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ASSESSING BIOMASS AVAILABILITY AND COMPRESSED BIOGAS (CBG) POTENTIAL IN SITAPUR 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 Sitapur 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 Sitapur

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

- **Major Biomass Feedstocks**: Sugarcane press mud, paddy straw, cattle dung, and municipal solid waste.
- **High-Potential Zones**: Sitapur, Biswan, and Misrikh tehsils emerged as top biomass sources. Potential locations for CBG plants could be sited close to the sugar mills present in tehsils of Maholi, Sitapur, Laharpur, and Biswan, or in tehsils where the paddy cultivation is high, or both.
- **CBG Generation Potential**: The district has the potential to generate approximately 60 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

Tehsil	Sugarcane Press mud	Paddy Straw	Cattle Dung	Total
Biswan	5.51	2.14	3.61	11.26
Laharpur	1.83	1.87	2.548	6.248
Mahmudabad	1.78	2.86	2.532	7.172
Maholi	0.647	1.38	0.70	2.727
Misrikh	2.92	0.08	3.113	6.113
Sidhauli	0	2.39	2.924	5.314
Sitapur	15.55	1.54	4.018	21.108
Total	**28.237**	**12.268**	**19.445**	**59.942**

- **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 60 TPD CBG plants can abate 60,225 T CO_2 emissions annually[1].
  - In other words, 60 TPD of CBG can replace 60 TPD of CNG which will correspond to daily carbon emission savings of 165 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 sour ces like solar, wind and biomass[3] are gaining focus. Biomass energy not only meets 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 India's total final energy consumption, with a projected growth rate of 45 percent between 2023 and 2030.[4] India's abundant biomass availability (*See Fig.1* which describes the potential of biomass power in India), position 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

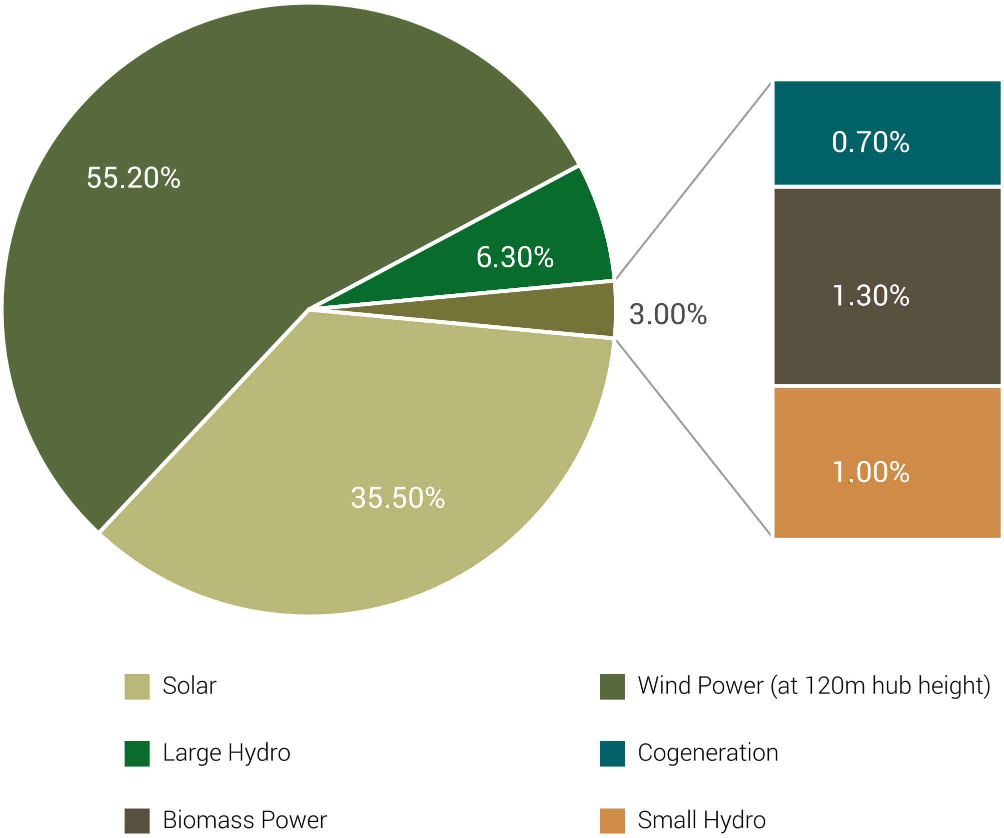


Figure 1: Source-wise renewable power potential in India, 2023[5,6]

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) including approximately 234.5 MT of surplus residues[12] annually.

In India, Uttar Pradesh is a leading agrarian[13] State (*See Fig.3*) and has the highest bio energy potential in India (See *Fig.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)

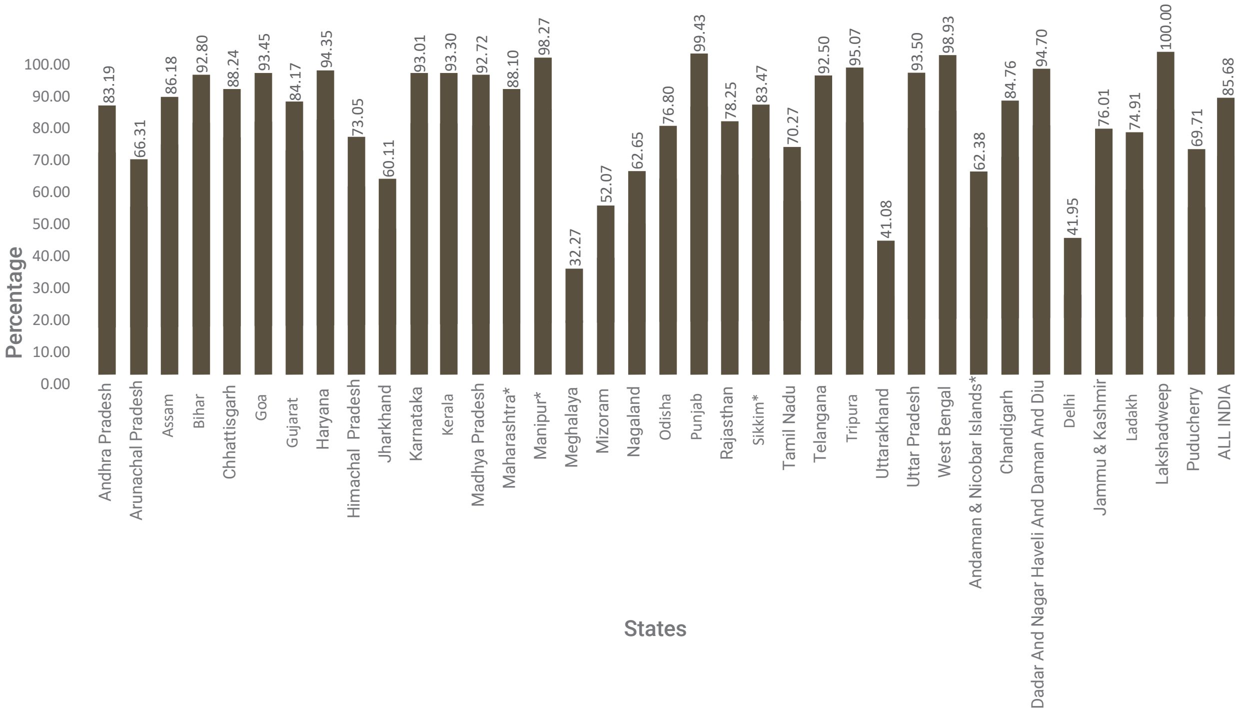


Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23[15]

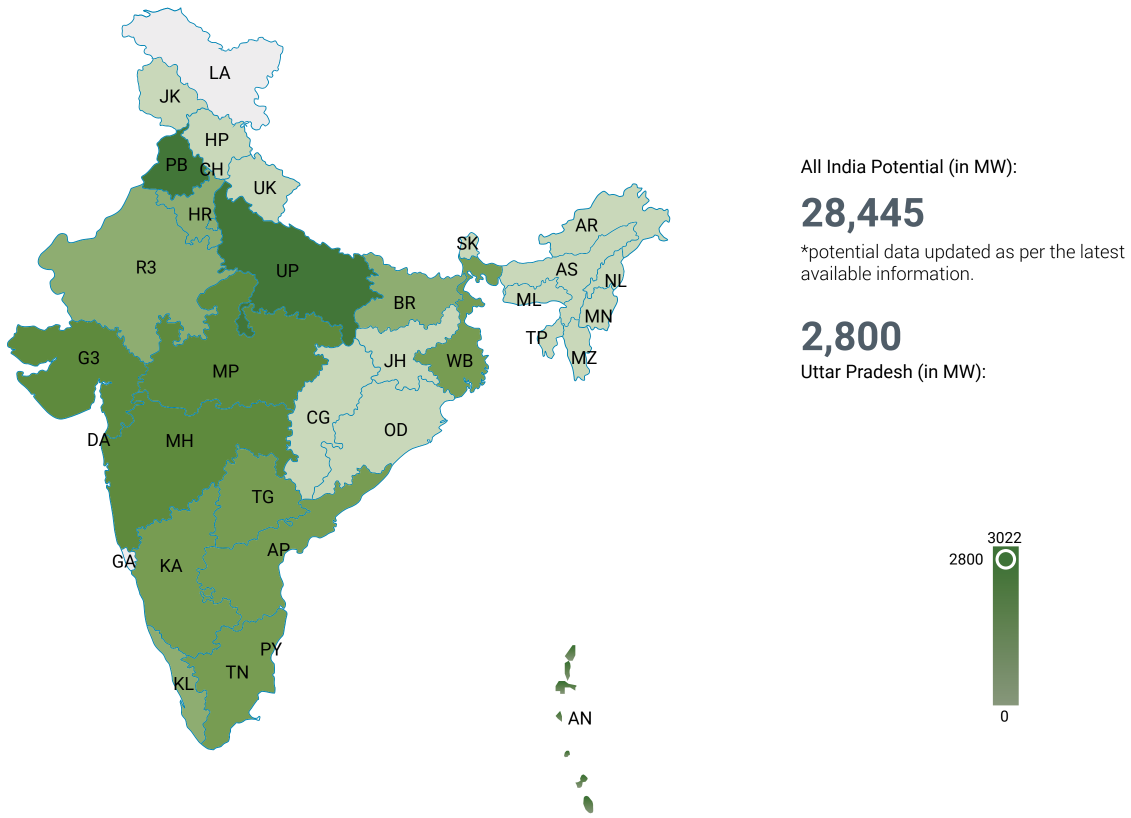


Figure 3: Biomass power potential in India[16]

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, has one of the highest total biomass and surplus biomass residue in India i.e., 124 MT and 21 MT,[17] respectively (See *Fig.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), they can enable CBG stakeholders to plan and execute projects that are commercially viable and sustainable.

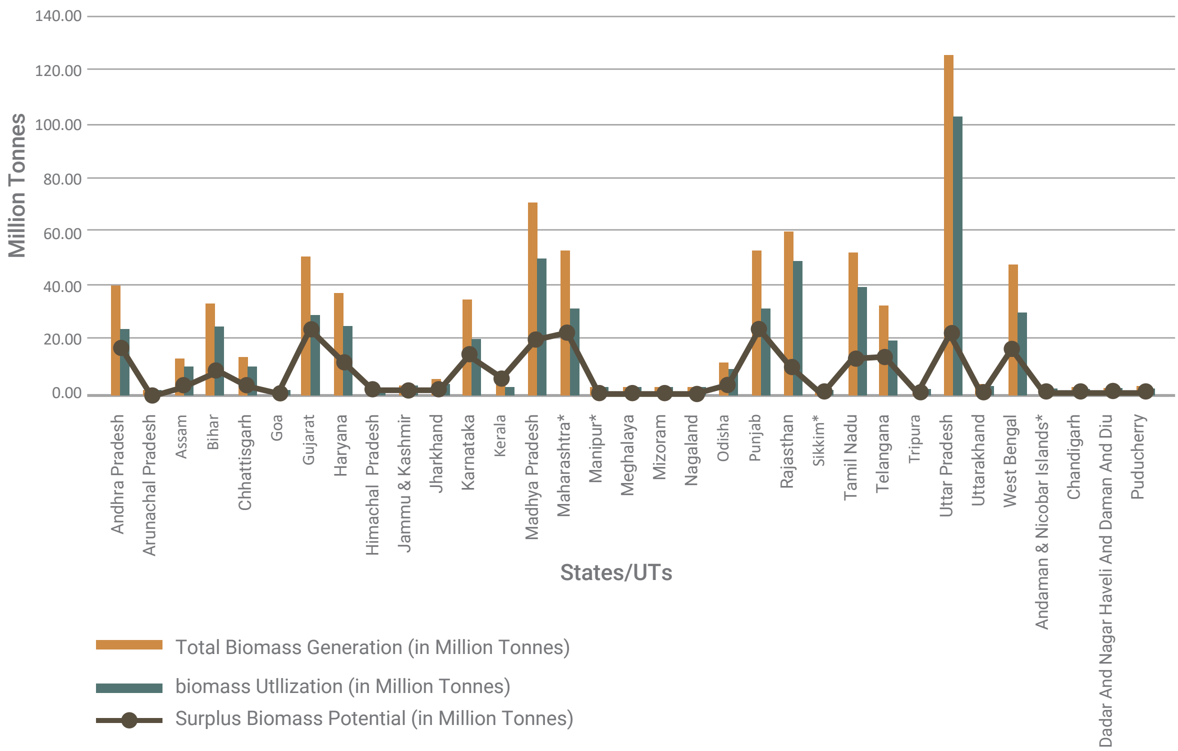


Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass[19]

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 (both commercial and household livestock) and crop residue (includes non-edible plant parts that are left in the field after the crop is harvested, thrashed or left after pastures grazed including stalk, stubbles, straws, bagasse, seed pods, and roots[20]
- Industrial waste and residue streams and other feedstocks

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 the reduction of GHG emissions is 30-35 percent greater compared to the food-based biofuels.[22]

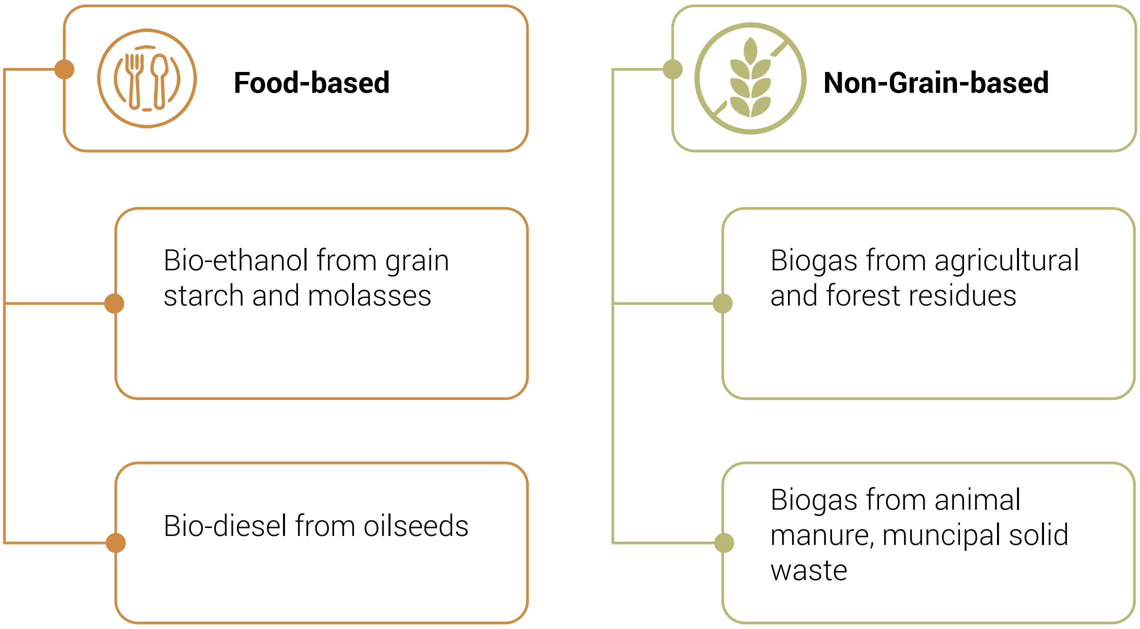


Figure 5: Classification of biofuels

2.1 Scope of the Study

This research aims to measure the actual net biomass residue production during 2023-24 across all seven tehsils (administrative subdivisions) of Sitapur district in Uttar Pradesh. The resulting data will help determine the appropriate capacity and number of CBG plants that can be sustainably established district-wide and 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, effluents and other wastes from industries such as paper and pulp, food processing, etc. It provides an *'as-is'* condition and excludes in its estimation, 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). The biomass residue usage patterns by sugar mill owners for their own self as well as the residues sold to others for industrial or agricultural purposes - are compiled to estimate the net available biomass residue.

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 where it can be procured).

