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

UTTAR PRADESH

Authors

Jaideep Saraswat, Nikhil Mall and Srinivas Ethiraj

Reviewer

Srinivas Krishnaswamy

Researchers

Dr. Preeti Singh, Naveen Kumar and Mradul Sharma

Geographic Information System Mapping

Gourav Panchal, Suman Kumar, Amit Yadav and Dr. Akinchan Singhai

Editorial

Rohin Kumar

Cover & Layout Design

Santosh Kumar Singh, Sasadhar Roy

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D-2, 2nd Floor, Southern Park, Saket District Centre,
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ASSESSING

BIOMASS AVAILABILITY AND COMPRESSED BIOGAS (CBG) POTENTIAL IN HARDOI DISTRICT

UTTAR PRADESH

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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 Hardoi 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 Hardoi

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

- **Major Biomass Feedstocks**: Sugarcane Press Mud, Sugarcane Leaves, Paddy Straw, and Cow Dung.
- **High-Potential Zones**: Hardoi, Shahabad, and Sandila tehsils emerged as top biomass sources. Potential locations for CBG plants could be sited close to the sugar mills present in tehsils of Shahabad and Hardoi, or in tehsils where the paddy cultivation is high that include Hardoi and Sandila, or both.
- **CBG Generation Potential**: The district has the potential to generate approximately 108 tonnes per day (TPD) of CBG from major feedstocks, such as sugarcane press mud, paddy straw, 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

Tehsil	Sugarcane Leaves	Sugarcane Pressmud	Paddy Straw	Cattle Dung	Total
Bilgram	10.66	0	2.12	0.25	13.03
Hardoi	19.98	8.28	5.36	1.001	34.621
Sandila	10.46	0	4.94	0.392	15.792
Sawayajpur	8.91	0	2.76	0.42	12.09
Shahabad	24.51	4.1	3.79	0.469	32.869
Hardoi District	**74.52**	**12.38**	**18.97**	**2.532**	**108.402**

- **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 108 TPD capacity CBG plants can collectively abate 1,08,405 T CO_2 emissions annually[1].

  In other words, 108 TPD of CBG can replace 108 TPD of CNG which will correspond to daily carbon emission savings of 297 T of CO_2.

- **Supply Chain Considerations**: Efficient logistics and storage solutions are essential for sustainable biomass utilisation.

1 Sutheo, G., et al. (2024). Comparison of carbon-dioxide emissions of diesel and LNG heavy-duty trucks in test track environment. Clean Technologies, 6, 1465–1479..

Recommendations

1. **Hybrid Feedstock Utilisation**
   - Encourage blending of paddy straw, 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 the total final energy consumption, with a projected growth rate of 45 percent between 2023 and 2030.[4] India's abundant biomass availability (See *Figure 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

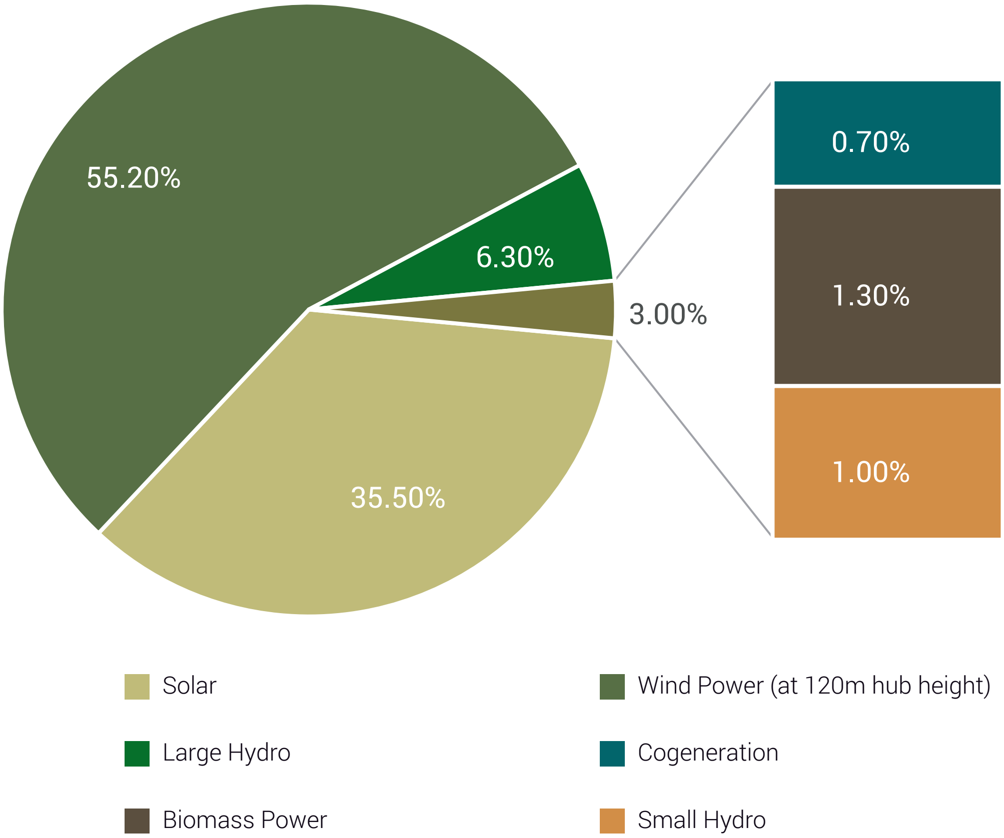


Figure 1: Source-wise renewable power potential in India, 2023[5,6]

India is the second largest agro-based economy and has 58 percent of its total land area available for agricultural purposes,[7] with net cultivated area of around 219.16 million hectares and has about 141.6 percent cropping intensity.[8,9] Therefore, it generates a huge amount of agricultural residues which can contribute to biofuel and bioenergy production.[10] At the national level, India generates approximately 686 Million Tonnes (MT) of gross crop residues[11] CRg and approximately 234.5 MT of surplus residues[12] annually.

In India, Uttar Pradesh is a leading agrarian[13] 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[14] 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.

7 Ministry of Agriculture & Farmers Welfare, Land Use Statistics At A Glance: 2022-23, September 2024

8 Cropping Intensity is the ratio of the Net Area Sown to the Total Cropped Area. (Source: Explanatory Notes, Directorate of Economics and Statistics, Ministry of Agriculture & Farmers Welfare)

9 Ministry of Agriculture & Farmers Welfare, PIB Press Release dated 30 July 2024, https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2039218

10 D, Singh. U, Mina., 2022 On and Off Farm Crop Residue Management: A brief review on Options, Benefits, Drawbacks, Limitations and Policy Interventions, Journal of Cereal Research Vol. 14(2): 108-128

11 Gross crop residue can be defined as the sum total of crop residues produced for a particular crop.

12 Surplus crop residue of a particular crop represents the amount of crop residues that are available for energy production after all other competing uses such as cooking fuel, cattle feed, roof thatching, composting, animal bedding and others.

13 As per National Policy on Crop Residue Management 2017, Uttar Pradesh generates 115.68 MT of crop residues every year making it the highest in India

14 Bio-CNG (Compressed Natural Gas), chemically same as CBG (Compressed Biogas) has methane content of more than 90% and can be used a green automotive fuel and in city gas distribution networks replacing CNG, etc. (Source: IREDA)

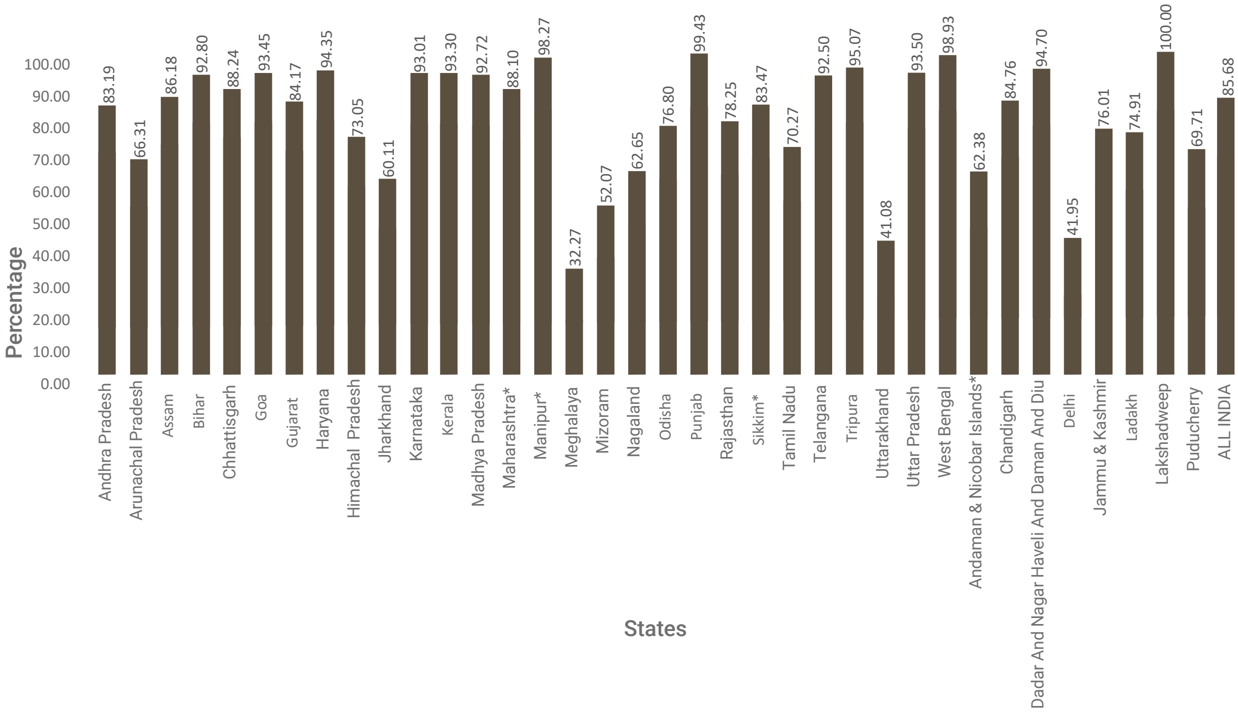


Figure 2: **State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23**[15]

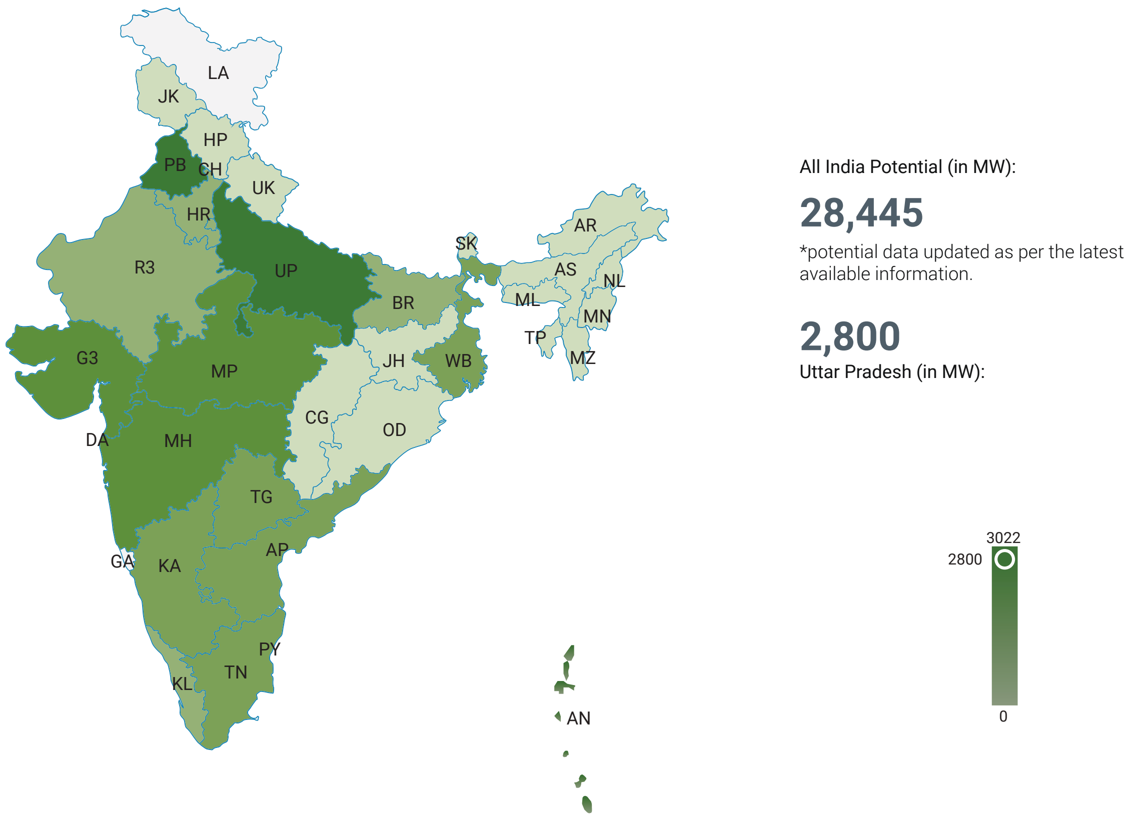


Figure 3: **Biomass power potential in India**[16]

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

16 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,[17] 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:[18]

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.

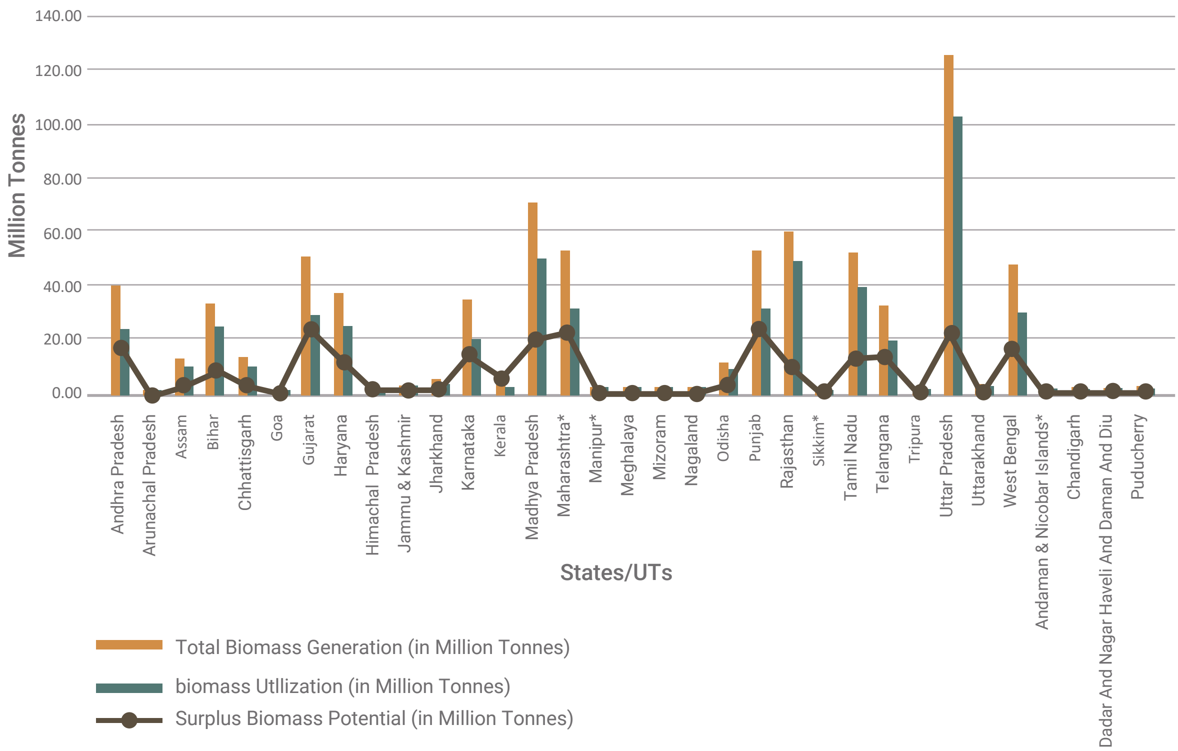


Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential[19]

17 SSS-NIBE, National Biomass Atlas of India: 2023

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

19 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)[20].
- 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[21]. Further, the contribution of NGB biofuels in reduction of GHG emissions is 30-35 percent greater compared to food-based biofuels.[22]

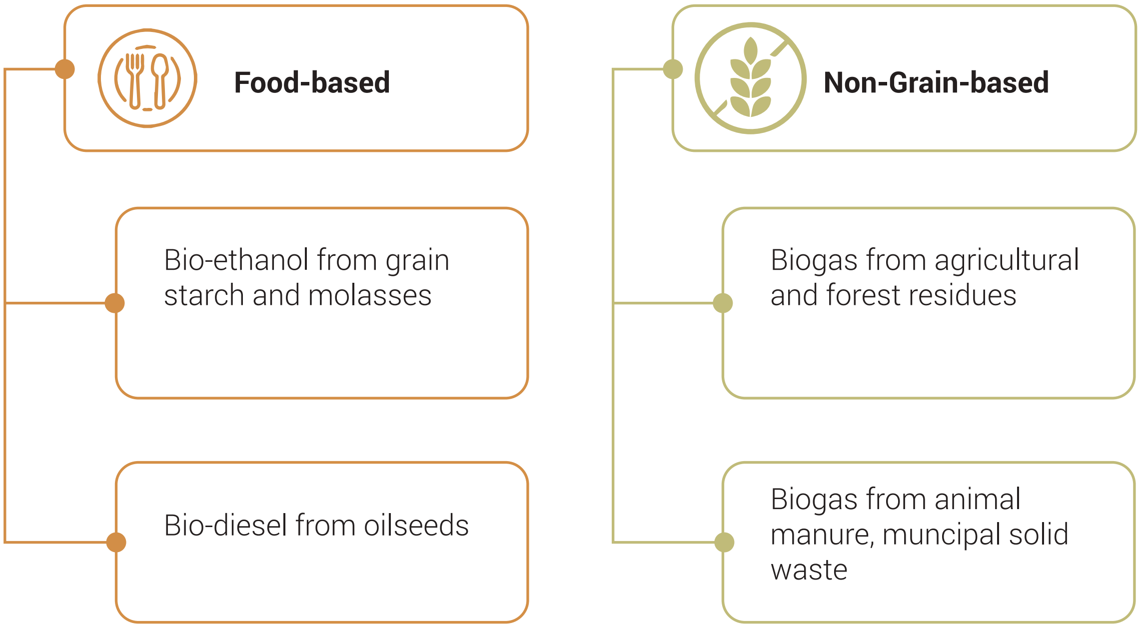


Figure 5: Classification of biofuels

2.1 Scope of the Study

This study aims to measure the net biomass residue production during 2023-24 across all five tehsils (administrative subdivisions) of Hardoi 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.

