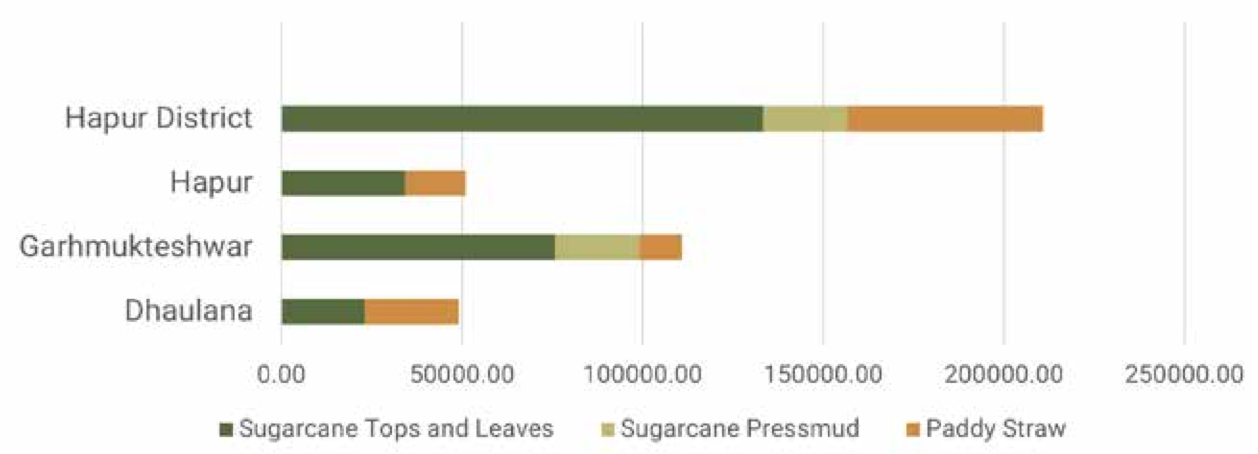


Figure 25: Tehsil-wise annual availability of paddy straw, press mud and cattle dung

9.2 Variations in Biomass Availability and Pricing

The availability and generation of sugarcane press mud have varied over the years. From the figures Figure 25 and Figure 26, the variation in availability of press mud in all the sugar mills can be attributed to the varying quantities of sugarcane crushed annually in these mills. Figure 27 depicts the year-on-year change in press mud that is generated. The reasons that can be attributed to varying production could be due to adverse weather conditions (drought and excessive rainfall), crop diseases, etc. This condition is prevalent across the State. This can affect the pricing of the press mud. Based on the data that was shared by the Cane Commissioner, the cost of press mud for all sugar mills hovered between INR 15 to 30 per quintal during 2022-25.

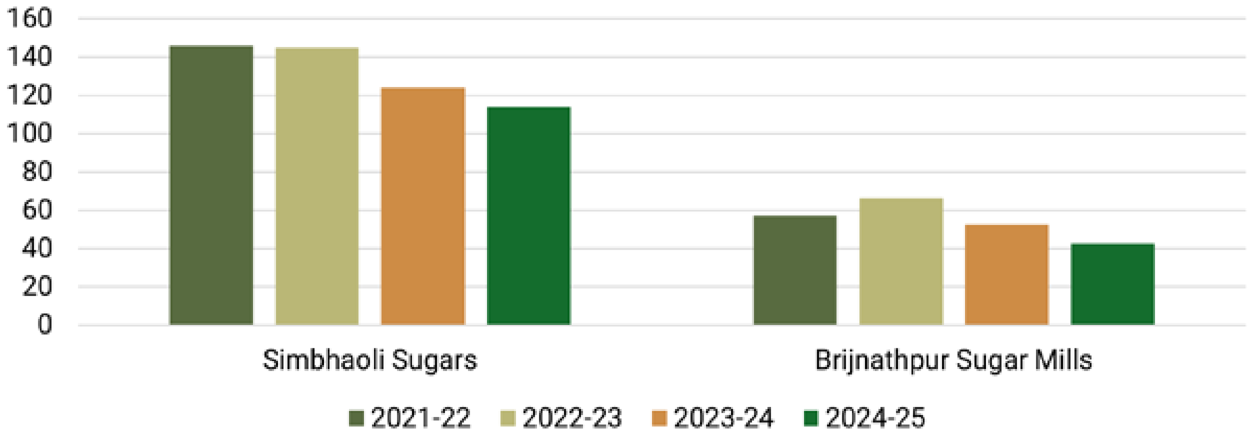


Figure 26: Annual cane crushed in sugar mills during 2021-25[52]

