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ASSESSING

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

UTTAR PRADESH

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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 Pilibhit 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 Pilibhit

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

- **Major Biomass Feedstocks**: Sugarcane press mud, Sugarcane leaves, paddy straw, and cattle dung emerge as the major biomass feedstock.
- **High-Potential Zones**: Pilibhit and Bisalpur emerge as the top biomass source. Potential locations for CBG plants could be sited close to the sugar mills or sugarcane farms present in tehsils of Pilibhit and Bisalpur, or in tehsils including Pilibhit where the paddy cultivation is high, or both.
- **CBG Generation Potential**: The district has the potential to generate approximately 125 tonnes per day (TPD) of CBG from major feedstocks, such as sugarcane leaves, 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 Press mud	Paddy Straw	Cattle Dung	Sugarcane Leaves	Total
Amariya	0	3.28	0.66	8.95	12.89
Bisalpur	4.19	0	1.874	23.79	29.854
Kalinagar	0	2.69	0.008	6.48	9.178
Pilibhit	2.05	31.04	0.41	16.97	50.47
Puranpur	2.29	1.07	0.475	19.56	23.395
Pilibhit District	**8.53**	**38.08**	**3.427**	**75.75**	**125.787**

- **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 125 TPD CBG plants can abate approximately 125468 T CO_2 emissions annually[1].
    - In other words, 125 TPD of CBG can replace 165 TPD of CNG which will correspond to daily carbon emission savings of 343.75 T of CO_2.
- **Supply Chain Considerations**: Efficient logistics and storage solutions are essential for sustainable biomass utilisation.

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

Recommendations

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

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

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

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

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

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

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

02 Introduction

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

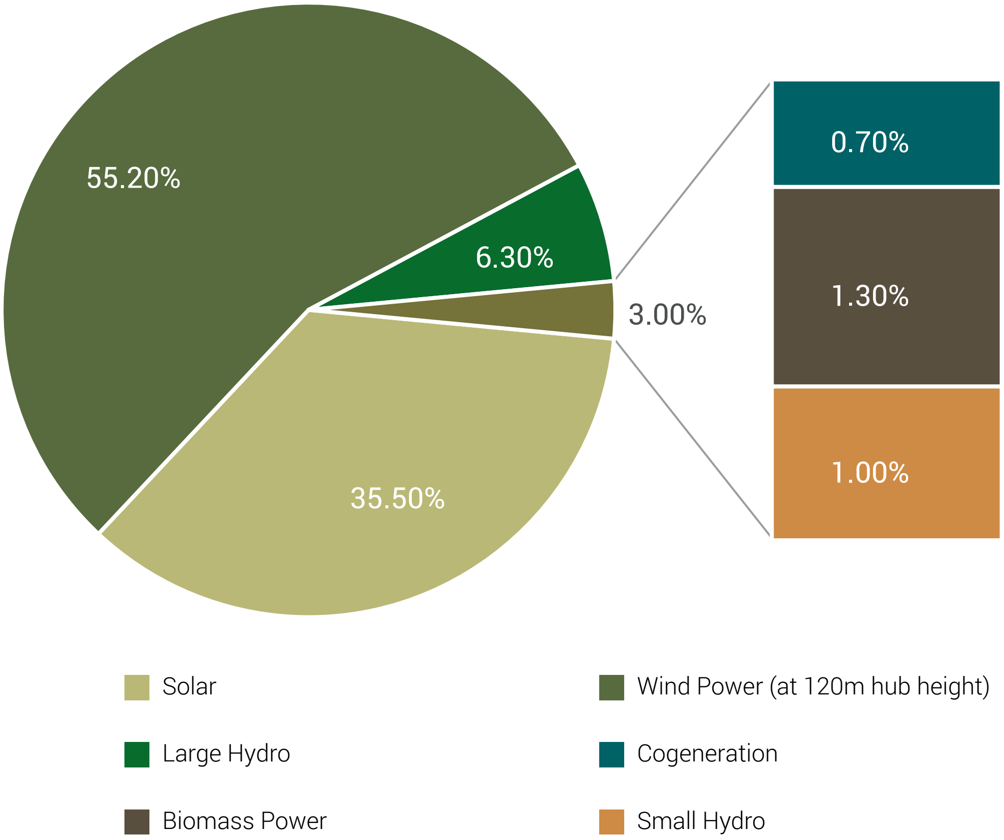


Figure 1: Source-wise renewable power potential in India, 2023[5,6]

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)

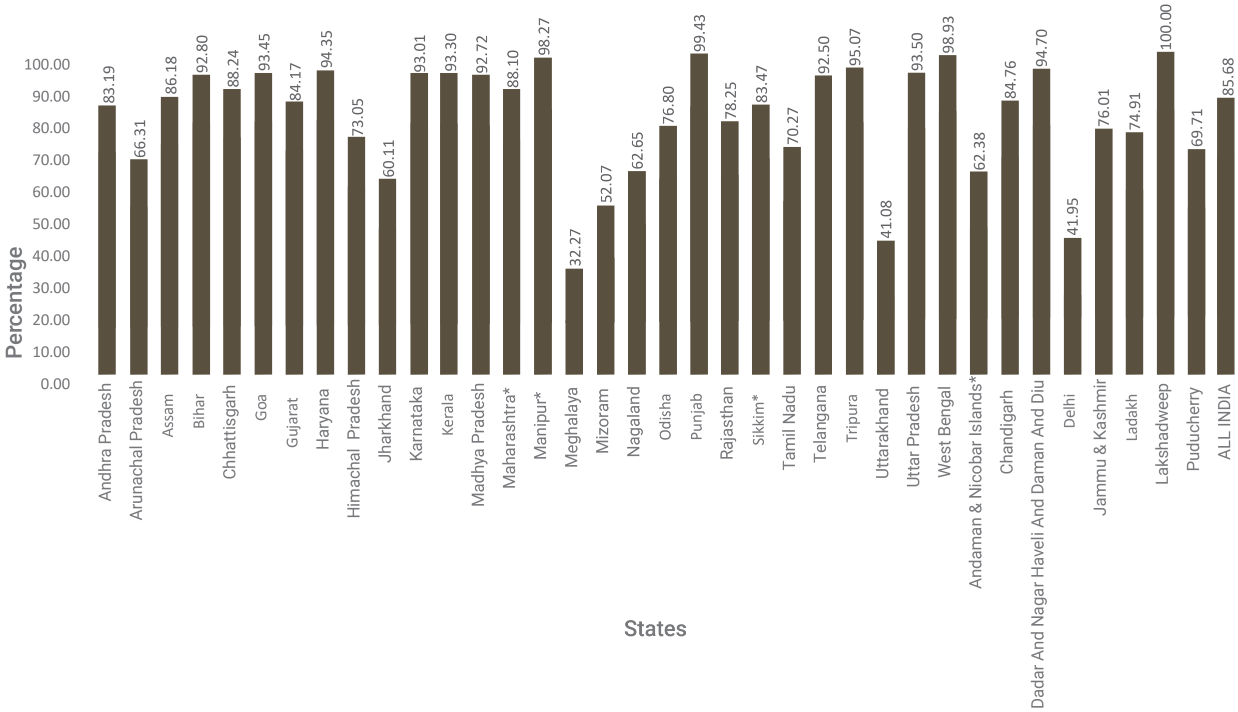


Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23[15]

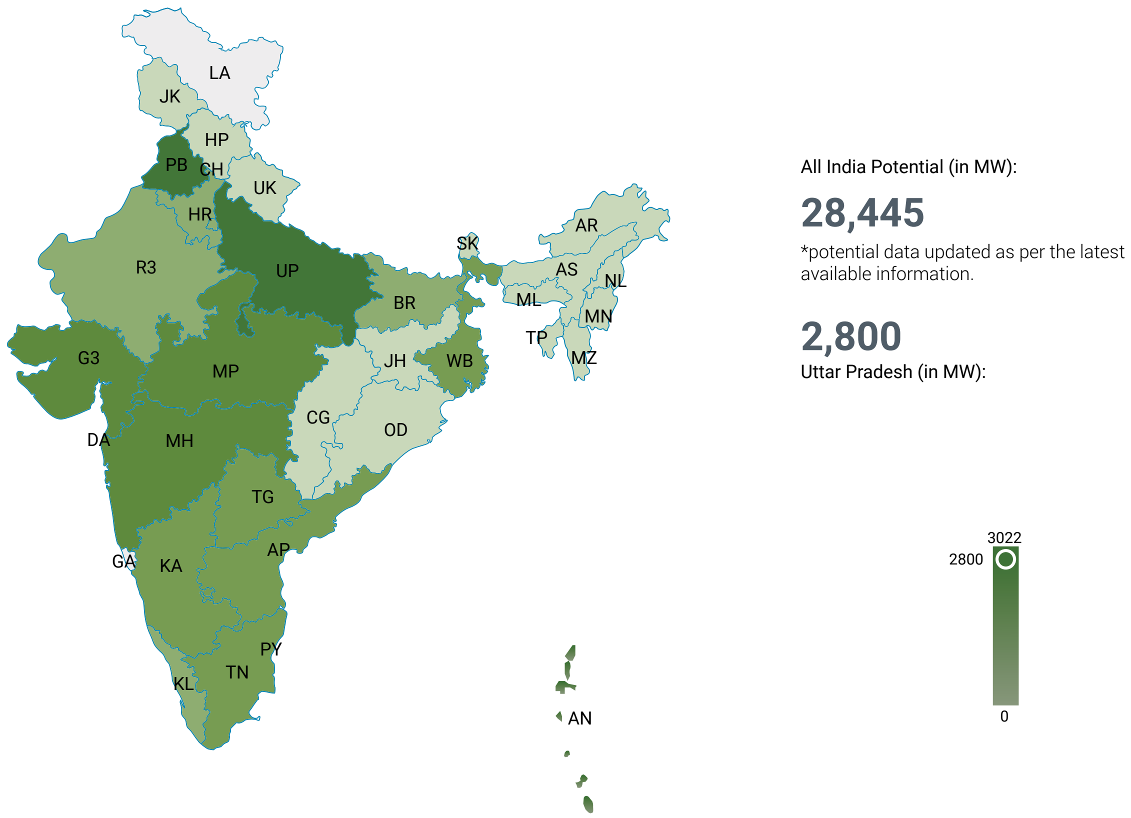


Figure 3: Biomass power potential in India[16]

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 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.

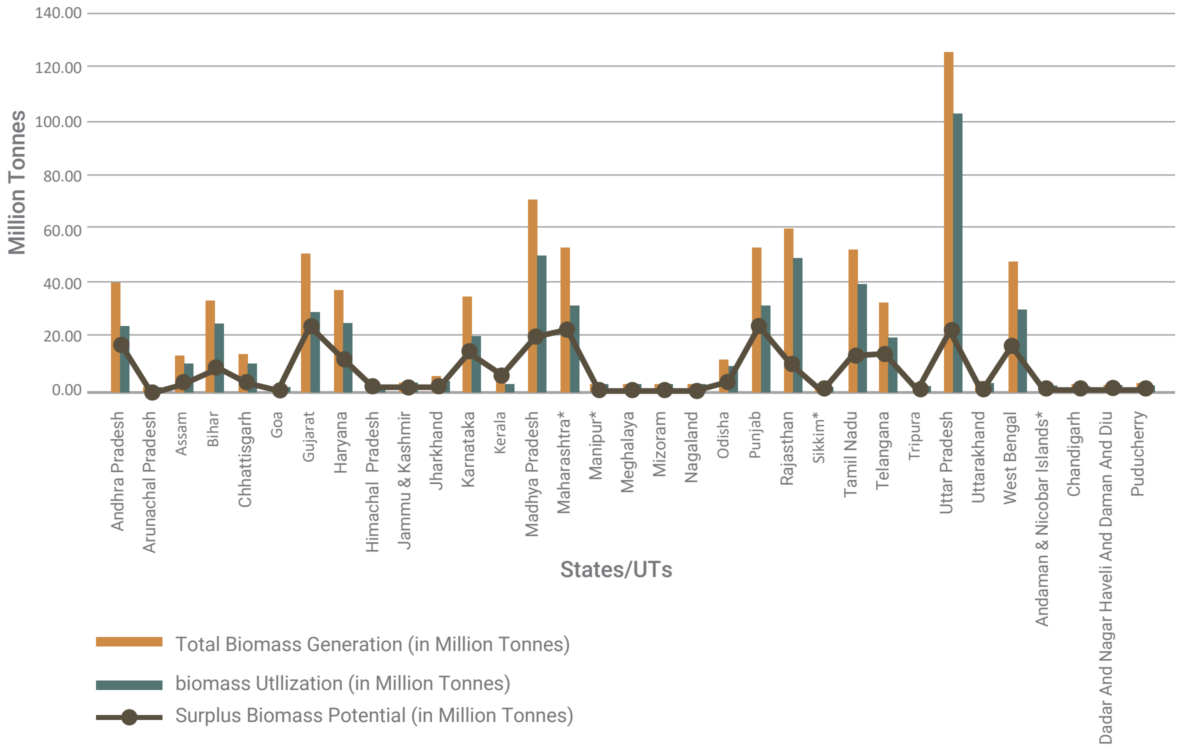


Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential[19]

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]

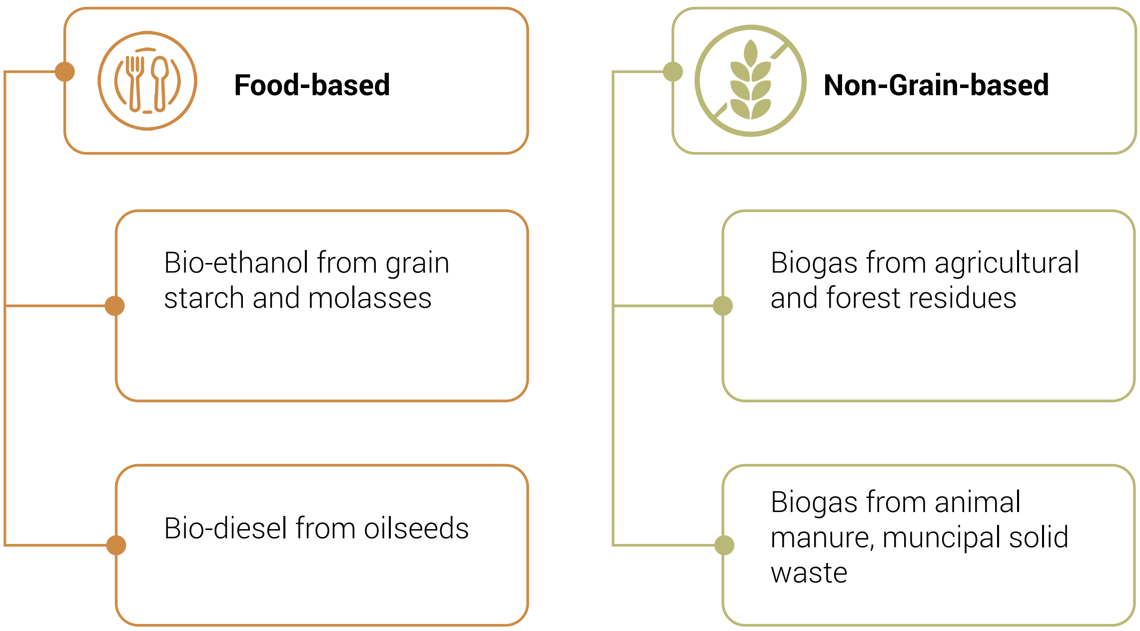


Figure 5: Classification of biofuels

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 Pilibhit 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

The study excludes the following feedstocks which include forestry residues, municipal solid waste effluents and other wastes from industries such as paper and pulp, food processing, etc. It provides an *'as-is'* condition and excludes, the potential of biomass residues that can be generated by utilising barren and uncultured land or fallow lands, etc. It takes into consideration of the current biomass residue management 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, 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 biochemical 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%) and carbon dioxide (30-35%), with small amounts of impurities such as Hydrogen Sulphide (H_2S), ammonia and moisture. This biogas can be used directly as cooking fuel or undergo additional processing. An important secondary benefit of biogas production is the digestate byproduct, which contains high concentrations of carbon and nitrogen compounds. Once dewatered, this digestate can be marketed as premium fertiliser.[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), H_2S, and moisture content, resulting in a fuel of higher calorific value. If the methane content of the upgraded product is above 90 percent, it can be used directly as a transportation fuel to replace Compressed Natural Gas (CNG) or injected into gas grids as CBG, which should meet IS 16087:2016 specifications of Bureau of Indian Standards (BIS). Table: 4 & 5 summarise the characteristics of raw biogas and Bio-CNG/CBG.