20 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.

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

22 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 utilizing barren and uncultured land or fallow lands, etc. It takes into consideration of the current biomass residue management practises and further the 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.[23] 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.

23 A, Chakraborty, et.al., 2019 Spatial Disaggregation of the Bioenergy Potential from Crop Residues Using Geospatial Technique, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XLII-3/W6

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_2), and carbon dioxide (CO_2). Finally, in the methanogenesis phase (Phase 4), methanogenic microorganisms follow two pathways: acetolactic methanogens convert acetate into methane (CH_4) and CO_2, while CO_2-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 percent) and carbon dioxide (30-35 percent), 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.[24] 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), H2S, 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: 3 & 4 summarise the characteristics of raw biogas and Bio-CNG/CBG.

24 R, Jain. K, Jawed., Biogas digestate: This high-value byproduct deserves more attention, DownToEarth 12 February 2023, https://www.downtoearth.org.in/renewable-energy/biogas-digestate-this-high-value-byproduct-deserves-more-attention-87649

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 8* 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 9*).[25] 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.[26] After the substrate is homogenised and dewatered, it is preheated in a preparation tank before it is actually fed into a digestor.[27]

25 F.R., Lucy, et. al., Pretreatment of feedstock for enhanced biogas production, IEA Bioenergy 2014

26 N, John, P.S., Fathima, et.al., 2023, Physical Conversion of Biomass: Dewatering, Drying, Size Reduction, Densification, and Separation, Handbook on Biomass, Springer

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

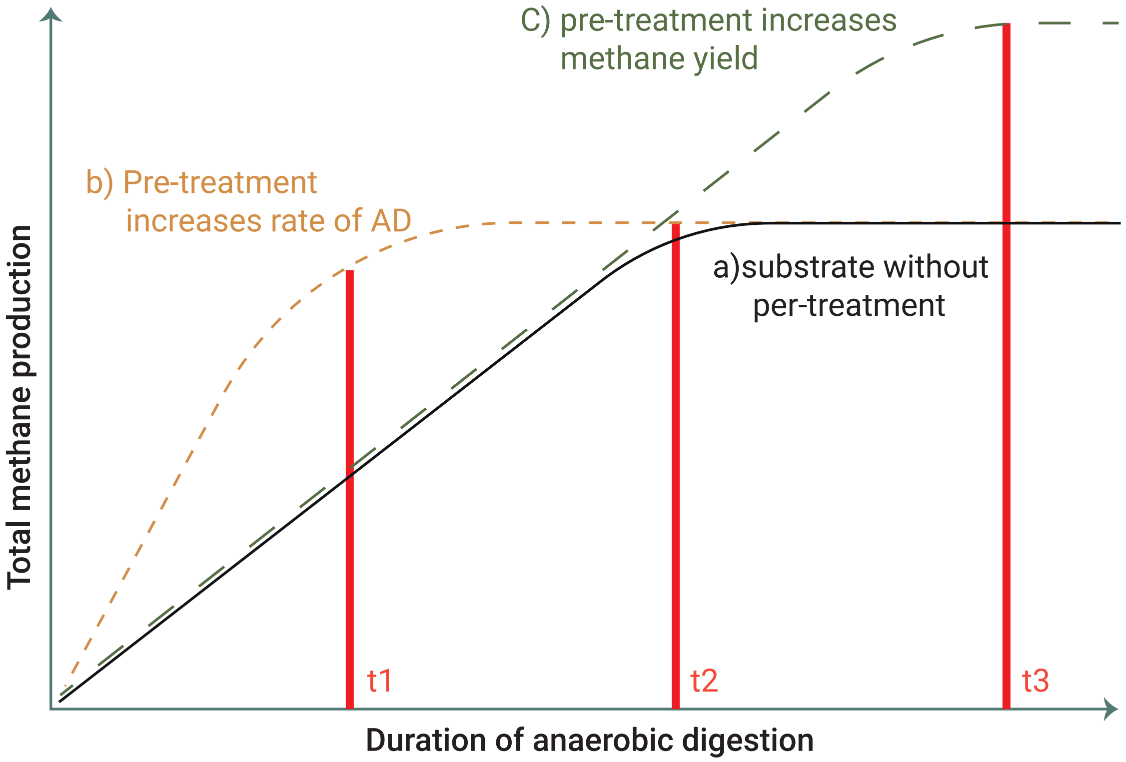


Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[28]

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.[29] This is followed by removal of hydrogen sulphide which not only contaminates the environment, but also minimises 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.

28 IEA Bioenergy 2014

29 J, Reina., 2018, Study of effect of the water vapor removal on the biogas stream, 5th International Conference on Renewable Energy Gas Technology

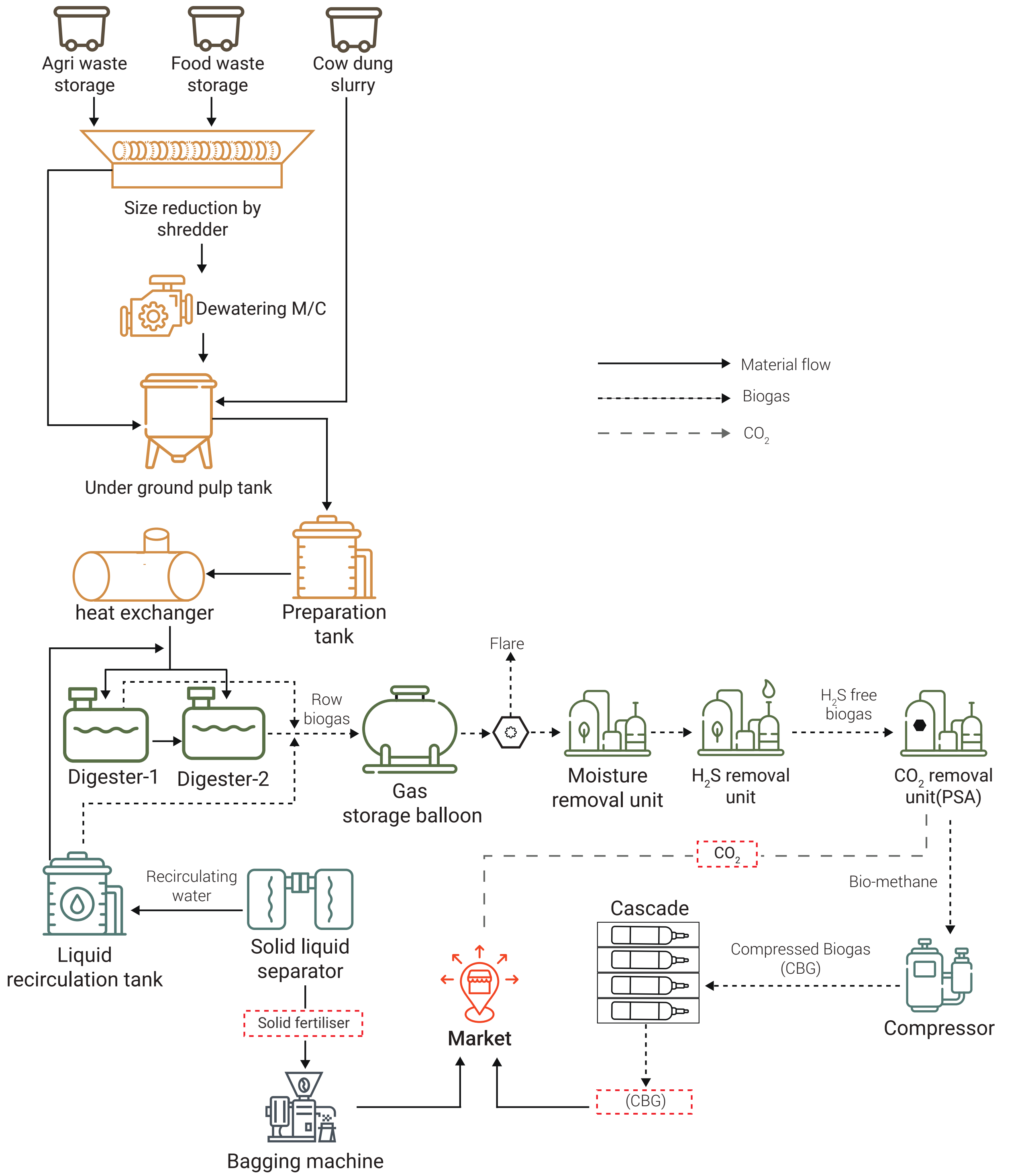


Figure 8: Processflow diagram for a Compressed Biogas Plant[30]

India's CBG potential is estimated at approximately 87 bcm/yr[31], 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:

30 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

31 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.[32]
- Under the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative, Government has introduced the phase-wise mandatory blending of CBG in transport and PNG (Petroleum Natural Gas) in City Gas Distribution network.[33]
- 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[34], 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.

Among all States, Uttar Pradesh accounts for 24 percent of the total CBG generation potential in India [35]due to abundant organic feedstock availability.

32 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

33 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

34 Fertilizer (Inorganic, Organic or Mixed) (Control) (Third) Amendment Order, 2025 introduced a new category of fertilizer termed "organic carbon enhancers from CBG plants"

35 Centre for Science and Environment (CSE) 2024, Compressed Biogas Landscape in Uttar Pradesh

03 District Profile

3.1 Geographic Overview

Hardoi District is situated between 260 53' to 270 46' N north latitude and 790 41' to 800 46' E east longitude. Its north border touches districts of Shahjahanpur and Lakhimpur Kheri. On the western side, it touches districts of Kanpur (industrial city) and Farrukhabad. On the eastern border, the Gomati River separates the district from Hardoi. The length of this district from northwest to southeast is 125.529 km and width from east to west is 78.43 km[36]. The total geographical area of the district is 5837 sq. km.

According to 2011 census, Hardoi district has a population of 4092845. The district has a population density of 683 inhabitants per square kilometre. There are 730,442 households in the district accounting for 2.2 per cent of the total households in the state. The average size of households in the district is 5.6 persons.

36 District Census Handbook, Hardoi, Directorate of Census Operations, Government of Uttar Pradesh

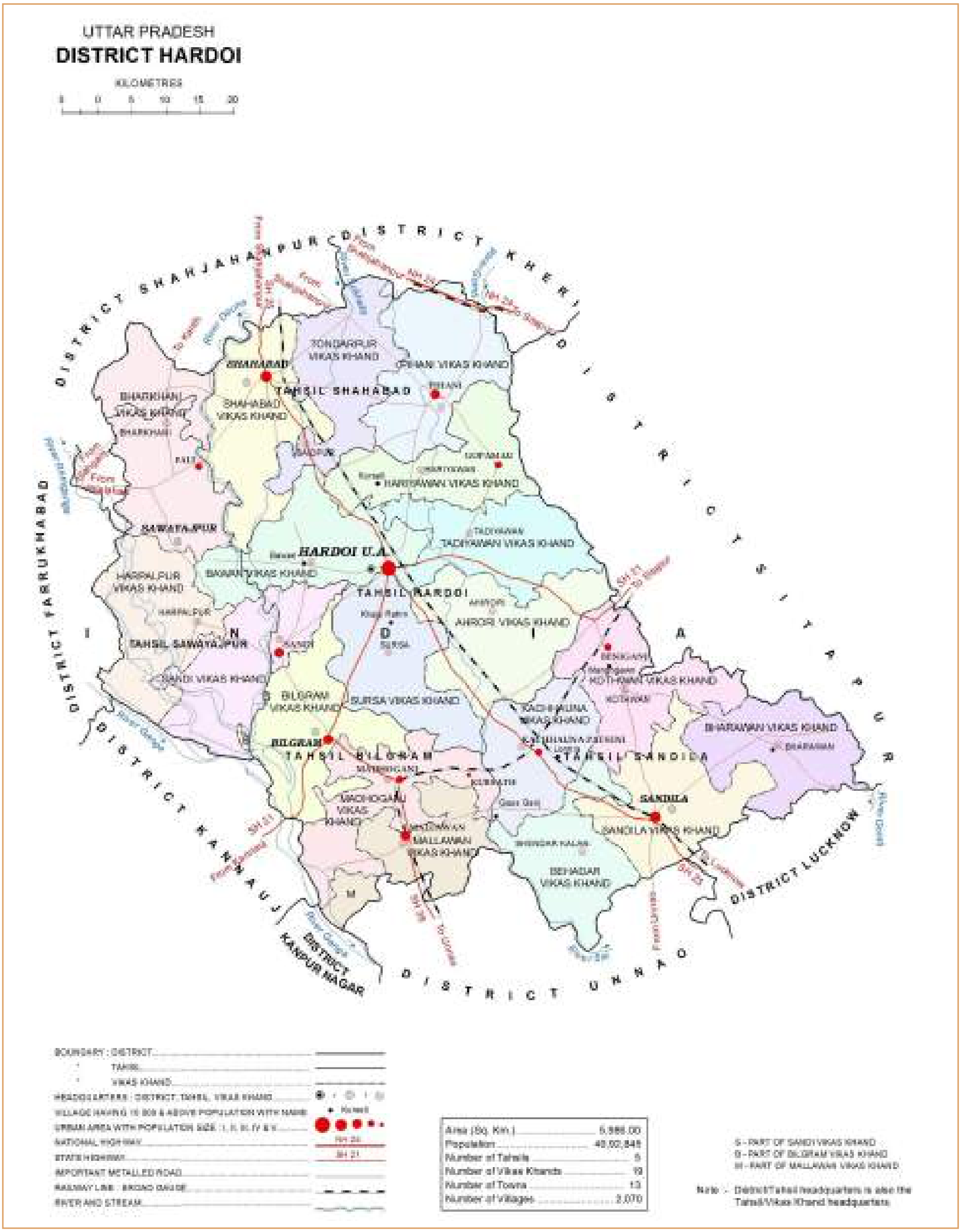


Figure 9: District Map of Hardoi as per the 2011 Census

Hardoi district prominently hosts agro-based industries ranging from rice mills to large scale sugar mills and flour mills. In addition, the district has cotton textiles, ready made garments and embroidery, leather-based and metal-based industrial units operating in micro-scale.[37]

37 Brief Industrial Profile of Hardoi District, MSME-Development Institute, Kanpur

3.2 Administrative Units (Tehsils/Blocks)

For administrative convenience, the district[38] is divided into 5 Tehsils which are: Hardoi, Shahabad, Sawayajpur, Bilgram and Sandila. There are 19 blocks in the district.[39] There are 1101 Gram Panchayats, 2070 revenue villages and 7 municipal boards. The rural area of the district covers 5837.8 sq. km. and urban recorded 148.2 sq. km

Table 6: Tehsil-wise Revenue Village Count in Hardoi District

Tehsil	Total Revenue Villages
Bilgram	361
Hardoi	473
Sandila	419
Sawayajpur	380
Shahabad	459
Total	2092

3.3 Climatic Conditions

The climate is generally healthy and pleasant. The river Ganga, Ramganga, Gomti and several tributaries of river Ganga are flowing the district. Average rain in the district is approximately 941 mm.

Table 7: District Agricultural and Climate Profile of Hardoi

District Agricultural and Climate Profile				
Agro-Climatic Zone[40] (State Agricultural Profile[41])	Central Plain Zone, Climatic Zone – Upper Gangetic Plain Region			
Rainfall[42]				
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Southwest Monsoon (June-September)	767.9	-	2nd week of June	4th week of September
Post-monsoon (October-December)	45.8	-	-	-

38 Uttar Pradesh Statistical Diary 2023, Economic & Statistics Division p.13, Planning Department, Government of Uttar Pradesh

39 District Irrigation Plan, Hardoi

40 India has been classified into 15 Agro-climatic zones based on land use, soil type, irrigation, amount of rainfall received, etc. Each zone is further classified into regions and sub-regions at the district level for developing long-term land use strategies. Sub-regions are characterized by homogenous soil, climate, physiography and moisture.

41 State Agricultural Profile: Uttar Pradesh 2024, Directorate of Sugarcane Development

42 Agriculture Contingency Plan for District: Hardoi, 2019, Department of Agriculture and Farmers' Welfare

District Agricultural and Climate Profile				
Winter (January-March)	41.6	-	-	-
Pre-monsoon (April-May)	19.5	-	-	-
Annual	874.8	-	-	-
Temperature (in degree Celsius)[43]	**Maximum** 36.7		**Minimum** 27.5	
Soil	Deep, loamy soils and slightly eroded			

Major Climate Contingency and Frequency	**Regular**	**Occasional**	**None**
Drought			√
Flood	√		
Cyclone			√
Hailstorm		√	
Heat wave			√
Cold wave		√	
Frost			√

A report[44] which measured district-level climate vulnerabilities in India highlighted that Hardoi district in Uttar Pradesh fall under the relatively very 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.