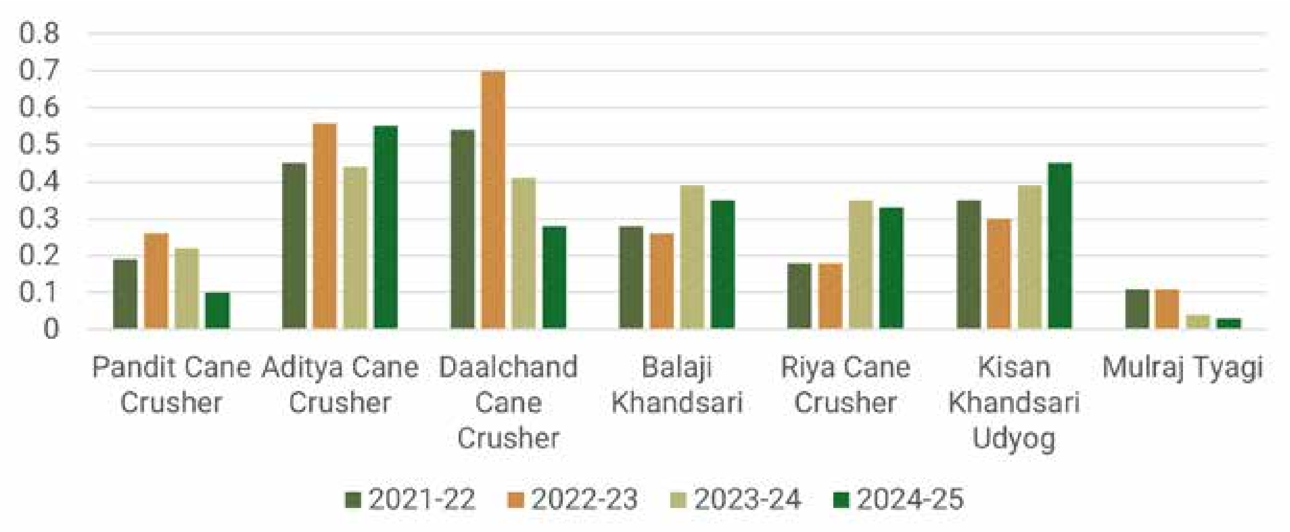


Figure 27: Annual press mud generated in sugar mills

52 Data shared by the Cane Development Department, Government of Uttar Pradesh

Figure 28: YoY change in annual cane crushed and press mud generated during 2021-25

It can be observed from Figure 28 that the press mud price varies significantly in a year. A typical sugar mill runs only for 180 days in a year during the kharif season (mid-November to April). This season is characterised as a peak season. During this period, the price of sugarcane press mud is usually lowest in the year. As we move to non-sugar or off-peak season, price for press mud spikes. The reasons for the spike in price include: high demand for supply of press mud, shortage in availability of coal, high temperature, etc. As temperature increases, quality of press mud increases due to low moisture content. In speaking with the sugar mill operators following reasons were identified for fluctuations in press mud prices during the year 2020-25:

- Price varies from plant to plant based on the operating efficiency, cane crushing capacity, quality of press mud that is generated (usually press mud with low sulphur content is preferred and is priced higher)
- Sugar Mills use coal as a supplementary fuel to run their co-generation unit and in seasons where the coal availability or its price is not favourable, press mud is captively used for cogeneration which reduces the surplus pressmud
- Price also varies between sugar and non-sugar season in a particular year. Usually, it remains low in winter and increases as the temperature increases