Government agencies and industry developers/investors can utilise these biomass quantification findings to evaluate crop residue availability throughout the region. By providing detailed information on both quantity and specific types of crop residues (such as paddy straw and wheat husk) available in each area, the research supports the design and implementation of customised 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 a intricate biological process unfolfding 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 the transportation fuel to replace Compressed Natural Gas (CNG) or injected into gas grids as Compressed Biogas (CBG), which should meet IS 16087:2016 specifications of Bureau of Indian Standards (BIS). Table: 4 & 5 summarises 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-atvvtention-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. *Fig. 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 Fig. 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

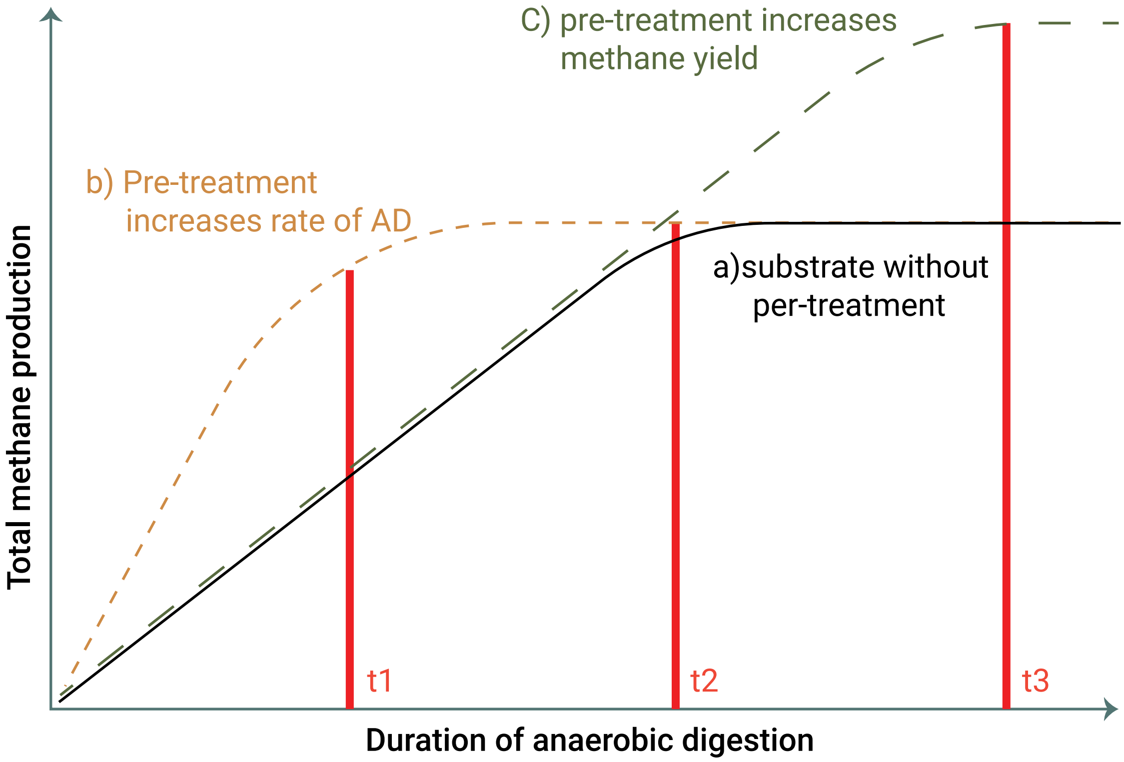


Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[28]

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 steam 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

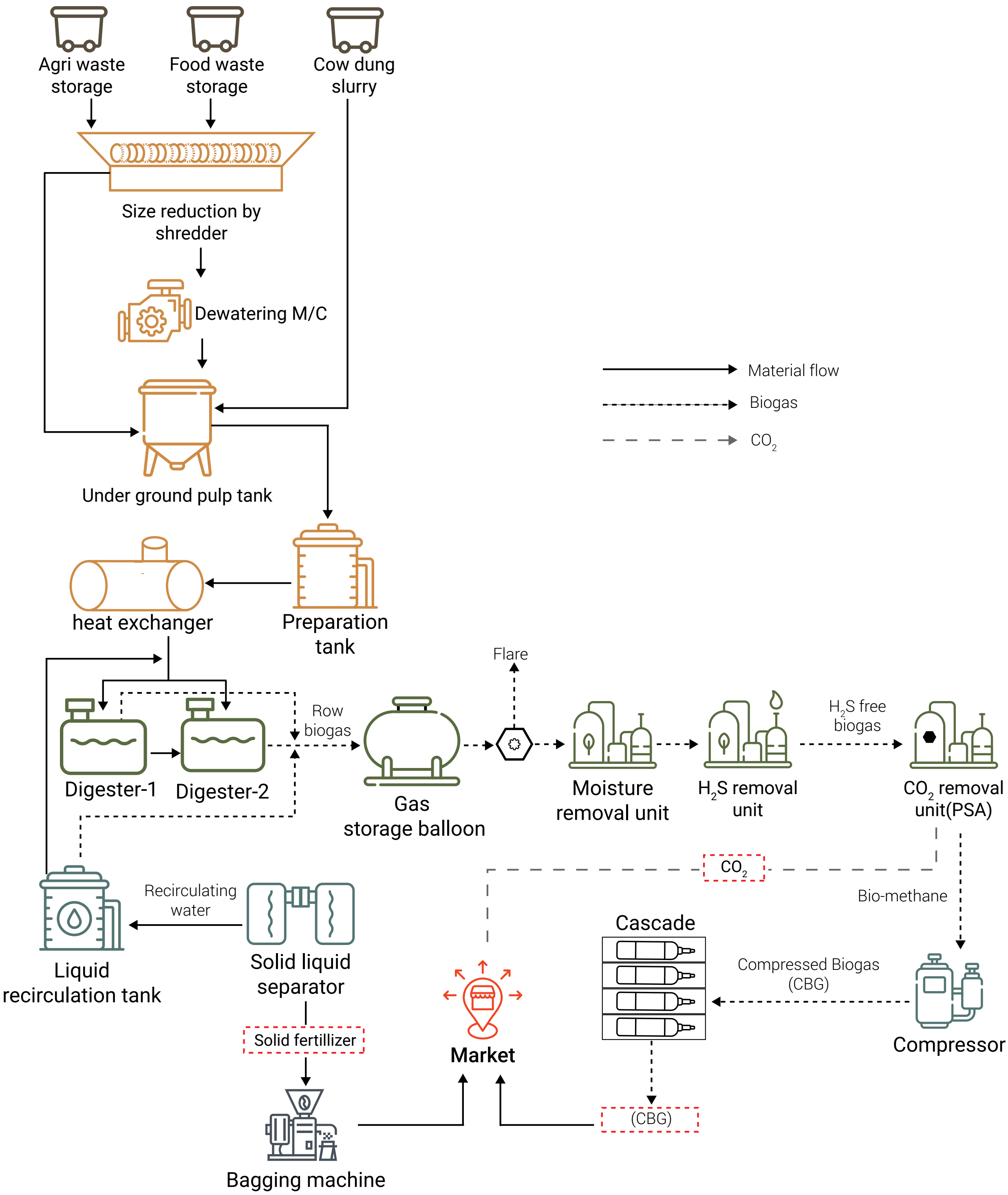


Figure 8: Processflow diagram for a Compressed Biogas Plant[30]

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 (Compressed Natural Gas) in transport and PNG (Petroleum Natural Gas) in City Gas Distribution (CGD) network[33]
- Under the National Bioenergy Programme, government has been promoting energy generation from urban/industrial/agricultural residues.

Among all states, Uttar Pradesh accounts for 24 percent of the total CBG generation potential in India[34] 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 Centre for Science and Environment (CSE) 2024, Compressed Biogas Landscape in Uttar Pradesh

03 District Profile

3.1 Geographic Overview

The District of Sitapur is located in Uttar Pradesh's Central Region and is bordered on the north by the Districts of Lakhimpur Kheri, Bahraich, Barabanki, and Hardoi. The district is situated in the central part of the Lucknow Division between 27.6^0 to 27.54^0 longitude in north of Lucknow and in between 80.19^0 to 81.24^0 latitude in east of Lucknow. Spanning a total geographical area of 5743 sq. km[35]. Sitapur is house to 4484,000 people as per the 2011 Census. Out of this total geographical area, rural area covers 5636.3 sq. km.

35 UP District Wise Development Indicators 2023, Economics and Statistics Division, State Planning Institute, Planning Department, Government of Uttar Pradesh

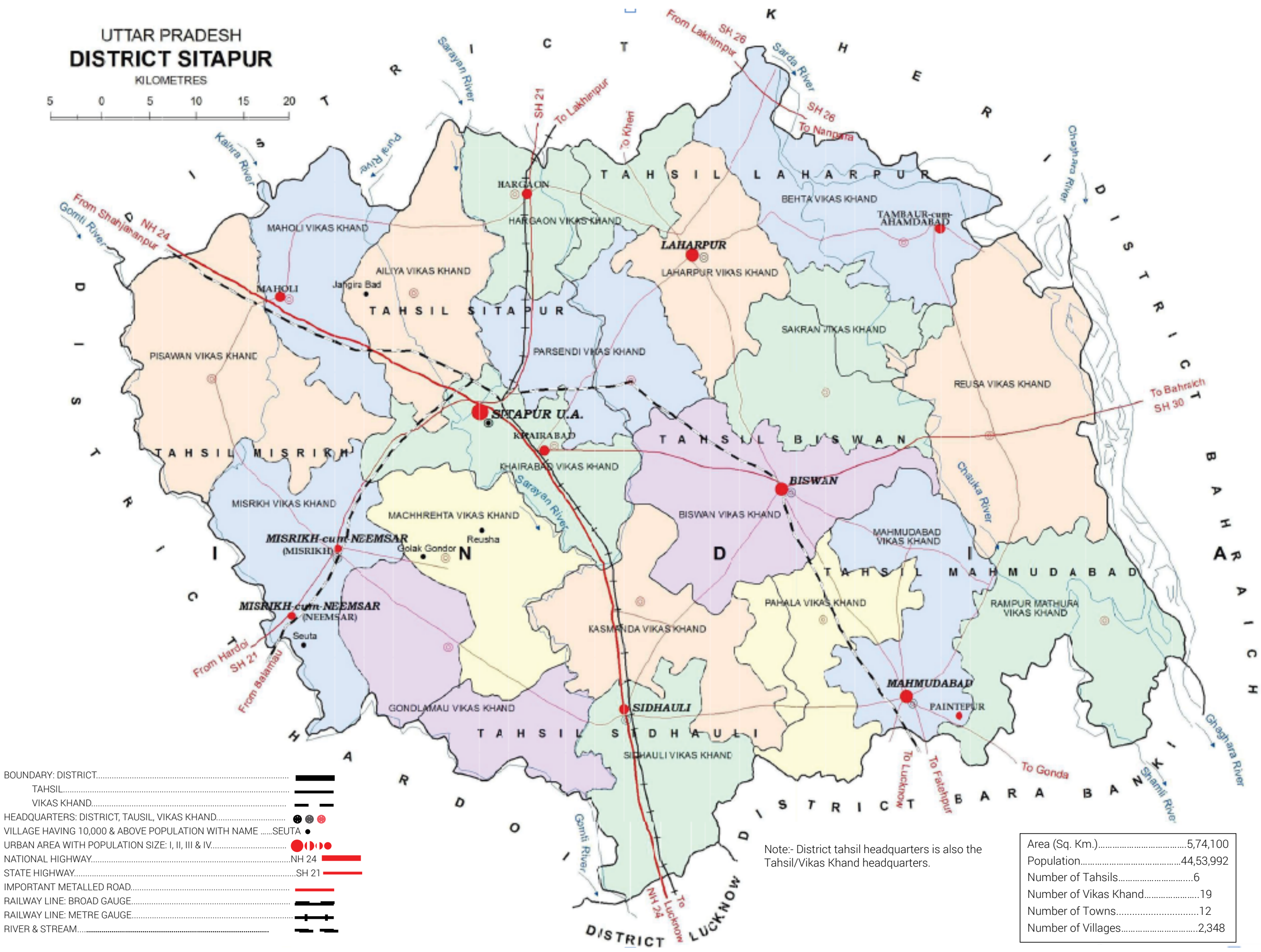


Figure 9: District map of Sitapur as per the 2011 Census[36]

Numerous streams and ravines divide the district. Gomti, Kathana, Pirai, Sarayan, Ghaghra, and Sharda are the five rivers that go through Sitapur. The riverbanks in Sitapur have sand which is used in construction works and making clay bricks. The district is predominantly an agrarian based economy with wheat, paddy and urad as the main crops and sugarcane, mustard and groundnuts as the cash crops. District Sitapur is a part of middle Ganga plain. On the basis of geology, soils, topography, climate and natural vegetation, the district is sub-divided into three sub-micro regions such as: Ghaghra-Chauka Khadar, Sitapur Plain (Central part of the district covering all the Tehsils), and Gomti Basin (Spreads over parts of Misrikh and Sidhauli Tehsils)

The principal large-scale industries of the district are sugar, glass, distilleries, and plywood. The principal cottage industries are agriculture implements, iron castings, cane-crushers, etc.

3.2 Administrative Units (Tehsils/Blocks)

For administrative convenience, the district[37] is divided into 7 Tehsils which are: Sidhauli, Sitapur, Mahmudabad, Misrikh, Biswan, Laharpur, and Maholi. There are 19 blocks in the district.[38] For effective

36 District Census Handbook, Sitapur, Census of India 2011 Part XII-B

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

38 P, Kumar, N. N, Kumar, and S, Shukla. 2022, Acreage Estimation of Sugarcane Crop in Sitapur District, Uttar Pradesh using Optical Remote Sensing Data, International Research Journal of Engineering and Technology (IRJET), Vol. 09, Issue 05

monitoring and implementation of rural development, the district is further divided into 19 community development blocks. There are 1329 Gram Panchayats, 6 Municipalities (Nagar Palika) and 5 Municipal Councils (Nagar Palika Parishad).

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

Tehsil	Total Revenue Villages
Sitapur	373
Biswan	347
Laharpur	331
Mahmudabad	354
Maholi	320
Misrikh	326
Sidhauli	319
Total	2370

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 Sitapur.

Table 7: District agricultural and climate profile of Sitapur

District Agricultural and Climate Profile	
Agro-Ecological Sub Region[39] (ICAR[40])	Agro-Eco Region 09
Agro-Climatic Zone[41] (State Agricultural Profile[42])	Mid-Western Plain Zone
Rainfall[43]	

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: Sitapur, 2019, Department of Agriculture and Farmers' Welfare

District Agricultural and Climate Profile				
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Southwest Monsoon (June-September)	989 mm	46	2nd week of June	4th week of September
Post-monsoon (October-December)	52.3	10	-	-
Winter (January-March)	47.6	-	-	-
Pre-monsoon (April-May)	24.3	-	-	-
Annual	974.0	56	-	-
Temperature (in degree Celsius)[44]	**Maximum** 45.3		**Minimum** 3.6	
Soil	Deep, fine soils moderately saline and sodic associated			
Major Climate Contingency and Frequency	**Regular**	**Occasional**		**None**
Drought				
Flood		√		
Cyclone				
Hailstorm		√		
Heat wave		√		
Cold wave		√		
Frost		√		

A report[45] which measured district-level climate vulnerabilities in India highlighted that Sitapur district in Uttar Pradesh (0.694[46]) scored the highest value (as described in the Fig. 11) in vulnerability index and the major drivers of vulnerability include high % of marginal and small operational holders, low % area covered under centrally funded crop insurance, lack of forest area per 1000 rural population, etc.

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

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

46 Indicators used for District-level Assessment include Livestock per 1000 rural households, % of marginal and small operational holders, Forest area (in ha) per 1000 rural population, Yield variability of food grain, health infrastructure, etc.