43 Krishi Vigyan Kendra, Hardoi, Agriculture Department, Government of Uttar Pradesh

44 Department of Science and Technology, 2019-20, Submitted by IIT Mandi, IIT Guwahati and IISc Bengaluru

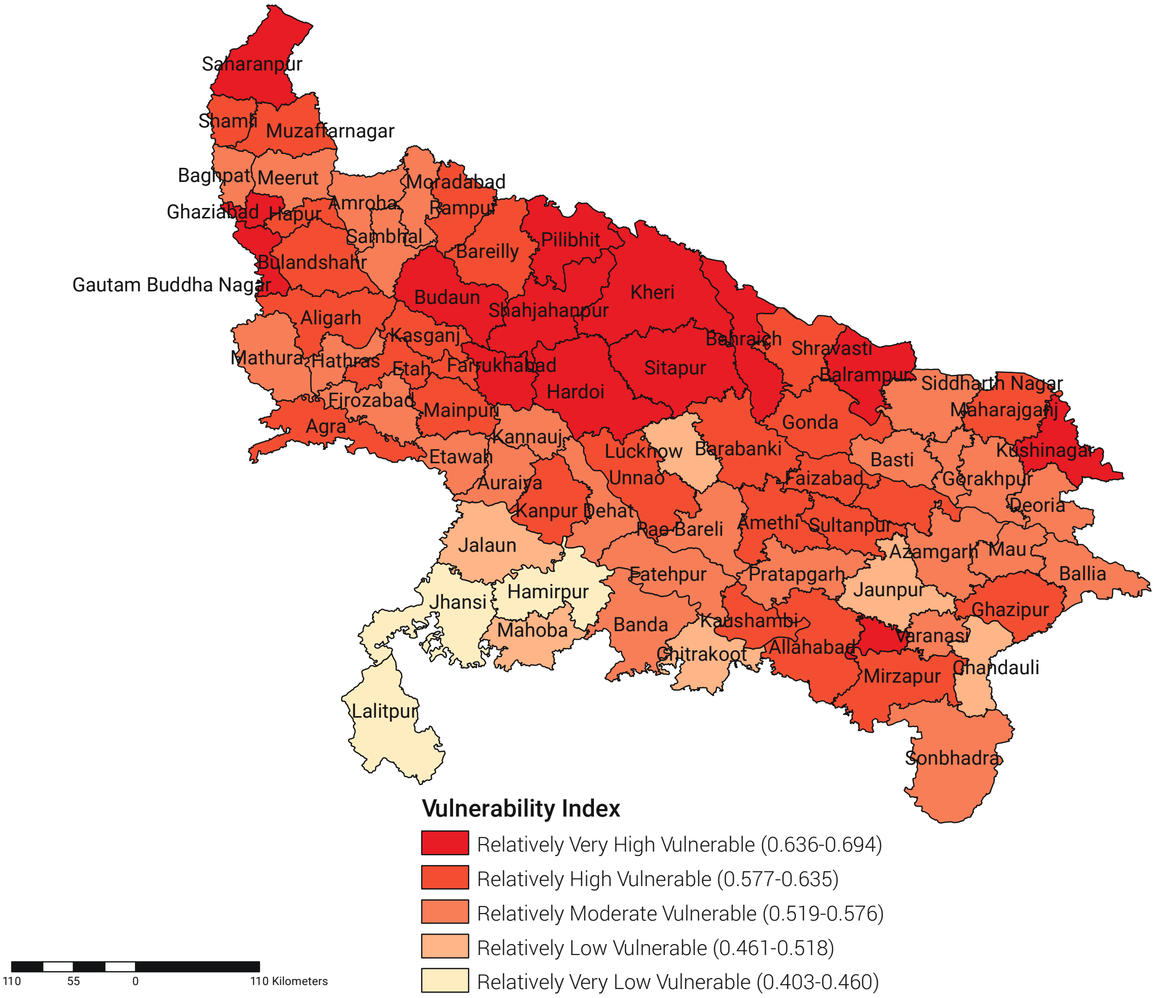


Figure 10: **District-wise climate vulnerability index**

On the basis of soil, climate, topography, vegetation, and crops, Uttar Pradesh has been divided into nine agro-climatic zones. Hardoi is located in the Mid-Western Plain Zone (as described in *Figure 11*) and records medium to 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	

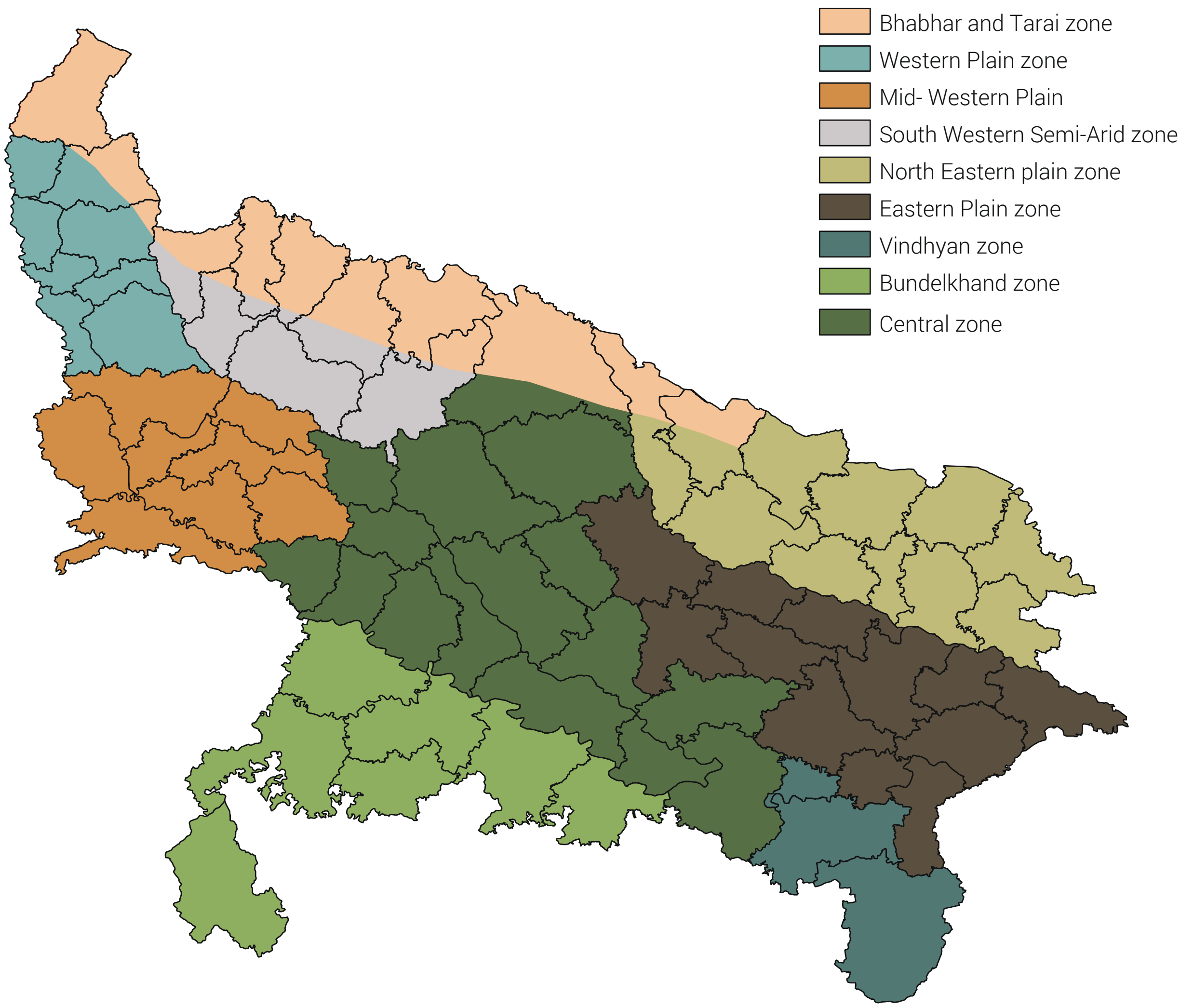


Figure 11: Agro-climatic zones in Uttar Pradesh[45]

3.4 Demographics (Urban/Rural)

Agriculture is the primary occupation in the district with over 75 percent involved either as cultivators or agriculture labourers.[46]

In terms of agricultural landholdings, 80.79 percent of the holdings in the district were less than 1 hectare (ha.) while 13.38 percent of the holdings were 1-2 ha, 4.77 percent of the holdings lie between 2-4 ha and 1.06 percent of the holdings were 4 ha or more during 2015-16. In terms of agricultural income, during 2021-22, the gross value of agricultural produce per ha. of net area sown was INR 2,77,265.70.

45 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

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

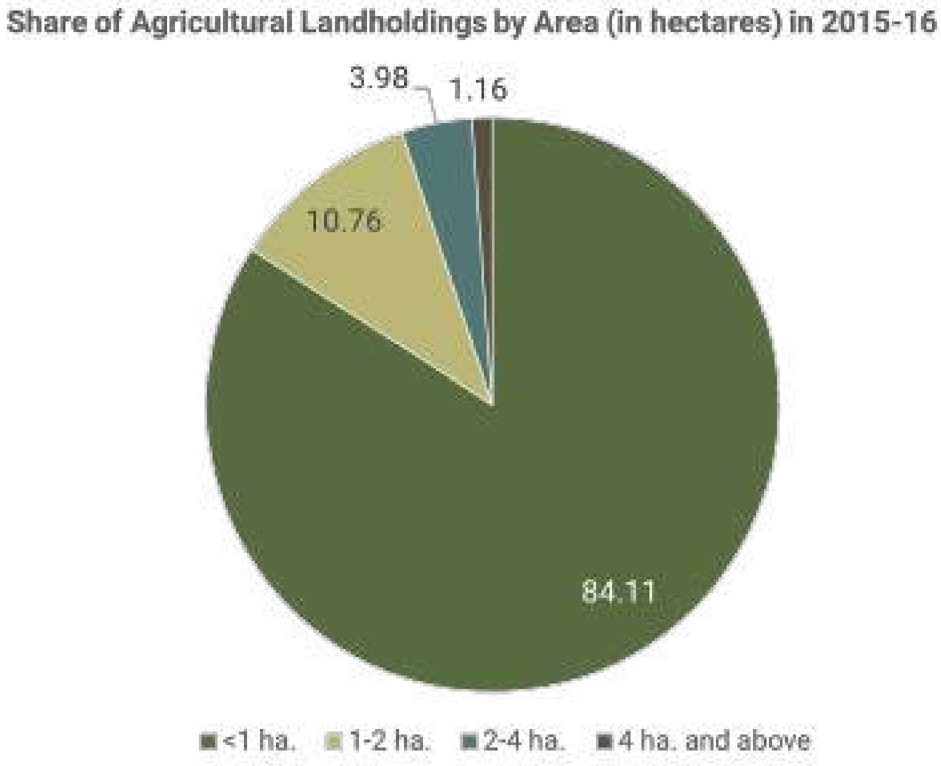


Figure 12: Agricultural Land Holdings in Hardoi

3.5 Agricultural Overview

Hardoi is predominantly an agricultural district in Uttar Pradesh. At the district-level, around 4.3 lakh hectares (ha.) of geographical area is sown with a cropping intensity of 130 percent.[47] Gross cropped area is approximately 6.7 lakh ha. with over 2.37 lakh ha. area sown more than once. The net irrigation area is around 3.85 lakh ha. out of which 48000 ha. is rain fed. Major sources of irrigation include bore wells (tube wells) and canals.

3.5.1 Total Agricultural Area[48]

Table 9: Agricultural Land Area and Cropping Intensity in Hardoi District

Agricultural Land Use	Area ('000 ha)	Cropping Intensity (%)
Net sown area	433.3	174.04[49]
Area sown more than once	237.4	
Gross cropped area	670.6	

47 Agriculture Contingency Plan for District: Hardoi, Government of Uttar Pradesh

48 District Profile, Krishi Vigyan Kendra, Hardoi

49 District Development Indicators, Uttar Pradesh 2023, Planning Department, Government of Uttar Pradesh

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

Major agricultural crops by production in the district include wheat, gram, moong, barley, pea, sugarcane, jowar, mustard, potato and horticulture crops during *Rabi* season and jawar, millet, bajra, maize, paddy, and pulses (tur/arhar) during *Kharif* season. Zaid are intermediate harvest and is of little significance. Cash crops that are popularly sown in the district include sugarcane, potato, etc. At times, double cropping is practised in the district to obtain more yield. *Figure 14* describes the extent of land use in terms of gross area sown for *Kharif* and *Rabi* crops in Hardoi District during 2021-22.

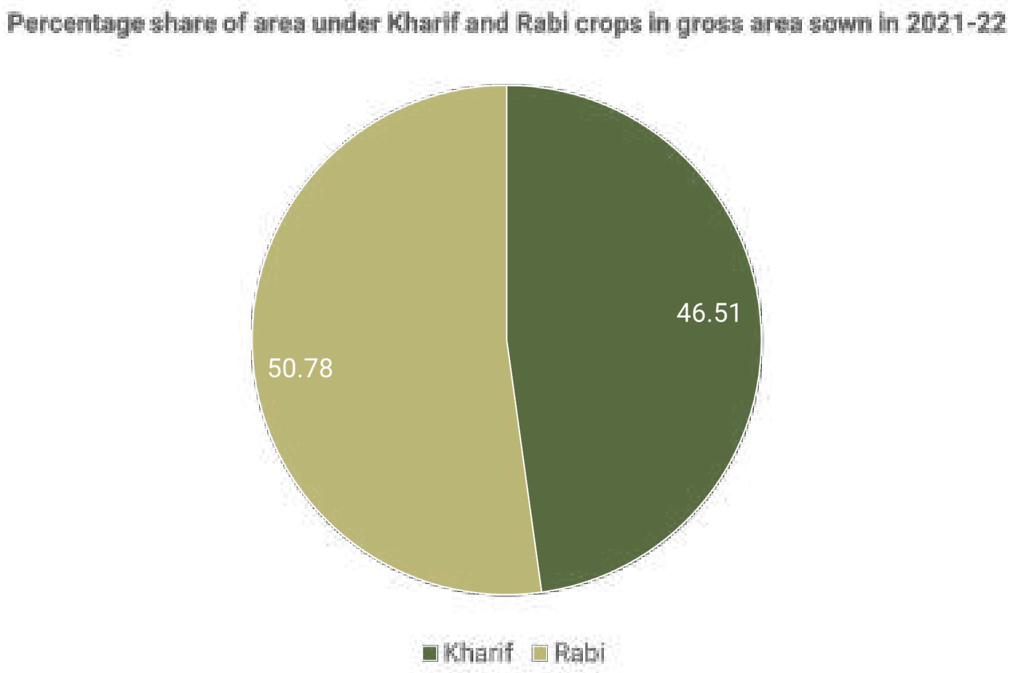


Figure 13: **Gross Area Sown during both the cropping seasons in Hardoi**

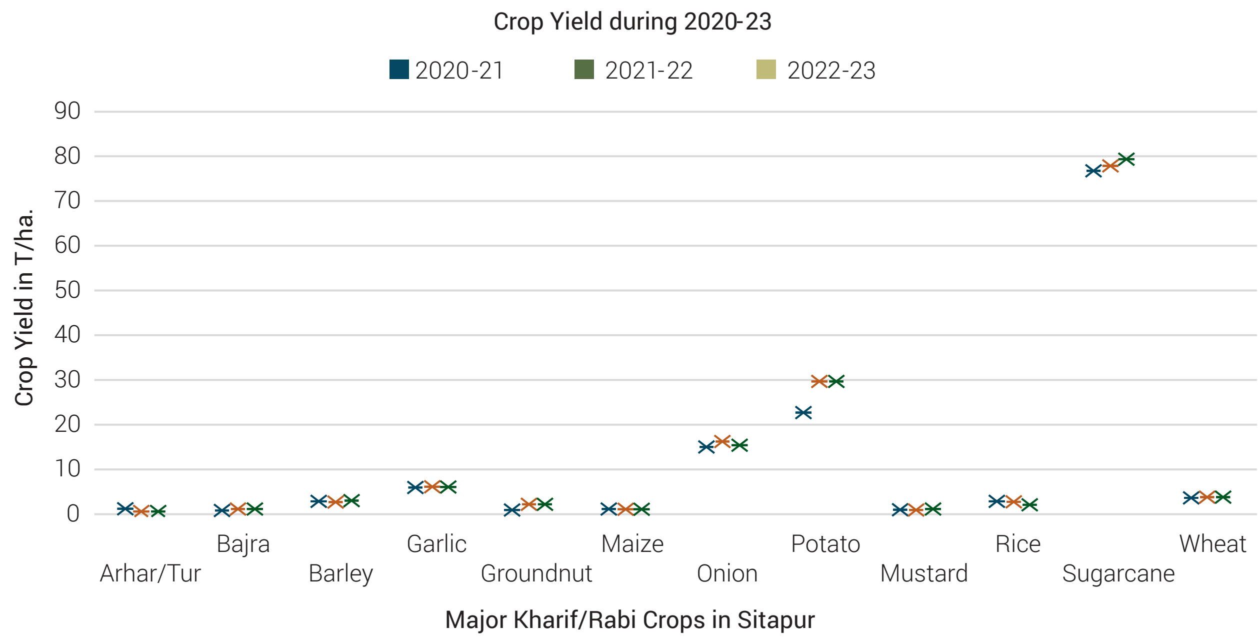


Figure 14: **Crop yield during 2020-23 for major crops sown in Hardoi during *Kharif* and *Rabi*[50]**

50 Area Production Statistics, Ministry of Agriculture and Farmers Welfare

Rabi crops 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, mustard, and barley where wheat alone occupied close to 72 percent of the total cropped area. Other *rabi* crops include potato, other vegetables, etc.