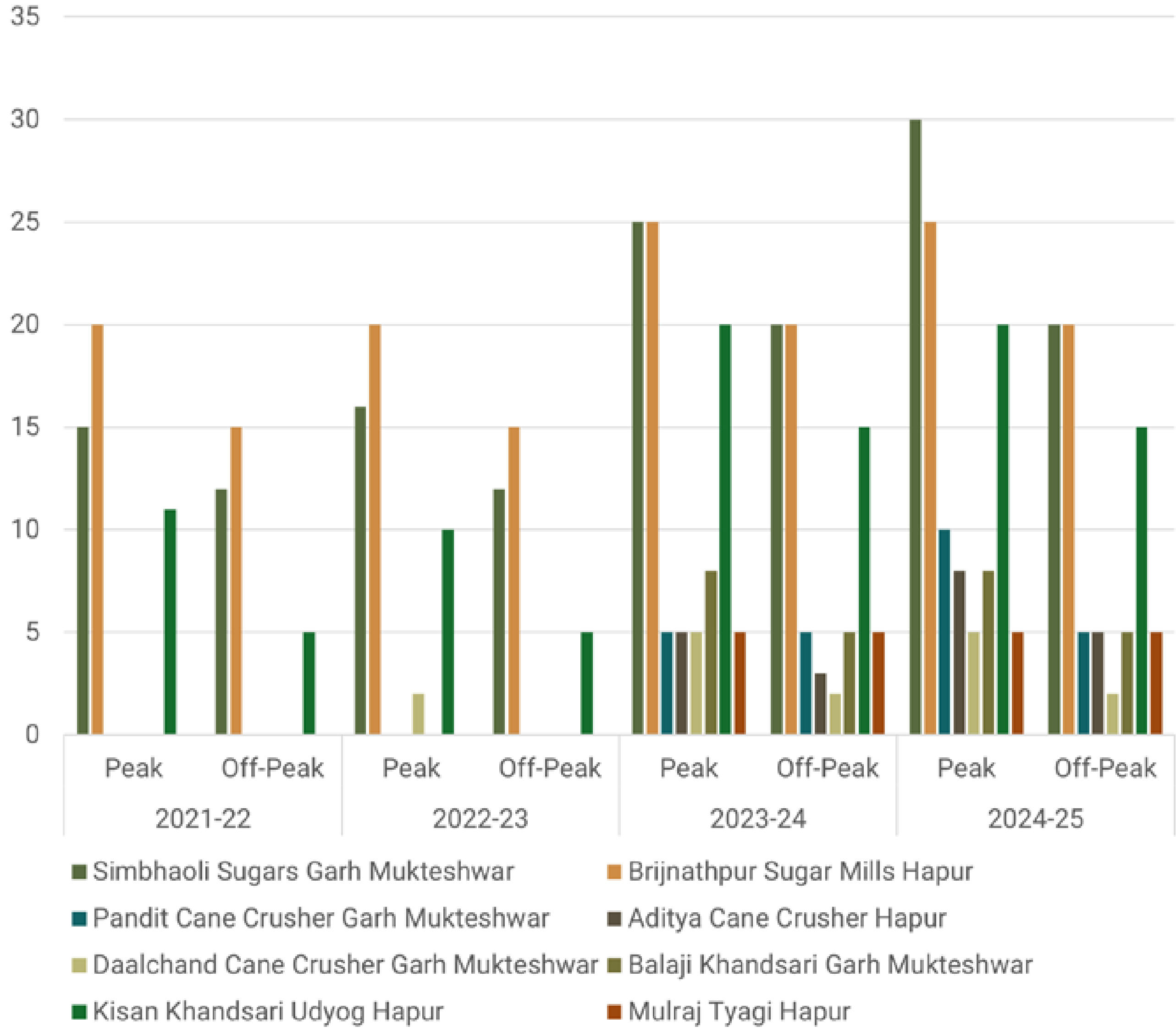


Figure 29: Press mud price variations during peak and off-peak season

9.3 High-Potential Zones for Biomass Supply and CBG Production

It can be observed that Garhmukteshwar has the highest sugarcane cultivation and hence, availability of sugarcane tops and leaves. Dhaulana tehsil has the highest paddy cultivation among all tehsils in the district.