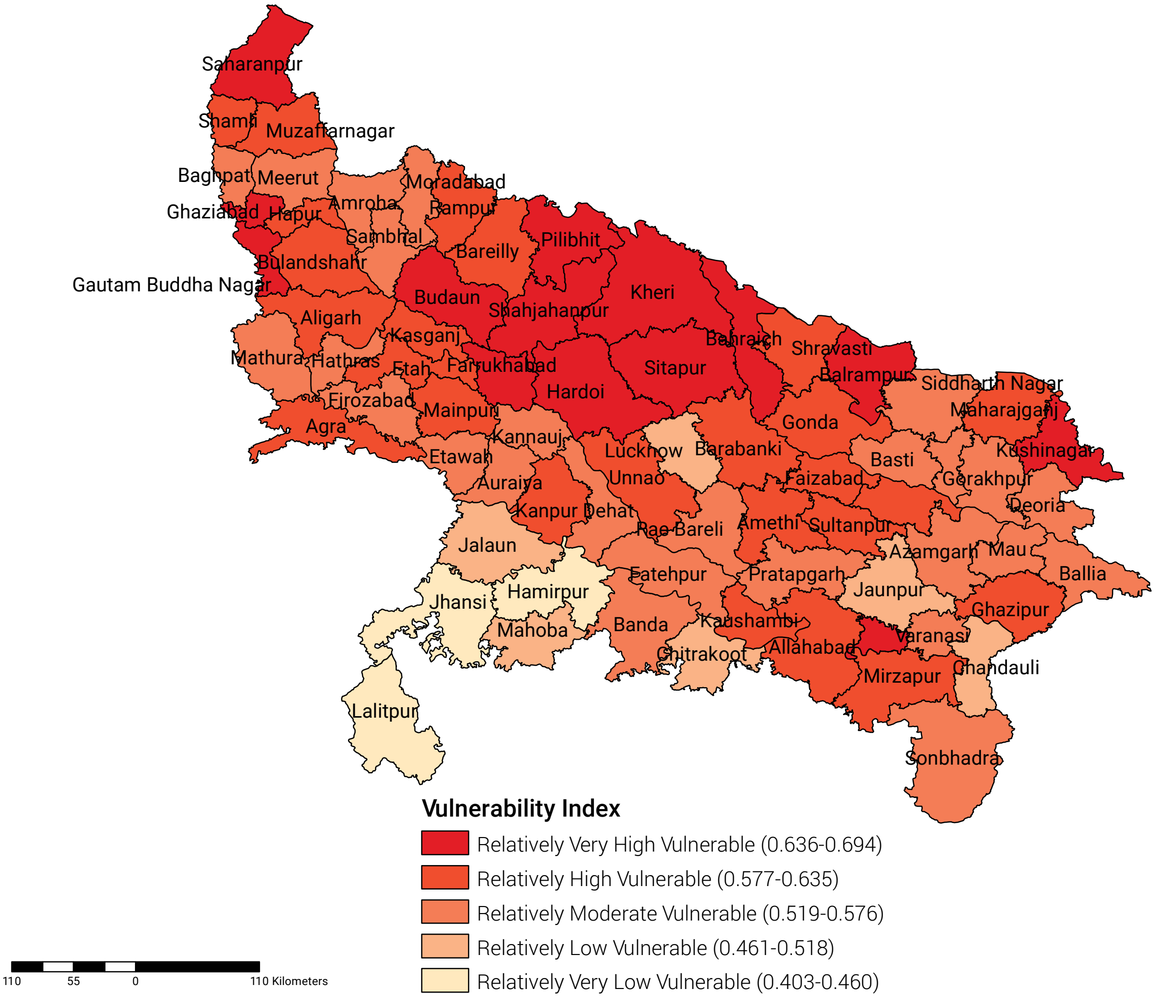


Figure 10: District-wise climate vulnerability index

On the basis of soil, climate, topography, vegetation, and crops, Uttar Pradesh has been divided into nine agro-climatic zones. Sitapur is located in the Mid-Western Plain Zone (as described in *Fig. 12*) and records high productivity of food grains as seen in the table 8:

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

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

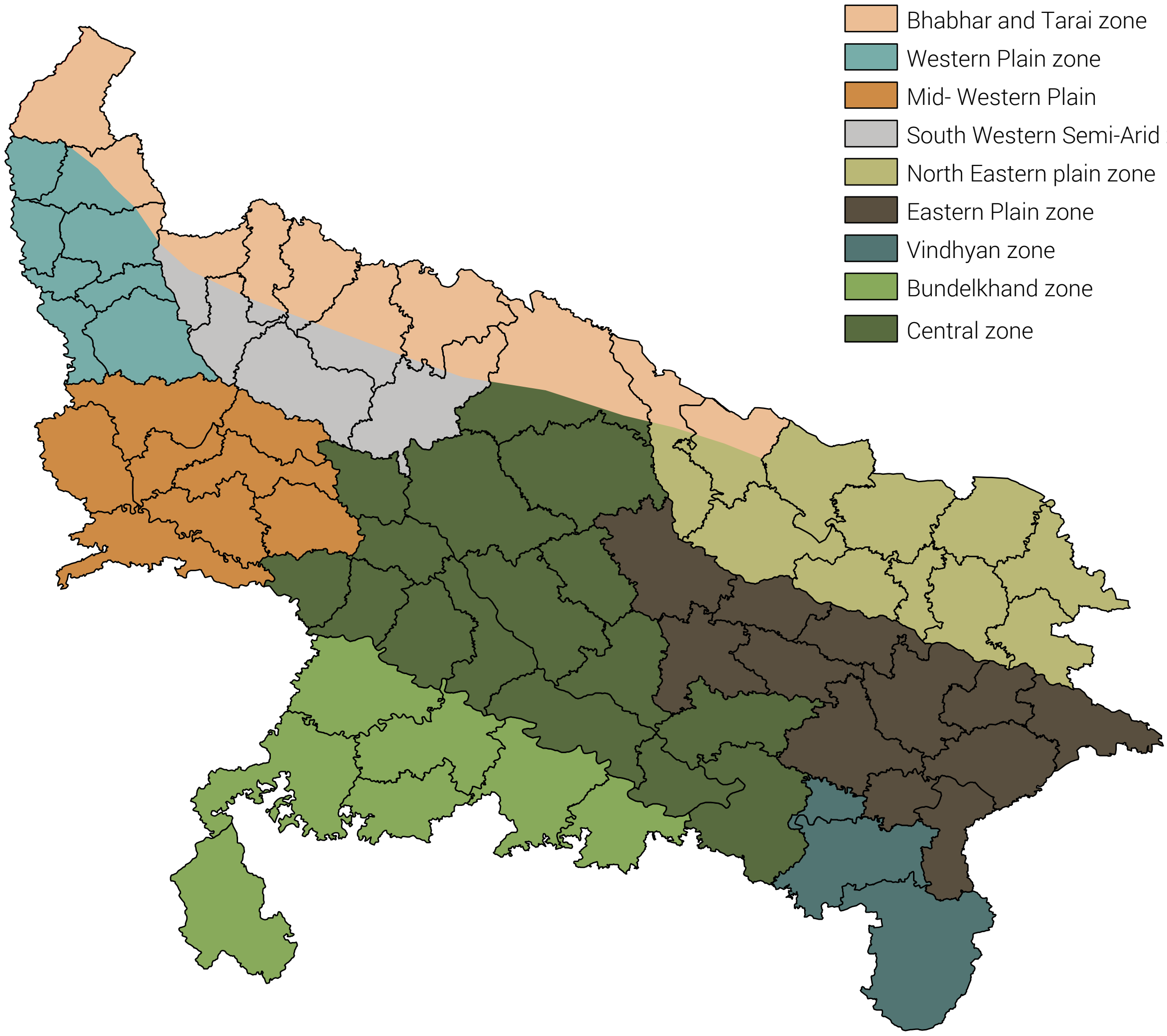


Figure 11: Agro-climatic zones in Uttar Pradesh[47]

3.4 Demographics (Urban/Rural)

The total population of Sitapur is 4,483,992 with over 88 percent comprising of rural population and 11.8 percent live in urban areas. Agriculture is the primary occupation in the district with over 70 percent involved either as cultivators or agriculture labourers. [52]

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.

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

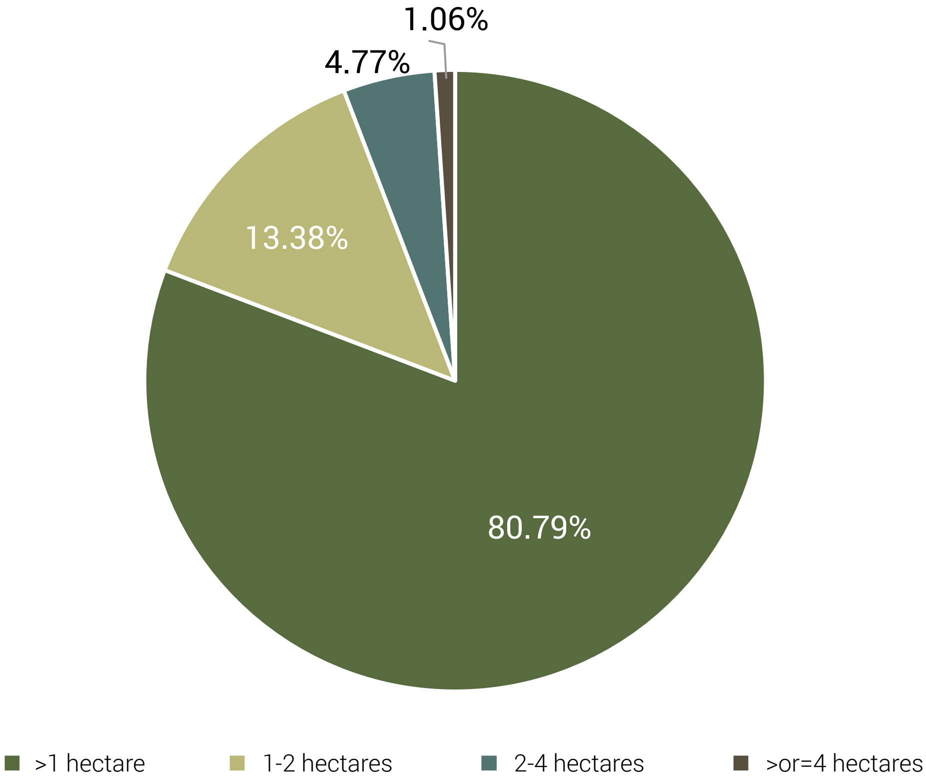


Figure 12: Agricultural land holdings in Sitapur[48]

3.5 Agricultural Overview

Sitapur is one of the predominantly agricultural districts of the State. At the district-level, 95.49 percent area is cultivated, out of which 87.71 percent of total cultivable area has got irrigation facility.[49] As discussed in the previous section, the majority of population in the district are dependent on agriculture.

3.5.1 Total Agricultural Area[50]

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

Agricultural Land Use	Area (‘000 ha)	Cropping Intensity (%)
Net sown area	436.01	133.63%
Area sown more than once	227.1	
Gross cropped area	663.1	

48 Uttar Pradesh Statistical Diary, Economics and Statistics Division, Planning Department, Government of Uttar Pradesh
49 District Census Handbook for Sitapur, 2011
50 District Profile, Krishi Vigyan Kendra, Sitapur

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, 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 popular in the state include sugarcane, potato, and more. Double cropping was practised to obtain more yield in the district. *Fig. 14* describes the extent of land use in terms of gross area sown for *Kharif* and *Rabi* crops in Sitapur District during 2021-22.

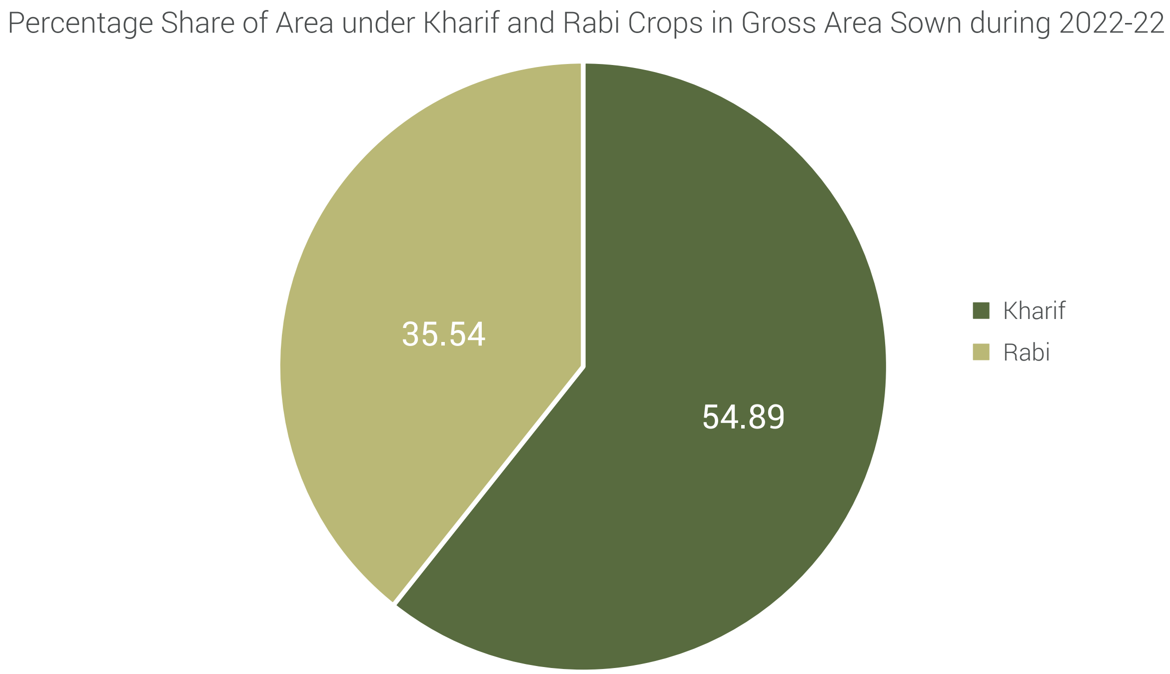


Figure 13: Gross area sown during both the cropping seasons in Sitapur[51]

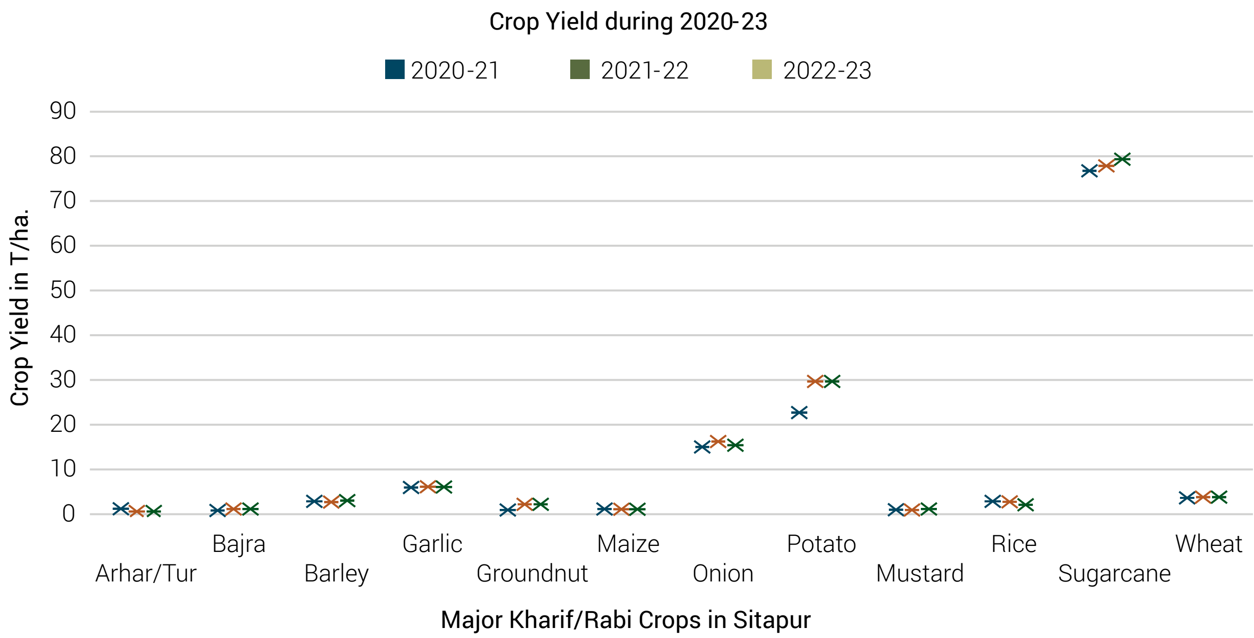


Figure 14: Crop yield during 2020-23 for major crops sown in Sitapur during *Kharif* and *Rabi*

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 the period from September to October. In Sitapur district, during 2023-24, the prominent rabi crops were wheat and mustard where wheat alone occupied 53 percent of the total cropped area. Other rabi crops include potato, barley, etc. that were sown and cultivated during the same period.