Table 10: Tehsil-wise cropped area of *Rabi* crops (in ha.) during 2023-24[51]

Tehsil	Mustard	Other Crop	Potato	Sugarcane	Vegetable	Wheat	Total Area
Bilgram	6523.70	5349.07	1068.76	926.53	181.01	47879.06	61928.12
Hardoi	11368.22	7696.06	1756.50	9468.78	363.74	70460.64	101113.94
Sandila	5695.60	3681.34	1837.84	3443.80	134.29	69030.92	83823.78
Sawayajpur	4357.53	3996.07	846.60	2083.99	61.01	49302.06	60647.26
Shahabad	10760.16	7907.73	1292.40	10796.54	73.59	37014.69	67845.11
Total	**38705.21**	**28630.26**	**6802.10**	**26719.63**	**813.64**	**273687.37**	**375358.22**

During 2023-24, the prominent *Kharif* crops in Hardoi were sugarcane and paddy where together they comprised 58 percent of the total cropped area. Other major *kharif* crops include oil seeds, maize, barley, and bajra that were sown and cultivated during the same period. Among all tehsils, Hardoi had the highest share of cropped area for paddy while Shahabad dominated in cultivation of sugarcane, followed by Hardoi, Bilgram, and Sandila.

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

Tehsil	Mustard	Other Crop	Potato	Sugarcane	Vegetable	Wheat	Total Area
Bilgram	3258.12	1497.46	2224.16	11309.23	4007.26	13596.02	2830.88
Hardoi	7381.56	1856.64	3152.45	9641.51	6025.57	34319.42	4426.98
Sandila	12332.03	773.98	3224.54	8891.29	3889.53	31599.94	3139.42
Sawayajpur	1032.61	2790.91	1292.34	7233.68	4657.15	17663.17	4807.83
Shahabad	3661.27	1301.30	1466.33	6765.72	5036.23	24252.29	2950.84
Total	**27665.60**	**8220.29**	**11359.82**	**43841.43**	**23615.75**	**121430.83**	**18155.94**

51 Analysis by Vasudha Foundation, 2025

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

In Hardoi, the percent of irrigated area to the total cultivable area is 89.50[52]. The gross irrigated area of the district is at 553,000 ha. During 2021-22, 13272 ha. of land in Hardoi was affected by floods and rains.[53]

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

Sowing window for major field crops	Rice	Urad	Sugarcane	Maize	Groundnut	Mustard	Wheat
Kharif – Rainfed	3rd week of June to last week of July	3rd week of June to 2nd week of July	Last week of June to 2nd week of July	-	-		
Kharif – Irrigated	3rd week of June to last week of July	3rd week of June to 2nd week of July	-	-	-	-	
Rabi – Rainfed	-	-	-	-	2nd week of October to 3rd week of October	2nd week of September to 1st week of October	-
Rabi – Irrigated	-	-	-	3rd week of November to last week of December	-	2nd week of September to 1st week of October	2nd week of November to 2nd week of December

3.6 Forest Resources

3.6.1 Total Forest Area[54]

Table 13: Total Forest Area (by classification) in Hardoi

District	Calculated Area (km^2)	Very Dense Forest (km^2)	Moderate Dense Forest (km^2)	Open Forest[55] (km^2)	Total (km^2)	Scrub[56] (km^2)
Hardoi	5985.66	0	15.62	129.58	145.20	9.36

52 District Census Handbook for Hardoi, 2011

53 Land Use Statistics at a Glance: 2022-23, 2024, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare

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

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

56 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)

Forest area consists of Babul, Dhak, Neem, Sheesham, and Bamboo trees which are grown in scattered and barren land. In sandy areas, palm trees and thorny bushes are grown. In Ganga area, there are moderately dense forests comprising of huge trees and different kinds of vegetation. The district abounds in orchards. Mango trees are grown in groves and on the roadsides. The other variety of trees include Banyan, Gular, Pakar, Fig, Vaska, etc.

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)[57]. 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.[58]

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.[59] 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 and cattle in Cowsheds[60]

Tehsil	Cattle	Goat/Sheep	Swine	Poultry (Chicken)
Bilgram	6447	0	0	0
Hardoi	25446	0	0	2,10,000
Sandila	9981	0	0	0
Sawayajpur	11159	0	0	0
Shahabad	11915	0	0	0
Hardoi District	64948	0	0	2,10,000

Tehsil	Bilgram	Hardoi	Sandila	Sawayajpur	Shahabad	Hardoi District
Total Govansh	6447	25446	9981	11159	11915	64948

57 IEA 2020, Outlook for biogas and biomethane: Prospects for organic growth

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

59 Basic Animal Husbandry Statistics, 2022, Department of Animal Husbandry and Dairying

60 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[61,62,63,64] 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

Step 1

Fresh cow-dung from farm

Collected and shaped into 8-10 inches cakes

Collected and thrown on previous day heap

Step 2

Cakes dried in sun and heap allowed to ferment

Dried, tough cakes

Heap ferments and degrades into nitrogenous compounds

Step 3

Step 3: Utilisation

Cakes ignited and burnt to cook meals

Heap collected after 4 to 6 weeks and mixed in soil in agricultural fields

Figure 15: Traditional use of cow-dung as kitchen fuel and manure[65]

61 Avcioglu, A.O., Turker. et. al., Status and potential of biogas energy from animal wastes in Turkey, Renew, Sustain,, Energy Rev. 2012, Vol. 16, pp. 1557-1561

62 Kaygusuz, K., Renewable and sustainable energy use in Turkey: A review, Renew, Sustain, Energy Rev, 2002, Vol. 6, pp. 339-366

63 Afazeli, H. et. al., Potential of biogas production from farm animal waste in Malaysia, Renew, Sustain, Energy Rev. 2016, Vol. 60, pp. 714-723

64 G, Kaur. et. al., Potential of Livestock Generated Biomass: Untapped Energy Sources in India, MDPI, energies, 20 June 2017

65 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 is an under-construction Compressed Biogas Plant in Sawayajpur Tehsil and one large biogas plant in Hardoi Tehsil.

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

Plant Capacity	Feedstock/ Raw Material	By-Products	Off taker	Procurement Plan
2.4 (TPD) in Sawayajpur Teshil	Pressmud[66], Cattle Dung, Paddy Straw, Mustard Straw	CBG, FOM, LFOM	CBG is proposed to be sold to Indian Oil Corporation at INR 72/ Kg CBG	Sugarcane Pressmud is to be procured from a Sugar Mill in the same Tehsil on a long-term MoU basis. Cattle dung is procured from nearby Cow sheds. Since paddy straw price is high, developer is planning to blend it with mustard straw
140 m3 Per Day (MPD) in Hardoi Tehsil	Cattle Dung	Bio-slurry	Biogas used for heating purposes in cowshed	Commercial-scale biogas plant installed and functional inside a cowshed facility in Hardoi Tehsil (under GOBARdhan)

The feedstock procurement plan for the 2.4 TPD under-construction CBG plant is described below:

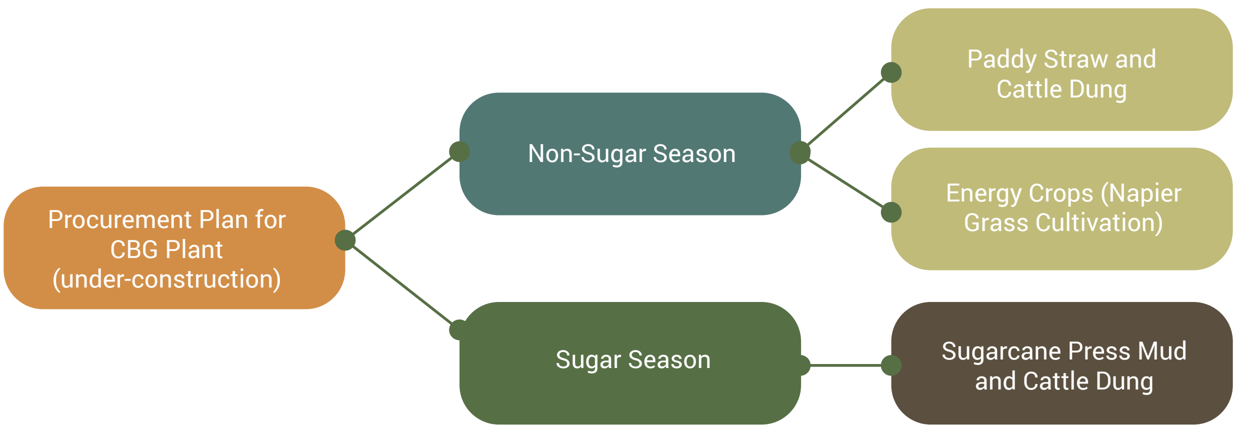


Figure 16: Feedstock Procurement Plan for existing CBG Plant[67]

66 Pressmud, also known as filter cake or press cake, is a residual byproduct in the sugar industry

67 Every year, the crushing season in Uttar Pradesh usually starts mid-October and continues till the end of March or even the first week of April (accounting for 140-150 days of crushing). However, if the sugarcane cultivation is low during any particular year, the crushing season may get delayed and start towards the end of November. (Source: Uttar Pradesh Cane Development Department)

Figure 17: **Operational large biogas plant in Hardoi tehsil and Under-construction CBG plant in Sawayajpur tehsil**

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[68]
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[69])	150 days
Number of Operating Days (Medium Sugar Mill[70])	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:

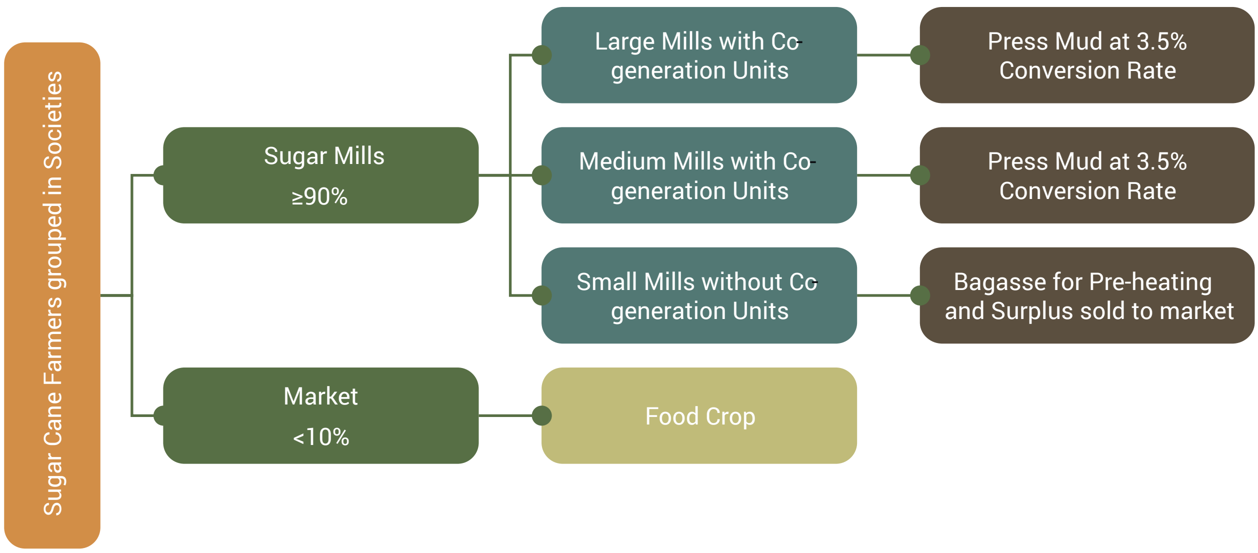


Figure 18: Mapping the value chain of Sugar Industries

Sugar mills and Rice mills were located on the district map with tehsil boundaries to locate potential sites for sourcing feedstock/raw material for CBG plants.

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

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

70 Medium Sugar Mills use Horizontal Crushers to crush Sugarcane

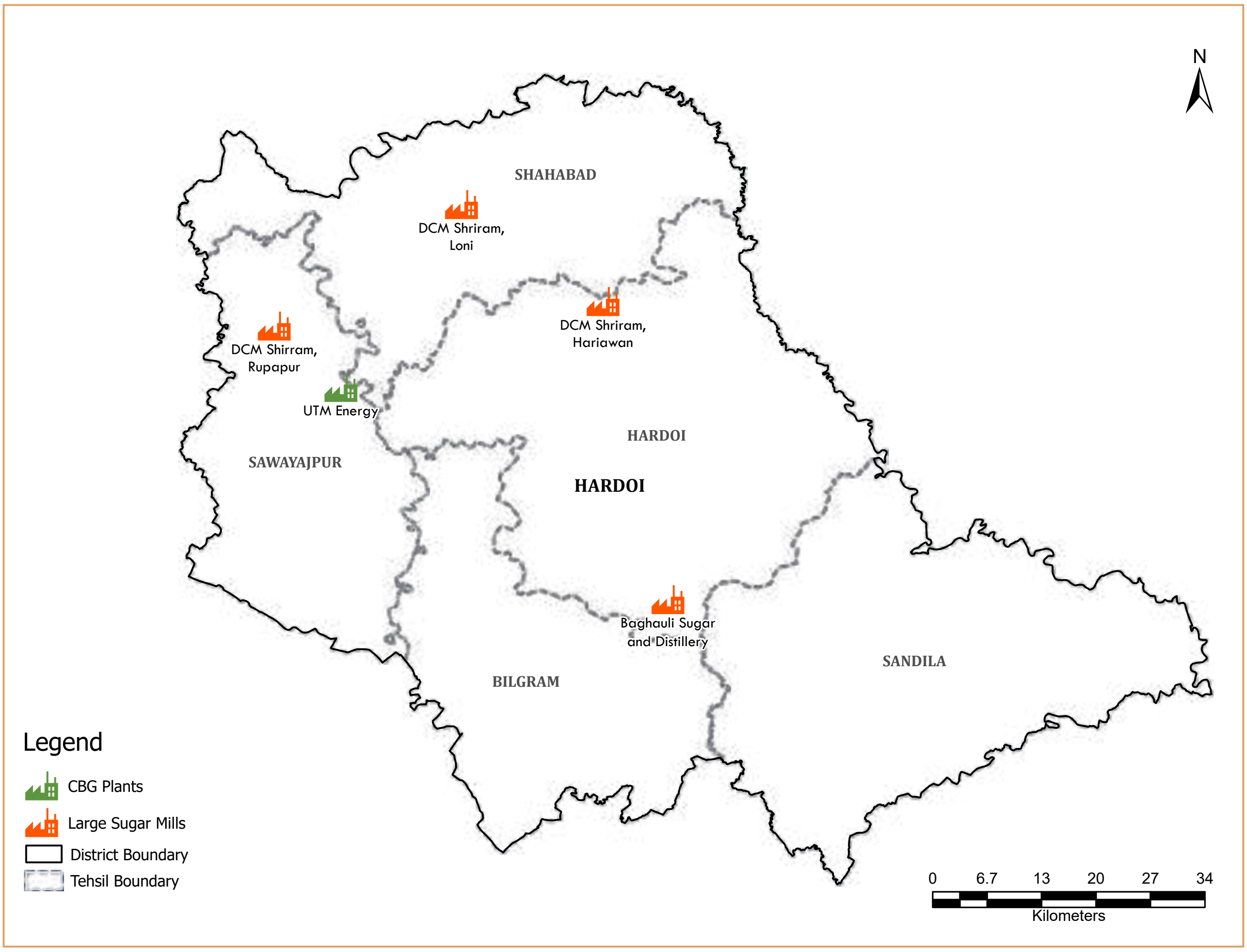


Figure 19: Location of Sugar Mills in Hardoi District[71]

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)**
Hardoi	16500 (2 Mills)	1000	2730
Sawayajpur	6500	x	x
Shahabad	8000	x	X

71 Analysis by Vasudha Foundation, 2025

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[72] 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.[73]

72 National Biomass Atlas of India, 2023

73 As per the NIBE's approximations

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

Category	Animal	Collectable Dung (Kg/day)	Total Solids	Availability Coefficient	Biogas in m^3	Multiplication Factor[74]
Large	Cows, Buffalo	22.5	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 m^3 of biogas can be generated from 1 kg of cattle dung.

Table 22: Calorific values[75,76] for animal residue

Animal Residue	Calorific Value
Cattle Dung	3900 Kcal/Kg
Sheep/Goat Dung	3000 Kcal/Kg

Animal Residue	Calorific Value
Swine Dung	17.9 MJ/Kg
Poultry Litter	16 MJ/Kg

74 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.