On the basis of available feedstock, the CBG potential (TPD) was estimated for each feedstock in each tehsil which are described in the charts below:

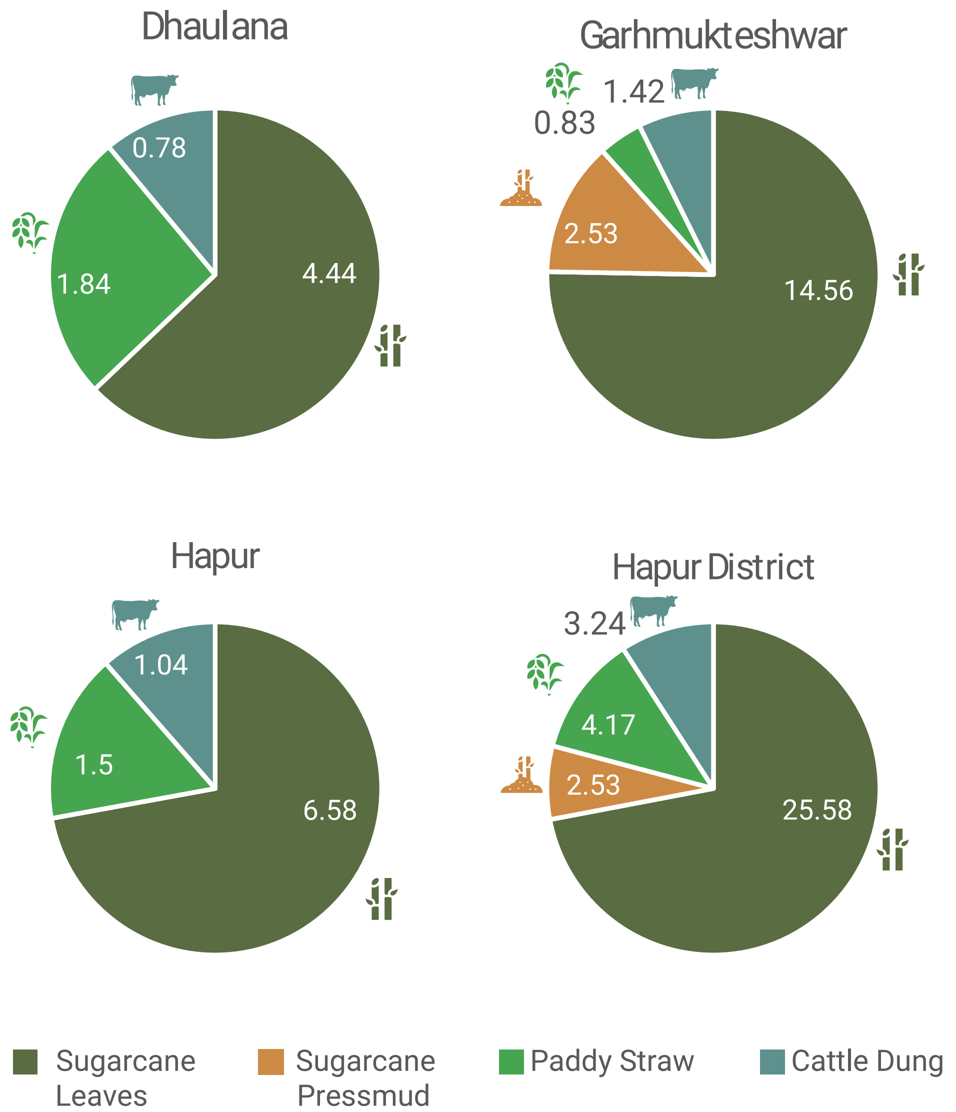


Figure 30: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per NIBE estimates)

However, the figures showed a different result taking into consideration of the conversion factors suggested by SATAT.