Table 10: Tehsil-wise cropped area of *Rabi* crops (in ha.) during 2023-24[52]

Tehsil	Mustard	Other Crop[53]	Potato	Sugarcane	Vegetable	Wheat	Total Area
Biswan	9911.99	904.18	749.82	6524.78	736.42	26817.79	51975.70
Laharpur	8696.01	877.76	558.43	6805.22	456.89	22034.79	46835.37
Mahmudabad	9697.09	131.37	1160.95	3264.36	816.15	30019.53	47447.57
Maholi	7253.91	529.63	486.98	5219.64	44.77	20752.69	43933.16
Misrikh	4925.51	761.34	285.30	5776.93	151.91	18307.96	37190.91
Sidhauli	5301.87	466.48	349.81	3079.66	248.77	29776.39	40994.99
Sitapur	5919.81	719.24	90.18	6218.25	76.54	17621.53	38866.31
Total	**51706.20**	**4390.00**	**3681.46**	**36888.82**	**2531.45**	**165330.69**	**307244.01**

52 Analysis by Vasudha Foundation, 2025

53 Other Crop here means majorly Bajra

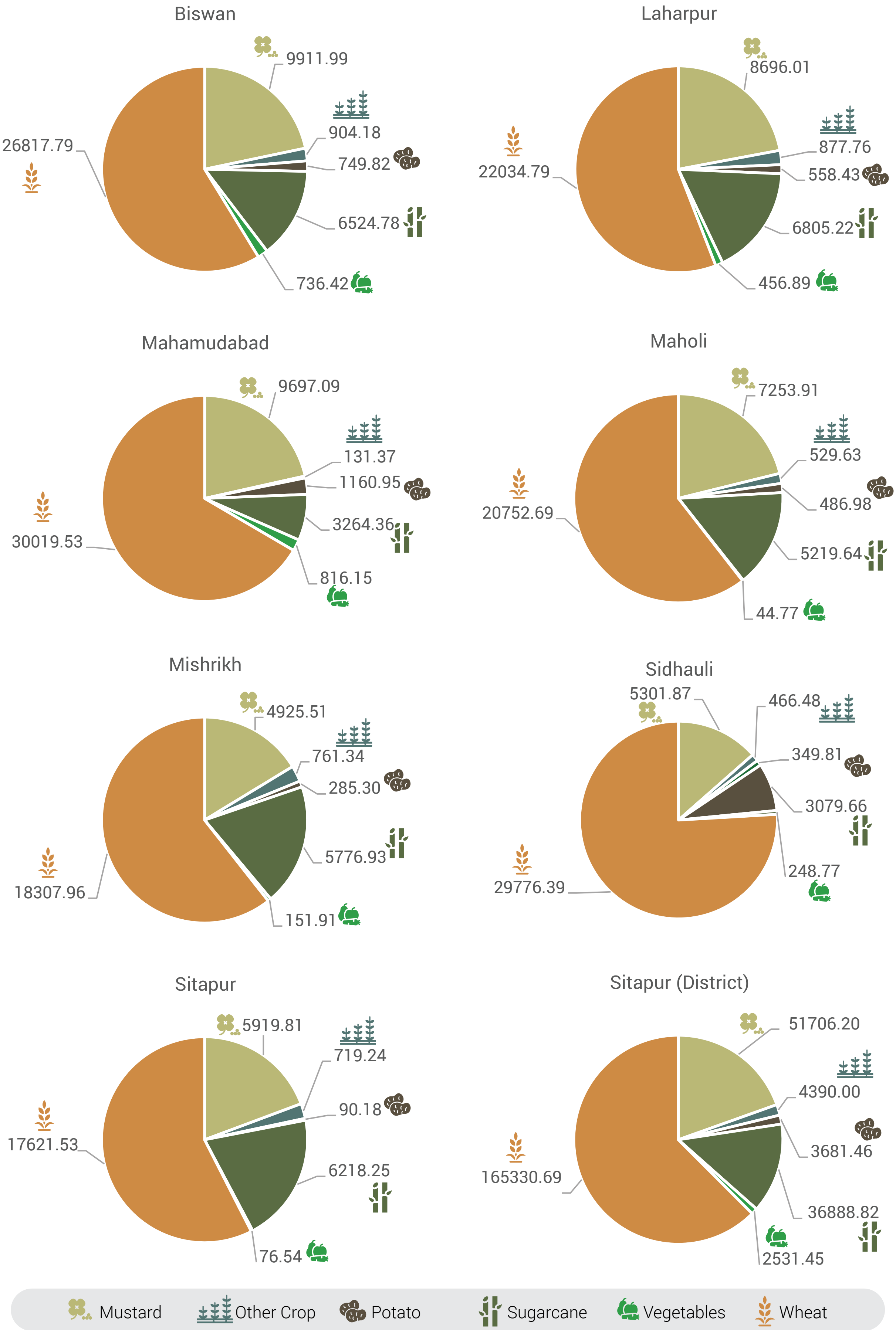


Figure 15: Tehsil-wise acreage estimation of *Rabi* crops sown during 2023-2024

During 2023-24, the prominent *Kharif* crops in Sitapur were sugarcane and paddy where together they comprised 85 percent of the total cropped area. Other major kharif crops include bajra and maize that were sown and cultivated during the same period. Among all tehsils, Mahmudabad had the highest share of cropped area for paddy while Laharpur dominated in cultivation of sugarcane, followed by Biswan, Maholi and Misrikh.

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

Tehsil	Agri-plantation	Maize	Paddy	Pulses	Sugarcane	Total
Biswan	4852.11	1862.40	17764.16	749.89	32466.98	57695.54
Laharpur	4474.15	1637.99	15507.14	566.18	37513.65	59699.10
Mahmudabad	2443.46	1012.56	23777.24	1749.41	18897.32	47879.98
Maholi	1828.34	567.68	11422.92	1282.72	32750.60	47852.27
Misrikh	5356.34	1947.06	14056.24	1738.64	26158.85	49257.13
Sidhauli	5422.32	5475.29	19819.65	2667.42	10506.01	43890.69
Sitapur	4760.59	1424.15	12776.99	828.48	26821.11	46611.32
Total	**29137.33**	**13927.12**	**115124.33**	**9582.73**	**185114.53**	**352886.05**

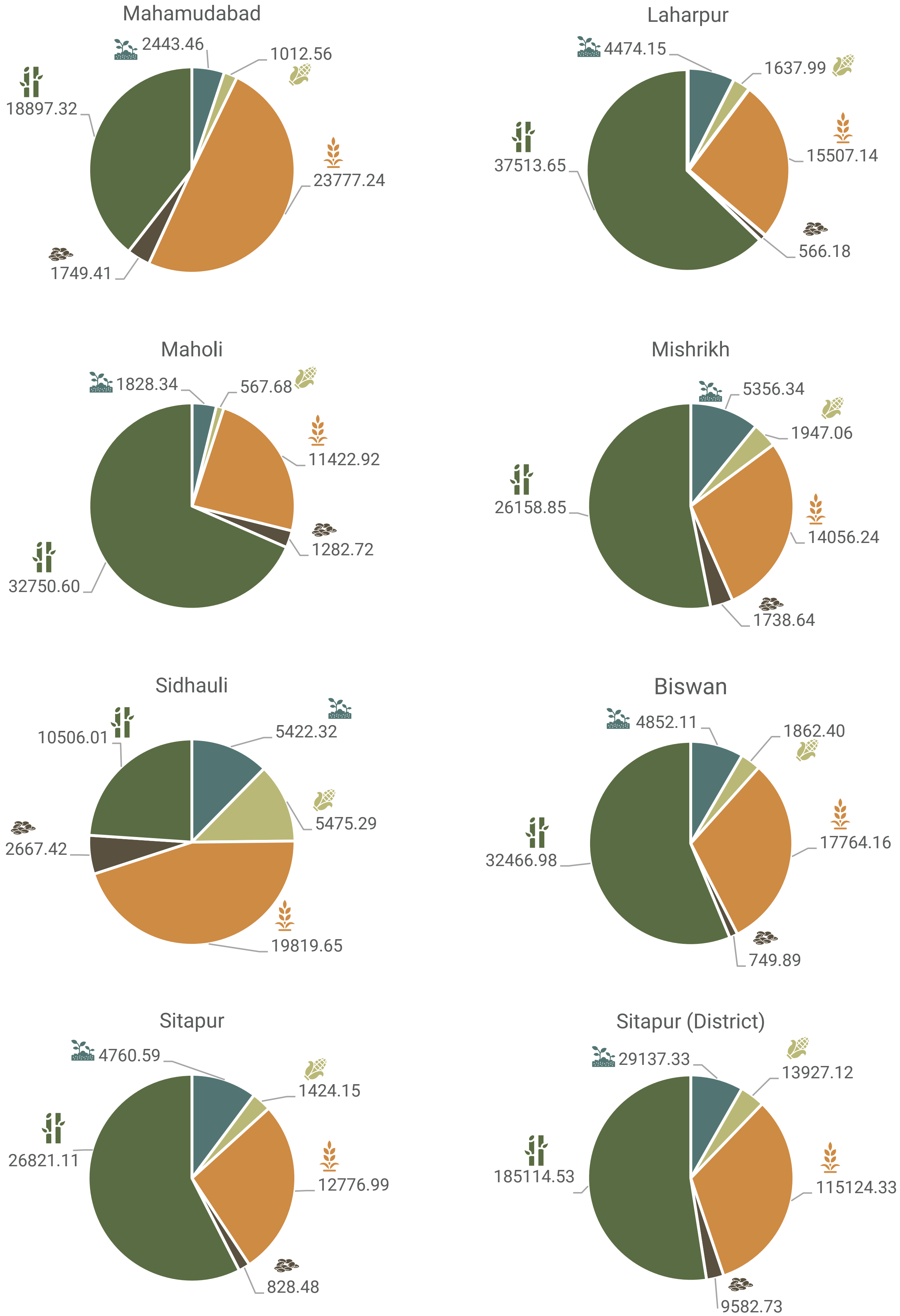


Figure 16: Tehsil-wise acreage estimation of *Kharif* crops sown during 2023-2024

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

In Sitapur, the percent of irrigated area to the total cultivable area is 87.71[54]. The gross irrigated area of the district is at 704,000 ha. During 2021-22, 1,07,976 ha. of land in Sitapur was affected by floods and rains.[55]

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	-	2nd week of July to last week of August	-	1st week of July to 3rd week of July	1st week of July to last week of July		
Kharif – Irrigated	1st week of July to 1st week of August	-	2nd week of February to last week of March	1st week of June to 1st week of July	1st week of June to 1st week of July		
Rabi – Rainfed	-	-	-	-	-	1st week of September to 2nd week of October	-
Rabi – Irrigated	-	-	-	-	-	-	2nd week of November to 2nd week of December

3.6 Forest Resources

3.6.1 Total Forest Area[56]

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

District	Calculated Area (km^2)	Very Dense Forest (km^2)	Moderate Dense Forest (km^2)	Open Forest[57] (km^2)	Total (km^2)	Scrub[58] (km^2)
Sitapur	5743	0	18.77	182.4	201.7	4.62

54 District Census Handbook for Sitapur, 2011

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

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

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

58 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)

The forest 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 are Banyan, Gular, Pakar, Fig, Vaska which are found in the district.

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, collectively)[59]. To produce a stream of biomethane of high purity, this syngas is cleaned to remove any acidic and corrosive components. Therefore, woody biomass which consists 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 given the technology and the economics, it is not suitable for the commercial biogas generation.[60]

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.[61] The continuous rise in the population of animals has also led to significant increase in livestock residues. Uttar Pradesh also has one of the highest number of livestock among all states.

3.7.1 Cattle, Poultry, and Other Livestock Statistics

Table 14: Tehsil-wise livestock statistics have been collected, and their manure and waste generation potential[62]

Tehsil	Cattle	Goat/Sheep	Swine	Poultry (Chicken)
Biswan	91882	103570	980	50000
Laharpur	64784	61609	453	20000
Mahmudabad	64396	83744	358	39000
Maholi	18023	13299	146	30000
Misrikh	79275	55956	480	135000
Sidhauli	74366	67795	646	123000
Sitapur	68354	68600	604	140000
Total	**461080**	**454573**	**3667**	**537000**

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

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

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

62 Animal Husbandry Department, Government of Uttar Pradesh

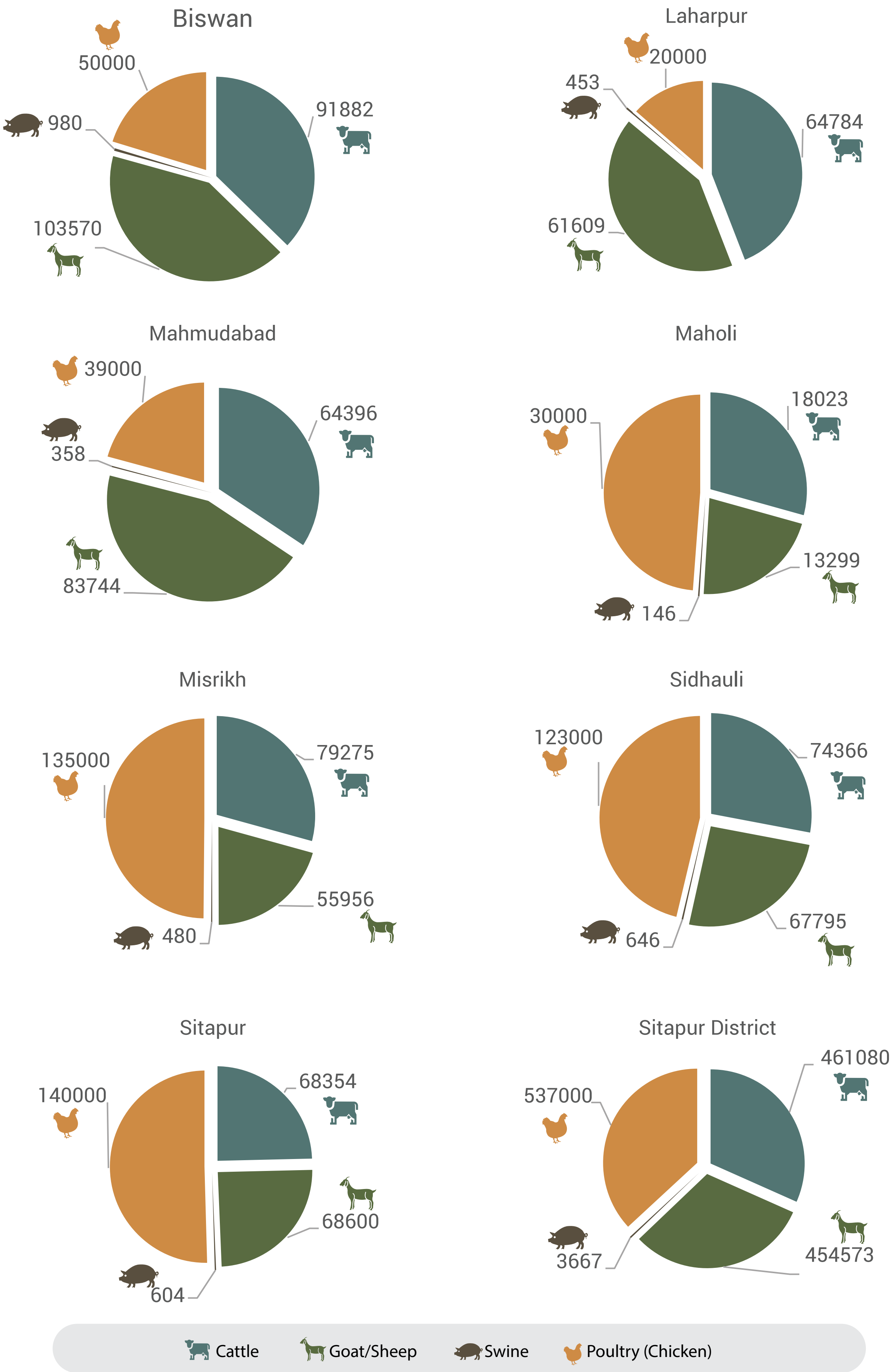


Figure 17: Tehsil-wise livestock count in Sitapur

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 family biogas and small biogas plants. Based on the existing literature[63,64,65,66] 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 18: Traditional use of cow-dung as kitchen fuel and manure[67]

63 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

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

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

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

67 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 Misrikh Tehsil. It is proposed to be operational by October 2025. The plant specifications are as follows:

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

Plant Capacity	Feedstock/ Raw Material	By-Products	Off taker	Procurement Plan
3 Tonnes Per Day (TPD)	Pressmud,[68] Cattle Dung, Paddy Straw, Napier Grass	Solid Fertiliser (17,600 Kg/day, Liquid Fertilizer (25,000 Litres/ day)	CBG sold to Indian Oil Corporation Limited at INR 70 per Kg under SATAT Scheme	Pressmud is to be procured from neighbouring Large Sugar Mill; Cow dung will be procured at 10-15 TPD; Paddy Straw at 40-50 TPD in the absence of Press mud when the Sugar Mills are not operational; Napier Grass is to be grown and fed along with Paddy straw as a combination feedstock; The plant has planned to stock 4200 T of Press mud (with useful life of 2 months) in a year and 1200 T of Paddy Straw as reserve;
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 Maholi Tehsil (under GOBARdhan)
45 MPD	Cattle Dung	Bio-slurry	Biogas used for heating purposes in cowshed	Commercial-scale biogas plant installed and functional inside a cowshed facility in Sitapur Tehsil (under GOBARdhan)

The feedstock procurement plan for the 3 TPD under-construction CBG plant is described below:

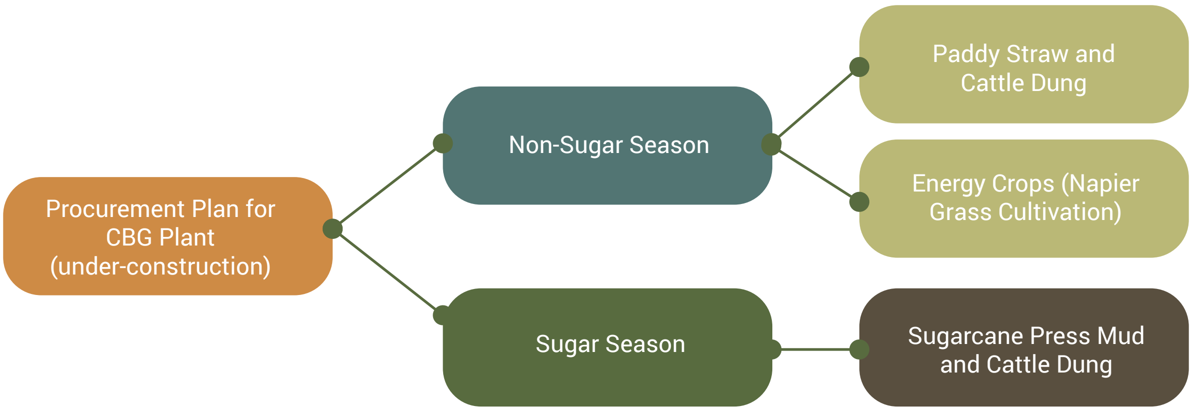


Figure 19: Feedstock procurement plan for existing CBG plant[69]

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

69 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 20: **Construction site of the CBG plant in Misrikh**

04 Data Collection

4.1 Primary Data Collection

Primary data sets of land cover, usage, and cropping pattern of specified timeframe 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 however, 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 generation, 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[70]
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[71])	150 days
Number of Operating Days (Medium Sugar Mill[72])	150 days

Figure 21: A small vertical crusher sugar mill in Sitapur District

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:

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

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

72 Medium Sugar Mills use Horizontal Crushers to crush Sugarcane

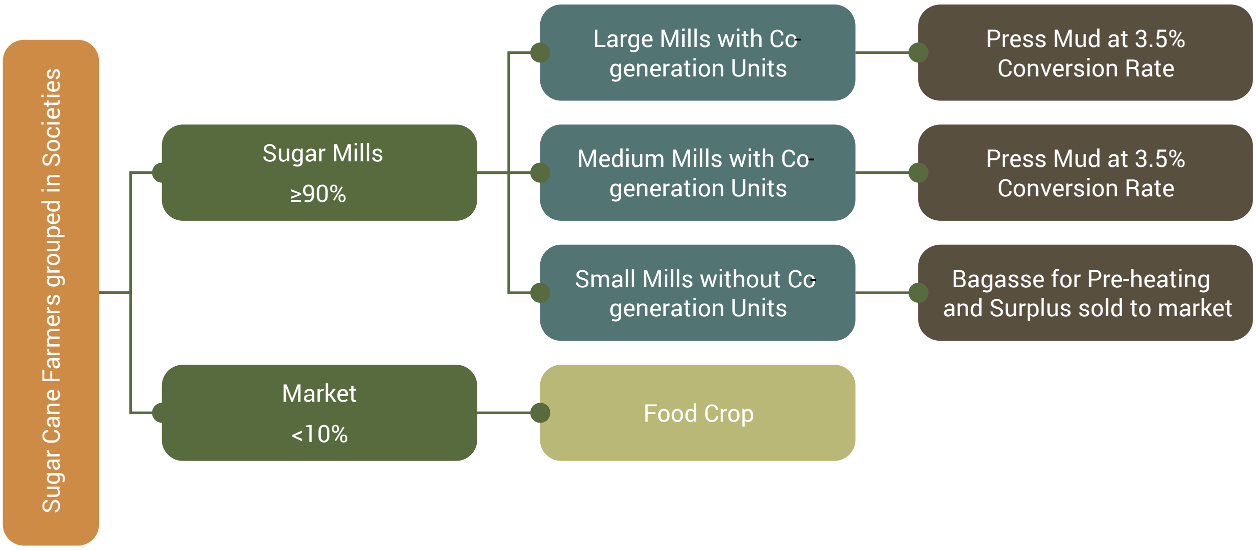


Figure 22: Mapping the value chain of sugar industries

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.