75 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

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

To understand which feedstock is best for CBG production, we used SATAT data published by the Ministry of Petroleum and Natural Gas (MoPNG)[77]. The tentative yield of various feedstocks is tabulated as under:

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

77 MoPNG, SATAT, Frequently Asked Questions, https://satat.co.in/satat/#/faq

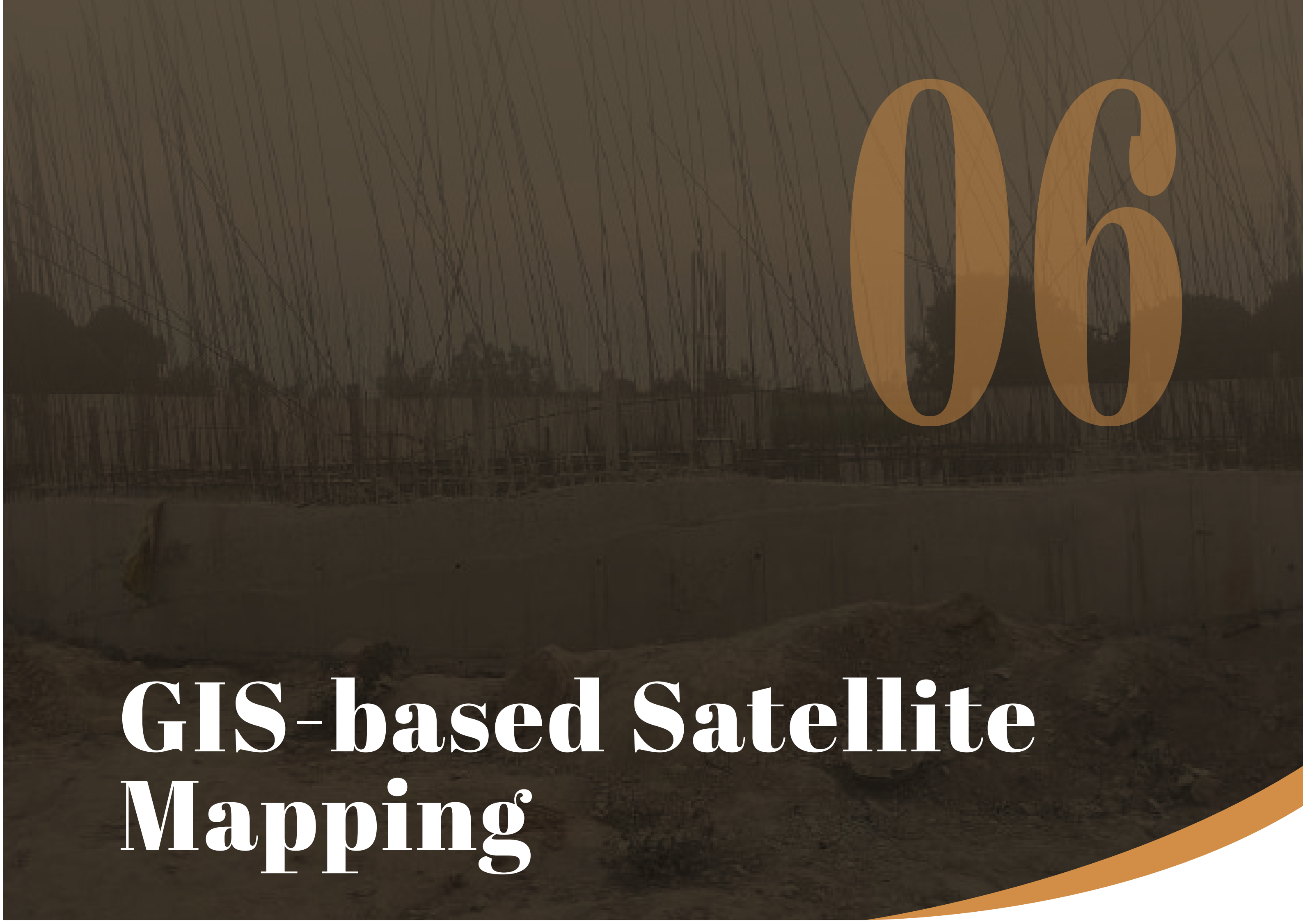
05 Stakeholder Mapping

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 T) into potential CBG capacity (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
	Directorate of Economics and Statistics	Tehsil-wise land use, irrigation, crop production statistics for Hardoi 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, etc.
	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 while sugarcane is cultivated across the district, they are prominent crops in tehsils of Shahabad, Bilgram and Sawayajpur. Paddy can be seen cultivated across all tehsils. Shahabad, Bilgram and Hardoi tehsils grow and cultivate bajra and oil seeds alongside major *kharif* crops.

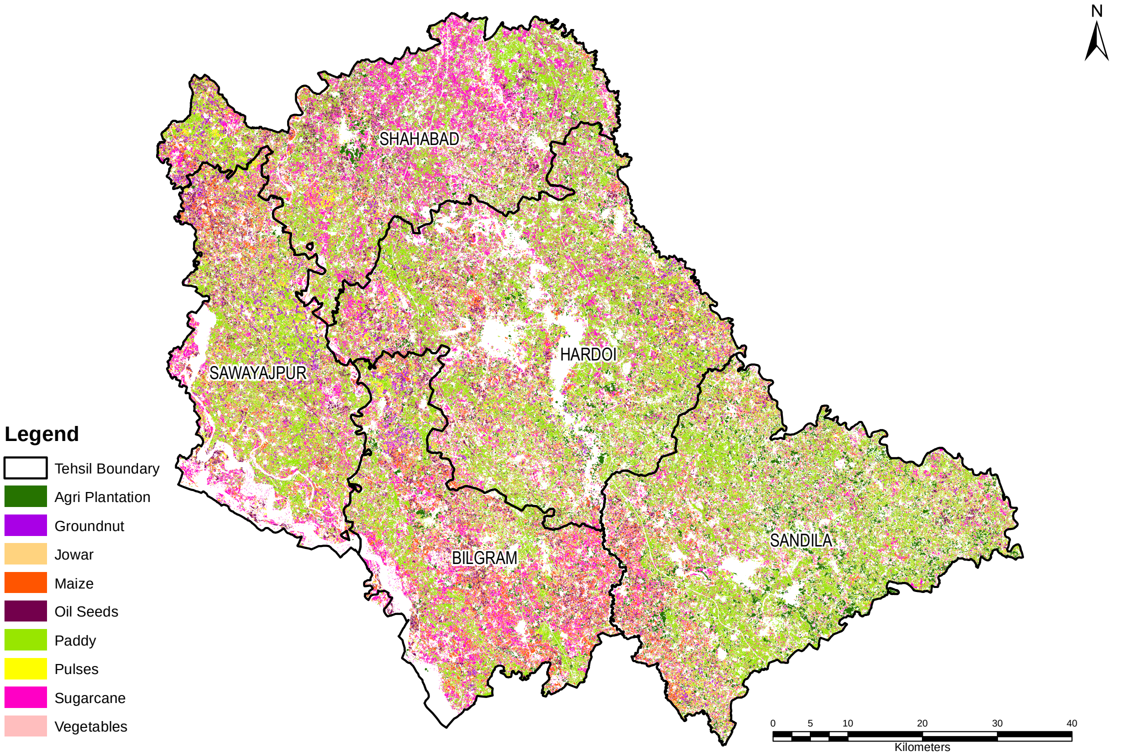


Figure 20: Geographical Spread of *Kharif* Crops in Tehsils of Hardoi District during 2023-24[78]

During the *Rabi* season of 2023-24, wheat was prominently cultivated in all the tehsils especially Iin Sawayajpur, Hardoi and Bilgram tehsils. Tehsils of Shahabad and Bilgram, among others also grew mustard alongside other *rabi* crops.

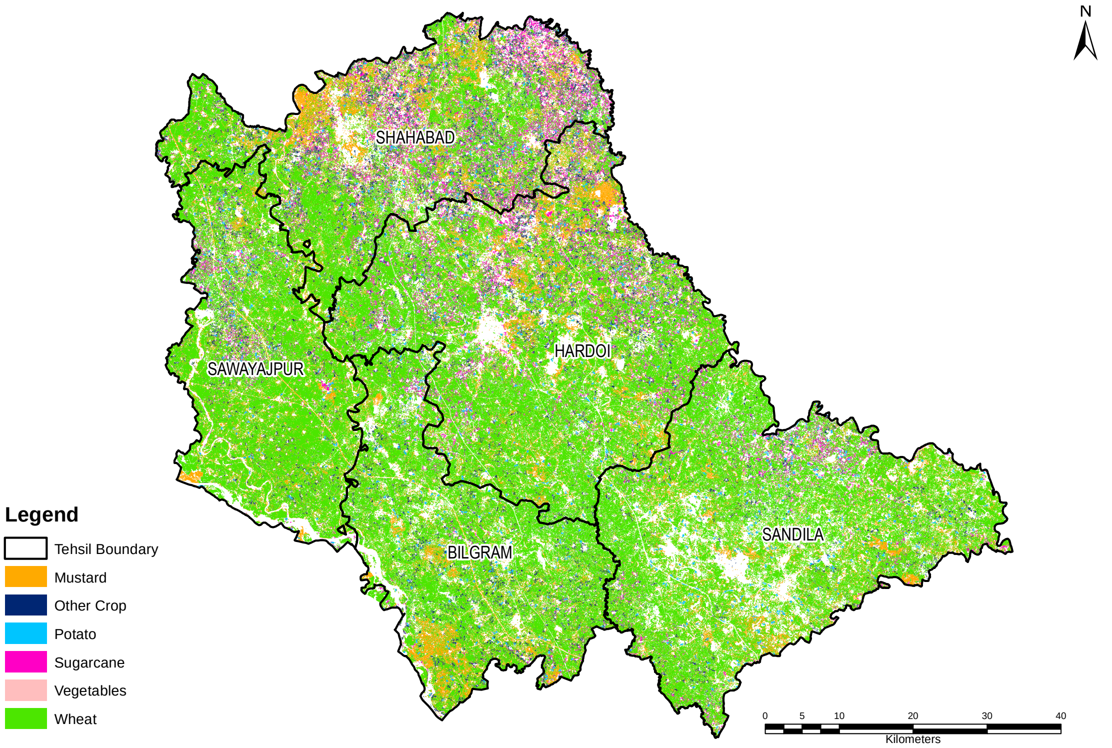


Figure 21: Geographical Spread of *Rabi* Crops in Tehsils of Hardoi District during 2023-24[79]

78 Analysis by Vasudha Foundation, 2025

79 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 pattern, cropping pattern, impact of development programmes as well as efficient utilisation of most valuable natural resource. Land Use was analysed for Hardoi during the year 2023-24 and the results are summarised below:

Table 25: Tehsil-wise Land-Use Analysis for Hardoi in ha.

Tehsil	Barren/Waste land	Built Area	Crop land	Scrub	Waterbodies	Grand Total
BILGRAM	1536.16	7266.35	84589.77	118.24	993.05	94503.57
HARDOI	563.41	14422.32	142377.03	555.21	852.96	158770.94
SANDILA	586.36	13329.11	128390.52	1371.16	554.44	144231.58
SAWAYAJPUR	2250.83	5546.99	78297.10	492.92	2215.81	88803.66
SHAHABAD	61.16	8057.30	102648.70	459.03	748.69	111974.88
Total (ha)	**4997.92**	**48622.08**	**536303.12**	**2996.57**	**5364.95**	**598284.63**

It can be observed from the Land Use analysis[80] that nearly 80 percent of the total geographical area of the district was under cultivation during 2023-24.

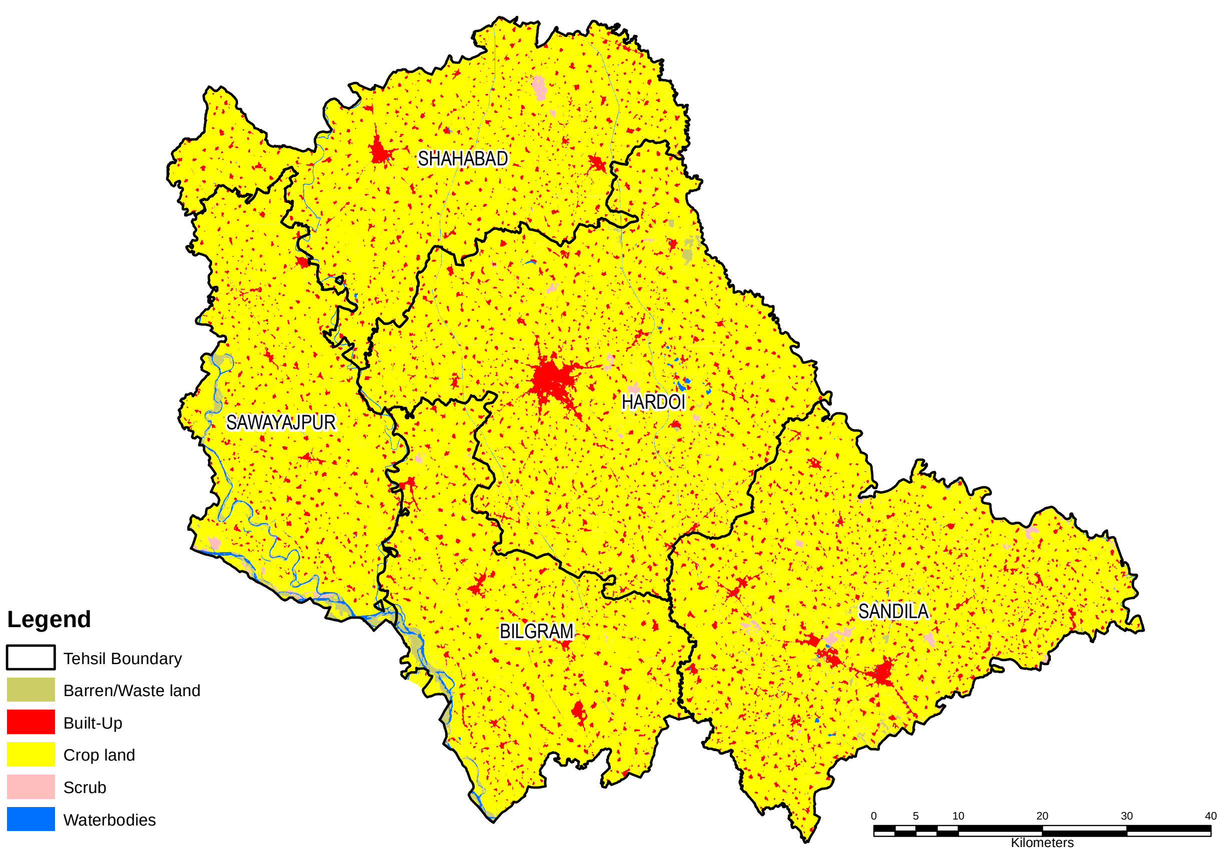


Figure 22: Land Cover Analysis for Tehsils of Hardoi District during 2023-24[81]

80 Analysis by Vasudha Foundation, 2025

81 Analysis by Vasudha Foundation, 2025

07

Methodology

This study estimates annual net biomass residue availability in all the 5 Tehsils of Hardoi 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 Hardoi 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)[82], 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

82 Support Vector Machine (SVM) is a supervised machine learning algorithm used for classification and regression tasks.

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.

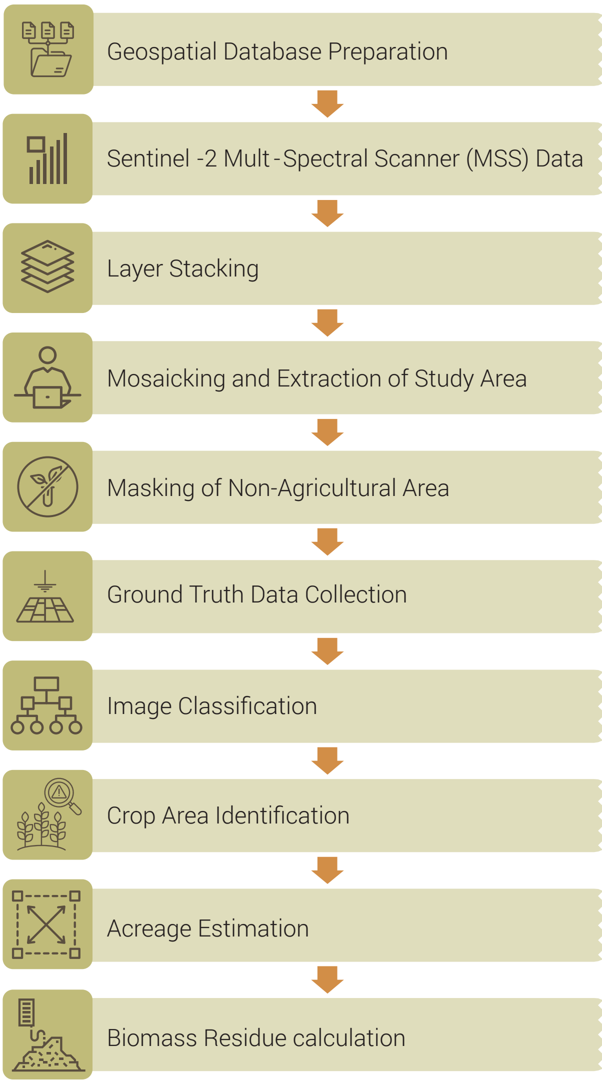


Figure 23: Flow diagram of the methodology used

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[83] 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.[84,85] 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.

83 S,K, Lohan. et.al., 2018, Burning issues of paddy residue management in north-west states of India, Renewable and Sustainable energy reviews, 81, pp.693-706.