24 Jain, R., & Jawed, K. (2023, February 12). Biogas digestate: This high-value byproduct deserves more attention. Down To Earth. 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 7* illustrates significant advantages that can be achieved through appropriate feedstock pretreatment. A single feedstock or a combination of feedstocks is fed into shredders (mechanical pretreatment) that make the substrate smaller or break open their cellular structure, increasing the specific surface area of the biomass (*See Figure 8*).[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

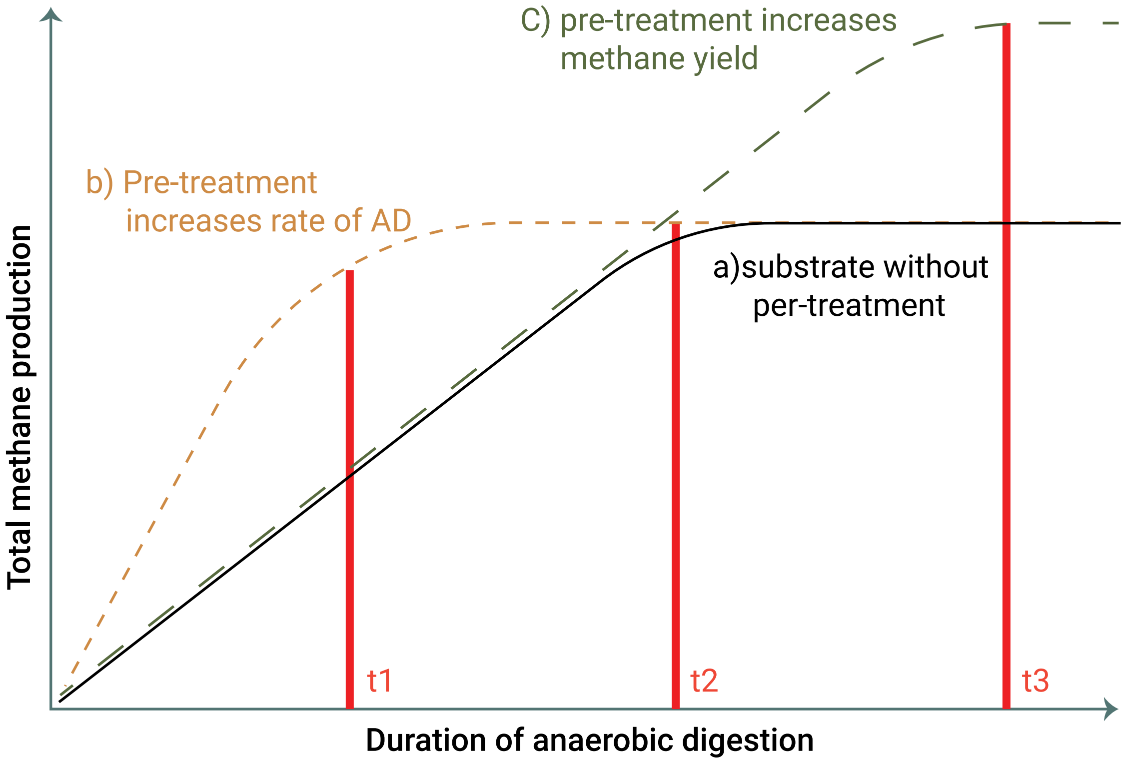


Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[28]

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

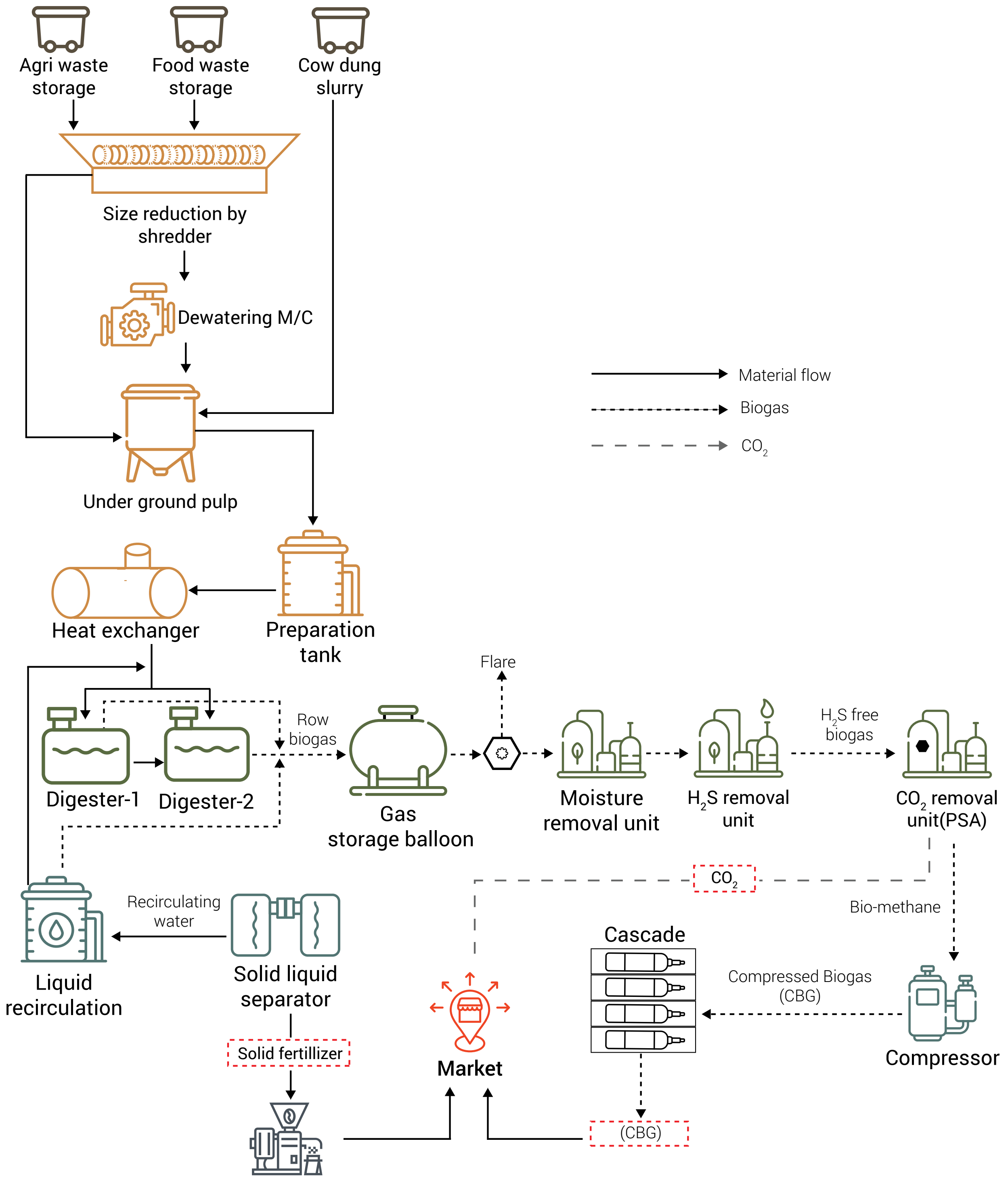


Figure 8: Processflow diagram for a Compressed Biogas Plant[30]

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 CNG 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 fertilizers i.e., manure produced at CBG plants. This further enables farmers to get access to organic fertilizers 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

The district of Pilibhit is located in the northeastern most part of the Rohilkhand division, situated in the sub-Himalayan belt along the border of Nepal. Geographically, it lies between 28°6' and 28°53' north latitude and 79°57' and 80°27' east longitude. Pilibhit is bounded to the north by Udham Singh Nagar district and the territory of Nepal; to the south by Shahjahanpur district; to the east, it is bordered briefly by Lakhimpur Kheri district and for the remaining stretch by Shahjahanpur district; and to the west, it shares its boundary with Pilibhit district. Spanning a total geographical area of 3,504 sq. km[36], Pilibhit is home to 20,31,007 people as per the 2011 Census.

36 https://pilibhit.nic.in/about-district/

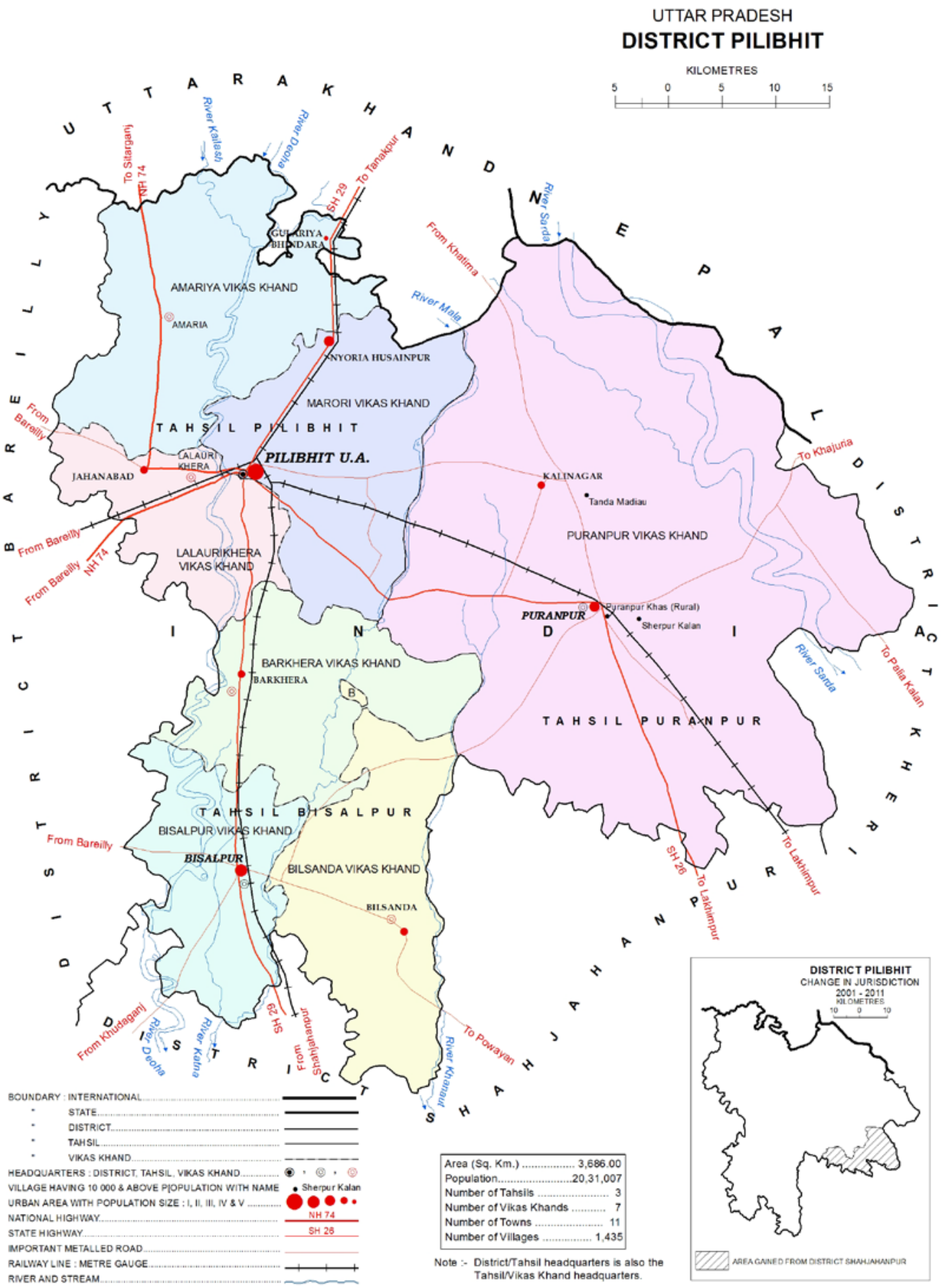


Figure 9: District map of Pilibhit as per the 2011 Census[37]

3.2 Administrative Units (Tehsils/Blocks)

For administrative convenience, the district[38] is divided into 5 Tehsils which are: Amariya, Bisalpur, Kalinagar, Pilibhit and Puranpur. There are 7 blocks in the district. There are 721 Gram Panchayats in the District.

37 District Census Handbook, Pilibhit, Census of India 2011 Part XII-B

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

3.3 Climatic Conditions

The climate in the district is generally moderate. The low-lying parts on the eastern border have proximity of moisture to the surface. The cold weather is good and bracing frost often occur in the winter. The prevailing winds are from the east during the rains and from the west during the remainder of the year. The wettest tehsil of the district is Pilibhit.

Table 6: District agricultural and climate profile of Pilibhit

District Agricultural and Climate Profile				
Agro-Ecological Sub Region[39] (ICAR[40])	Agro-Eco Region 09.2			
Agro-Climatic Zone[41] (State Agricultural Profile[42])	Mid-Western Plain Zone 4			
Rainfall[43]				
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Southwest Monsoon (June-September)	1085.4 mm	70	2nd week of June	3rd week of September
Post-monsoon (October-December)	50.7	14	3rd week of Dec	2nd week of Jan
Winter	47.6	-	-	-
(January-March)	74	16	-	-
(April-May)	31.9	7	-	-
Temperature (in degree Celsius)[44]	**Maximum** 47		**Minimum** 4.5	
Soil	Deep, fine soils moderately saline and sodic associated			
Major Climate Contingency and Frequency	**Regular**	**Occasional**		**None**
Drought		√		
Flood		√		

39 Agro-ecological zone is a land unit, carved out of climatic zone, correlated with landforms, climate, and length of growing period (number of days available for crop growth with suitable conditions).

40 ICAR-CRIDA (Central Research Institute for Dryland Agriculture), Indian Council for Agricultural Research

41 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.

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

43 Agriculture Contingency Plan for District: Pilibhit, 2019, Department of Agriculture and Farmers' Welfare

44 Krishi Vigyan Kendra, Pilibhit, Agriculture Department, Government of Uttar Pradesh

District Agricultural and Climate Profile		
Cyclone		√
Hailstorm	√	
Heat wave	√	
Cold wave	√	
Frost	√	

On the basis of soil, climate, topography, vegetation, and crops, Uttar Pradesh has been divided into nine agro-climatic zones. Pilibhit is located in the Mid-Western Plain Zone (as described in Figure 10) and records high productivity of food grains as seen in the Table 7.