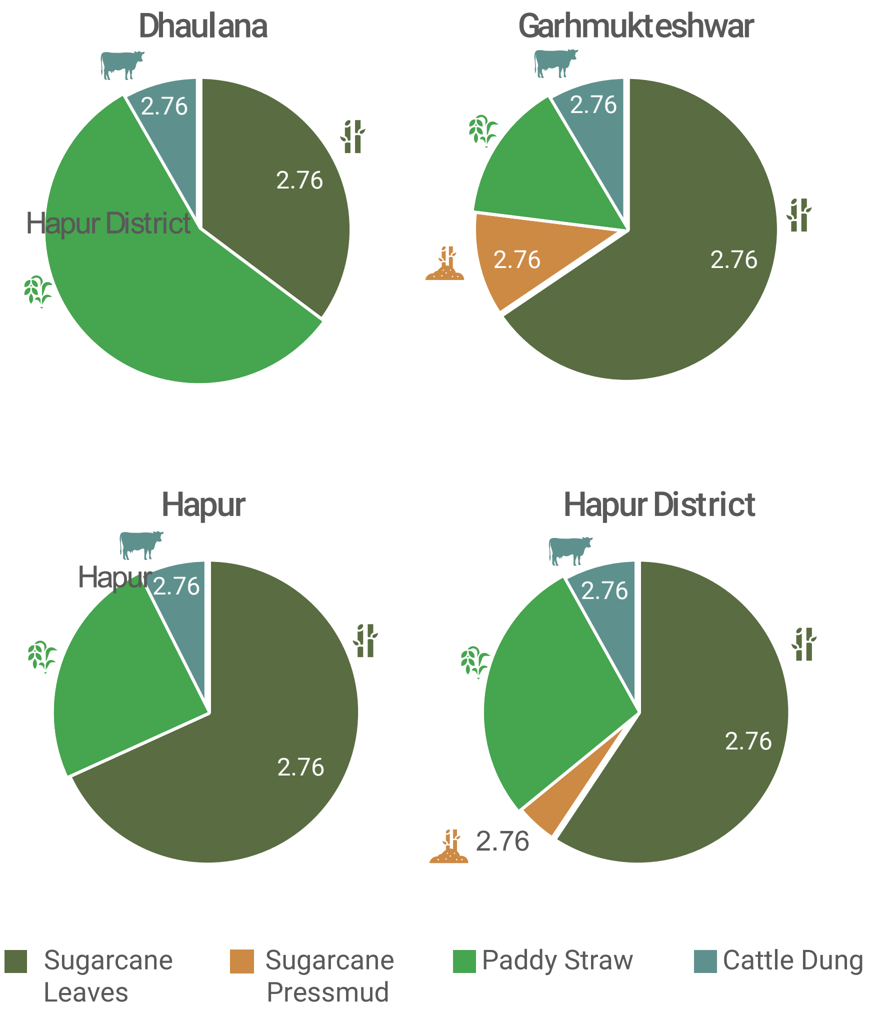


Figure 31: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per SATAT estimates)