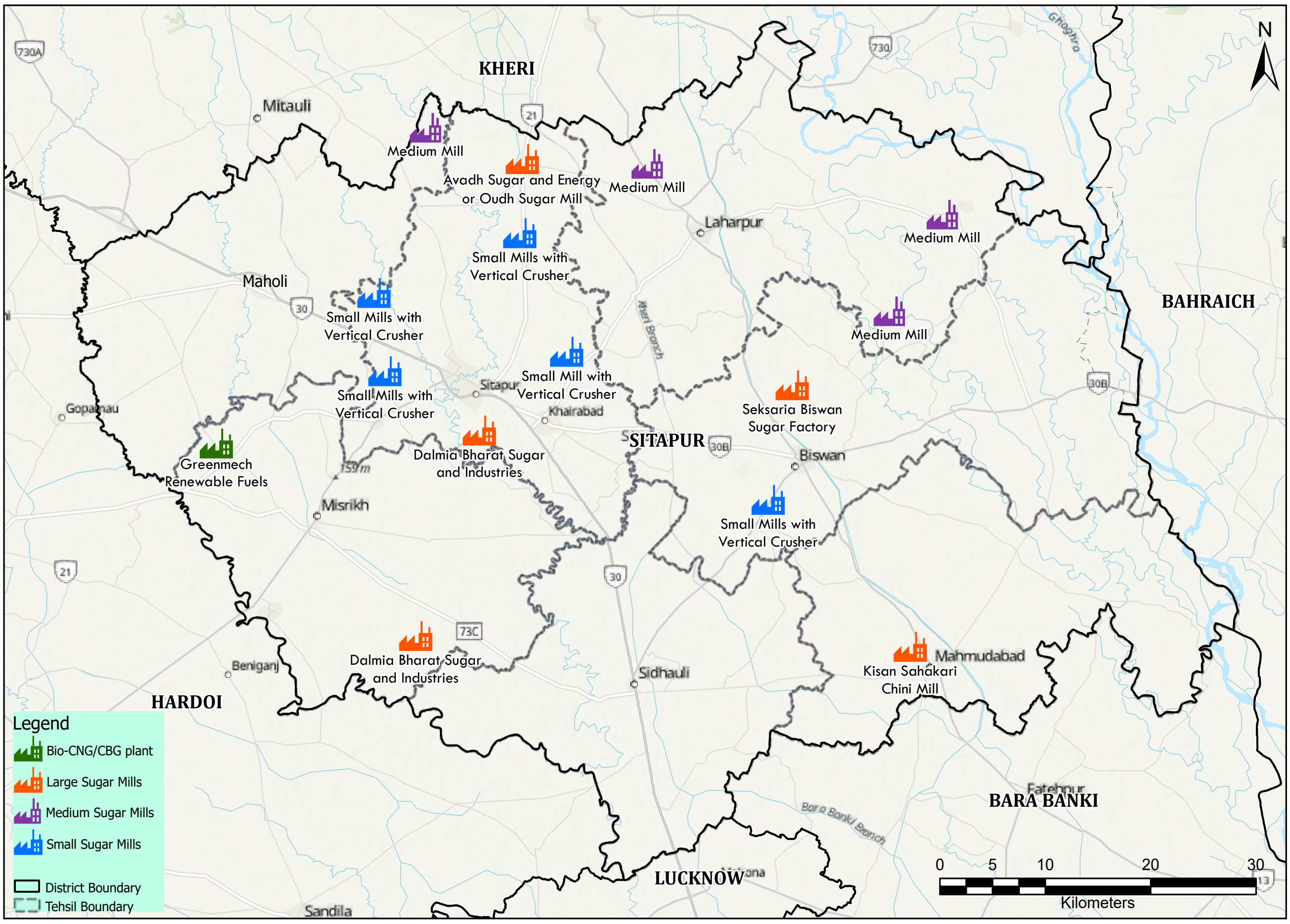


Figure 23: Location of sugar mills in Sitapur District[73]

73 Analysis by Vasudha Foundation, 2025

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)
Sitapur	13000	1000	2730
Misrikh	7500	x	x
Biswan	8500	x	880
Mahmudabad	2750	x	x
Maholi	x	1000	x
Laharpur	X	3400	x

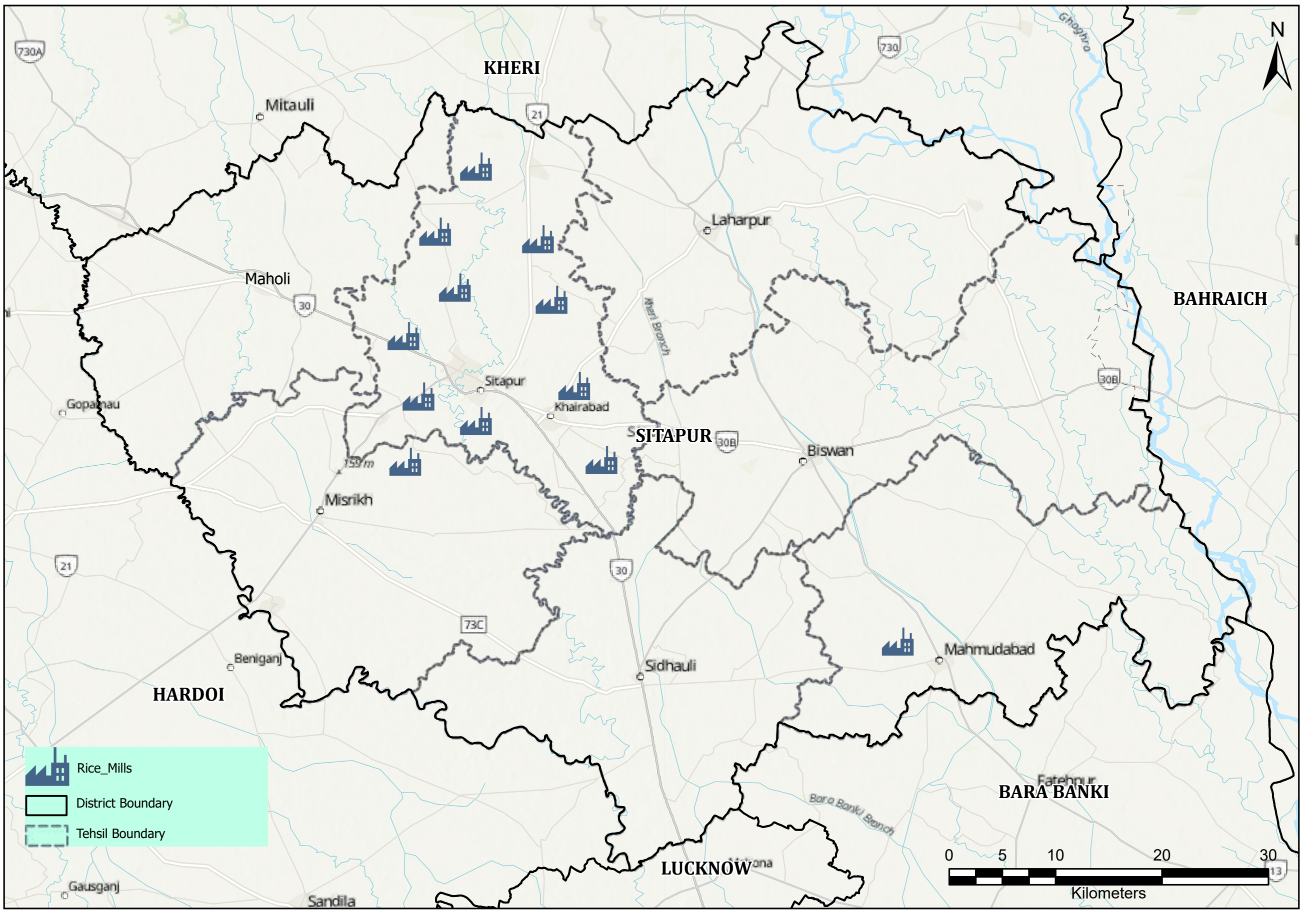


Figure 24: Location of rice mills in Sitapur District

4.2 Secondary Data Collection

Major reliance was placed on secondary data that was shared by the Government at the Central, State, District, and sub-District level. Crop Yield data was collected from the Crop Production Statistics published by the Ministry of Agriculture and Farmer's Welfare for three-year period (2021-24) to arrive at an average. Further, the Crop-to-Residue Ratio (on dry weight basis) was borrowed from the latest National Biomass Atlas[74] 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 were shared by National Institute of Bioenergy (NIBE) periodically generates the National Biomass Atlas. 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.[75]

74 National Biomass Atlas of India, 2023

75 As per the NIBE's approximations

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

Feedstock/Raw Material	Biogas Yield in m³/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 m³	Multiplication Factor[76]
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, 0.04 m^3 of biogas can be generated from 1 kg of cattle dung.

Table 22: Calorific values[77,78] for animal residue

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

76 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.

77 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

78 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 from Ministry of Petroleum and Natural Gas (MoPNG)[79]. 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

79 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 survey. This study involved engagement with stakeholders from government at the Centre, State, District and sub-District level, and a few private players to primarily collect data on biomass production, yield, livestock population, biomass supply chain, etc.

Table 24: Stakeholders in bio-energy value chain

Sector	Stakeholder	Data
Central Government	National Institute of Bioenergy	Clarification on surplus factors (the proportion of agricultural/industrial residues available beyond existing uses) and the conversion factor used to translate surplus biomass residues (in tonnes, T) into potential compressed biogas (CBG) capacity (tonnes per day, TPD). Additionally, the support was provided to identify priority biomass residues (e.g., crop stubble, livestock manure, agro-processing waste) with the highest biogas potential, alongside assessing the suitability of industrial organic waste as feedstock.
State Government	Animal Husbandry and Dairying Department	Livestock Census 2019 data (Tehsil-wise), List of cowsheds in the district
	Agriculture Department	Tehsil-wise and block-wise crop production and yield statistics
	Sugar Industry and Cane Development Department	Society-wise cane production and yield across the district
	Horticulture and Food Processing Department	List of Food Processing, Paper and Pulp Industries located in Sitapur and their effluent capacity/management
	Directorate of Economics and Statistics	Tehsil-wise land use, irrigation, crop production statistics for Sitapur District
Private	Sugar Mills – Large, Medium and Small	Annual cane crushing capacity, press mud market and management, biogas 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, land area, raw material stocking and reserves, contingency planning
	Under-construction CBG Plant	Plant Capacity, Feedstock mix, raw material procurement plan, land area, raw material stocking and reserves, 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 Maholi, Misrikh, Sitapur, and Laharpur. Similarly, paddy cultivation is higher in tehsils of Sitapur, Mahmudabad, Sidhauli and to some extent, Laharpur. Biswan, Sitapur and Misrikh tehsils grow and cultivate bajra alongside major kharif crops. Sidhauli, Sitapur, Biswan and Laharpur tehsils also cultivate pulses (tur/arhar) during this season.

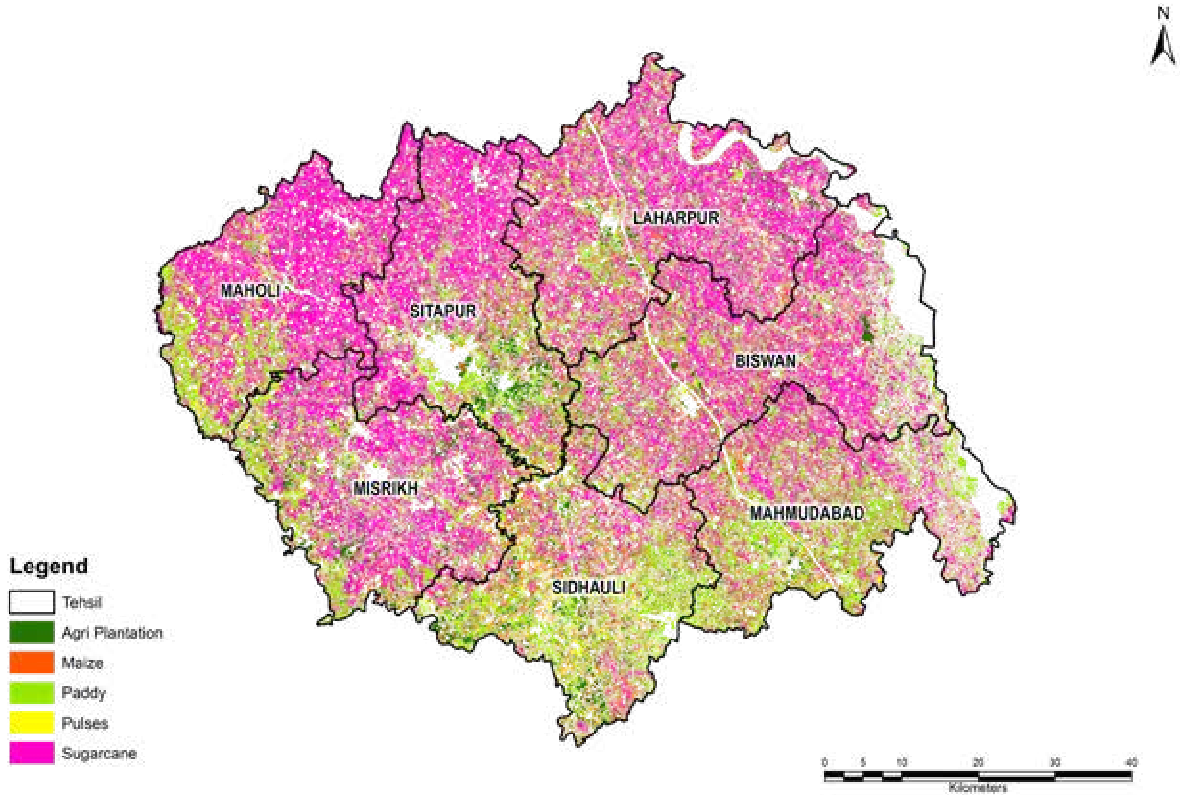


Figure 25: **Geographical spread of *Kharif* crops in tehsils of Sitapur District during 2023-24**

During the *Rabi* season of 2023-24, the major crop, wheat and mustard was prominently cultivated in Mahmudabad, Maholi, Sidhauli and Biswan. It is observed that tehsils of Misrikh, Sitapur, and Maholi also cultivate, to a large extent, horticulture crops like vegetable during this season.