Table 7: 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	

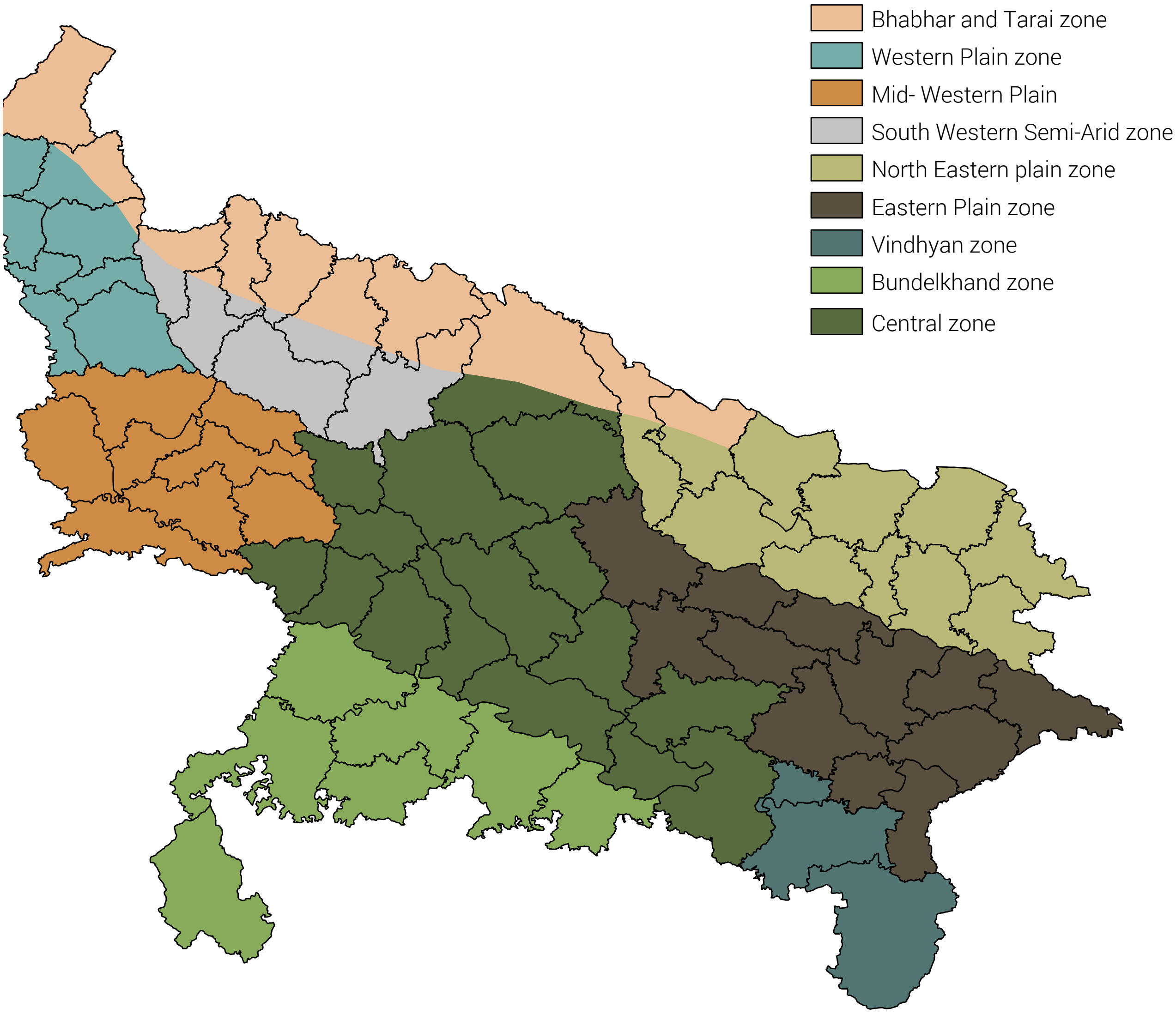


Figure 10: Agro-climatic zones in Uttar Pradesh[45]

3.4 Demographics (Urban/Rural)

The total population of Pilibhit stands at 2,031,007, with approximately 82.7 percent residing in rural areas and 17.3 percent living in urban centers. Agriculture serves as the primary occupation in the district, with over 71.2 percent of the population engaged as cultivators or agricultural labourers.[51]

In terms of agricultural landholdings, 65.7 percent of the land holdings in the district were less than 2 hectares (ha.) while 20.4 percent of the holdings were between 2-4 ha., while less than 15 percent of holdings were 4 ha. and above.[46] 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 Statistical Diary, Uttar Pradesh 2022

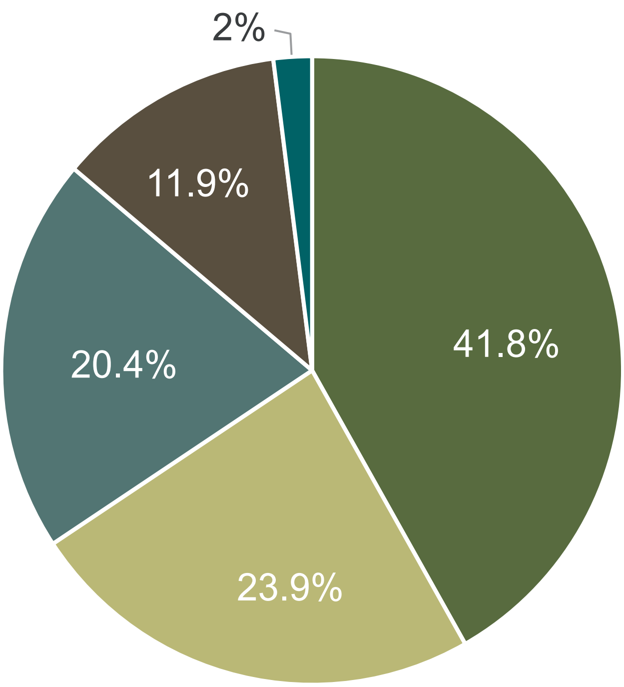


Figure 11: Agricultural land holdings in Pilibhit[47]

3.5 Agricultural Overview

Pilibhit is predominantly an agricultural district in Uttar Pradesh. There are **1,295 inhabited villages** in the district, covering a **total reported area of 313,948 hectares**. At the district level, approximately **92.49 percent of the total area is under cultivation**, and among this cultivable area, about **98.28 percent is equipped with irrigation facilities**.[48]

3.5.1 Total Agricultural Area[49]

Pilibhit is predominantly an agricultural district in Uttar Pradesh. At the district-level, 92.49 percent land area is cultivated, out of which 87.71 percent of total cultivable area has got irrigation facility.[50]

Table 8: Agricultural land area and cropping intensity in Pilibhit District

Agricultural Land Use	Area ('000 ha)	Cropping Intensity (%)
Net sown area	239.014	167.56%
Area sown more than once	161.478	
Gross cropped area	400.492	

47 Agricultural Labourers Census for Pilibhit, 2011
48 District Census Handbook for Pilibhit, 2011
49 District Profile, Krishi Vigyan Kendra, Pilibhit
50 District Census Handbook for Pilibhit, 2011

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

Agriculture is the primary economic activity in the district, with wheat, rice, and sugarcane serving as the major crops. The main kharif crops of the district are rice, maize, bajra and those of rabi are wheat, barley, gram, arhar, pea, and masoor. Sugarcane is an important crop of the district.

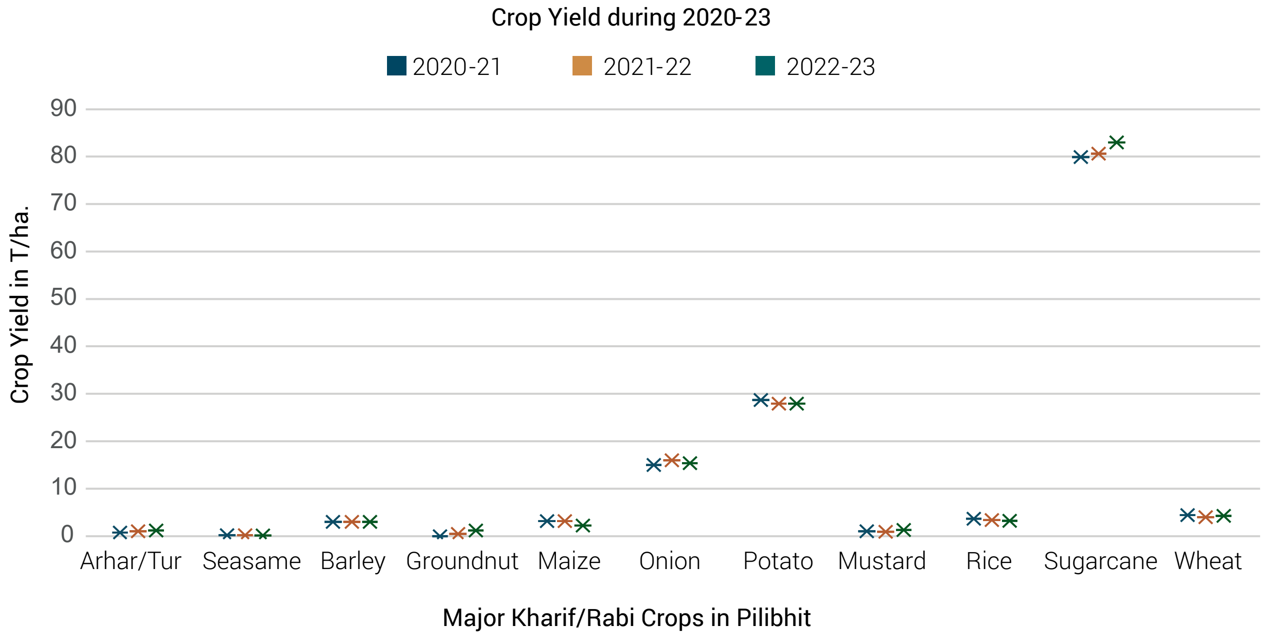


Figure 12: Crop yield during 2020-23 for major crops sown in Pilibhit during kharif and rabi[51]

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 and mustard where wheat alone occupied 79 percent of the total cropped area. Other rabi crops include sugarcane, vegetables, etc. that were sown and cultivated during the same period. .

Table 9: Tehsil-wise cropped area of *Kharif* crops (in ha.) during 2023-24[52]

Tehsil	Agri Plantation	Maize	Paddy	Sugarcane	Vegetable	Total
Amariya	689.56	402.96	16935.92	9860.96	65.90	27955.30
Bisalpur	1743.71	1074.91	16587.42	32138.24	173.01	51717.30
Kalinagar	708.35	375.09	13895.62	6265.85	53.52	21298.42
Pilibhit	1064.94	483.02	10558.63	20137.45	132.59	32376.62
Puranpur	823.51	410.42	29074.05	21945.54	102.91	52356.43
Total	**5030.07**	**2746.40**	**87051.63**	**90348.04**	**527.93**	**185704.08**

51 Area Production Statistics, Ministry of Agriculture and Farmers Welfare

52 Analysis by Vasudha Foundation, 2025

Table 10: Tehsil-wise cropped area of *Rabi* crops (in ha.) during 2023-24[49]

Tehsil	Agri-plantation	Maize	Paddy	Pulses	Sugarcane	Total
Amariya	1090.29	222.78	1638.90	2.67	20273.62	23228.26
Bisalpur	8973.97	643.78	4578.95	229.75	29665.29	44091.74
Kalinagar	755.89	543.25	2054.34	-	20745.06	24098.53
Pilibhit	3811.12	322.67	1666.44	80.93	15432.59	21313.75
Puranpur	1689.12	440.46	3184.04	-	35659.76	40973.39
Total	**16320.39**	**2172.94**	**13122.68**	**313.34**	**121776.31**	**153705.67**

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

In Pilibhit, 96 percent of its total geographical area is irrigated. The land level is plain and fertile.

Table 11: Sowing pattern for major *Kharif* and *Rabi* crops which are both irrigated and rainfed

Sowing window for major field crops	Rice	Wheat	Sugarcane	Sesame & Black gram	Toria	Mustard
Kharif – Rainfed	July	-	-	-	-	-
Kharif – Irrigated	June-July	-	-	July	-	-
Rabi – Rainfed	-	Nov-Dec	March-April	-	September	Oct
Rabi – Irrigated	-	Nov-Dec	March-April	-	September	Oct-Nov

3.6 Forest Resources

3.6.1 Total Forest Area[53]

The forest area in the district features a variety of trees, including Babul, Dhak, Neem, Sheesham, and Bamboo, primarily found in scattered and barren lands. In sandy regions, palm trees and thorny bushes are commonly grown. The Ganga belt supports moderately dense forests with large trees and diverse vegetation. The district is also rich in orchards, with mango trees thriving both in groves and along roadsides. Other commonly found tree species include Banyan, Gular, Pakar, Figure, and Vaska.

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

Table 12: Total forest area (by classification) in Pilibhit

District	Calculated Area (km^2)	Very Dense Forest (km^2)	Moderate Dense Forest (km^2)	Open Forest[54] (km^2)	Total (km^2)	Scrub[55] (km^2)
Pilibhit	3,498.90	486.20	81.75	105.89	673.84	9.92

3.6.2 Types of Forests and Residue Generated

Forestry residue consist 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)[56]. 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 may theoretically be suitable for biogas generation but practically not suitable for the commercial biogas generation.[57]

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.[58] The continuous rise in 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.

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

55 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)

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

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

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

3.7.1 Cattle, Poultry, and Other Livestock Statistics

Table 13: Tehsil-wise livestock statistics and operational Cowsheds[59]

Tehsil	Animal	Population
Amariya	Cattle	16897
	Goat/Sheep	0
	Swine	1019
	Poultry (Chicken)	4,298
Bisalpur	Cattle	55997
	Goat/Sheep	0
	Swine	299
	Poultry (Chicken)	60,000
Kalinagar	Cattle	213
	Goat/Sheep	0
	Swine	0
	Poultry (Chicken)	0
Pilibhit	Cattle	36132
	Goat/Sheep	0
	Swine	254
	Poultry (Chicken)	1,20,000
Puranpur	Cattle	50360
	Goat/Sheep	0
	Swine	1019
	Poultry (Chicken)	4543

Tehsil	Total Cattle
Amariya	61
Bisalpur	2923
Kalinagar	62
Pilibhit	632
Puranpur	768
Total	**4446**

59 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[60,61,62,63] around dung/litter yield from the respective livestock, the following figures are derived:

Table 14: Animal Categories and their Dung/Litter generation potential

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

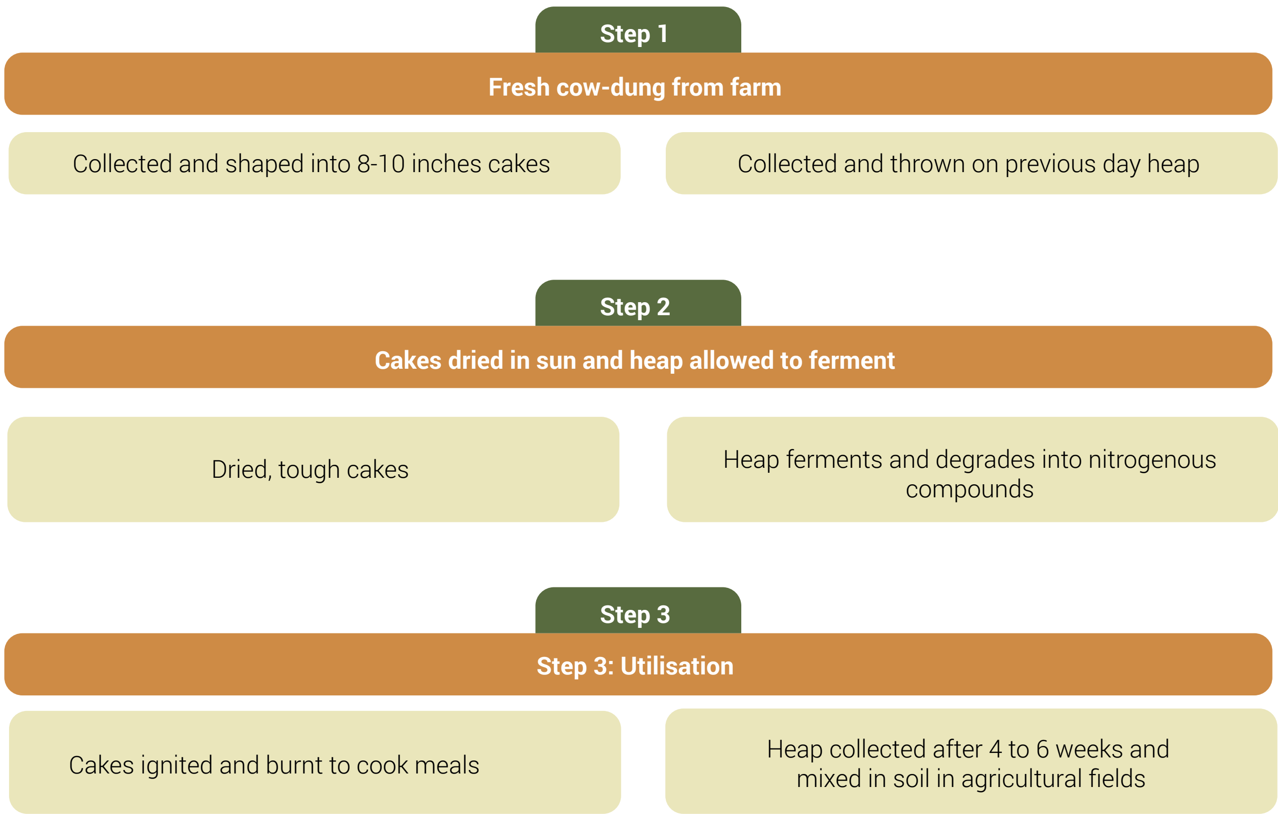


Figure 13: Traditional use of cow-dung as kitchen fuel and manure[64]