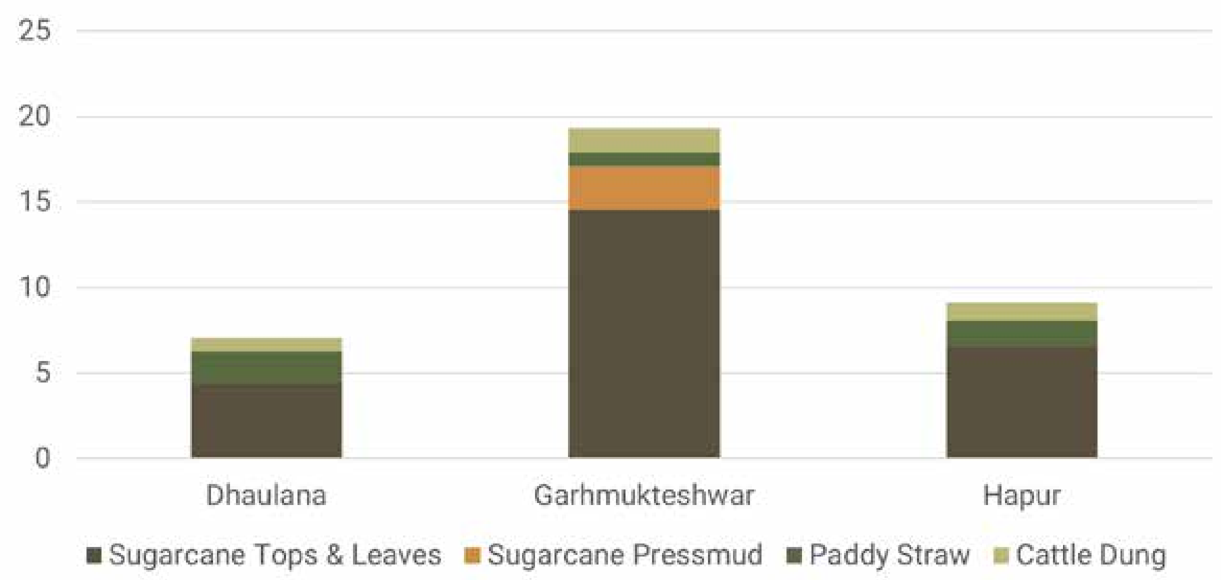


Figure 32: CBG potential from major feedstocks (NIBE estimates)

With respect to cattle dung as a feedstock, CBG developers prefer procuring cattle from nearby cowsheds (either government-owned or private). Based on the data from the Animal Husbandry department, we derived the tehsil-wise cattle population in these cowsheds.

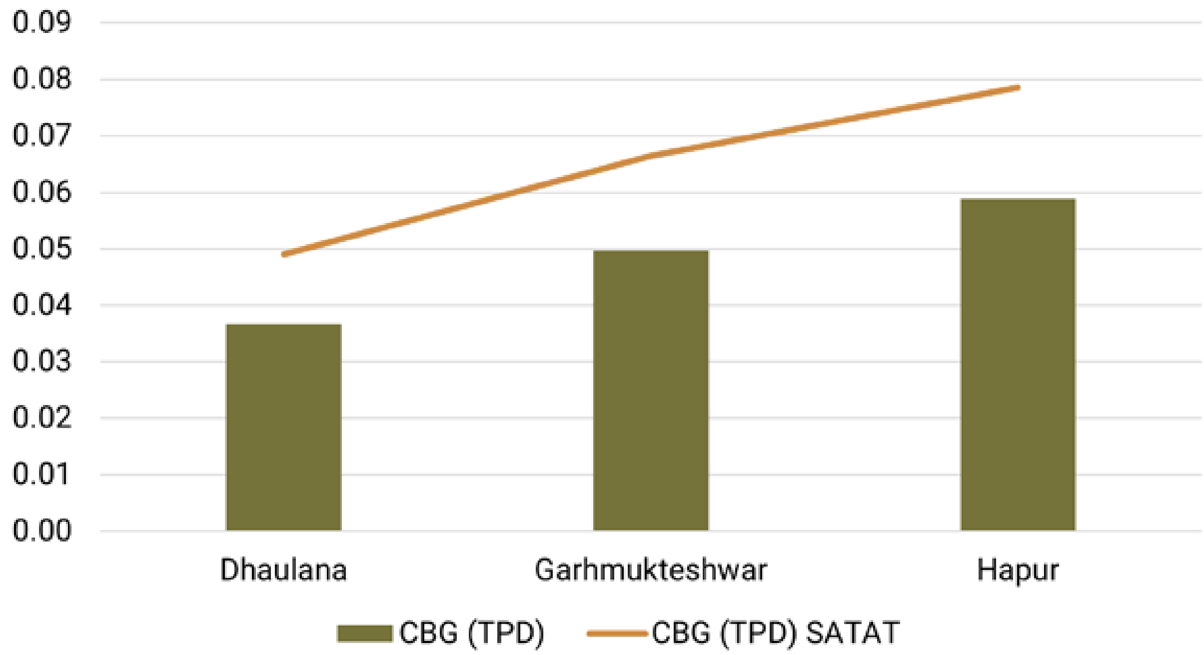


Figure 33: Tehsil-wise CBG potential from cattle sheds

While the CBG capacity from various feedstocks has been outlined, it's essential to recognise that CBG plants often operate on a mix of feedstocks rather than a single type. The sizing and design of these plants depend on a comprehensive set of factors (as captured in the Fig 33), including the quantity and variety of organic waste to be processed, the primary objective of waste treatment, demand for CBG, consumption patterns, local environmental conditions such as soil type and groundwater levels, regional climate factors like temperature and seasonal wind patterns, and the expertise level of the operational staff. This multifaceted approach ensures that CBG plants are optimised for efficiency, sustainability, and adaptability to local conditions