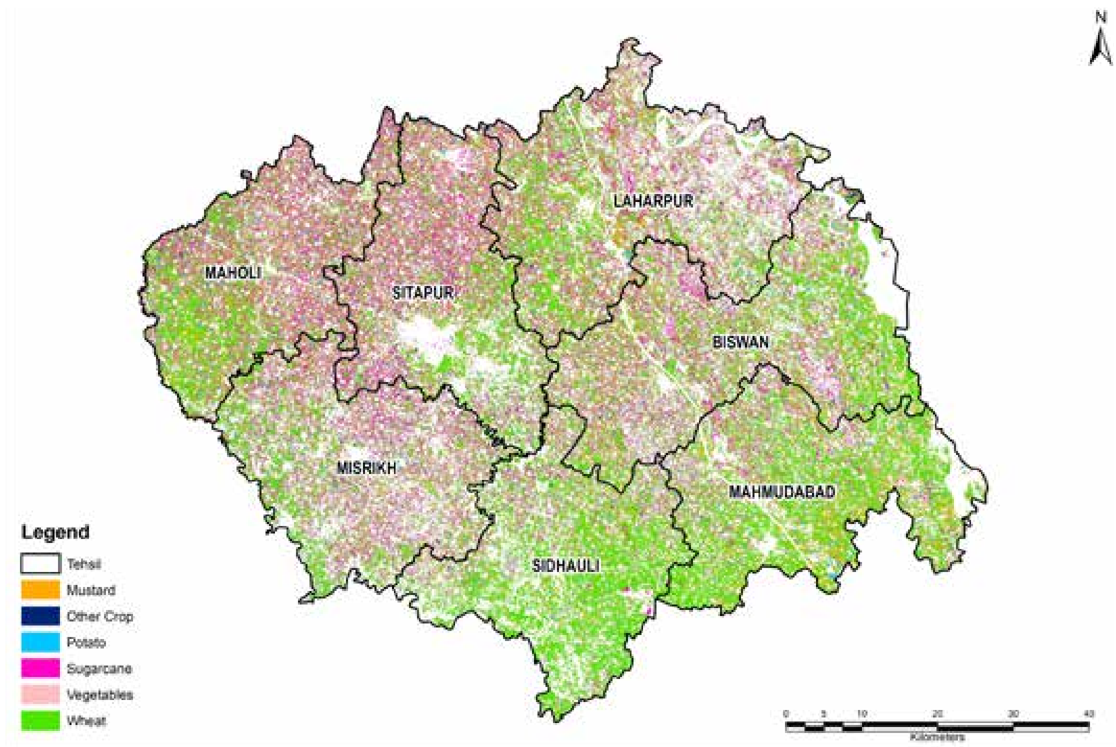


Figure 26: **Geographical spread of *Rabi* crops in tehsils of Sitapur District during 2023-24**

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 Sitapur during the year 2023-24 and the results are summarised below:

Table 25: Tehsil-wise land-use analysis for Sitapur

Tehsil	Built-Up	Agricul-tural	Fallow	Forest	Plan-tation	Scrub	Barren/ Waste/ Open	Water-bodies	Total
Biswan	2486.45	70779.22	17279.16	-	4776.73	190.20	-	1212.63	96724.38
Laharpur	2569.47	66792.01	19061.93	51.94	5866.00	232.30	-	1570.53	96144.18
Mahmu-dabad	1924.38	61585.44	12971.35	53.64	2481.55	114.37	13.52	1494.11	80638.37
Maholi	2007.64	52909.81	11701.58	-	2029.92	118.96	227.32	303.80	69299.03
Misrikh	1566.09	56852.65	13371.13	555.84	6562.81	208.52	527.87	369.19	80014.10
Sidhauli	2404.86	58175.11	8782.40	698.10	4934.34	320.47	462.20	481.69	76259.17
Sitapur	5841.40	52369.27	10746.74	339.12	4962.40	212.68	-	369.60	74841.22
Total	**18800.28**	**419463.51**	**93914.29**	**1698.64**	**31613.77**	**1397.50**	**1230.91**	**5801.54**	**573920.45**

It can be observed from the Land Use analysis[80] that tehsils of Misrikh, Sidhauli, Maholi hold few tracts of barren/waste land. Nearly 65-70 percent of total land cover in all the tehsils of Sitapur district are agricultural lands. The district has very minimal forest cover with Sidhauli having the highest share among all other tehsils.

80 Analysis by Vasudha Foundation, 2025

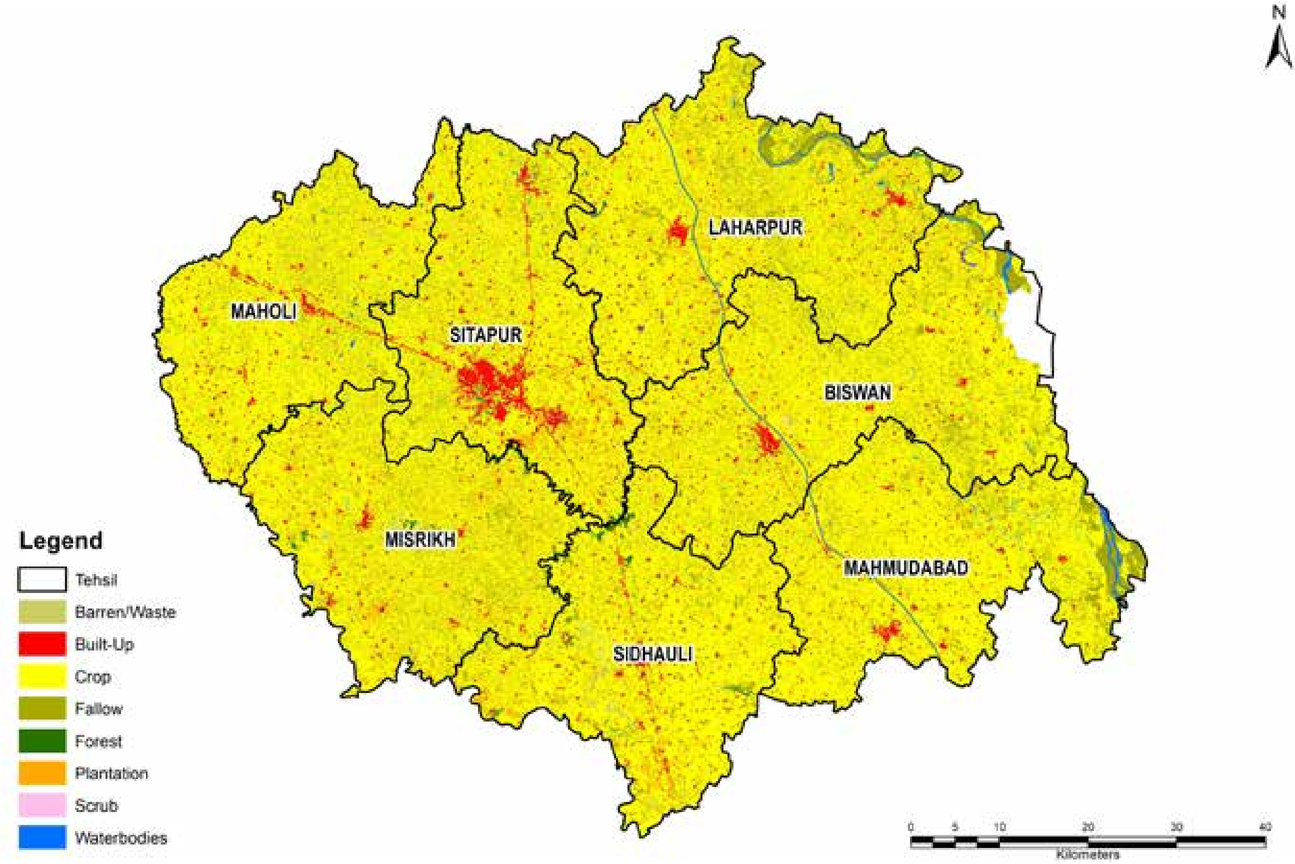


Figure 27: Land cover analysis for tehsils of Sitapur District during 2023-24

07

Methodology

This study estimates annual net biomass residue availability in all the 7 Tehsils of Sitapur 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 the corresponding theoretical value of Compressed Biogas (in Tonnes Per Day) that can be generated out of it. The following approach was adopted for various feedstocks/raw materials 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 Sitapur 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)[81], a supervised machine learning algorithm trained on ground-truth data to classify satellite imagery into distinct crop

81 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.

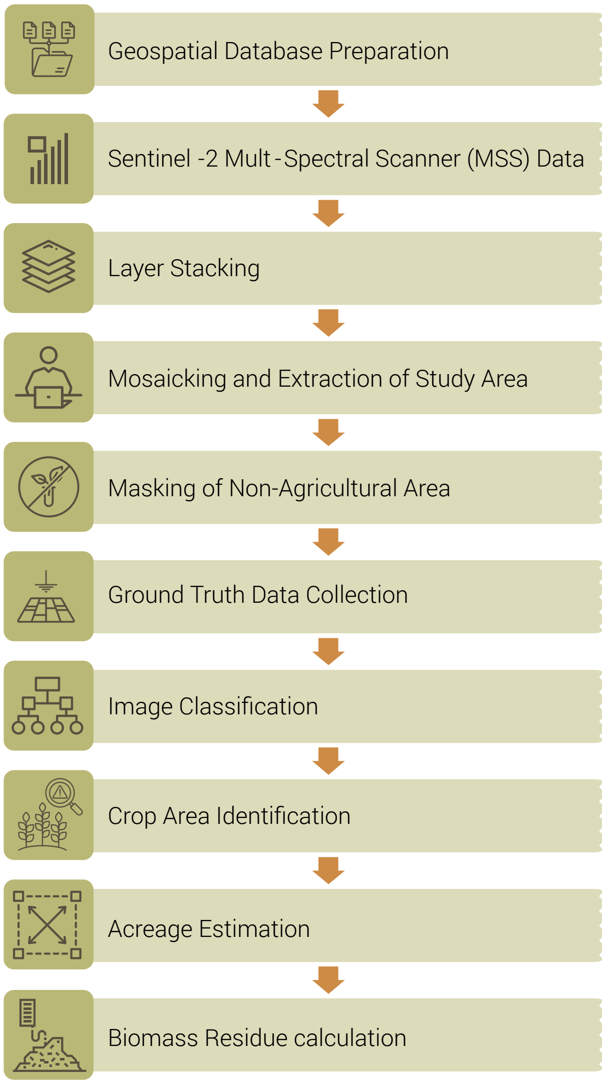


Figure 28: Flow diagram of the methodology used

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[82] 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.[83,84] 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.

82 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.

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

84 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 *Fig.18*).[85]

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

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.[86][87]

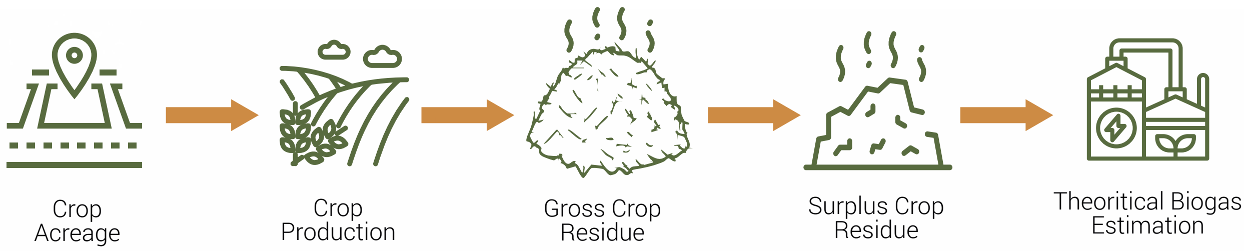


Figure 29: Flow diagram for crop residue estimation

85 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

86 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

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

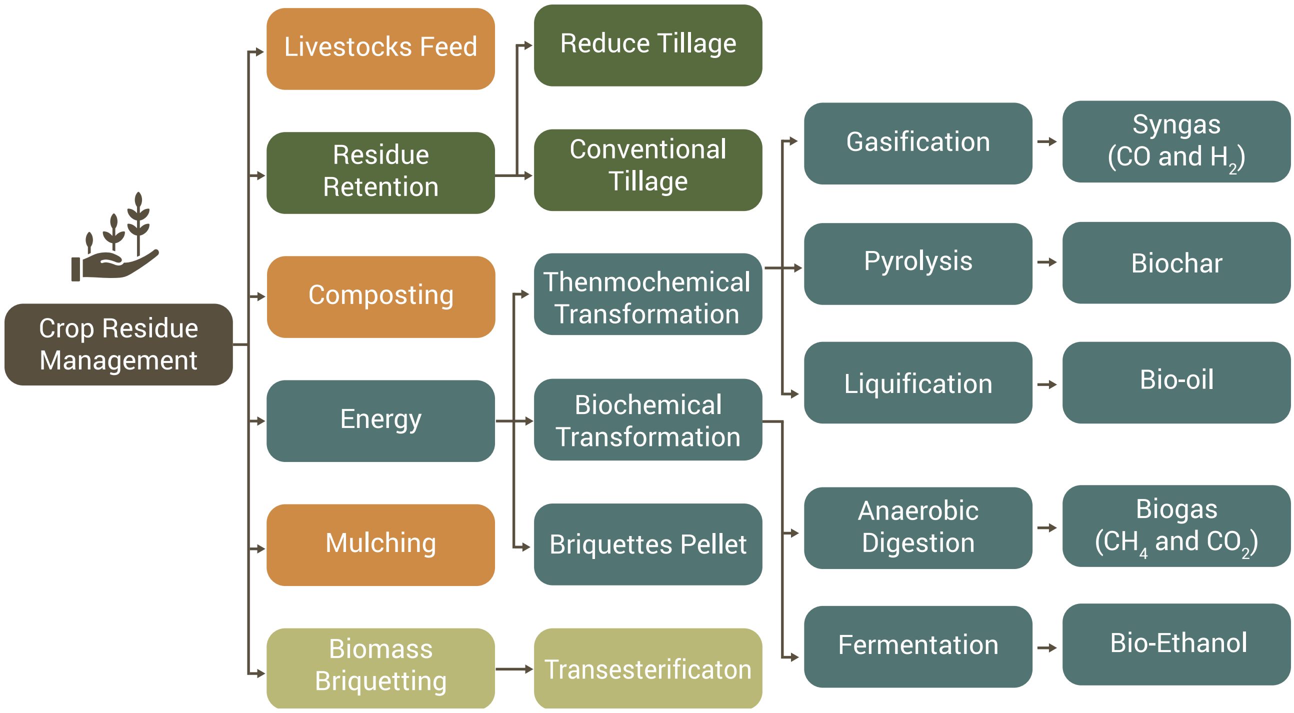


Figure 30: Crop residue management practices[88]

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.

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

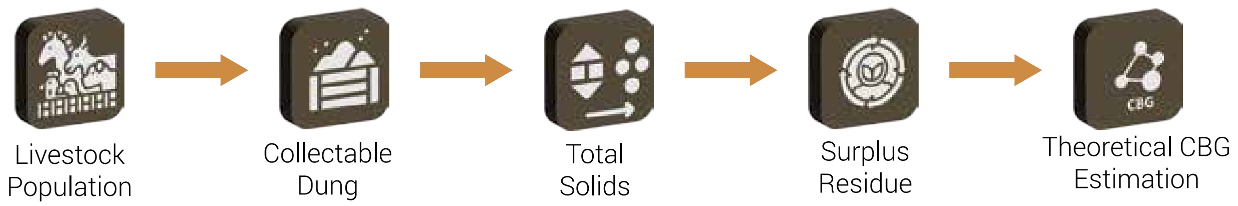
*Equation 4: **Theoretical Estimation of CBG from Agricultural Residues***

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.

88 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 in 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.

7.3 Municipal Solid Waste

Municipal Solid Waste (MSW) is a potential feedstock/raw material for CBG generation. Since Sitapur has especially urban centres that generates MSW, it can be used for production of CBG. As discussed earlier, Sitapur District has 6 Municipalities and 5 Municipal Councils, from where we have collected through primary surveys, the daily generation of MSW (in TPD), as tabulated below[89].

Table 26: Tehsil-wise daily generation of MSW

Tehsil	ULB[90] Name	Dry Waste	Wet Waste	Hazard-ous	House-hold	C&D[91]	Sanitary	Total
Biswan	Biswan	9.68	14.45	0.83	0.76	1.38	0.55	27.65
Sitapur	Hargaon	2.36	3.52	0.13	0.19	0.34	0.2	6.74
Sitapur	Khairabad	6.9	10.93	0.15	0.64	1.17	0.23	18.21
Laharpur	Laharpur	8.16	12.18	0.7	0.64	1.17	0.47	23.3
Mahmu-dabad	Mah-mu-dabad	11.14	16.74	0.86	0.25	1.36	0.57	30.92
Maholi	Maholi	2.65	4.17	0.15	0.21	0.38	0.23	7.79
Misrikh	Misrikh-cum-Neemsar	3.74	5.59	0.32	0.22	0.21	0.53	10.61

89 Based on figures shared by Sitapur Nagar Palika Parishad, Government of Uttar Pradesh
90 ULB stands for Urban Local Body
91 C&D denotes Construction and Demolition Waste

Tehsil	ULB[90] Name	Dry Waste	Wet Waste	Hazard-ous	House-hold	C&D[91]	Sanitary	Total
Sidhauli	Sidhauli	3.04	0.9	0.4	0.4	0.7	10.24	15.68
Sitapur	Paintepur	1.71	2.69	0.15	0.13	0.11	0.1	4.89
Sitapur	Sitapur	29.88	19	0.75	2.5	2.5	1	55.63
Laharpur	Tambaur-cum-Ahmadabad	3.17	4.98	0.27	0.25	0.45	0.18	9.3
Total		**82.43**	**95.15**	**4.71**	**6.19**	**9.77**	**14.3**	**210.72**

Out of the overall waste, around 45-55 percent waste is organic in nature. Out of this organic waste, only about 35-40 percent waste is suitable for Biogas.[92] Therefore, the following equation can be used to estimate the CBG potential in TPD,

$$TBEn = TW \times 0.45 \times 0.35 \times BY \times 0.55 \times 0.67 \times \frac{1}{1000}$$

*Equation 6: **Theoretical CBG Estimation for MSW***

Here, TW is the Total MSW generated from a particular Tehsil/ULB, 0.55 is the percent composition of methane, and 0.67 is the density of methane in Kg/m^3.