60 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

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

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

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

64 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 Bisalpur Tehsil. It is proposed to be operational by May 2026. The plant specifications are as follows:

Table 15: Details of Existing Biomass-based Industries in Pilibhit

Plant Capacity	Feedstock/Raw Material	By-products	Off-taker	Procurement Plan
22 Tonnes Per Day (TPD)	Sugarcane Leaves, Cattle Dung, Paddy Straw, Napier Grass	FOM, LFOM	CBG is proposed to be sold in their retail outlet	Sugarcane Leaves is to be procured from Sugarcane Farms after harvest, cow dung will be procured from nearby Cowsheds on a daily basis
45 m^3 Per Day (MPD)	Cattle Dung	Bio-slurry	Biogas used for heating purposes in cowshed	Commercial-scale biogas plant installed and functional inside a cowshed facility in Pilibhit Tehsil (under GOBARdhan)

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 16: Operating Parameters and Conversion Factors for Sugar Mills

Parameter	Value
Conversion Factor (Sugarcane to Bagasse)	40% TCD[65]
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[66])	150 days
Number of Operating Days (Medium Sugar Mill[67])	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:

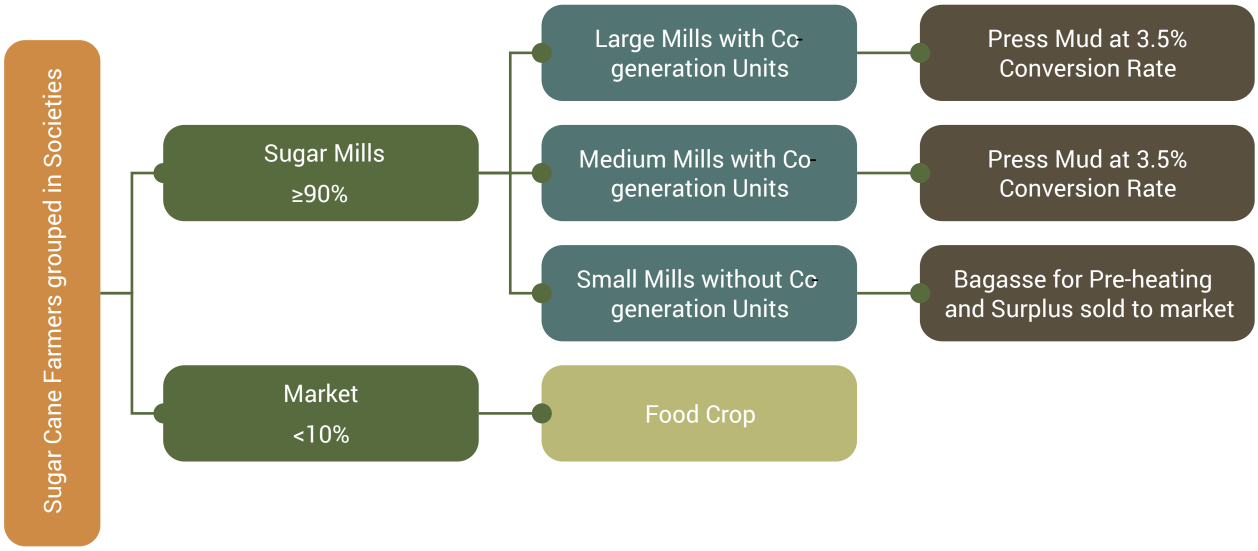


Figure 14: Mapping the value chain of sugar industries

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

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

67 Medium Sugar Mills use Horizontal Crushers to crush Sugarcane

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

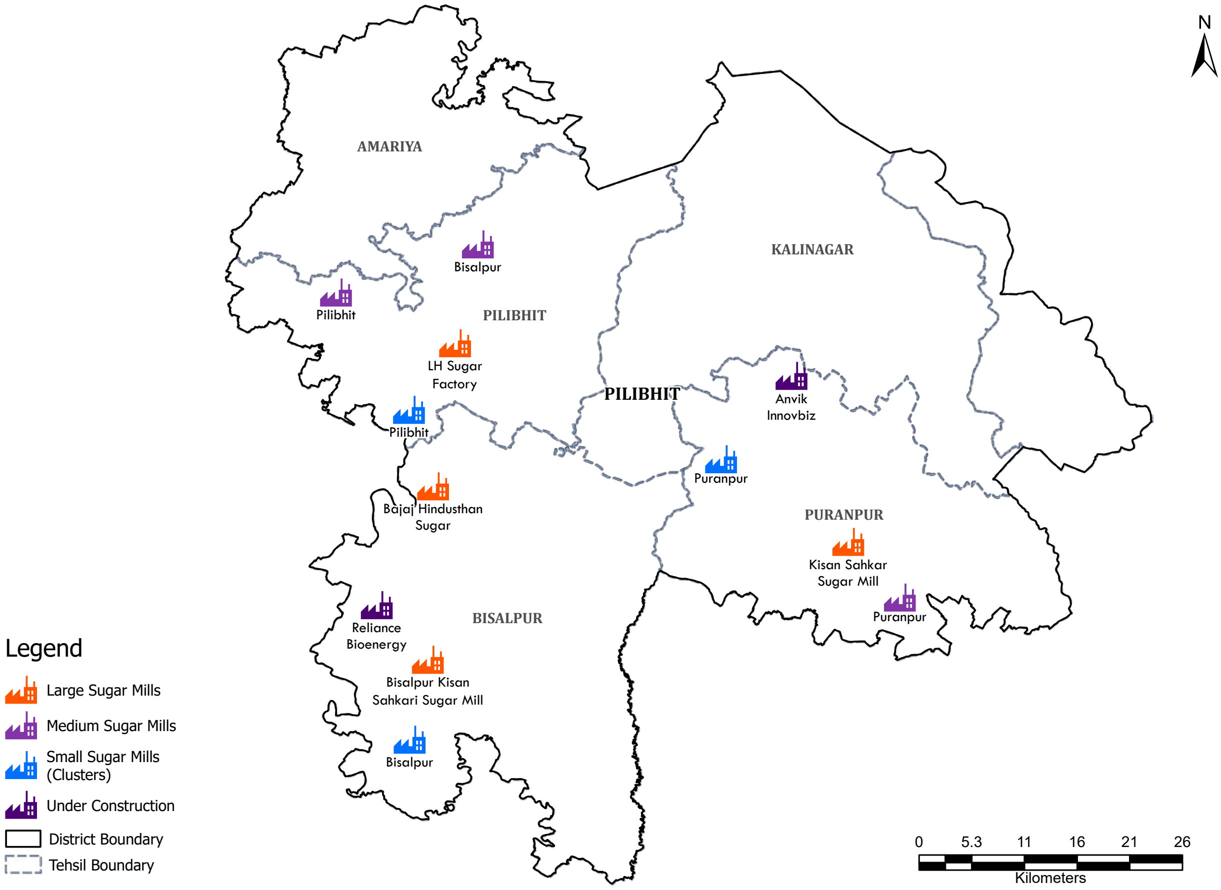


Figure 15: Location of sugar mills in Pilibhit district[68]

Table 17: Tehsil-wise Sugar Mills and their Annual Crushing Capacity

Tehsil	Cane Crushing Capacity in TCD		
	Large Mills	**Medium Mills**	**Small Mills (Vertical Crushers)**
Amariya	X	X	X
Bisalpur	10,250	x	x
(2 Mills)	2000	11 (55 Mills)	880
Kalinagar	X	800	X
Pilibhit	12500	120	11 (20 Mills)
Puranpur	2500	X	11 (20 Mills)

68 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[69] which is described as under:

Table 18: 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.[70]

69 National Biomass Atlas of India, 2023

70 As per the NIBE's approximations

Table 19: 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 20: 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[71]
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 21: Calorific Values[72,73] for Animal Residue

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

71 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.

72 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

73 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)[74]. The tentative yield of various feedstocks is tabulated as under:

Table 22: Tentative CBG Yield from Various Feedstocks[80]

Feedstock	CBG Production (T)	Feedstock requirement
Agriculture Residue	1	10 T
Press Mud	1	25 T
Sugarcane Leaves	1	7 T[75]
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

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

75 Biogas yield would be approximately 7% for Sugarcane Leaves as per the CBG industry

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 23: 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 Pilibhit 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.

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 Pilibhit, Bisalpur and to some extent, western Puranpur. Similarly, paddy cultivation is higher in tehsils Puranpur and Amariya.

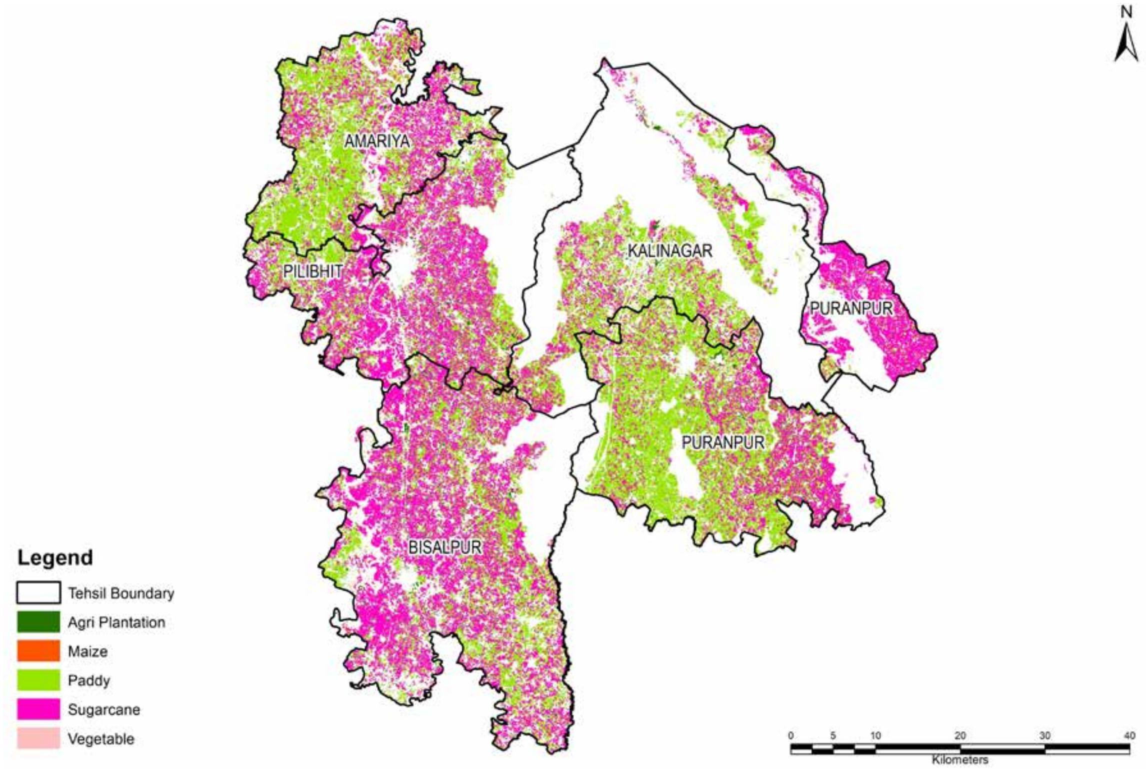


Figure 16: Geographical spread of kharif crops in tehsils of Pilibhit district during 2023-24[76]

During the Rabi season of 2023-24, wheat was prominently cultivated in almost all the Tehsils.

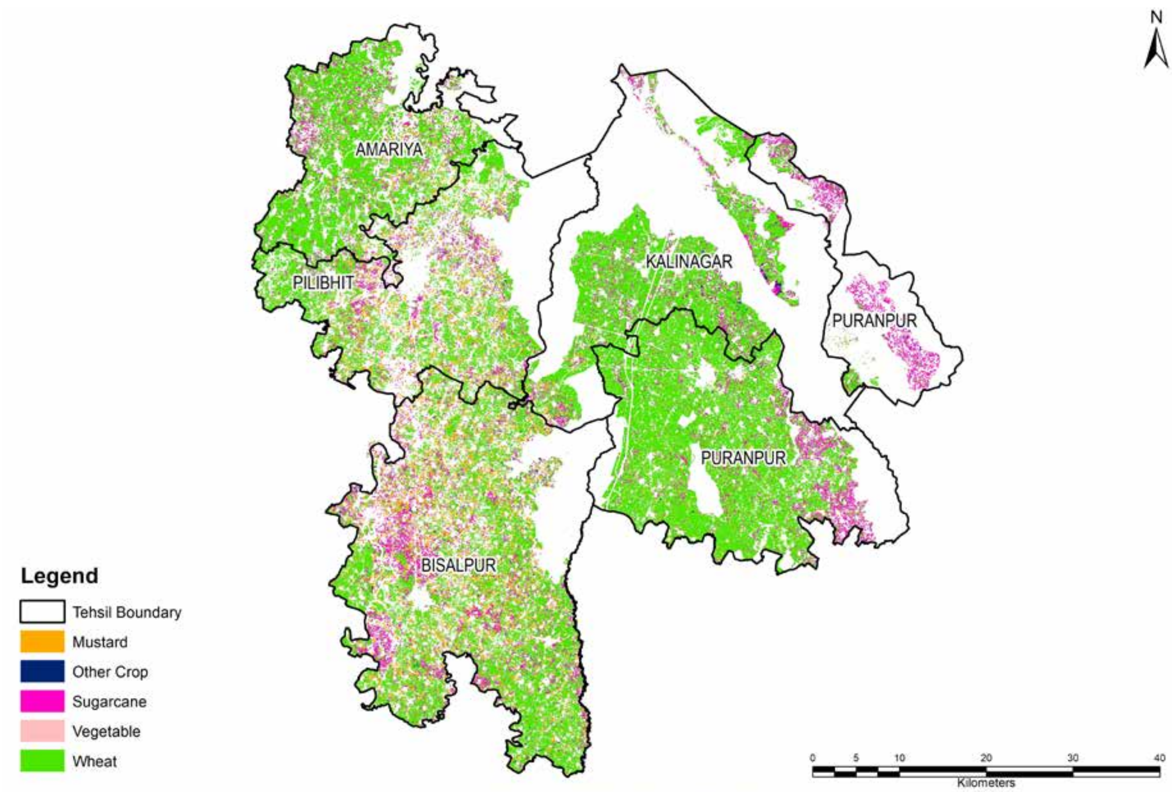


Figure 17: Geographical spread of rabi crops in tehsils of Pilibhit district during 2023-24[77]

76 Analysis by Vasudha Foundation, 2025

77 Analysis by Vasudha Foundation, 2025

6.2 Land Use and Biomass Distribution Mapping

Land use statistics play a crucial role in understanding changes in land use patterns, cropping trends, the impact of development programs, and ensuring the efficient utilisation of land—one of our most valuable natural resources. A detailed land use analysis for the district of Pilibhit was conducted for the year 2023–24, and the key findings are summarised below:

Table 24: Tehsil-wise Land-Use Analysis (in ha) for Pilibhit.

Tehsil	Barren/ Waste land	Built-Up	Crop land	Forest	Grass land	Scrub	Water-bodies	Wet-land	Grand Total
Amariya	283.36	1176.50	40785.04	-	157.75	1690.99	182.72	17.93	44294.29
Bisalpur	868.20	2477.19	79915.73	10251.03	9.81	1010.18	59.49	5.51	94597.13
Kalinagar	514.66	632.62	35306.32	38149.08	141.92	3085.03	6885.83	221.01	84936.49
Pilibhit	448.72	2394.33	47083.47	11198.03	544.49	695.20	73.60	35.09	62472.92
Puranpur	770.63	1847.33	70227.97	9745.04	148.72	4422.84	2696.82	49.77	89909.12
Total (ha)	**2885.57**	**8527.97**	**273318.53**	**69343.18**	**1002.68**	**10904.25**	**9898.47**	**329.31**	**376209.96**

It can be observed from the Land Use analysis[78] that tehsils Kalinagar and Puranpur hold few tracts of barren/waste land. The district has prominent forest cover in Tehsils of Pilibhit, Kalinagar, Bisalpur and Puranpur.