84 G, Kaur. K, Yadwinder. et.al., 2017 Potential of Livestock Generated Biomass: Untapped Energy Source in India, Energies MDPI

85 J, Sheehan, et. al., 2003, Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol, Journal of Industrial Ecology 7:117-46

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

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 *Figure 18*).[86]

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

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.[87][88]

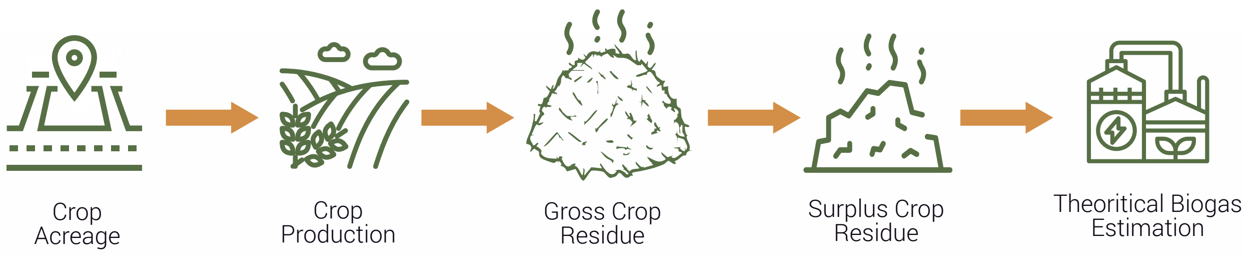


Figure 24 Flow diagram for crop residue estimation

86 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

87 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

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

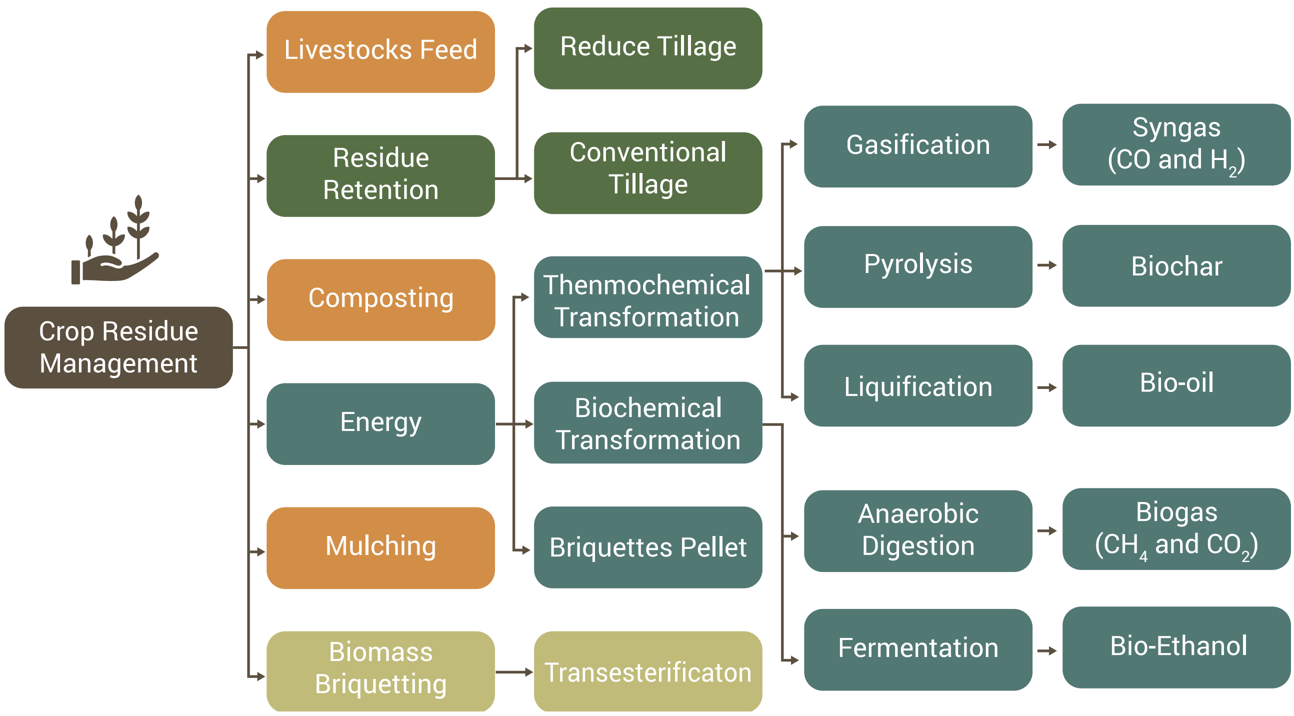


Figure 25: Crop residue management practices[89]

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

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.

89 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

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

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

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
Biswan	Wheat	47879.06	3.82	182898.01	Straw	274347.01	54869.40	54869.40	10.86	15.03
					Husk	54869.40	10973.88	10973.88	2.17	3.01
	Paddy	13596.02	2.75	37389.06	Straw	56083.58	9534.21	9534.21	2.12	9.28
					Husk	7477.81	1271.23	1271.23	0.28	
	Sugarcane	13823.99	80.42	1111725.28	Bagasse (Small)			0.00	0.00	0.00
					Press Mud (Large)			0.00	0.00	0.00
					Press Mud (Medium)			0.00	0.00	0.00
					Leaves	55586.26	55586.26	55586.26	10.66	10.66
	Jowar	2224.16	1.34	2980.37	Stalks	5066.64	5066.64	5066.64	1.39	1.39
					Husk/Leaves	596.07	596.07	596.07	0.16	0.16
					Cobs	1490.19	1490.19	1490.19	0.41	0.41

90 According to NIBE, 0.17% of the gross crop residue is surplus and available for CBG production, where according to UPNEDA, 0.40% of the gross crop residue is surplus

91 According to SATAT, 10T of Net Agricultural Biomass Residue can generate around 1T of CBG

92 Under this column, for paddy straw, we used the following factors:
(a) Crop-to-Residue Ratio: 2.0
(b) Surplus Biomass Fraction: 0.40

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
	Maize	11309.23	2.22	25106.49	Stalks	50212.98	502.13	502.13	0.14	0.14
					Cobs	7531.95	75.32	75.32	0.021	0.02
					Leaves	3012.78	30.13	30.13	0.008	0.01
	Mustard	6523.7	1.18	7697.97	Stalks	13856.34	13856.34	13856.34	3.796	3.80
	Rapeseed	4007.26	1.18	0.00	Stalks	0.00	0.00	0.00	0.00	2.33
	Pulses (Tur/Arhar)	2830.88	0.78	2208.09	Stalks	5520.22	5520.22	5520.22	1.512	2.14
	Potato	1068.76	31.21	33356.00	Stalks	3335.60	3335.60	3335.60	0.914	0.91
	Vegetables	116.37	15.55	1809.55	Stalks	180.96	180.96	180.96	0.050	0.05
	Agri-Plantation (Bajra)	3258.12	1.5	4887.18	Stalks	9774.36	9774.36	9774.36	2.678	2.90
					Husk	1466.15	1466.15	1466.15	0.402	0.43
					Cobs	1612.77	1612.77	1612.77	0.442	0.48
Hardoi	Wheat	70460.64	3.82	0.00	Straw	0.00	0.00	0.00	0.00	22.12
					Husk	0.00	0.00	0.00	0.00	4.42
	Paddy	34319.42	2.75	94378.41	Straw	141567.61	24066.49	24066.49	5.36	20.69
					Husk	18875.68	3208.87	3208.87	0.71	0

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
	Sugarcane	25910.01	80.42	2083683.00	Bagasse (Small)			0.00	0.00	0.00
					Press Mud (Large)			76055.00	8.28	8.33
					Press Mud (Medium)			0.00	0.00	0.00
					Leaves	104184.15	104184.15	104184.15	19.98	19.98
	Jowar	3152.45	1.34	4224.28	Stalks	7181.28	7181.28	7181.28	1.97	1.97
					Husk/Leaves	844.86	844.86	844.86	0.23	0.23
					Cobs	2112.14	2112.14	2112.14	0.58	0.58
	Maize	9641.51	2.22	21404.15	Stalks	42808.30	428.08	428.08	0.12	0.12
					Cobs	6421.25	64.21	64.21	0.0176	0.02
					Leaves	2568.50	25.68	25.68	0.00704	0.01
	Mustard	11368.22	1.18	13414.50	Stalks	24146.10	24146.10	24146.10	6.62	6.62
	Rapeseed	6025.57	1.18	7110.17	Stalks	12798.31	12798.31	12798.31	3.51	3.51
	Pulses	4426.98	0.78	3453.04	Stalks	8632.61	8632.61	8632.61	2.37	2.37
	Potato	1756.5	31.21	54820.37	Stalks	5482.04	5482.04	5482.04	1.50	1.50
	Vegetables	198.83	15.55	3091.81	Stalks	309.18	309.18	309.18	0.08	0.08

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
	Other Crops (Barley)	7696.06	2.77	21318.09	Straw	27713.51	27713.51	27713.51	7.59	7.59
	Agri-Plantation (Bajra)	7381.56	1.5	11072.34	Stalks	22144.68	22144.68	22144.68	6.07	6.07
					Husk	3321.70	3321.70	3321.70	0.91	0.91
					Cobs	3653.87	3653.87	3653.87	1.00	1.00
Sandila	Wheat	69030.92	3.82	263698.11	Straw	395547.17	79109.43	79109.43	15.66	21.67
					Husk	79109.43	15821.89	15821.89	3.13	4.33
	Paddy	31599.94	2.75	86899.84	Straw	130349.75	22159.46	22159.46	4.94	19.05
					Husk	17379.97	2954.59	2954.59	0.66	0
	Sugarcane	13567.84	80.42	1091125.69	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
					Leaves	54556.28	54556.28	54556.28	10.46	10.46

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
	Jowar	8891.29	1.34	11914.33	Stalks	20254.36	20254.36	20254.36	5.55	5.55
					Husk/Leaves	2382.87	2382.87	2382.87	0.65	0.65
					Cobs	5957.16	5957.16	5957.16	1.63	1.63
	Maize	8891.29	2.22	19738.66	Stalks	39477.33	394.77	394.77	0.11	0.11
					Cobs	2566.03	25.66	25.66	0.01	0.01
					Leaves	2368.64	23.69	23.69	0.01	0.01
	Mustard	5695.6	1.18	6720.81	Stalks	806.50	806.50	806.50	0.22	0.22
	Rapeseed	3889.53	1.18	4589.65	Stalks	550.76	550.76	550.76	0.15	0.15
	Pulses	3139.42	0.78	2448.75	Stalks	6121.87	6121.87	6121.87	1.68	1.68
	Potato	1837.84	31.21	57358.99	Stalks	5735.90	5735.90	5735.90	1.57	1.57
	Vegetables	328.01	15.55	5100.56	Stalks	510.06	510.06	510.06	0.14	0.14
	Other Crops (Barley)	3681.34	2.77	10197.31	Straw	13256.51	13256.51	13256.51	3.63	3.63
	Agri-Plantation (Bajra)	12332.03	1.5	18498.05	Stalks	36996.09	36996.09	36996.09	10.14	10.14
					Husk	5549.41	5549.41	5549.41	1.52	1.52
					Cobs	6104.35	6104.35	6104.35	1.67	1.67

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
Sawaya-jpur	Wheat	49302.06	3.82	188333.87	Straw	282500.80	56500.16	56500.16	11.19	15.48
					Husk	56500.16	11300.03	11300.03	2.24	3.10
	Paddy	17663.17	2.75	48573.72	Straw	72860.58	12386.30	12386.30	2.76	10.65
					Husk	9714.74	1651.51	1651.51	0.37	0
	Sugarcane	11558.47	80.42	929532.16	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00
					Tops and Leaves	189010.88	189010.88	189010.88	51.78	51.78
					Leaves	46476.61	46476.61	46476.61	8.91	8.91
	Jowar	1292.34	1.34	1731.74	Stalks	2943.95	2943.95	2943.95	0.81	0.57
					Husk/Leaves	346.35	346.35	346.35	0.09	0.09
					Cobs	865.87	865.87	865.87	0.24	0.24

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
	Maize	7233.68	2.22	16058.77	Stalks	32117.54	321.18	321.18	0.09	0.09
					Cobs	4817.63	48.18	48.18	0.01	0.01
					Leaves	1927.05	19.27	19.27	0.01	0.01
	Mustard	4357.53	1.18	5141.89	Stalks	9255.39	9255.39	9255.39	2.54	2.54
	Rapeseed	4657.15	1.18	5495.44	Stalks	9891.79	9891.79	9891.79	2.71	2.71
	Pulses	4807.83	0.78	3750.11	Stalks	9375.27	9375.27	9375.27	2.57	2.57
	Potato	846.6	31.21	26422.39	Stalks	2642.24	2642.24	2642.24	0.72	0.72
	Barley	529.63	3.05	1615.37	Straw	2099.98	2099.98	2099.98	0.58	0.58
	Other Crops (Barley)	3996.07	2.77	11069.11	Straw	14389.85	14389.85	14389.85	3.94	3.94
	Agri-Plantation (Bajra)	1032.61	1.5	1548.92	Stalks	3097.83	3097.83	3097.83	0.85	0.85
					Husk	464.67	464.67	464.67	0.13	0.13
					Cobs	511.14	511.14	511.14	0.14	0.14
Shahabad	Wheat	37014.69	3.82	141396.12	Straw	212094.17	42418.83	42418.83	8.31	11.62
					Husk	42418.83	8483.77	8483.77	1.66	2.32
	Paddy	24252.29	2.75	66693.80	Straw	100040.70	17006.92	17006.92	3.79	14.62
					Husk	13338.76	2267.59	2267.59	0.51	0

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
	Sugarcane	31779.42	80.42	2555700.96	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
					Press Mud (Large)		37632.00		4.10	4.12
					Tops and Leaves	154483.97	154483.97	154483.97	42.32	42.32
					Leaves	127785.05	127785.05	127785.05	24.51	24.51
	Jowar	1466.33	1.34	1964.88	Stalks	3340.30	3340.30	3340.30	0.92	0.92
					Husk/Leaves	392.98	392.98	392.98	0.11	0.11
					Cobs	982.44	982.44	982.44	0.27	0.27
	Maize	6765.72	2.22	15019.90	Stalks	30039.80	300.40	300.40	0.08	0.08
					Cobs	4505.97	45.06	45.06	0.01	0.01
					Leaves	4505.97	45.06	45.06	0.01	0.01
	Mustard	10760.16	1.18	12696.99	Stalks	22854.58	22854.58	22854.58	6.26	6.26
	Rapeseed	5063.23	1.18	5974.61	Stalks	10754.30	10754.30	10754.30	2.95	2.95
	Pulses	2950.84	0.78	2301.66	Stalks	5754.14	5754.14	5754.14	1.58	1.58

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[90]	CBG (SATAT) (TPD)[91,92]
		Area	Yield	Total						
	Potato	1292.4	31.21	40335.80	Stalks	4033.58	4033.58	4033.58	1.11	1.11
	Vegetables	73.6	15.55	1144.48	Stalks	114.45	114.45	114.45	0.03	0.03
	Other Crops (Barley)	7907.73	2.77	21904.41	Straw	28475.74	28475.74	28475.74	7.80	7.80
	Agri-Plantation (Bajra)	3661.27	1.5	5491.91	Stalks	10983.81	10983.81	10983.81	3.01	3.01
					Husk	1647.57	1647.57	1647.57	0.45	0.45
					Cobs	1812.33	1812.33	1812.33	0.50	0.50

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 standardised method for collecting dung is essential. Only through such standardised 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.

Table 27: Tehsil-wise surplus biomass residue and potential CBG generation from various animal residues

Tehsil	Animal	Population	Collectable Dung/ Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy (MW)	CBG in TPD (NIBE)	CBG in TPD (SATAT)
Bilgram	Cattle	6447	35297325	8824331.25	6177031.875	6177.03	100794335.32	0.05	0.25	0.34
	Goat/ Sheep	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Swine	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Poultry (Chicken)	0	0	0	0	0.00	0.00	0.00	0.00	0.00
Hardoi	Cattle	25446	139316850	34829212.5	24380448.75	24380.45	397830410.52	0.21	1.00	1.34
	Goat/ Sheep	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Swine	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Poultry (Chicken)	2,10,000	3449250	1000282.5	600169.5	600.17	9602712.00	0.01	0.04	0.07
Sandila	Cattle	9981	54645975	13661493.75	9563045.625	9563.05	156045953.29	0.08	0.39	0.52
	Goat/ Sheep	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Swine	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Poultry (Chicken)	0	0	0	0	0.00	0.00	0.00	0.00	0.00

Tehsil	Animal	Population	Collectable Dung/ Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy (MW)	CBG in TPD (NIBE)	CBG in TPD (SATAT)
Saway-ajpur	Cattle	10779	59015025	14753756.25	10327629.38	10327.63	168522125.09	0.09	0.42	0.57
	Goat/ Sheep	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Swine	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Poultry (Chicken)	0	0	0	0	0.00	0.00	0.00	0.00	0.00
Sha-habad	Cattle	11915	65234625	16308656.25	11416059.38	11416.06	186282690.46	0.10	0.47	0.63
	Goat/ Sheep	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Swine	0	0	0	0	0.00	0.00	0.00	0.00	0.00
	Poultry (Chicken)	0	0	0	0	0.00	0.00	0.00	0.00	0.00

8.3 Energy Crops

Poplar Trees, Willow, Jatropha

These crops were not identified in our GIS Crop Maps. As per the State Agriculture Department, there are no such crops grown and cultivated for energy purposes in Hardoi district.

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.[93]

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 8367 ha. of land accounting for a total annual production of 9756 T of the crop. Using SATAT's CBG conversion factor, the following results are observed

Table 28: Surplus biomass residue and CBG potential from groundnut shell

Crop	Area (ha.)	Yield (T/ha.)	Production (T)	Crop-to-Residue Groundnut Shell	Residue (T)	CBG Potential (TPD) (SATAT)
Groundnut	8367	1.17	9756	0.3	2926.8	0.801

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 Hardoi and Biswan (See *Figure 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 percent. Further, 40 percent 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.