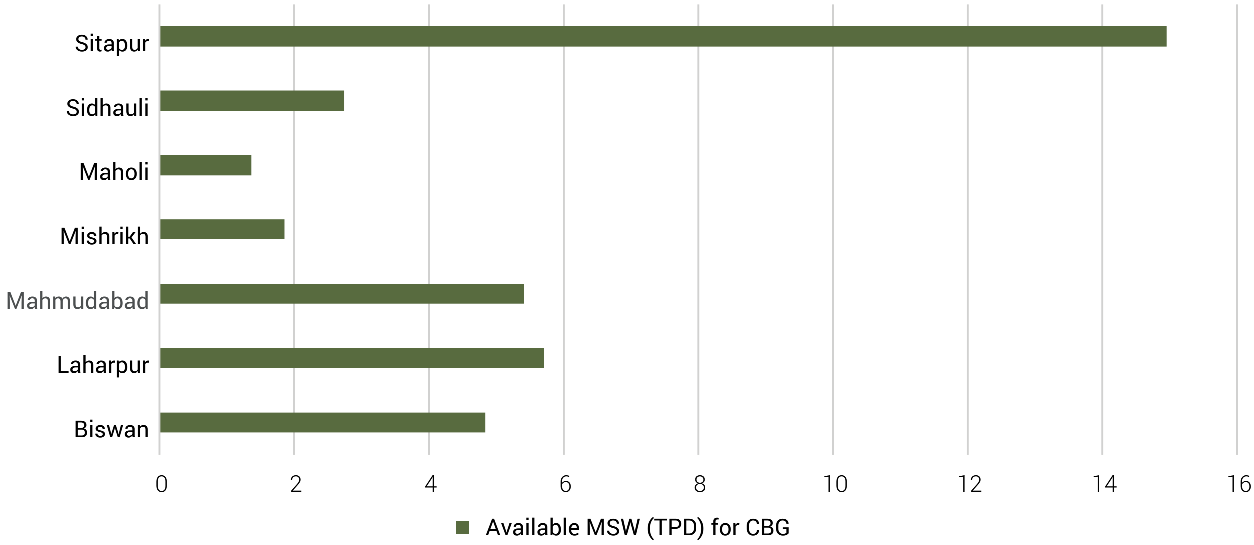


Figure 31: Tehsil-wise available MSW in TPD for CBG generation

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

08

Biomass Category, Sources and Availability

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

8.1 Agricultural Residues

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

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
Biswan	Wheat	26817.8	3.78	101371.25	Straw	152056.87	30411.37	30411.37	6.02	8.33
					Husk	30411.37	6082.27	6082.27	1.20	1.67
	Paddy	17764.2	2.12	37660.02	Straw	56490.03	9603.30	9603.30	2.14	8.25
					Husk	7532	1280.44	1280.44	0.29	0
	Sugarcane	38991.76	79.39	3095555.82	Bagasse		25344		2.15	6.94
					Press Mud (Large)		50575		5.51	5.54
					Press Mud (Medium)		0		0	0
					Tops and Leaves	179907.58	179907.58	179907.58	49.29	49.29

93 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

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

95 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)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Maize	1862.4	1.11	2067.26	Stalks	4134.53	41.35	41.35	0.01	0.01
					Cobs	620.18	6.20	6.20	0.002	0.02
					Leaves	248.07	2.48	2.48	0.001	0.001
	Mustard	9911.99	1.18	11696.15	Mustard	21053.07	21053.07	21053.07	5.768	5.768
	Pulses (Tur/Arhar)	749.89	1.32	989.85	Stalks	2474.64	2474.64	2474.64	0.678	0.678
	Potato	749.82	29.7	22269.65	Potato Stalks	2226.97	2226.97	2226.97	0.610	0.610
	Vegetables	736.42	6.06	4462.71	Vegetable Stalks	446.27	446.27	446.27	0.122	0.122
	Barley	904.18	3.05	2757.5	Barley Straw	3585.07	3585.07	3585.07	0.982	0.982
	Bajra	4852.11	1.16	5628.45	Bajra Stalks	11256.90	11256.90	11256.90	3.084	3.084
					Bajra Husk	1688.53	1688.53	1688.53	0.463	0.463
					Bajra Cobs	1857.39	1857.39	1857.39	0.509	0.509
Laharpur	Wheat	22034.8	3.78	83291.51	Straw	124937.26	24987.45	24987.45	4.95	6.85
					Husk	24987.45	4997.49	4997.49	0.99	1.37
	Paddy	15507.1	2.12	32875.14	Straw	49312.71	8383.16	8383.16	1.87	7.21
					Husk	6575.03	1117.5	1117.5	0.25	0

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Sugarcane	44318.87	79.39	3518475.08	Bagasse			0	0	0
					Press Mud (Large)		0		0	0
					Press Mud (Medium)		16830		1.83	1.84
					Tops and Leaves	205322.94	205322.94	205322.94	56.25	56.25
	Maize	1637.99	1.11	1818.17	Stalks	3636.34	36.36	36.36	0.01	0.01
					Cobs	545.45	5.45	5.45	0.0015	0.0015
					Leaves	218.18	2.18	2.18	0.0006	0.0006
	Mustard	8696.01	1.18	10261.29	Stalks	18470.33	18470.33	18470.33	5.06	5.06
	Pules (Tur/ Arhar)	566.18	1.32	747.36	Stalks	1868.39	1868.39	1868.39	0.51	0.51
	Potato	558.43	29.7	16585.37	Stalks	1658.54	1658.54	1658.54	0.45	0.45
	Vegetables	456.89	6.06	2768.75	Stalks	276.88	276.88	276.88	0.08	0.08
	Barley	877.76	3.05	2677.17	Straw	3480.32	3480.32	3480.32	0.95	0.95
	Bajra	4474.15	1.16	5190.01	Stalks	10380.03	10380.03	10380.03	2.84	2.84
					Husk	1557	1557	1557	0.43	0.43
					Cobs	1712.7	1712.7	1712.7	0.47	0.47

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
Mahmu-dabad	Wheat	30019.5	3.78	113473.82	Straw	170210.74	3402.15	3402.15	6.74	9.33
					Husk	3402.15	6808.43	6808.43	1.35	1.87
	Paddy	23777.2	2.12	50407.75	Straw	75611.62	12853.98	12853.98	2.86	11.05
					Husk	1008155	1713.86	1713.86	0.38	0
	Sugarcane	22161.68	79.39	1759439.59	Bagasse			0	0	0
					Press Mud (Large)		16362.5		1.78	1.79
					Press Mud (Medium)		0		0	0
					Tops and Leaves	97331.35	97331.35	97331.35	26.67	26.67
	Maize	1012.56	1.11	1123.94	Stalks	2247.88	22.48	22.48	0.01	0.01
					Cobs	146.11	1.46	1.46	0	0
					Leaves	134.87	1.35	1.35	0	0
	Mustard	9697.09	1.18	11442.57	Stalks	1373.11	1373.11	1373.11	0.38	0.38
	Pules (Tur/ Arhar)	1749.41	1.32	2309.22	Stalks	5773.05	5773.05	5773.05	1.58	1.58
	Potato	1160.95	29.7	34480.22	Stalks	3448.02	3448.02	3448.02	0.94	0.94
	Vegetables	816.15	6.06	4945.87	Stalks	494.59	494.59	494.59	0.14	0.14

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Barley	131.37	3.05	400.68	Straw	520.88	520.88	520.88	0.14	0.14
	Bajra	2443.46	1.17	2834.41	Stalks	5668.83	5668.83	5668.83	1.55	1.55
					Husk	850.32	850.32	850.32	0.23	0.23
					Cobs	935.36	935.36	935.36	0.26	0.26
Maholi	Wheat	20752.7	3.78	78445.17	Straw	11766.75	23533.55	23533.55	4.66	6.45
					Husk	23533.55	4706.71	4706.71	0.93	1.29
	Paddy	11422.9	2.12	24216.59	Straw	36324.89	6175.23	6175.23	1.38	5.31
					Husk	4843.32	823.36	823.36	0.18	0
	Sugarcane	37970.24	79.39	3014457.35	Bagasse		0		0	0
					Press Mud (Large)		5950		0.647955	0.65
					Press Mud (Medium)		0		0	0
					Tops and Leaves	189010.88	189010.88	189010.88	51.78	51.78
	Maize	567.68	1.11	630.12	Stalks	1260.25	12.60	12.60	0	0
					Cobs	189.04	1.89	1.89	0	0
					Leaves	75.61	0.76	0.76	0	0

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Mustard	7253.91	1.18	8559.61	Stalks	15407.30	15407.30	15407.30	4.22	4.22
	Pules (Tur/ Arhar)	1282.72	1.32	1633.19	Stalks	4232.98	4232.98	4232.98	1.16	1.16
	Potato	486.98	29.7	14463.31	Stalks	1446.33	1446.33	1446.33	0.40	0.40
	Vegetables	44.77	6.06	271.31	Stalks	27.13	27.13	27.13	0.01	0.01
	Barley	529.63	3.05	1615.37	Straw	2099.98	2099.98	2099.98	0.58	0.58
	Bajra	1828.34	1.16	2120.87	Stalks	4241.75	4241.75	4241.75	1.16	1.16
					Husk	636.26	636.26	636.26	0.17	0.17
					Cobs	699.89	699.89	699.89	0.19	0.19
Misrikh	Wheat	18308	3.78	69204.09	Straw	103806.13	20761.23	20761.23	4.07	5.69
					Husk	20761.23	4152.25	4152.25	0.81	1.14
	Paddy	14056.2	2.12	29799.23	Straw	44698.84	7598.8	398.8	0.088	4.229
					Husk	5959.85	1013.7	1013.7	0.23	0
	Sugarcane	31935.78	79.39	2535381.57	Bagasse		0		0	0
					Press Mud (Large)		0		0	0
					Press Mud (Medium)		26825		2.9212	2.92
					Tops and Leaves	154483.97	154483.97	154483.97	42.32	42.32

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Maize	1947.06	1.11	2161.24	Stalks	4322.47	43.22	43.22	0.01	0.01
					Cobs	648.37	6.48	6.48	0	0
					Leaves	648.37	6.48	6.48	0	0
	Mustard	4925.51	1.18	5812.10	Stalks	10461.78	10461.78	10461.78	2.87	2.87
	Pules (Tur/ Arhar)	1738.64	1.32	2295	Stalks	5737.51	5737.51	5737.51	1.57	1.57
	Potato	285.3	29.7	8473.41	Stalks	847.34	847.34	847.34	0.23	0.23
	Vegetables	151.91	6.06	920.57	Stalks	92.06	92.06	92.06	0.03	0.03
	Barley	761.34	3.05	2322.09	Straw	3018.71	3018.71	3018.71	0.83	0.83
	Bajra	5356.34	1.16	6213.35	Stalks	12426.71	12426.71	12426.71	3.40	3.40
					Husk	1864.01	1864.01	1864.01	0.51	0.51
					Cobs	2050.41	2050.41	2050.41	0.56	0.56
Sidhauli	Wheat	29766.4	3.78	112554.75	Straw	168832.13	33766.43	33766.43	6.69	9.25
					Husk	33766.43	6753.29	6753.29	1.34	1.85

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Paddy	19819.7	2.12	42017.66	Straw	63026.49	10714.50	10714.50	2.39	9.21
					Husk	8403.53	1428.60	1428.60	0.32	0
	Sugarcane				Bagasse		0		0	0
		13585.68	79.39	1073803.73	Press Mud (Large)		0		0	0
					Press Mud (Medium)		0		0	0
					Tops and Leaves	60962.27	60962.27	60962.27	16.70	16.70
	Maize	5475.29	1.11	6077.57	Stalks	12155.14	121.55	121.55	0.03	0.03
					Cobs	1823.27	18.23	18.23	0	0
					Leaves	729.31	7.29	7.29	0	0
	Mustard	5301.87	1.18	6256.21	Stalks	11261.17	11261.17	11261.17	3.09	3.09
	Pules (Tur/ Arhar)	2667.42	1.32	3520.99	Stalks	8802.49	8802.49	8802.49	2.41	2.41
	Potato	349.81	29.7	10389.36	Stalks	1038.94	1038.94	1038.94	0.28	0.28
	Vegetables	248.77	6.06	1507.55	Stalks	150.75	150.75	150.75	0.04	0.04
	Barley	466.48	3.05	1422.76	Straw	1849.59	1849.59	1849.59	0.51	0.51

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Bajra	5422.32	1.16	6289.89	Stalks	12579.78	12579.78	12579.78	3.45	3.45
					Husk	1886.97	1886.97	1886.97	0.52	0.52
					Cobs	2075.66	2075.66	2075.66	0.57	0.57
Sitapur	Wheat	17621.5	3.78	66609.38	Straw	99914.08	19982.82	1444.16	3.96	5.47
					Husk	19982.82	3996.56	3996.56	0.79	1.09
	Paddy	12777	2.12	27087.22	Straw	40630.83	6907.24	6907.24	1.54	5.94
					Husk	5417.44	920.97	920.97	0.21	0
	Sugarcane	33039.36	79.39	2622994.79	Bagasse			78624	6.66	21.54
					Press Mud (Large)			5950	0.65	0.65
					Press Mud (Medium)		136850		14.90	14.90
					Tops and Leaves	163782.01	163782.01	163782.01	44.87	44.87
	Maize	1424.15	1.11	1580.81	Stalks	3161.61	31.62	31.62	0.0087	0.0087
					Cobs	474.24	4.74	4.74	0.0013	0.0013
					Leaves	189.70	1.90	1.90	0.0005	0.0005
	Mustard	5919.81	1.18	6985.38	Stalks	12573.68	12573.68	12573.68	3.44	3.44

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)[93]	CBG (SATAT) (TPD)[94,95]
		Area	Yield	Total						
	Pules (Tur/ Arhar)	828.48	1.32	1093.59	Stalks	2733.98	2733.98	2733.98	0.749	0.749
	Potato	90.18	29.7	2678.35	Stalks	267.83	267.83	267.83	0.0734	0.0734
	Vegetables	76.54	6.06	463.83	Stalks	46.38	46.38	46.38	0.0127	0.0127
	Barley	719.24	3.05	2193.68	Straw	2851.79	2851.79	2851.79	0.7813	0.7813
	Bajra	4760.59	1.16	5522.28	Stalks	11044.57	11044.57	11044.57	3.02	3.02
					Husk	1656.69	1656.69	1656.69	0.45	0.45
					Cobs	1822.35	1822.35	1822.35	0.49	0.49

8.2 Animal Waste

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

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

Tehsil	Animal	Population[96]	Gross Residue (Kg)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
Biswan	Cattle	91882	503053950	88034.44	88034.44	3.61	4.824
	Goat/ Sheep	103570	60484880	3508.12	3508.12	0.19	0.275
	Swine	980	965790	168.05	168.05	0.01	0.013
	Poultry	50000	821250	142.90	142.90	0.01	0.01566
Laharpur	Cattle	64784	354692400	62071.17	62071.17	2.548	3.401
	Goat/ Sheep	61609	35979656	2086.82	2086.82	0.11	0.16
	Swine	453	446431.5	77.68	77.68	0.0039	0.0061
	Poultry	20000	328500	57.16	57.16	0.0040	0.0063
Mahmud-abad	Cattle	64396	352568100	61699.42	61699.42	2.252	3.381
	Goat/ Sheep	83744	48906496	2836.58	2836.58	0.151	0.222
	Swine	358	352809	61.39	61.39	0.003	0.005
	Poultry	39000	640575	111.46	111.46	0.00782	0.01221
Maholi	Cattle	17923	98128425	17172.474	17172.474	0.70	0.94

96 In Tehsils of Maholi and Misrikh, there is one 45 m^3 biogas plant installed in each tehsil. In this case, we assume that 1 cattle contribute to 0.45 m^3 of biogas generation

Tehsil	Animal	Population[96]	Gross Residue (Kg)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
	Goat / Sheep	13299	7766616	450.46	450.46	0.02	0.04
	Swine	146	143883	25.04	25.04	0	0.0020
	Poultry	30000	492750	85.74	85.74	0.01	0.01
Misrikh	Cattle	79175	433483125	75859.55	75859.55	3.113	4.157
	Goat / Sheep	555956	32678304	1895.34	1895.34	0.101	0.148
	Swine	480	473040	82.31	82.31	0.004	0.009
	Poultry	135000	2217375	385.82	385.82	0.02706	0.04228
Sidhauli	Cattle	74366	407153850	71251.923	71251.923	2.924	3.904
	Goat / Sheep	67795	39592280	2296.35	2296.35	0.122	0.180
	Swine	646	636633	110.77	110.77	0.006	0.009
	Poultry	123000	2020275	351.53	351.53	0.02466	0.03852
Sitapur	Cattle	68354	374238150	65491.676	65491.676	2.688	5.365
	Goat / Sheep	68600	40062400	2323.62	2323.62	0.124	0.182
	Swine	604	595242	103.57	103.57	0.005	0.008
	Poultry	140000	2299500	400.11	400.11	0.02806	0.04385

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 Sitapur district as of now.