78 Analysis by Vasudha Foundation, 2025

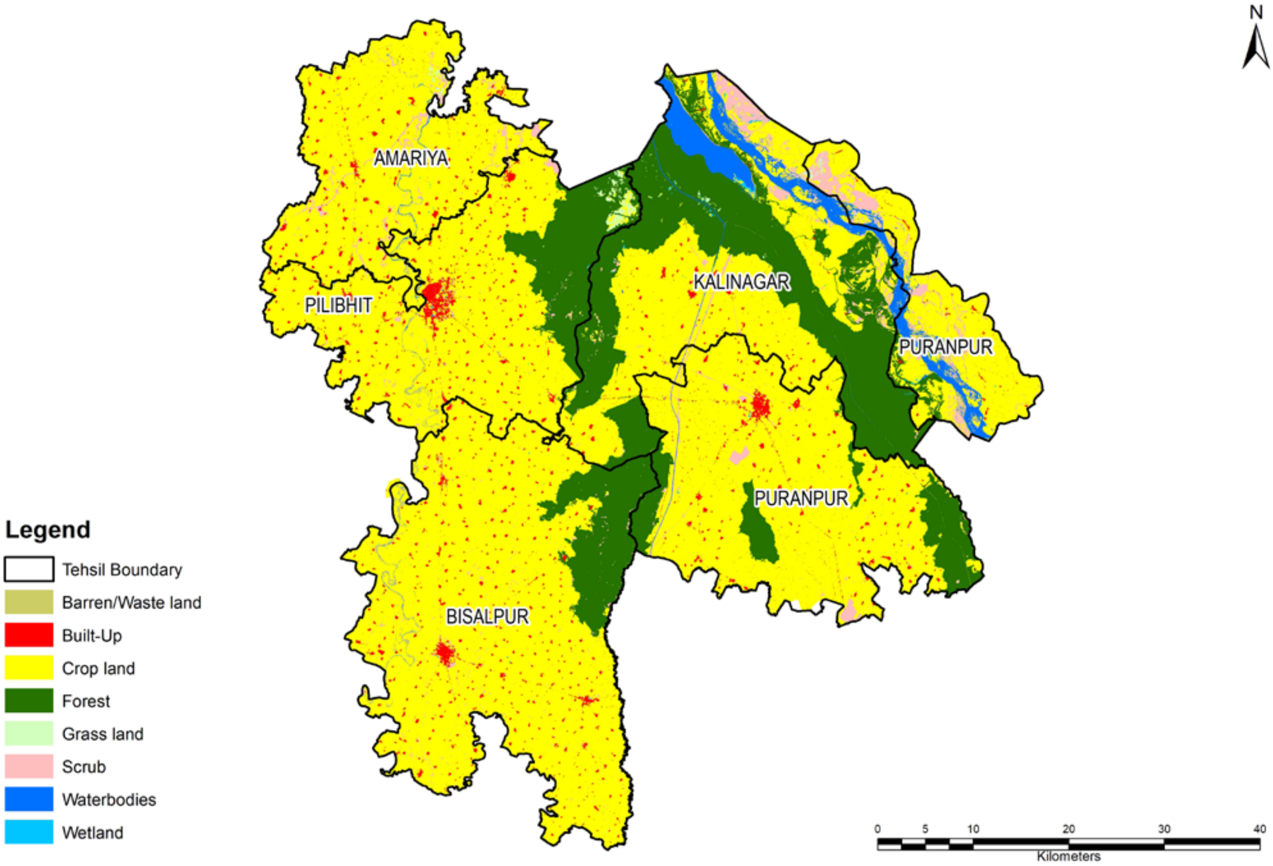


Figure 18: Land cover analysis for tehsils of Pilibhit district during 2023-24[79]

79 Analysis by Vasudha Foundation, 2025

07 Methodology

This study estimates annual net biomass residue availability in all the five Tehsils of Pilibhit 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 Pilibhit 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)[80], a supervised machine learning algorithm trained on ground-truth data to classify satellite imagery into distinct crop

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

categories. This approach enabled precise mapping of kharif and rabi cultivation zones by assigning pixel-level classifications. After determining crop-specific acreage, the study incorporated existing district- and tehsil-level agricultural statistics—such as yield per hectare—to calculate total production. By merging remote sensing data with regional agricultural records, the analysis provided granular insights into crop productivity patterns across administrative scales, enhancing understanding of spatial variations in agricultural output.

Figure 19: 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[81] 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.[82,83] 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.

81 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.

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

83 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.5*).[84]

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

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.[85][86]

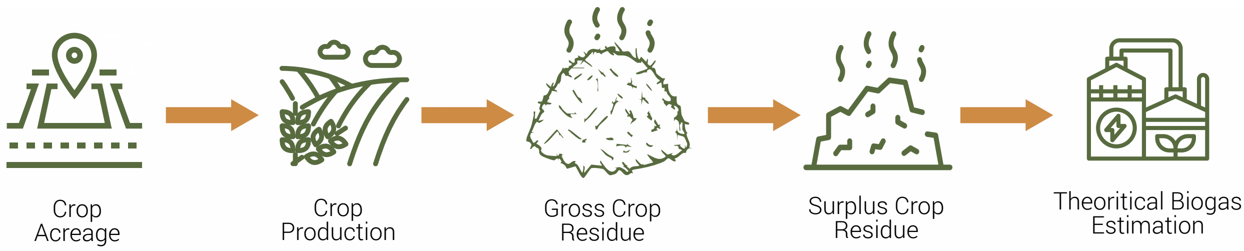


Figure 20: Flow diagram for crop residue estimation

84 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

85 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

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

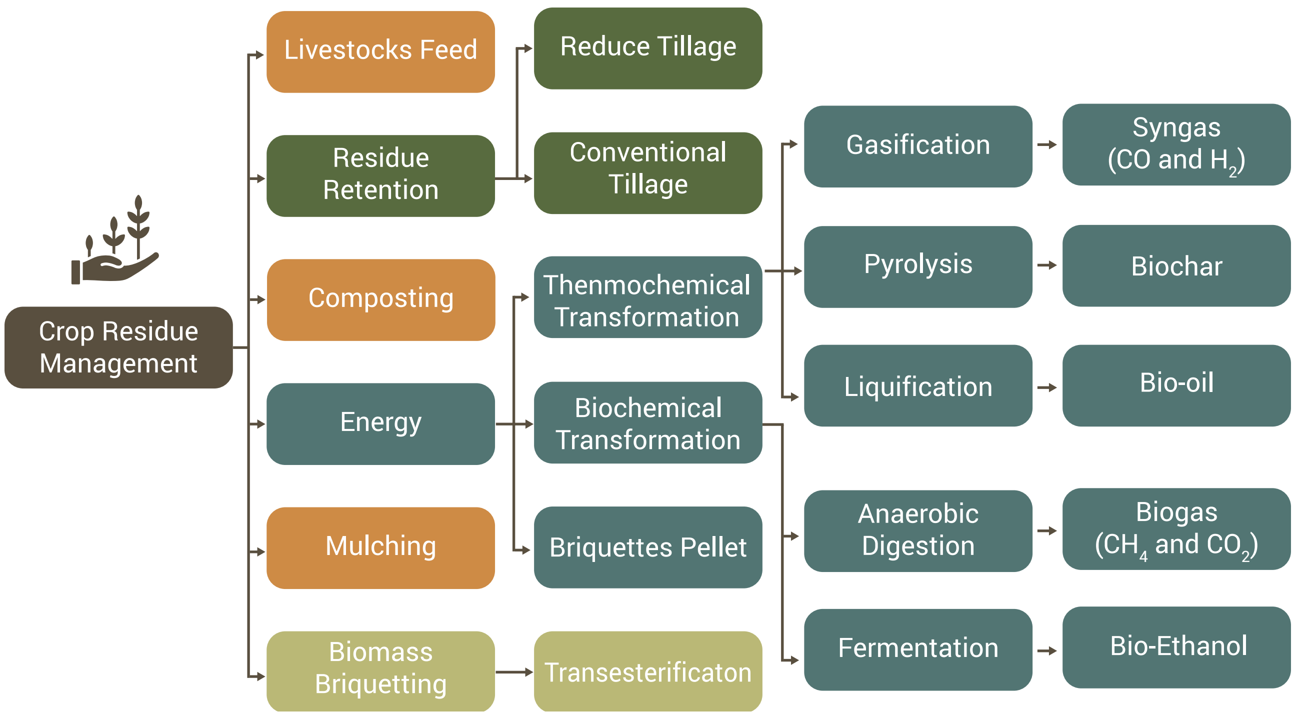


Figure 21: Crop residue management practices[87]

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.

87 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 Biomass Assessment are tabulated in Table 25. 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 crops are listed in Table 18. Similarly, the surplus animal dung/litter and biogas yield for various biomass residues are described in Table 26 and 20 respectively. *Equations 1-6* were applied to arrive at the biogas yield results. We have two distinct results for CBG potential for majority of the 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 25: 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)	CBG (SATAT) (TPD)
		Area	Yield	Total						
Amariya	Wheat	20273.62	4.23	85757.41	Straw	128636.1	25727.22	25727.22	5.09	7.05
					Husk	25727.22	5145.445	5145.445	1.02	1.41
	Paddy	16935.92	3.41	57751.49	Straw	86627.23	14726.63	14726.63	3.28	12.66
					Husk	11550.3	1963.551	1963.551	0.44	
	Sugarcane	11499.86	81.18	933558.6	Bagasse (Small)	0			0.00	0.00
					Press Mud (Large)	0			0.00	0.00
					Press Mud (Medium)	0			0.00	0.00
					Leaves	46677.93	46677.93	46677.93	8.95	8.95
	Maize	402.96	2.87	1156.495	Stalks	2312.99	23.1299	23.1299	0.01	0.01
					Cobs	346.9486	3.469486	3.469486	0.00	0.00
					Leaves	138.7794	1.387794	1.387794	0.00	0.00
	Mustard	1090.29	1.08	1177.513	Stalks	2119.524	2119.524	2119.524	0.58	0.58
	Pulses (Tur/Arhar)	0	0.98	0	Stalks	0	0	0	0.00	0.00
	Potato	0	28.18	0	Stalks	0	0	0	0.00	0.00

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
Bisalpur	Vegetables	68.57	15.47	1060.778	Stalks	106.0778	106.0778	106.0778	0.03	0.03
	Other Crops (Barley)	22.78	3	68.34	Straw	88.842	88.842	88.842	0.02	0.02
	Agri-Plantation (Seasame)	689.56	0.17	117.2252	Stalks	234.4504	234.4504	234.4504	0.06	0.06
					Husk	35.16756	35.16756	35.16756	0.01	0.01
					Cobs	38.68432	38.68432	38.68432	0.01	0.01
	Wheat	29665.29	4.23	0	Straw	0	0	0	0.00	0.00
					Husk	0	0	0	0.00	0.00
	Paddy	16587.42	3.41	56563.1	Straw	84844.65	14423.59	14423.59	3.21	12.40
					Husk	11312.62	1923.145	1923.145	0.43	
	Sugarcane	36717.19	81.18	2980701	Bagasse (Small)	11616			0.98	3.18
					Press Mud (Large)	28833			3.14	3.16
					Press Mud (Medium)	9625			1.05	1.05
					Leaves	149035.1	149035.1	124035.07	23.79	23.79
	Maize	1074.91	2.87	3084.992	Stalks	6169.983	61.69983	61.69983	0.02	0.02
					Cobs	925.4975	9.254975	9.254975	0.00	0.00
					Leaves	370.199	3.70199	3.70199	0.00	0.00

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Mustard	8973.97	1.08	9691.888	Stalks	17445.4	17445.4	17445.4	4.78	4.78
	Pulses	0	0.98	0	Stalks	0	0	0	0.00	0.00
	Potato	0	28.18	0	Stalks	0	0	0	0.00	0.00
	Vegetables	302.76	15.47	4683.697	Stalks	468.3697	468.3697	468.3697	0.13	0.13
	Other Crops (Barley)	643.78	3	1931.34	Straw	2510.742	2510.742	2510.742	0.69	0.69
	Agri-Plantation (Seasame)	1743.71	0.17	296.4307	Stalks	592.8614	592.8614	592.8614	0.16	0.16
					Husk	88.92921	88.92921	88.92921	0.02	0.02
					Cobs	97.82213	97.82213	97.82213	0.03	0.03
Kali-nagar	Wheat	20745.06	4.23	87751.6	Straw	131627.4	26325.48	26325.48	5.21	7.21
					Husk	26325.48	5265.096	5265.096	1.04	1.44
	Paddy	13895.62	3.41	47384.06	Straw	71076.1	12082.94	12082.94	2.69	10.39
					Husk	9476.813	1611.058	1611.058	0.36	
	Sugarcane	8320.19	81.18	675433	Bagasse (Small)	0			0.00	0.00
					Press Mud (Large)	0			0.00	0.00
					Press Mud (Medium)	0			0.00	0.00
					Leaves	33771.65	33771.65	33771.65	6.48	6.48

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Maize	375.09	2.87	1076.508	Stalks	2153.017	21.53017	21.53017	0.01	0.01
					Cobs	139.9461	1.399461	1.399461	0.00	0.00
					Leaves	129.181	1.29181	1.29181	0.00	0.00
	Mustard	755.89	1.08	816.3612	Stalks	97.96334	97.96334	97.96334	0.03	0.03
	Pulses	0	0.98	0	Stalks	0	0	0	0.00	0.00
	Potato	0	28.18	0	Stalks	0	0	0	0.00	0.00
	Vegetables	53.52	15.47	827.9544	Stalks	82.79544	82.79544	82.79544	0.02	0.02
	Other Crops (Barley)	543.25	3	1629.75	Straw	2118.675	2118.675	2118.675	0.58	0.58
	Agri-Plantation (Sesame)	708.35	0.17	120.4195	Stalks	240.839	240.839	240.839	0.07	0.07
					Husk	36.12585	36.12585	36.12585	0.01	0.01
					Cobs	39.73844	39.73844	39.73844	0.01	0.01
Pilibhit	Wheat	15432.59	4.23	65279.86	Straw	97919.78	19583.96	19583.96	3.88	5.37
					Husk	19583.96	3916.791	3916.791	0.78	1.07
	Paddy	10558.63	3.41	36004.93	Straw	54007.39	9181.257	9181.257	2.05	7.89
					Husk	7200.986	1224.168	1224.168	0.27	

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Sugarcane	21803.89	81.18	1770040	Bagasse (Small)	13728			1.16	3.64
					Press Mud (Medium)	12800			1.39	1.40
					Press Mud (Large)	62422.5			6.80	6.84
					Leaves	88501.99	88501.99	88501.99	16.97	16.97
	Maize	483.02	2.87	1386.267	Stalks	2772.535	27.72535	27.72535	0.01	0.01
					Cobs	415.8802	4.158802	4.158802	0.00	0.00
					Leaves	166.3521	1.663521	1.663521	0.00	0.00
	Mustard	3811.12	1.08	4116.01	Stalks	7408.817	7408.817	7408.817	2.03	2.03
	Pulses	0	0.98	0	Stalks	0	0	0	0.00	0.00
	Potato	0	28.18	0	Stalks	0	0	0	0.00	0.00
	Vegetables	213.52	15.47	3303.154	Stalks	330.3154	330.3154	330.3154	0.09	0.09
	Other Crops (Barley)	322.67	3	968.01	Straw	1258.413	1258.413	1258.413	0.34	0.34
	Agri-Plantation (Seasame)	1064.94	0.17	181.0398	Stalks	362.0796	362.0796	362.0796	0.10	0.10
					Husk	54.31194	54.31194	54.31194	0.01	0.01
					Cobs	59.74313	59.74313	59.74313	0.02	0.02

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
Puran-pur	Wheat	35659.76	4.23	150840.8	Straw	226261.2	45252.24	45252.24	8.86	12.40
					Husk	45252.24	9050.447	9050.447	1.77	2.48
	Paddy	29074.05	3.41	99142.51	Straw	148713.8	25281.34	25281.34	5.63	21.73
					Husk	19828.5	3370.845	3370.845	0.75	
	Sugarcane	25129.58	81.18	2040019	Bagasse (Small)	4224			0.36	1.16
					Press Mud (Medium)	3150			0.34	0.35
					Press Mud (Large)	6650			0.72	0.73
					Leaves	102001	102001	102001	19.56	19.56
	Maize	410.42	2.87	1177.905	Stalks	2355.811	23.55811	23.55811	0.01	0.01
					Cobs	353.3716	3.533716	3.533716	0.00	0.00
					Leaves	353.3716	3.533716	3.533716	0.00	0.00
	Mustard	1689.12	1.08	1824.25	Stalks	3283.649	3283.649	3283.649	0.90	0.90
	Pulses	0	0.98	0	Stalks	0	0	0	0.00	0.00
	Potato	0	28.18	0	Stalks	0	0	0	0.00	0.00
	Vegetables	102.91	15.47	1592.018	Stalks	159.2018	159.2018	159.2018	0.04	0.04

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Other Crops (Barley)	440.46	3	1321.38	Straw	1717.794	1717.794	1717.794	0.47	0.47
	Agri-Plantation (Seasame)	823.51	0.17	139.9967	Stalks	279.9934	279.9934	279.9934	0.08	0.08
					Husk	41.99901	41.99901	41.99901	0.01	0.01
					Cobs	46.19891	46.19891	46.19891	0.01	0.01

8.2 Animal Waste

The cumulative biogas yield from livestock waste is influenced by several key factors, including the type and breed of animal, average body weight, diet composition, and the total solids content in the excrement. To ensure accurate estimation of biogas production per unit, it is essential to adopt a standardised method for dung collection. Such standardisation is critical to obtaining a reliable measure of cumulative biogas volume, which forms the basis for calculating the availability coefficient factor. This factor is vital for projecting both the expected and likely biogas output from livestock waste under varying conditions.