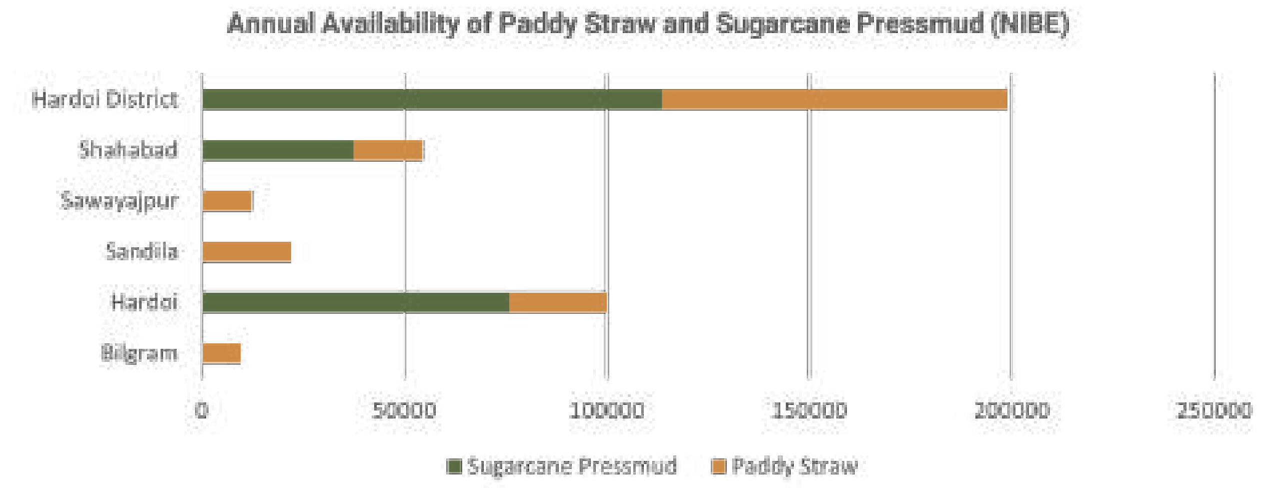
93 Pandey K.C. and Roy A.K., 2011. p.23, Forage Crops Varieties, Indian Grassland and Fodder Research Institute (IGFRI)

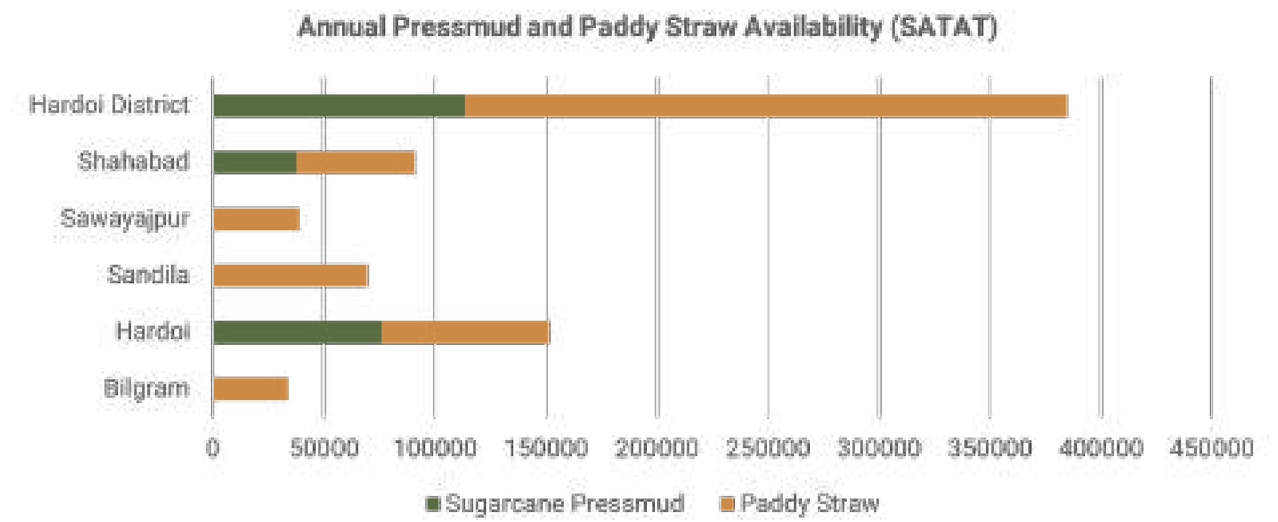
09

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 Hardoi District.





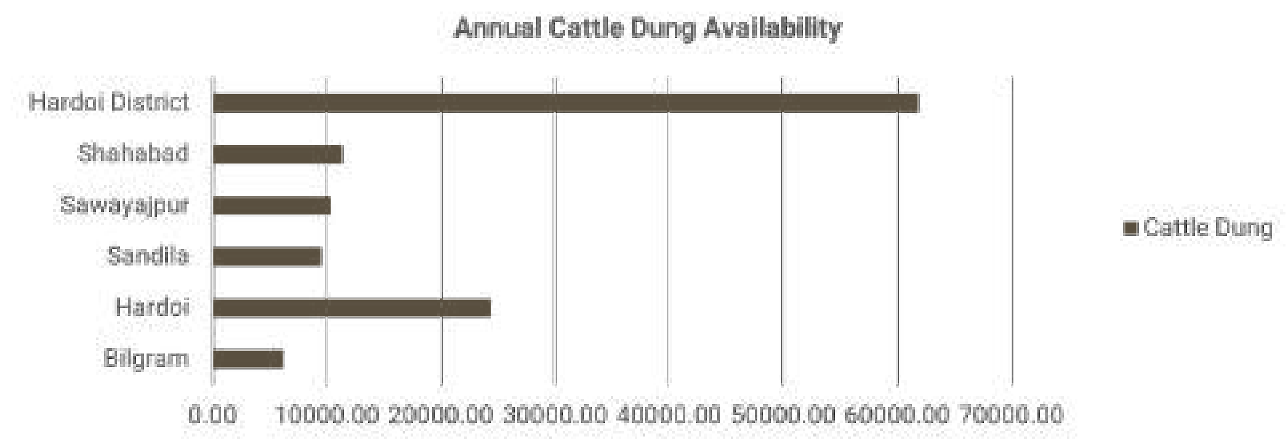


Figure 26: **Tehsil-wise Annual Availability of Paddy Straw, Press Mud and Cattle Dung**

9.2 Variations in Biomass Availability and Pricing

The availability and generation of sugarcane press mud has been varying over the years. From the figures *Figure 34* & *Figure 35*, the variation in availability of pressmud in all the sugar mills can be attributed to the varying quantities of sugarcane crushed annually in these mills. *Figure 36* depicts the year-on-year change in pressmud 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 average cost of press mud for all sugar mills hovered between INR 20 to 60 per quintal during 2022-25.

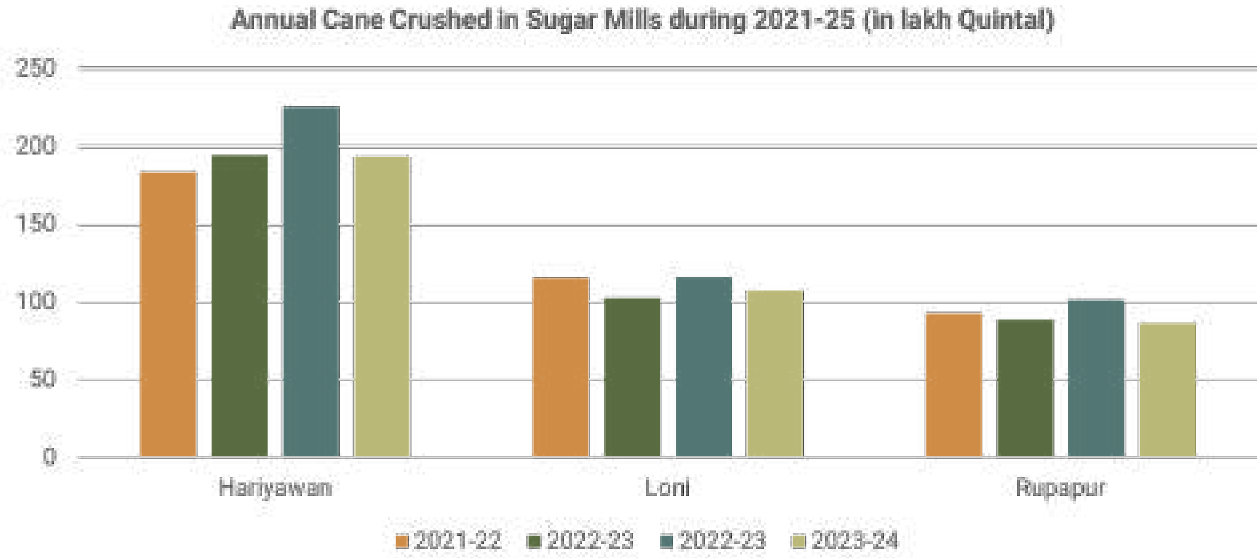


Figure 27: Annual Cane Crushed in Sugar Mills during 2021-25[94]

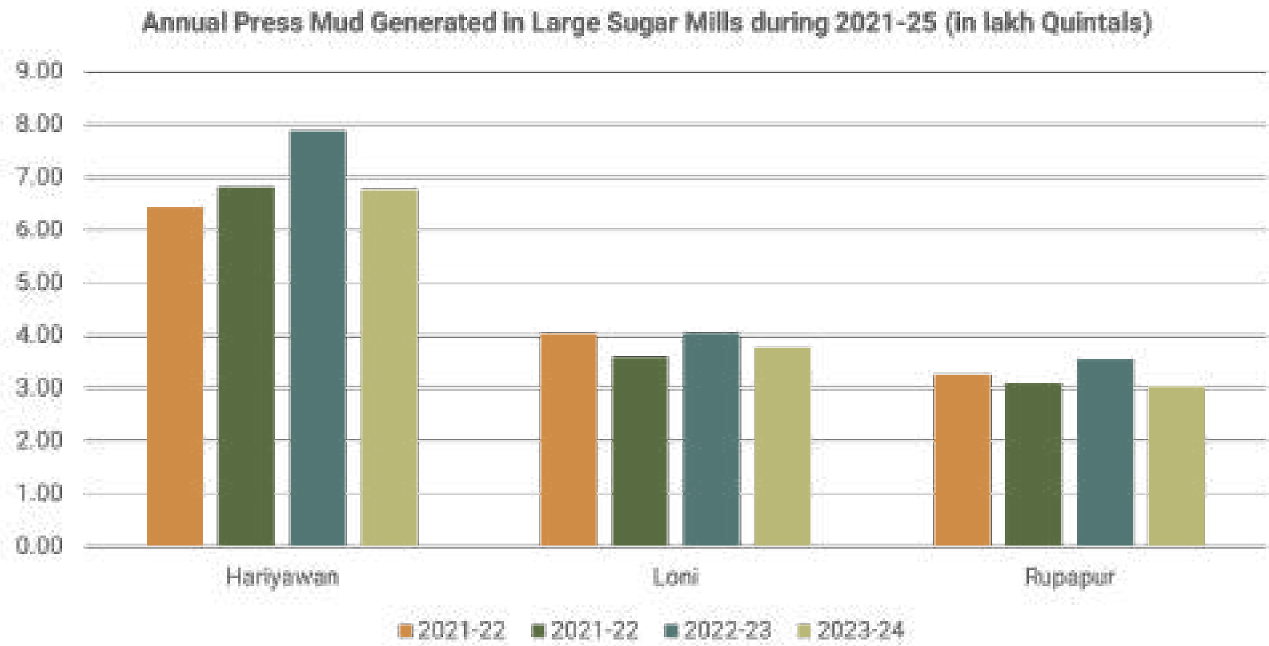


Figure 28: Annual Press Mud generated in Sugar Mills

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

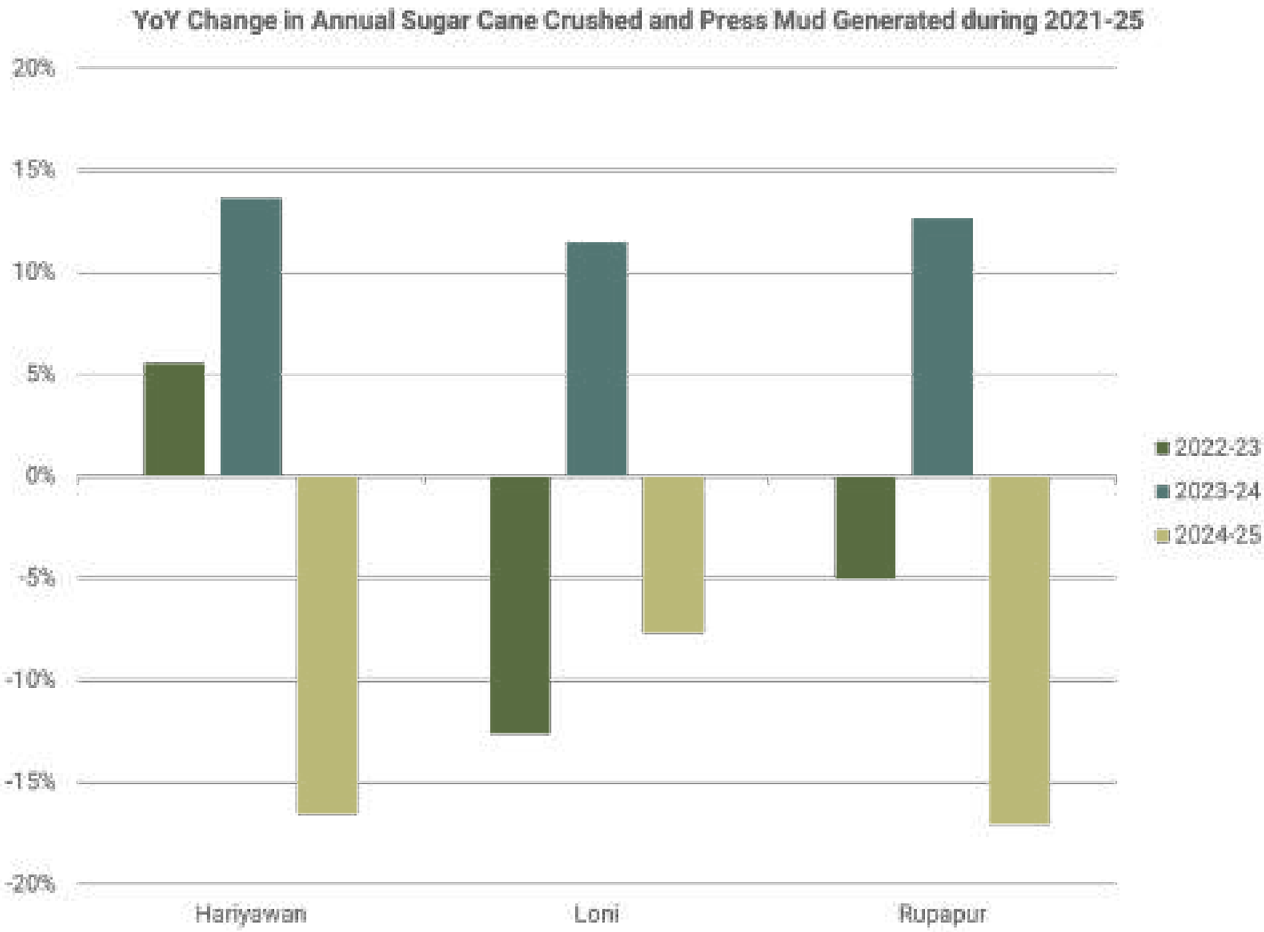


Figure 29: YoY Change in Annual Cane Crushed and Press Mud Generated during 2021-25

It can be observed from *Figure 37* 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. For instance, the prices of sugarcane press mud increased to 50 percent during 2023-24 between peak and off-peak periods in Hariyawan sugar mill in Hardoi tehsil and the reasons for the spike 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

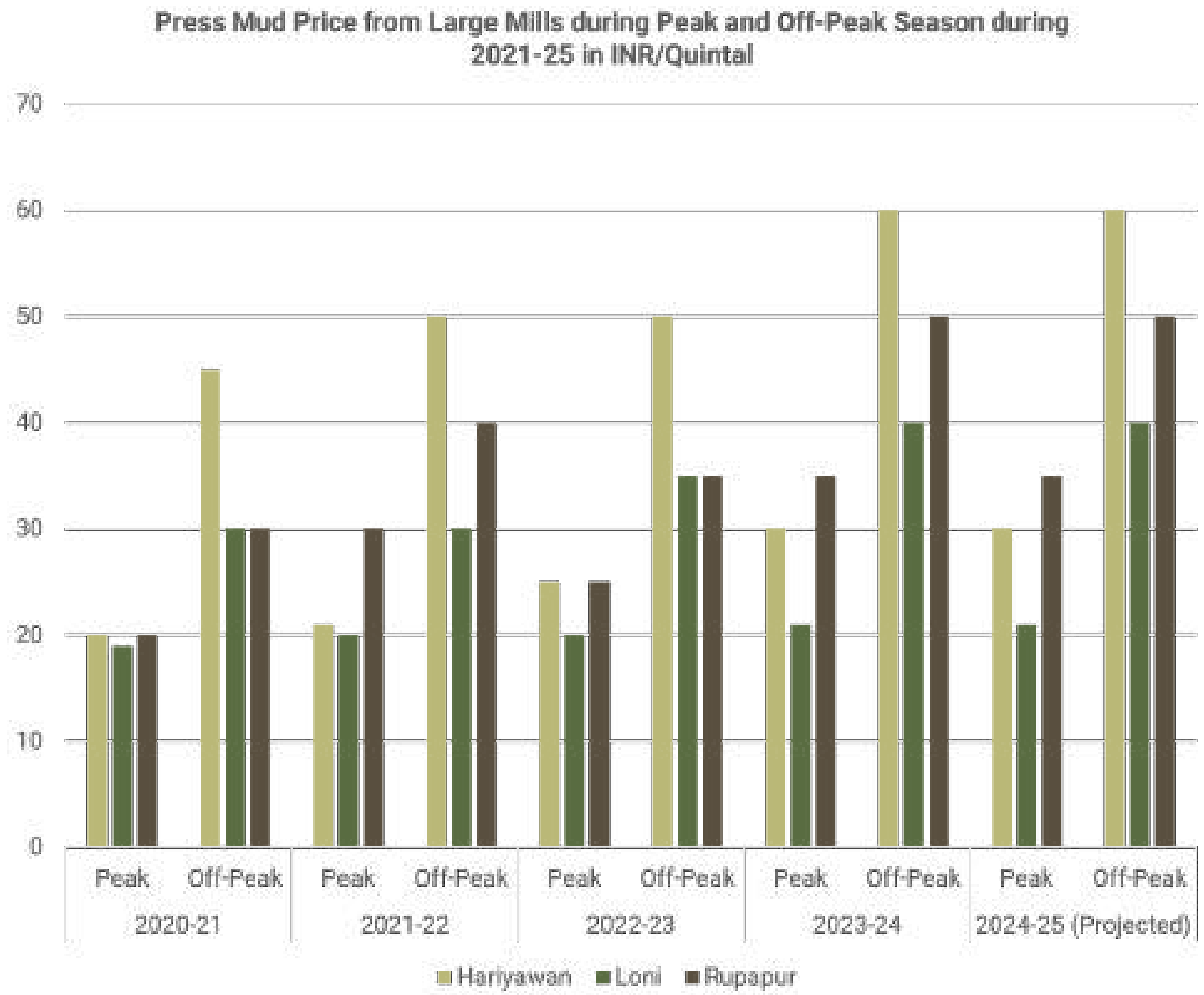


Figure 30: **Press Mud Price variations during Peak and Off-Peak Season**

9.3 High-Potential Zones for Biomass Supply and CBG Production

It can be observed that Shahabad and Hardoi had the highest annual press mud availability and sugarcane leaves. Tehsils of Bilgram and Sandila also have significant sugarcane leaves available. There are no sugar mills in Bilgram and Sandila tehsil. A CBG plant which is under construction would consume almost 100 percent of the press mud that will be generated from the sugar mill in Sawayajpur. Among all tehsils, Hardoi had the highest paddy straw availability followed by Sandila and Shahabad. All tehsils of Hardoi have low to moderate cattle dung availability which can be used as a combination feedstock with agricultural residue for CBG production. We can also see the variation in the availability of paddy straw in particular based on the different residue to crop ratios that were used.