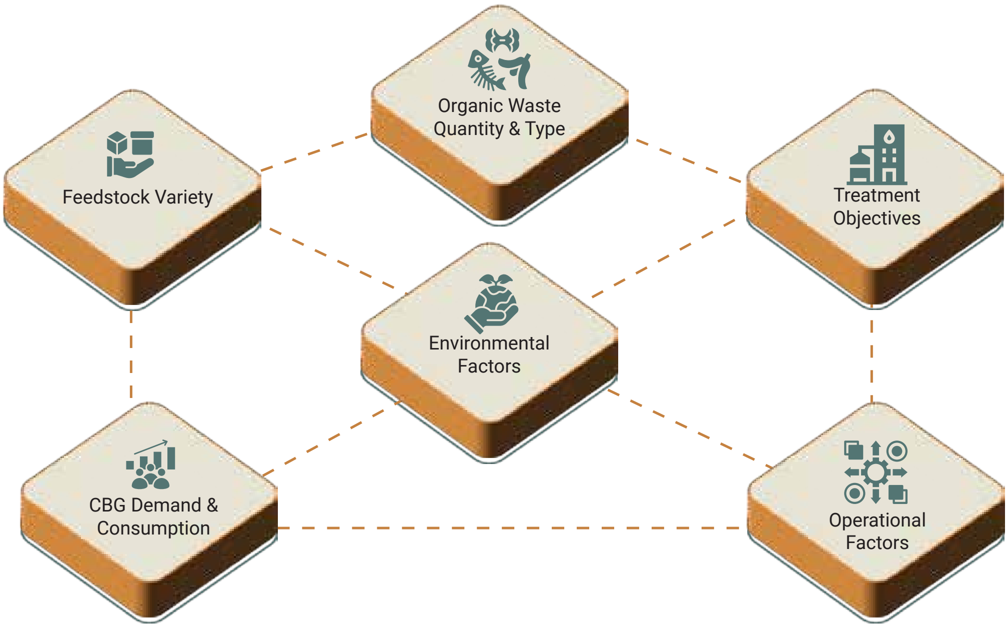


Figure 34: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

The total CBG potential (in TPD) can be summarised in a table as under:

Table 32: Potential daily generation of CBG as per NIBE and SATAT estimates

NIBE – CBG potential (in TPD) feedstock-wise in each tehsil					
Tehsil	**Sugarcane Tops & Leaves**	**Sugarcane Pressmud**	**Paddy Straw**	**Cattle Dung**	**Total**
Dhaulana	4.44	0	1.84	0.78	7.06
Garhmukteshwar	14.56	2.53	0.83	1.42	19.34
Hapur	6.58	0	1.5	1.043	9.123
Hapur District	25.58	2.53	4.17	3.243	35.523
SATAT – CBG potential (in TPD) feedstock-wise in each tehsil					
Tehsil	**Sugarcane Tops & Leaves**	**Sugarcane Pressmud**	**Paddy Straw**	**Cattle Dung**	**Total**
Dhaulana	4.44	0	7.12	1.044	12.604
Garhmukteshwar	14.56	2.54	3.22	1.896	22.216
Hapur	12.78	0	4.56	1.393	18.733
Hapur District	31.78	2.54	14.9	4.333	53.553

We derive two different CBG potential figures especially for paddy straw and cattle dung primarily because of the difference in Crop-to-Residue Ratios. According to NIBE, 0.17 percent of the gross crop residue is surplus and available for CBG production, whereas, according to UPNEDA, 0.40 percent of the gross crop residue is surplus.

As per the estimates, theoretically, Hapur district has a CBG potential of approximately 35 TPD based on the biomass available during the year 2023-24 and also on the net biomass available after considering the existing biomass-based industries. Out of all the Tehsils, Garhmukteshwar tehsil has the highest potential for CBG production with sugarcane tops and leaves and sugarcane pressmud contributing more than 88% of the total feedstock. Hapur leads after Garhmukteshwar with approximately 9 TPD of CBG production. At the end, it is crucial to note that the CBG quantification was conducted under ideal conditions. In reality, actual CBG production is influenced by several key operational parameters, including optimal temperature, pH levels, moisture content, toxicity levels, carbon-to-nitrogen (C/N) ratio, organic loading rate, and retention time. This underscores the importance for developers/investors to consider these multiple factors to maximise CBG yield.