Table 26: **Tehsil-wise surplus biomass residue and potential CBG generation from various Animal residues**

Tehsil	Animal	Population	Gross Residue (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
Amariya	Cattle	16897.00	23127768.75	16189.44	264172775.55	0.14	0.66	0.89
	Goat/ Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Swine	1019.00	291225.11	174.74	3127757.63	0.00	0.01	0.01
	Poultry (Chicken)	4298.00	20472.45	12.28	196535.51	0.00	0.00	0.00
Bisalpur	Cattle	55997.00	53652125.63	53652.13	875473925.10	0.46	2.20	2.94
	Goat/ Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Swine	299.00	51271.62	51.27	917762.05	0.00	0.00	0.00
	Poultry (Chicken)	60000.00	171477.00	171.48	2743632.00	0.00	0.01	0.02
Kalinagar	Cattle	213.00	204080.63	204.08	3330106.01	0.00	0.01	0.01
	Goat/ Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Swine	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Poultry (Chicken)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Tehsil	Animal	Population	Gross Residue (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
Pilibhit	Cattle	36132.00	197822700.00	9891.14	161399584.48	0.09	0.41	0.54
	Goat/ Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Swine	254.00	43555.16	43.56	779637.33	0.00	0.00	0.00
	Poultry (Chicken)	120000.00	342954.00	342.95	5487264.00	0.01	0.02	0.04
Puranpur	Cattle	50360.00	48251175.00	48251.18	787343373.18	0.42	1.98	2.64
	Goat/ Sheep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Swine	1019.00	174735.06	174.74	3127757.63	0.00	0.01	0.02
	Poultry (Chicken)	4543.00	12983.67	12.98	207738.67	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 Pilibhit district. However, existing CBG developers are planning to cultivate Napier Grass.

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.[88]

Napier Grass can be used as a combination feedstock with paddy straw and animal dung when sugar-cane 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 24 ha. of land accounting for a total annual production of 28 T of the crop. Using SATAT's CBG conversion factor, the following results are observed

Table 27: 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	24	1.17	28	0.3	8.4	0.002

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 tehsils of Bisalpur, Pilibhit, and Puranpur. They have a cumulative cane crushing capacity of 1540 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.

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

Table 28 Surplus Bagasse generated from Small Sugar Mills Cluster

Tehsil	Crushing Capacity in TCD	Number of Units	Surplus Bagasse (T)
Pilibhit Cluster	11	65	13728
Bisalpur Cluster	11	55	11616
Puranpur Cluster	11	20	4224

Figure 22 describes the corresponding CBG potential that can be generated from sugarcane bagasse.

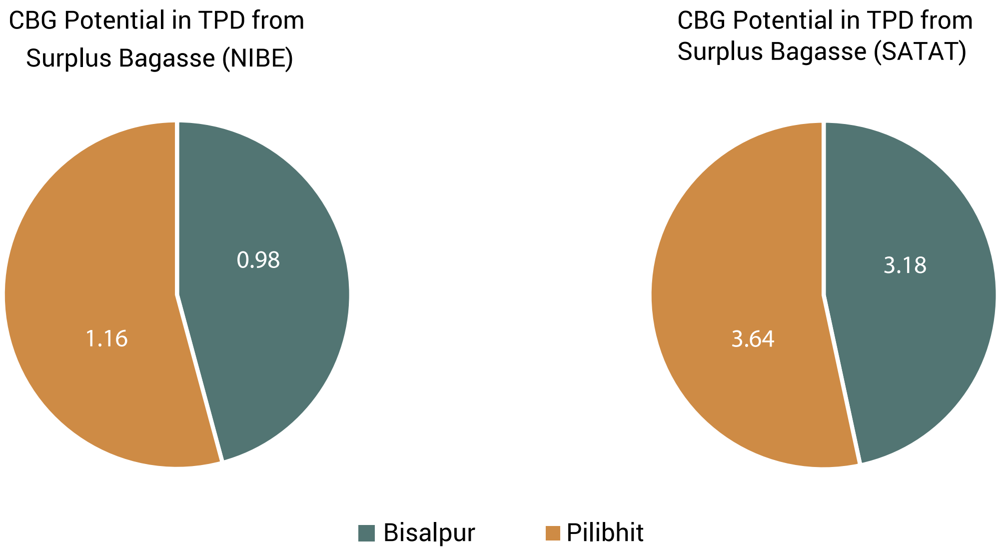
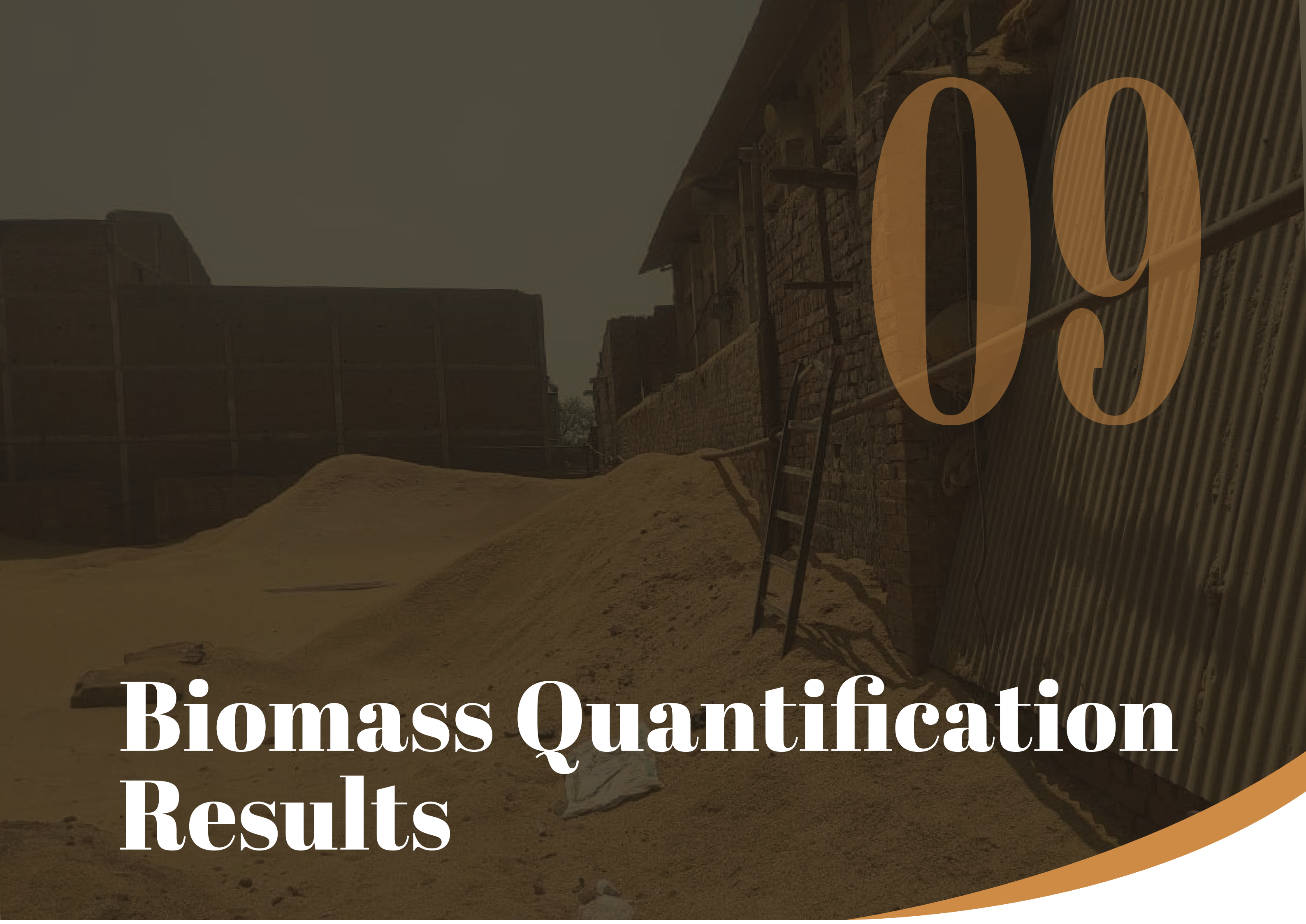


Figure 22: CBG Potential from Bagasse generated from Small Sugar Mills

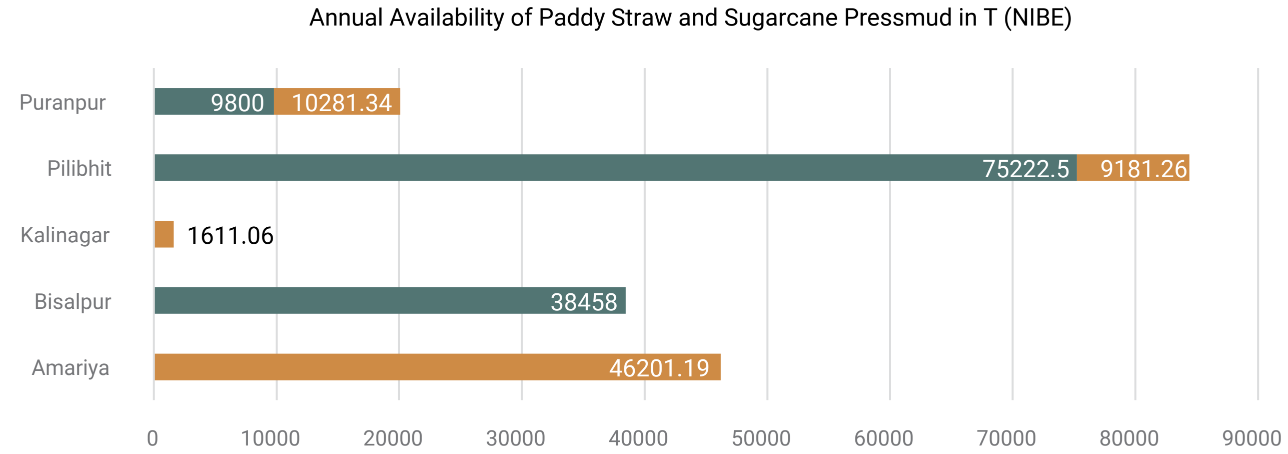


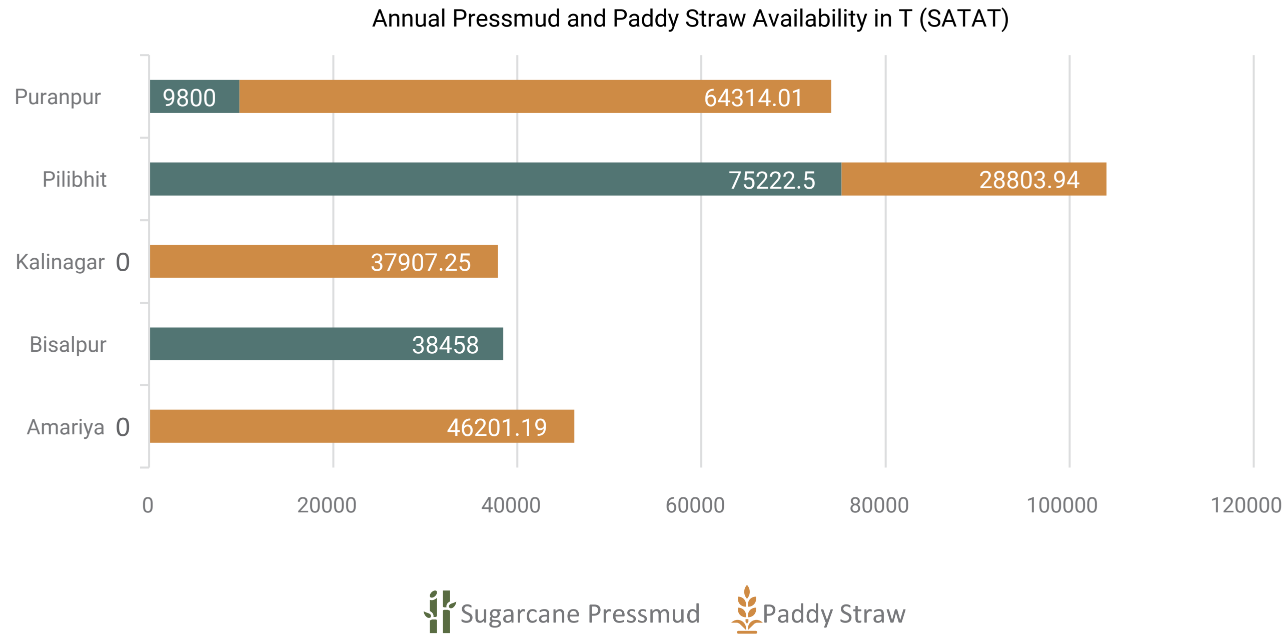
09

Biomass Quantification Results

9.1 Total Biomass Availability by Category

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





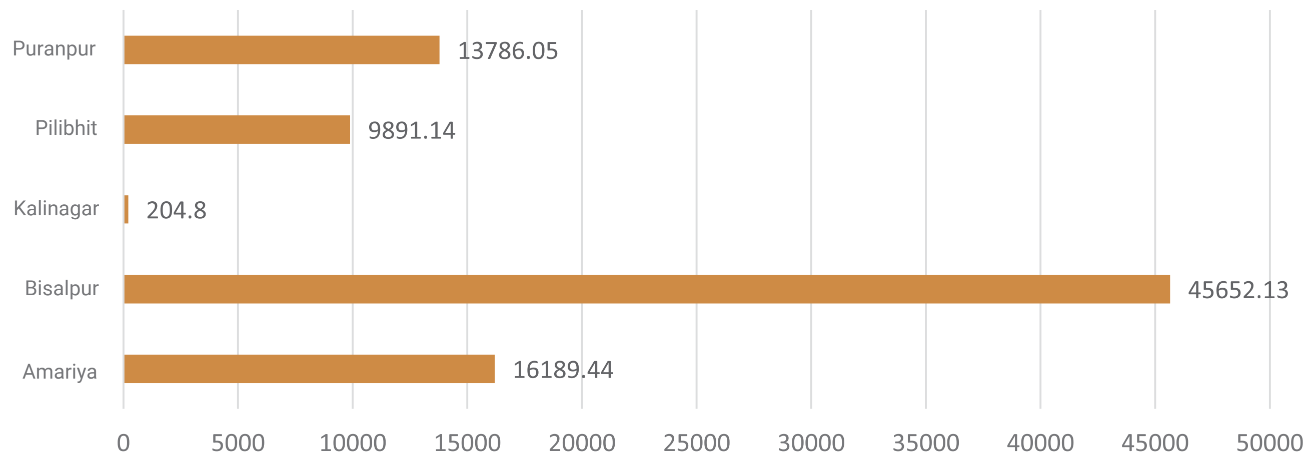


Figure 23: Tehsil-wise annual availability of paddy straw, press mud and cattle dung

9.2 Variations in Biomass Availability and Pricing

The availability and generation of sugarcane press mud has been varying over the years. From the *Figure 24 & 25,* 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 26* depicts the year-on-year change in press mud that is generated. 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 40 to 60 per quintal during 2021-25.