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:

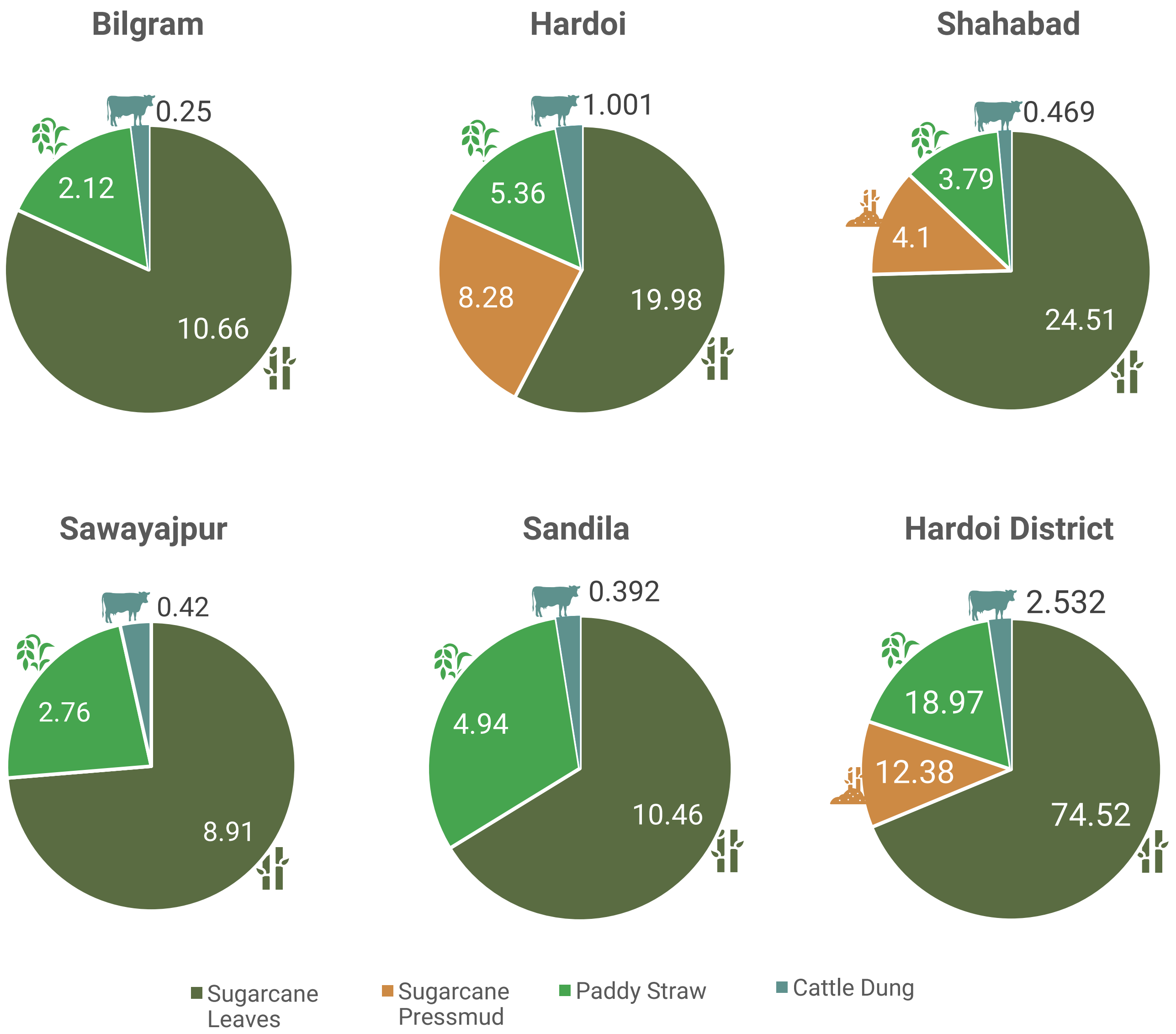


Figure 31: Tehsil-wise Daily CBG Generation Potential for Major Feedstocks: Paddy Straw, Cattle Dung, and Sugarcane Press mud (as per NIBE estimates)

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

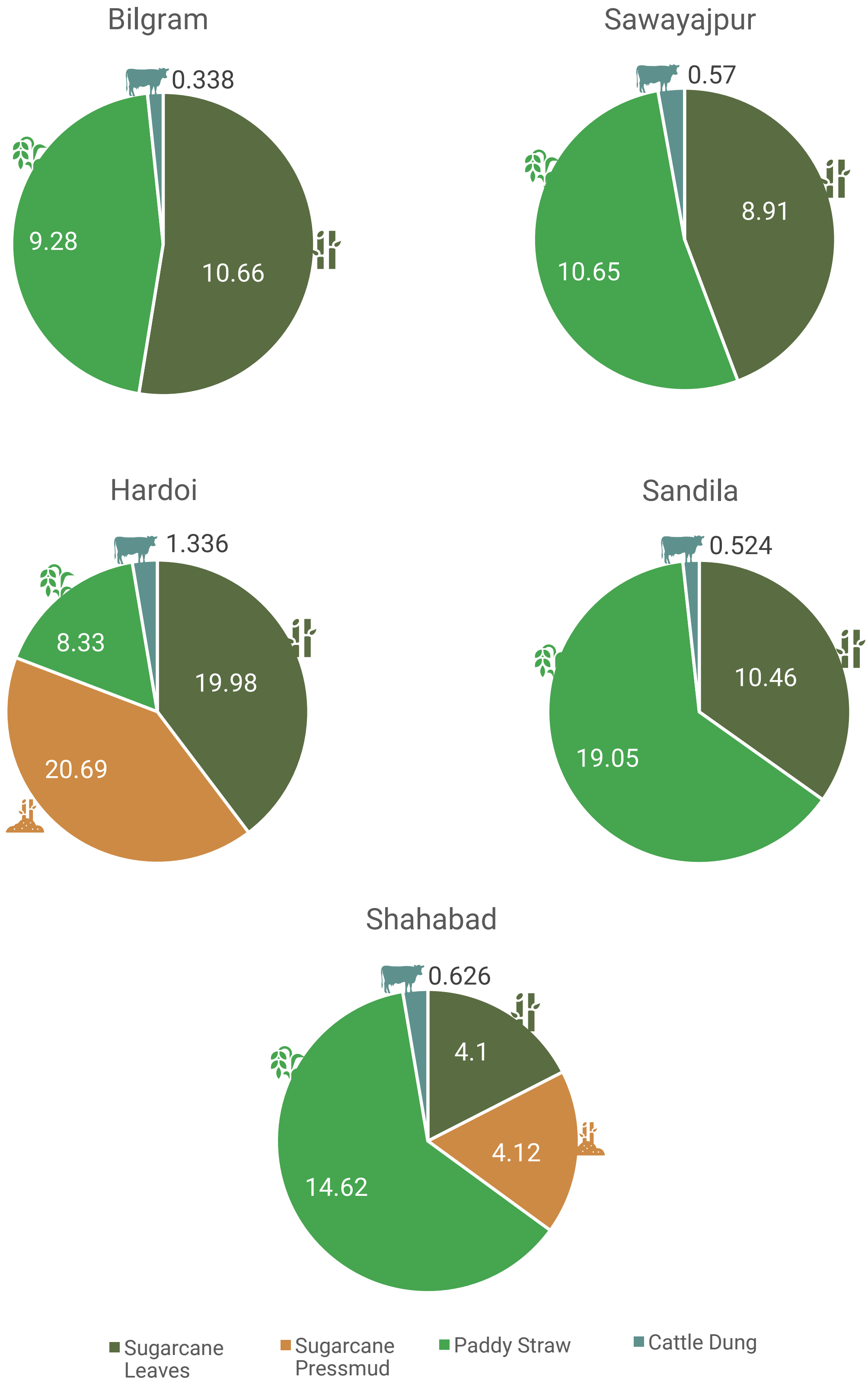


Figure 32: Tehsil-wise Daily CBG generation potential for major feedstocks: Paddy Straw, Cattle Dung, and Sugarcane Press mud (as per SATAT estimates)

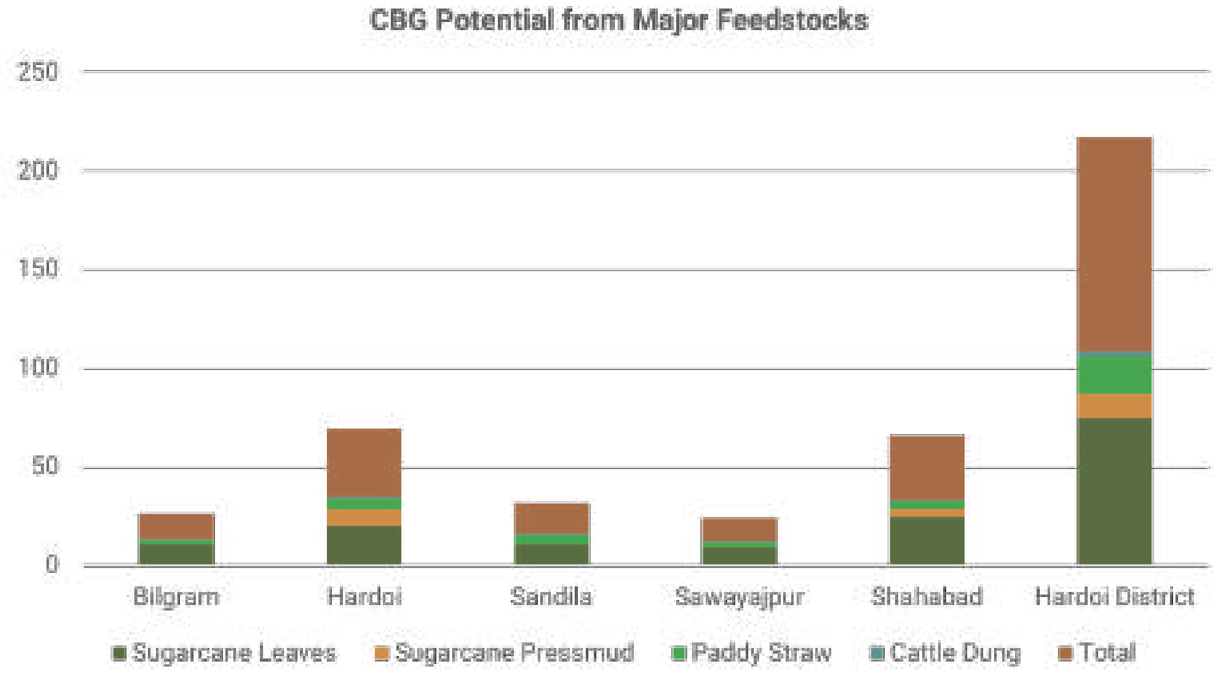


Figure 33: **CBG potential from major feedstocks (NIBE estimates)**

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.

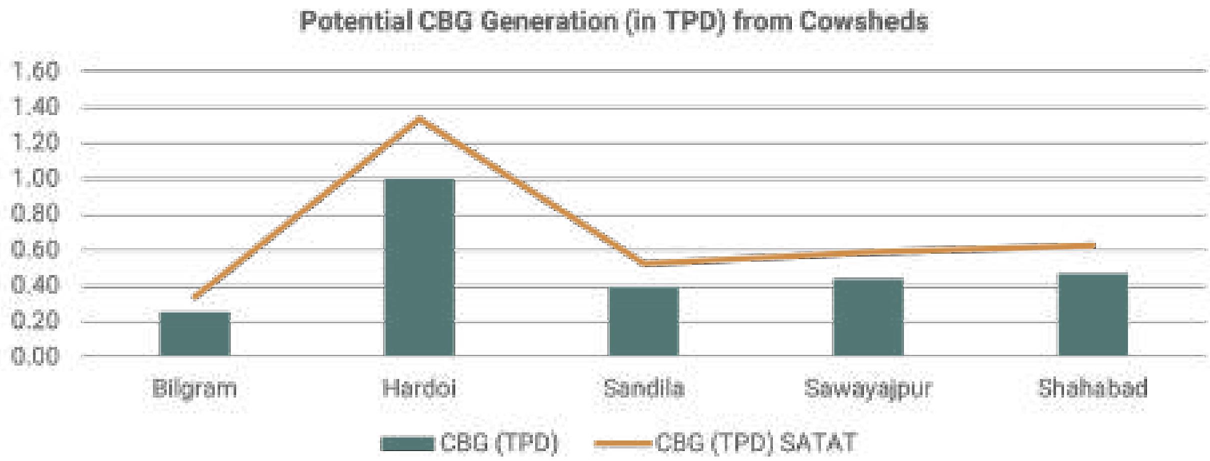


Figure 34: **Tehsil-wise CBG potential from Cattle Sheds**

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 *Figure 35*), 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.

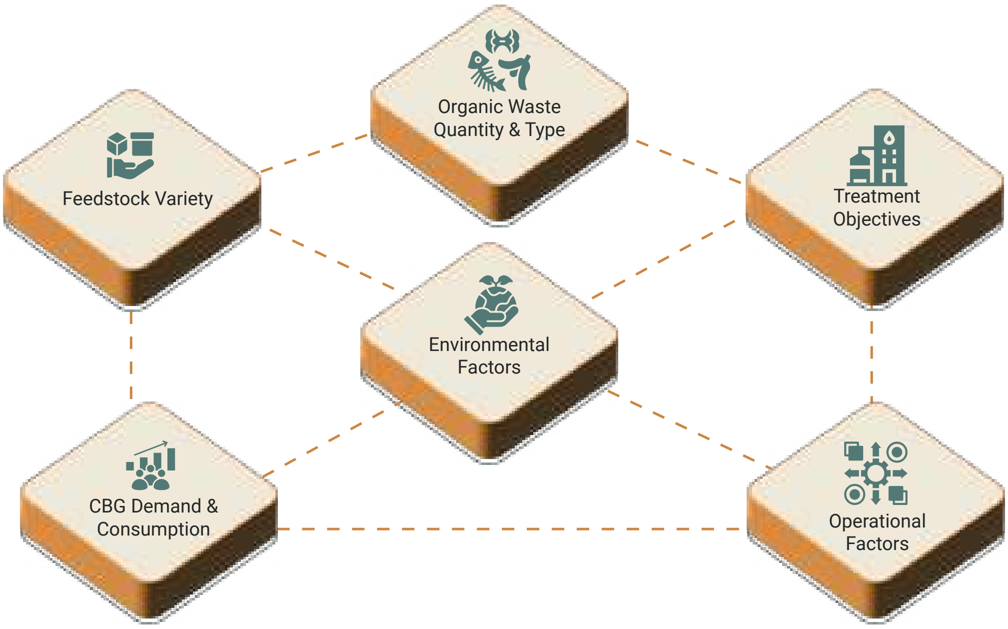


Figure 35: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

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

Table 29: Potential Daily Generation of CBG as per NIBE and SATAT Estimates

NIBE – CBG potential (in TPD) feedstock-wise in each tehsil					
Tehsil	**Sugarcane Leaves**	**Sugarcane Pressmud**	**Paddy Straw**	**Cattle Dung**	**Total**
Bilgram	10.66	0	2.12	0.25	13.03
Hardoi	19.98	8.28	5.36	1.001	34.621
Sandila	10.46	0	4.94	0.392	15.792
Sawayajpur	8.91	0	2.76	0.42	12.09
Shahabad	24.51	4.1	3.79	0.469	32.869
Hardoi District	74.52	12.38	18.97	2.532	108.402
SATAT – CBG potential (in TPD) feedstock-wise in each tehsil					
Tehsil	**Sugarcane Leaves**	**Sugarcane Pressmud**	**Paddy Straw**	**Cattle Dung**	**Total**
Tehsil	Sugarcane Leaves	Sugarcane Pressmud	Paddy Straw	Cattle Dung	Total
Bilgram	10.66	0	9.28	0.338	20.278
Hardoi	19.98	20.69	8.33	1.336	50.336

Sandila	10.46	0	19.05	0.524	30.034
Sawayajpur	8.91	0	10.65	0.57	20.13
Shahabad	4.1	4.12	14.62	0.626	23.466
Hardoi District	54.11	24.81	61.93	3.394	144.244

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, Hardoi district has a CBG potential of approximately 140 TPD based on the biomass available during the year 2023-24. Out of all the Tehsils, Hardoi has the highest potential for CBG production with sugarcane press mud and sugarcane leaves contributing more than 70 percent of the total feedstock. Shahabad leads after Hardoi on the potential CBG capacity with both sugarcane leaves, pressmud and paddy straw both contributing as the major feedstocks. 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. Hardoi has a high theoretical potential for CBG with sugarcane leaves, press mud and paddy straw as its major feedstock. 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.[95]
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.

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

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.
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.[96] 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 36: Cane moved from the field to sugar mills for crushing

96 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. Feedstocks like paddy straw involves careful handling to preserve its energy value and prevent degradation due to microbial activity, moisture, or fire hazards.

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