10 Recommendations

1. Hapur has a high theoretical potential for CBG with press mud and paddy straw as its major feedstocks. It is important to ensure that CBG plants are designed to handle combination feedstocks with paddy straw, Napier grass and cattle dung that can support year-round plant operation and maximises biogas yield. Among the feedstocks that were considered for the study, for a given quantity of biomass residue, press mud has the highest CBG yield.
2. Availability of appropriate biomass and reliable supply chain are indispensable for sustainability and financial feasibility of a CBG plant. Harvestable crop residues per unit of land also depend on region-specific crop production practises. Farmer's willingness to collect crop residues depend critically on the yields and on the biomass, prices provided in the market.[53]
3. A beneficial, reliable, and transparent pricing and payment mechanism can incentivise collection and availability of biomass. This would establish a biofuel-led economy that can offer unique opportunities for farmers, enhance their regular incomes by turning waste into wealth. This additional stream of income can be particularly beneficial during times of market volatility or poor harvests of traditional crops and continue to drive economic growth at grassroot level.
4. Encourage farmers to use bio-slurry from CBG plants as an organic fertiliser to improve soil health and crop productivity. Implement comprehensive training programs to educate farmers on its benefits and proper application methods. Additionally, provide hands-on demonstrations and success stories to encourage adoption. Establish support networks and incentives to facilitate widespread usage and long-term sustainability.

53 C, Xiaoguang., 2015, Assessment of Potential Biomass Supply from Crop Residues in China. Environment for Development

5. CBG/Bio-fuel plant has to be designed, and tailor-made based on the crop residues for which the long-term availability is guaranteed based on forecasting and observing past trends. [54]Sugarcane and paddy have been dominant kharif crops for a long period of time and will continue to do so. From Agriculture Production Statistics, we can infer that sugarcane production has been on a steady rise with an average YoY growth rate of approximately 65 percent.
6. Explore the installation of Agricultural Photovoltaics (AgriPV) systems on fallow land to establish a conducive microclimate, promoting land reclamation for cultivation. These systems can support the growth of crops like Napier grass by improving soil moisture retention, minimising evapotranspiration, and offering partial shade. By harnessing AgriPV technology, farmers can optimise land use, enhance agricultural resilience, and increase overall productivity.
7. Examine ways to assist farmers in integrating AgriPV systems within horticultural zones to improve crop yields and biomass production. Research has shown that certain crops, including leafy greens and shade-tolerant vegetables, thrive under AgriPV systems, leading to enhanced growth and increased biomass availability for CBG generation. Supporting this initiative can optimise land use while promoting sustainable energy and agriculture.
8. For viable operations of CBG plant, logistics is key which can include residue harvest, collection, storage, transportation, etc. These are spatially interlinked and need meticulous planning. Barren lands or Fallow lands around the sugar mills (in 3-5km radius) can be identified for development of CBG projects. Proximity to cowsheds, poultry farms, and off-takers can also be mapped. For example, Petrol or Gas stations are potential off takers for CBG. Cultivation of energy crops like Napier grass should be prioritised only after considering the local biodiversity concerns.

Figure 34: Cane moved from the field to sugar mills for crushing

54 A. Chakraborty, A. Biswal et. al., Spatial Disaggregation of the Bioenergy Potential from Crop Residues using Geospatial Technique, Agricultural Sciences & Applications, Remote Sensing Applications Area, National Remote Sensing Centre, Indian Space Research Organization (ISRO)

9. Dedicated biomass banks can be established either through a third-party agency or through existing institutions like FPOs that can ensure collection and storage of residues after harvest. Considering the seasonal availability of crop residues, efficient contingency planning should be in place in the event of supply shortage linked to any extreme event such as pandemic or climate-linked disaster. This can potentially cut off the supply chain and can leave the plant operations stranded. To ensure continuous operations, storage of excess crop residues can be planned either in-house or through an agency where the storage time could be decided based on the useful life of the residue. For example, press mud can last no longer than 60 days, so they can be organised in a live storage while paddy straw which can sustain longer can go into a dead storage.

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