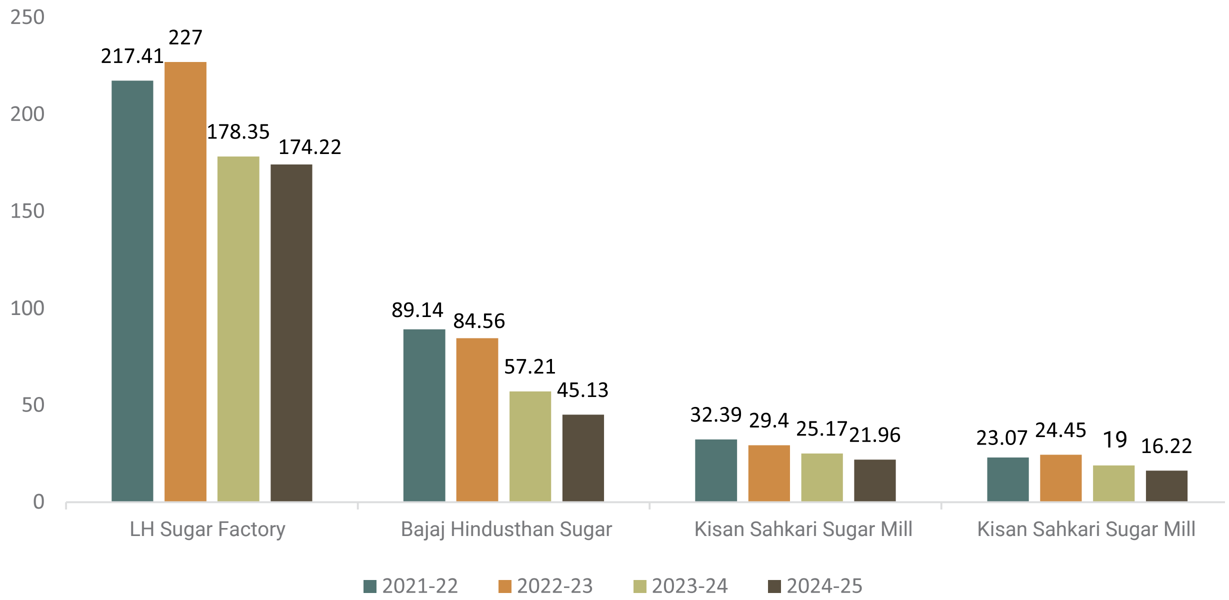


Figure 24: Annual cane crushed in sugar mills during 2021-25[89]

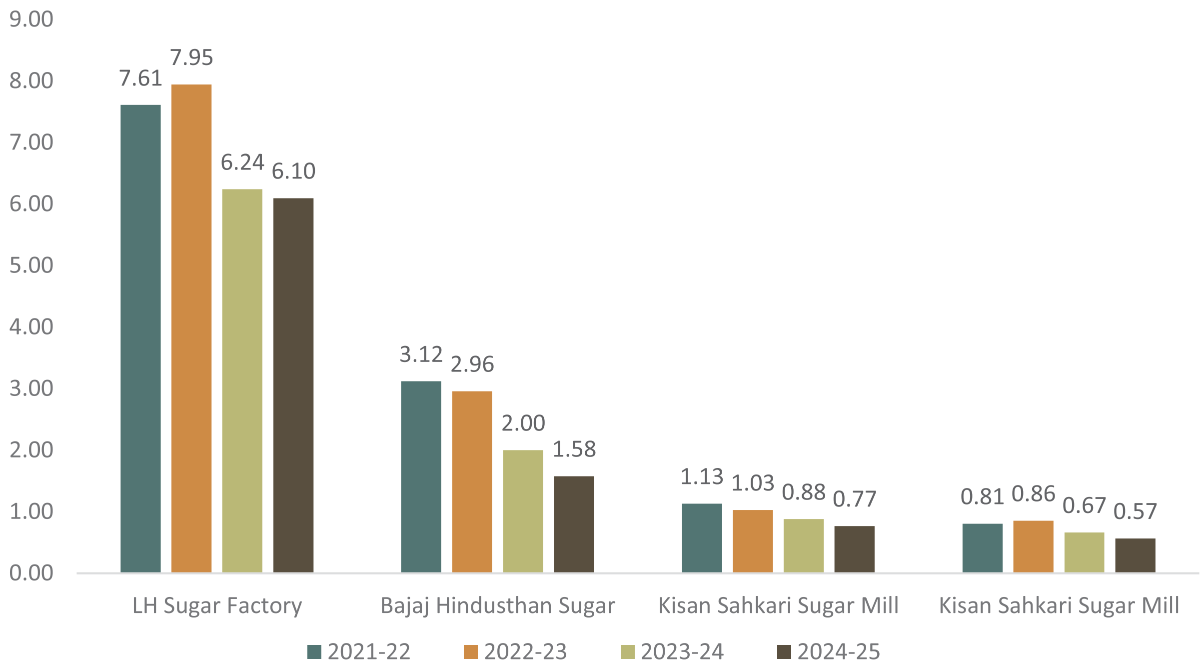


Figure 25: Annual press mud generated in sugar mills during 2021-25

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

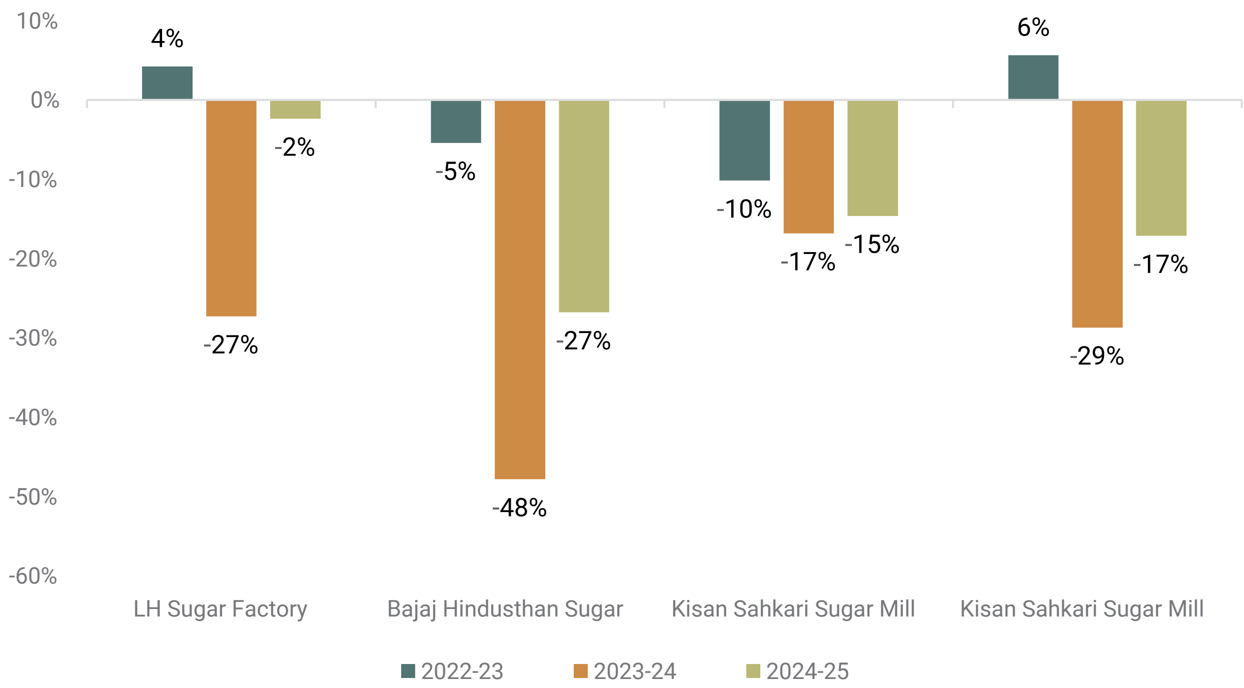


Figure 26: YoY Change in Annual Cane Crushed and Press Mud Generated during 2022-25

It can be observed from *Figure 27* the press mud price varies significantly in a year. A typical sugar mill runs only for 180 days in a year during the kharif season (mid-November to April). This season is characterised as a peak season. During this period, the price of sugarcane press mud is usually lowest in the year. As we move to non-sugar or off-peak season, price for press mud spikes.

The reasons for the spike 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

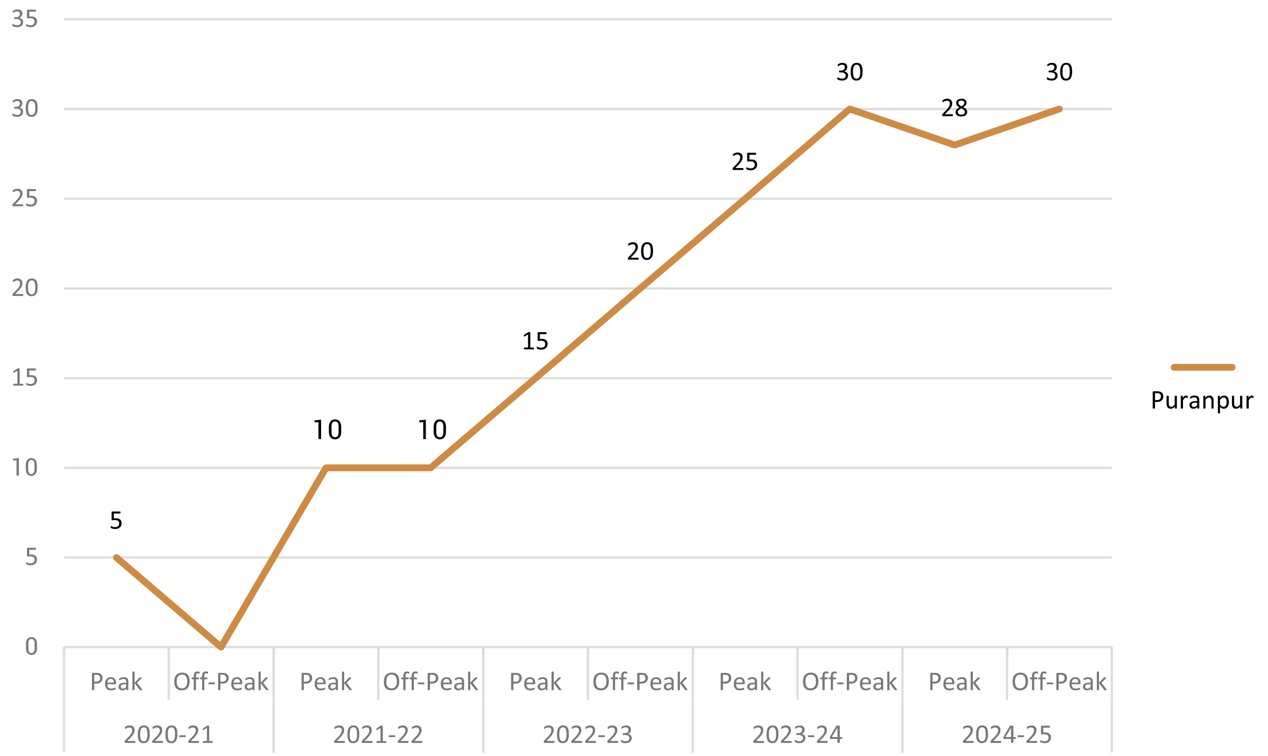


Figure 27: **Press mud price variations during 2021-25 (from medium sugar mills)**[90]

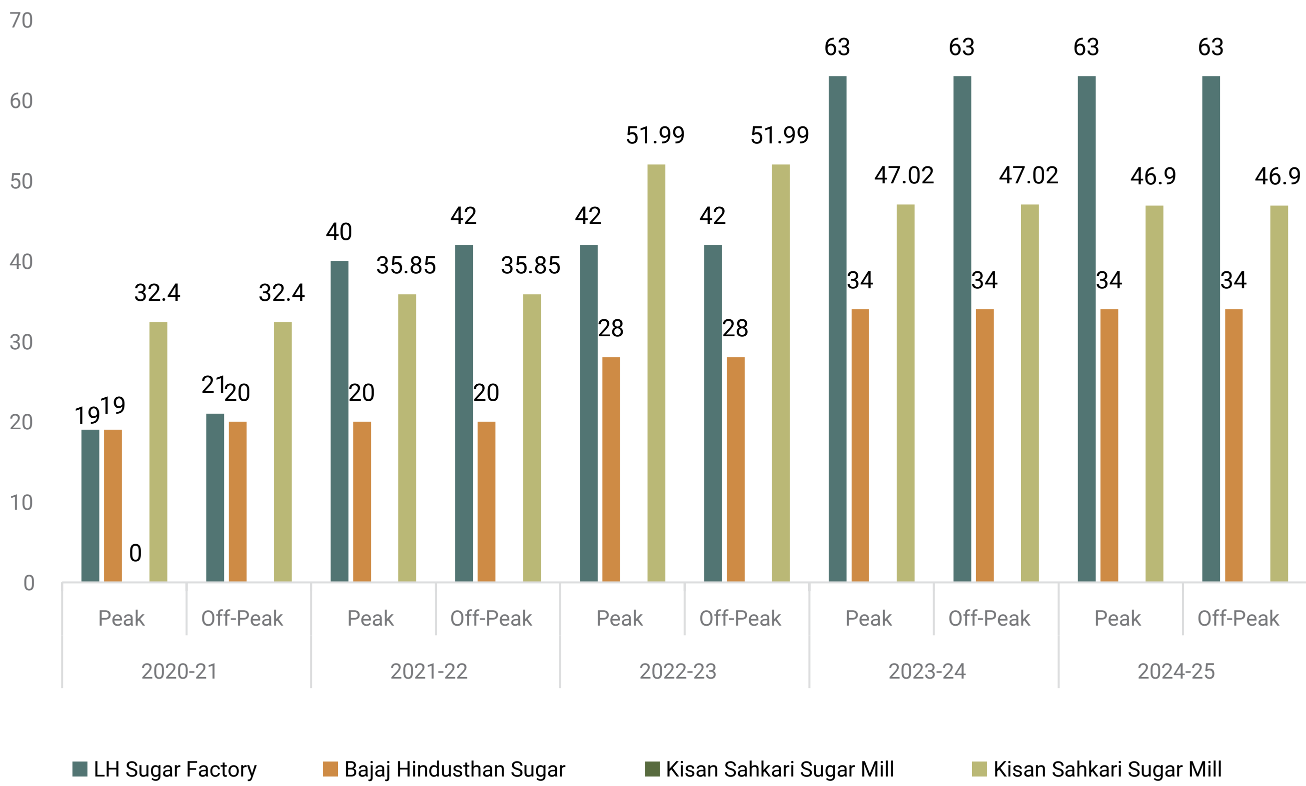


Figure 28: **Press mud price variations during peak and off-peak season**

90 Primary survey of sugar mills by Vasudha Foundation, 2025

9.3 High-Potential Zones for Biomass Supply and CBG Production

It can be observed that Pilibhit has the highest annual press mud availability followed by Bisalpur and Puranpur. However, there are no sugar mills located within the Amariya and Kalinagar tehsils. Among all tehsils, Pilibhit has the highest paddy straw availability, while the rest of them have comparable stock as agricultural residue. All tehsils of Pilibhit, excluding Kalinagar have rich 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:

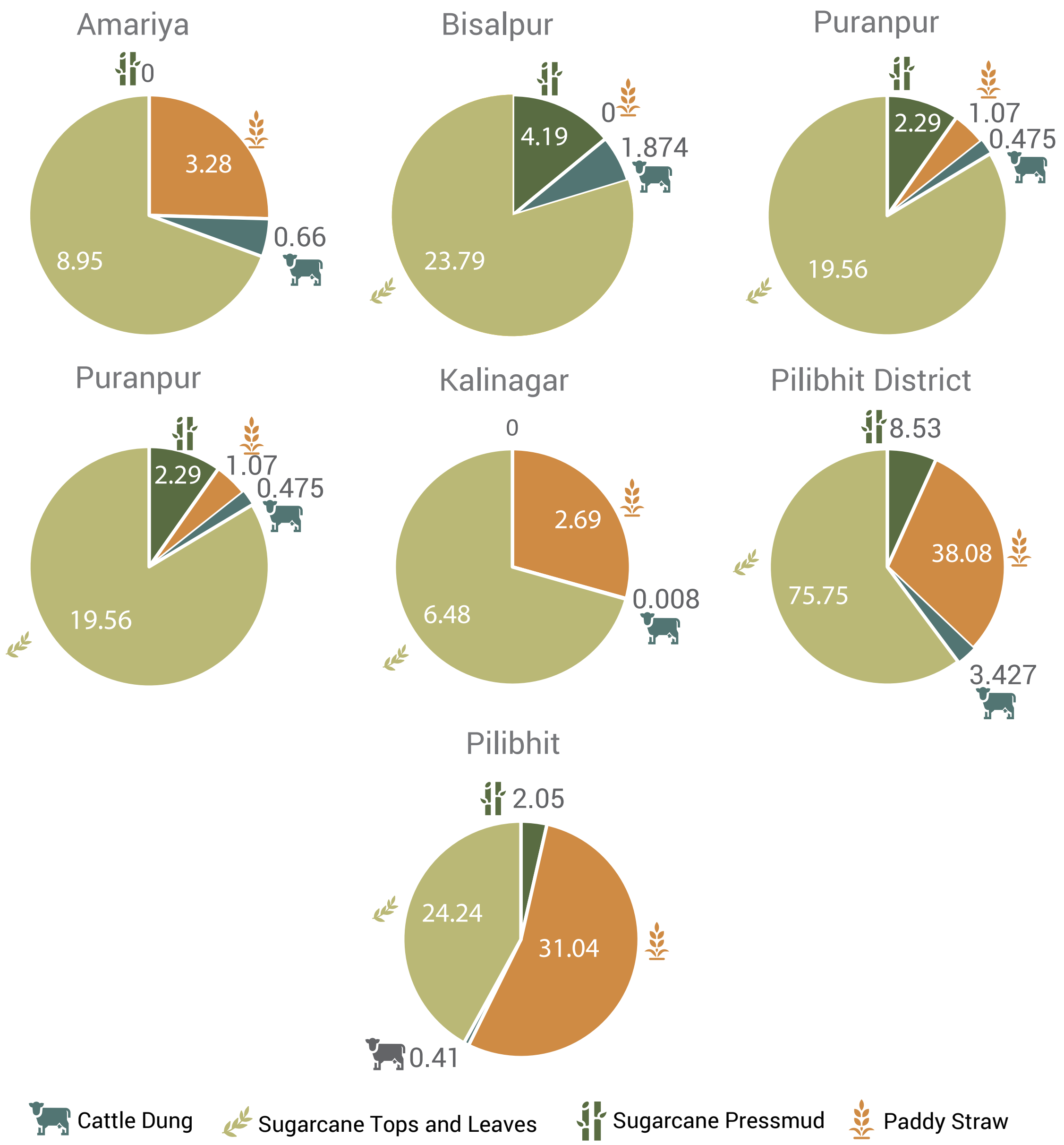


Figure 29: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per NIBE estimates)

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

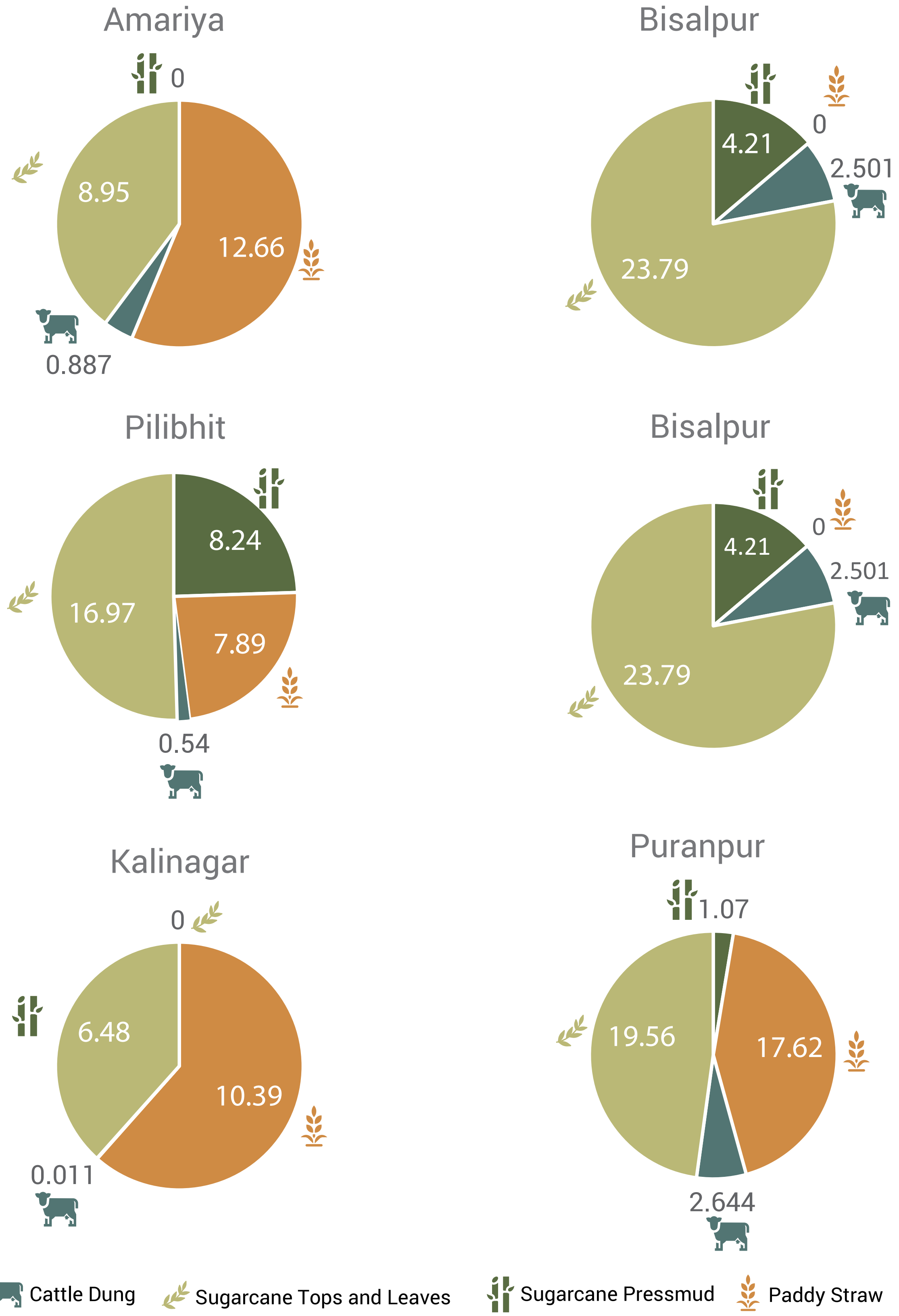


Figure 30: Tehsil-wise Daily CBG generation potential for major feedstocks: Paddy Straw, Cattle Dung, and Sugarcane Press mud (as per SATAT estimates)

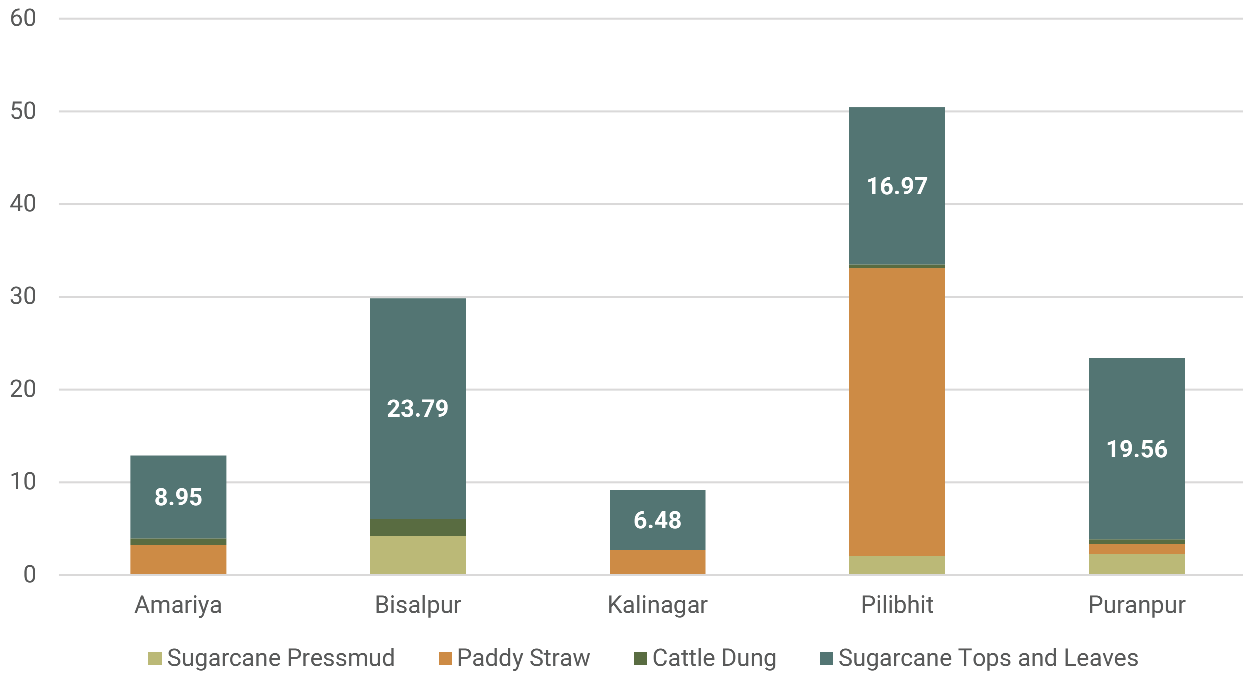


Figure 31: CBG potential from major feedstocks (NIBE estimates)

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.

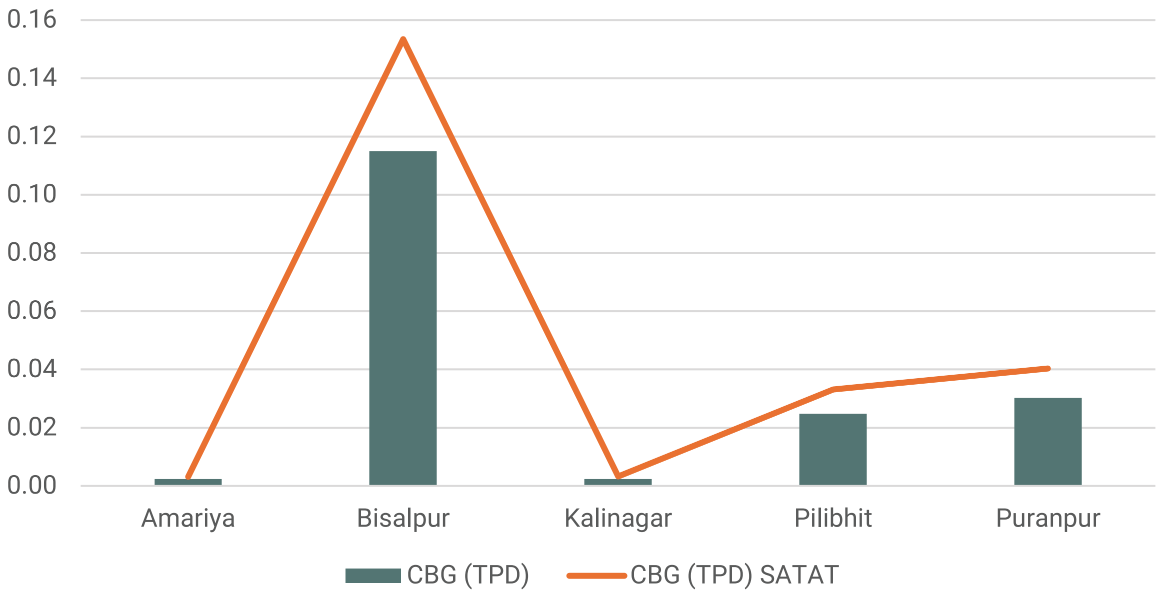


Figure 32: Tehsil-wise CBG potential from cattle in Cowsheds

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 29) including 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.

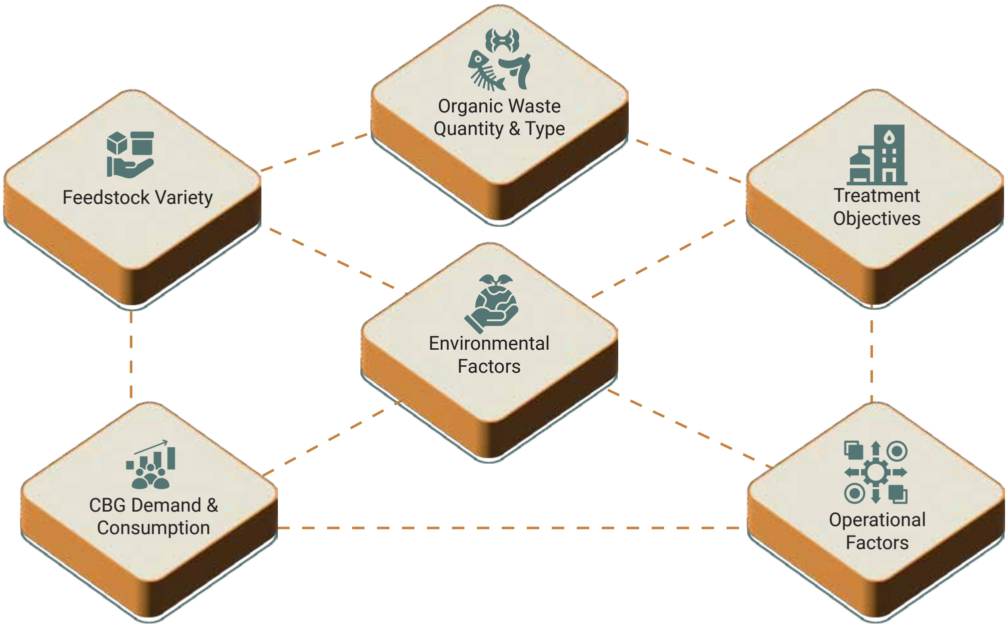


Figure 33: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

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 Pressmud	Paddy Straw	Cattle Dung	Sugarcane Leaves
Amariya	0	3.28	0.66	8.95
Bisalpur	4.19	0	1.874	23.79
Kalinagar	0	2.69	0.008	6.48
Pilibhit	2.05	31.04	0.41	16.97
Puranpur	2.29	1.07	0.475	19.56
Pilibhit District	8.53	38.08	3.427	75.75

SATAT – CBG potential (in TPD) feedstock-wise in each tehsil

Tehsil	Sugarcane Pressmud	Paddy Straw	Cattle Dung	Sugarcane Leaves
Amariya	0	12.66	0.887	8.95
Bisalpur	4.21	0	2.501	23.79
Kalinagar	0	10.39	0.011	6.48
Pilibhit	8.24	7.89	0.54	16.97
Puranpur	1.07	17.62	2.644	19.56
Pilibhit District	13.52	48.56	6.583	75.75

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, Pilibhit district has a CBG potential of approximately 165 TPD based on the biomass available during the year 2023-24. Out of all the Tehsils, Pilibhit has the highest potential for CBG production with sugarcane leaves contributing to 40 percent of the total feedstock. Bisalpur leads after Pilibhit on the potential CBG capacity with both sugarcane leaves contributing as the major feedstock. 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

Recommendations

1. Pilibhit has a high theoretical potential for CBG with sugarcane pressmud, leaves 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.[91]
3. A beneficial, reliable, and transparent pricing and payment mechanism can incentivise collection and availability of biomass. This would establish a biofuel-led economy that can offer unique opportunities for farmers, enhance their regular incomes by turning waste into wealth. This additional stream of income can be particularly beneficial during times of market volatility or poor harvests of traditional crops and continue to drive economic growth at grassroot level.
4. Encourage farmers to use bio-slurry from CBG plants as an organic fertiliser to improve soil health and crop productivity. Implement comprehensive training programs to educate farmers on its benefits and proper application methods. Additionally, provide hands-on demonstrations and

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

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

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

92 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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