Table 29: Surplus biomass residue and potential CBG generation from MSW

Biodegradable Waste (Municipal Solid Waste)

Tehsil	Gross Residue (T)	Surplus Residue[97] (T)	CBG (TPD)	CBG (SATAT) (TPD)
Biswan	27.65	5.53	0.50	0.277
Laharpur	32.6	6.52	0.59	0.326
Mahmudabad	30.92	6.184	0.56	0.31
Maholi	7.79	1.558	0.14	0.08
Misrikh	10.61	2.122	0.192	0.106
Sidhauli	15.68	3.136	0.28	0.16
Sitapur	85.47	17.094	1.54	0.85

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.[98]

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

8.4.2 Groundnut Shell

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

97 According to CPCB's Guidelines on Compressed Biogas, 50% of total MSW is organic, out of which only 35-40% is suitable for Biogas

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

Table 30: 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 (TBD) (SATAT)
Groundnut	3245	2.22	7217	0.3	2165.1	0.5931

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 Sitapur and Biswan (See *Fig.24*). They have a cumulative cane crushing capacity of 3610 TCD and based on the survey, it was noted that the conversion ratio of cane to bagasse in these mills is 40%. Further, 40% of the bagasse that is generated is captively consumed for sugar processing and the remainder is sold to bio-plastics industry and bagasse-based particleboards at around INR 700 per quintal.

Table 31: Surplus bagasse generated from small sugar mills cluster

Tehsil	Crushing Capacity in TCD	Number of Units	Surplus Bagasse (T)
Sitapur (Cluster I)	12	70	134.4
Sitapur (Cluster II)	12	60	115.2
Biswan	11	80	140.08
Sitapur (Cluster III)	13	70	145.6
Sitapur (Cluster IV)	13	20	41.6

Figure 32 describes the corresponding CBG potential that can be generated from sugarcane bagasse

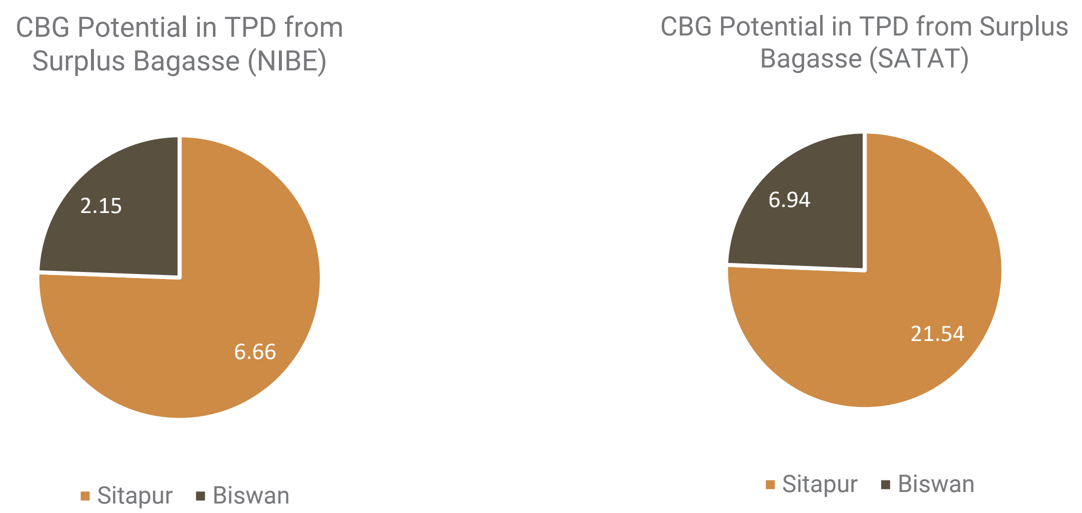


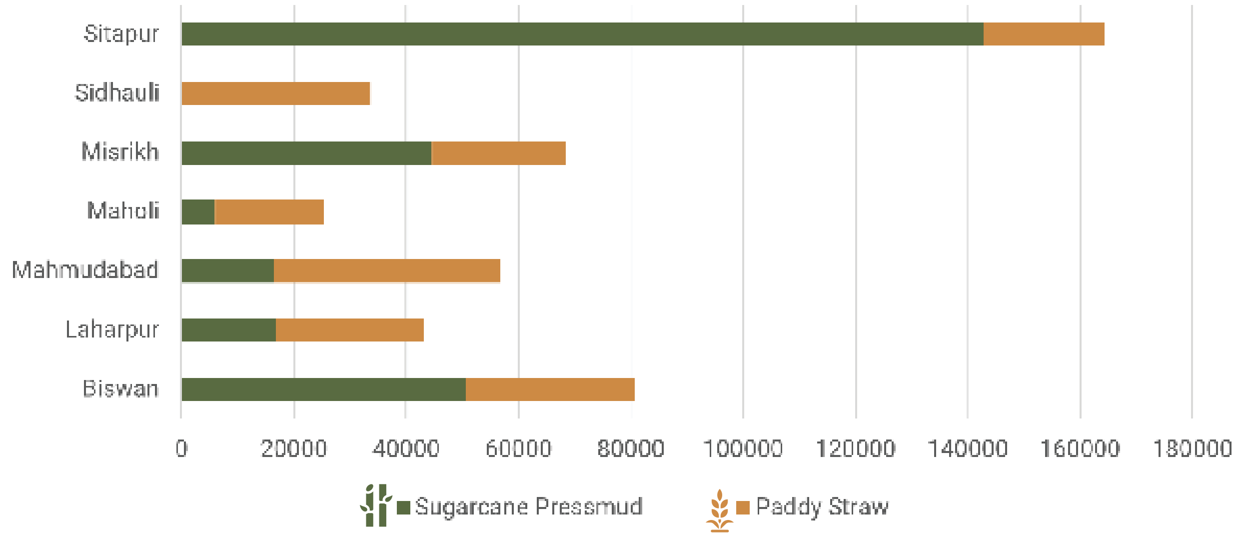
Figure 32: CBG potential from bagasse generated from small sugar mills

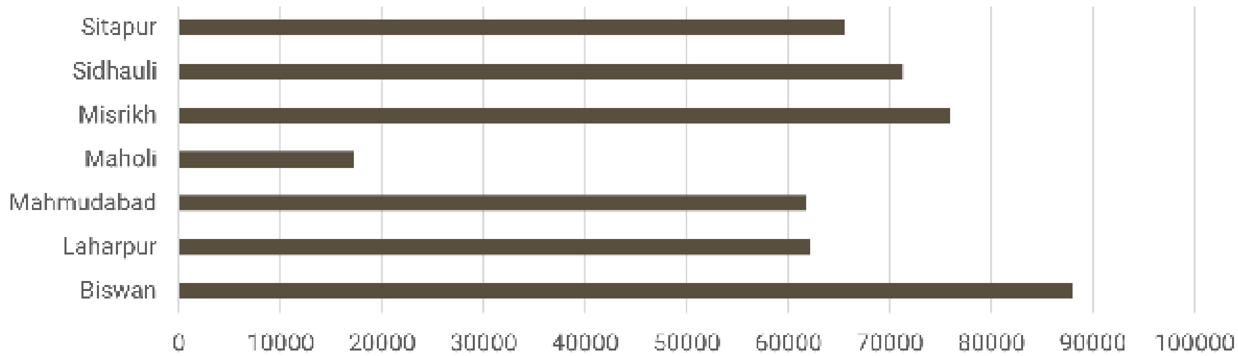
09

Biomass Quantification Results

9.1 Total Biomass Availability by Category

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





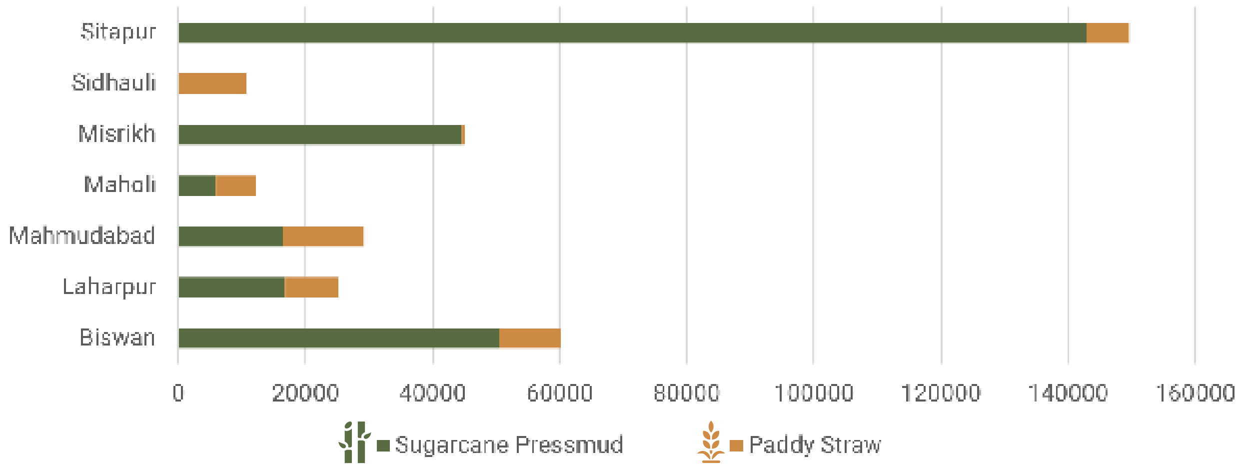


Figure 33: **Tehsil-wise annual availability of paddy straw, press mud and cattle dung**

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 *Fig.34 & Fig. 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. *Fig.36* depicts the year-on-year change in pressmud 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 50 per quintal during 2022-25.

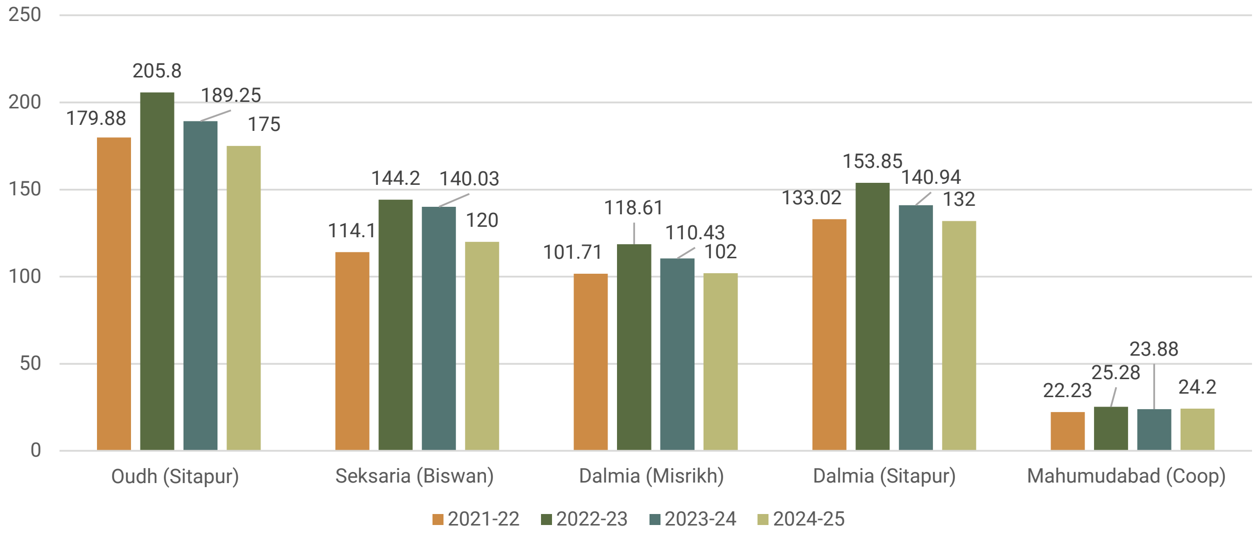


Figure 34: Annual cane crushed in sugar mills during 2021-25[99]

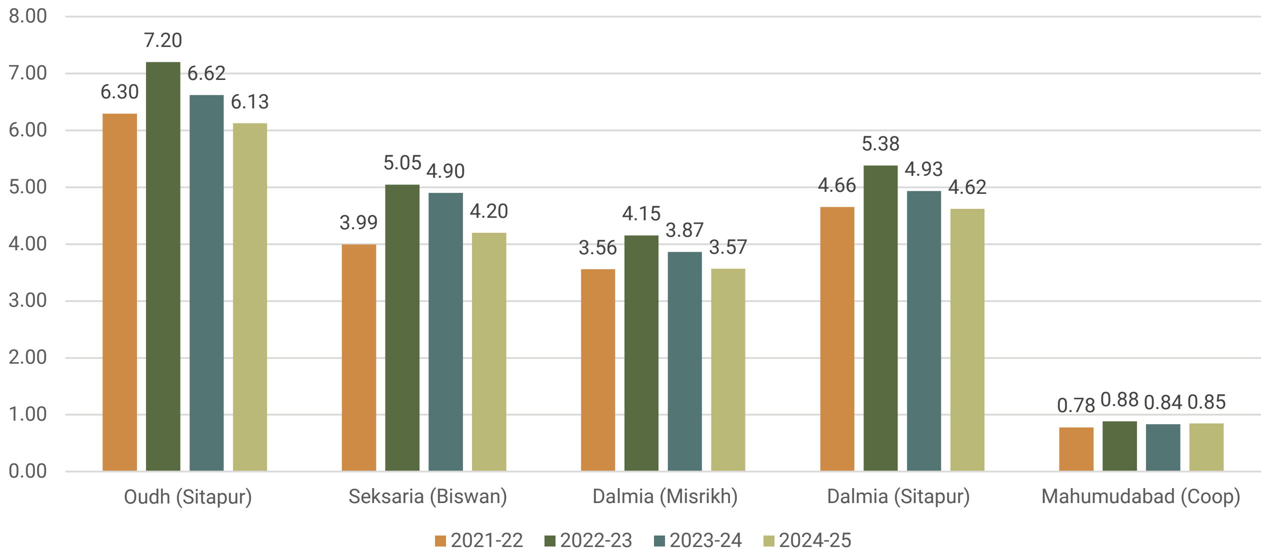


Figure 35: Annual press mud generated in sugar mills

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

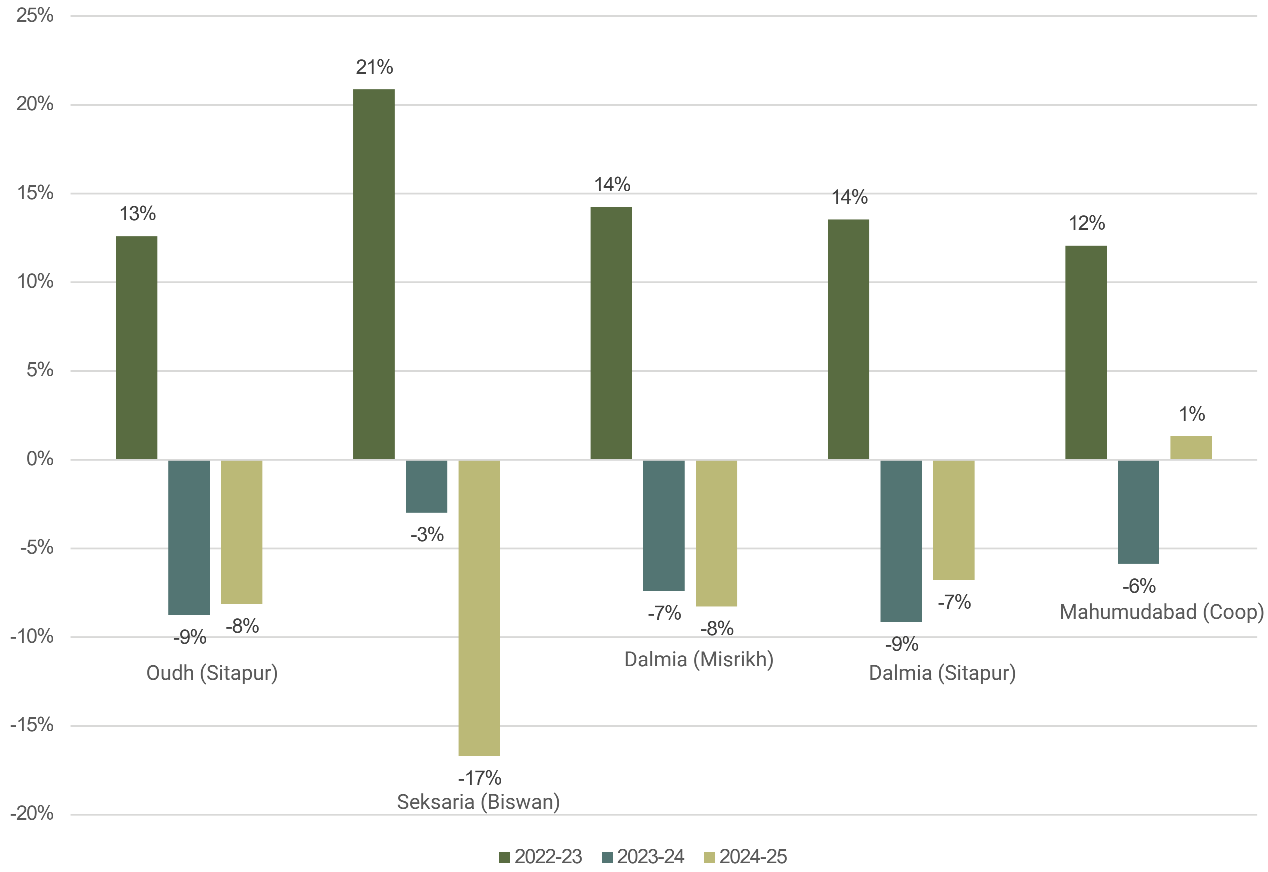


Figure 36: YoY change in annual cane crushed and press mud generated during 2021-25

It can be observed from *Fig. 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 off-peak price of pressmud from a large sugar mill in Misrikh increased 200% from its peak season price during 2022 and the reasons for the spike include: high demand for supply of press, 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

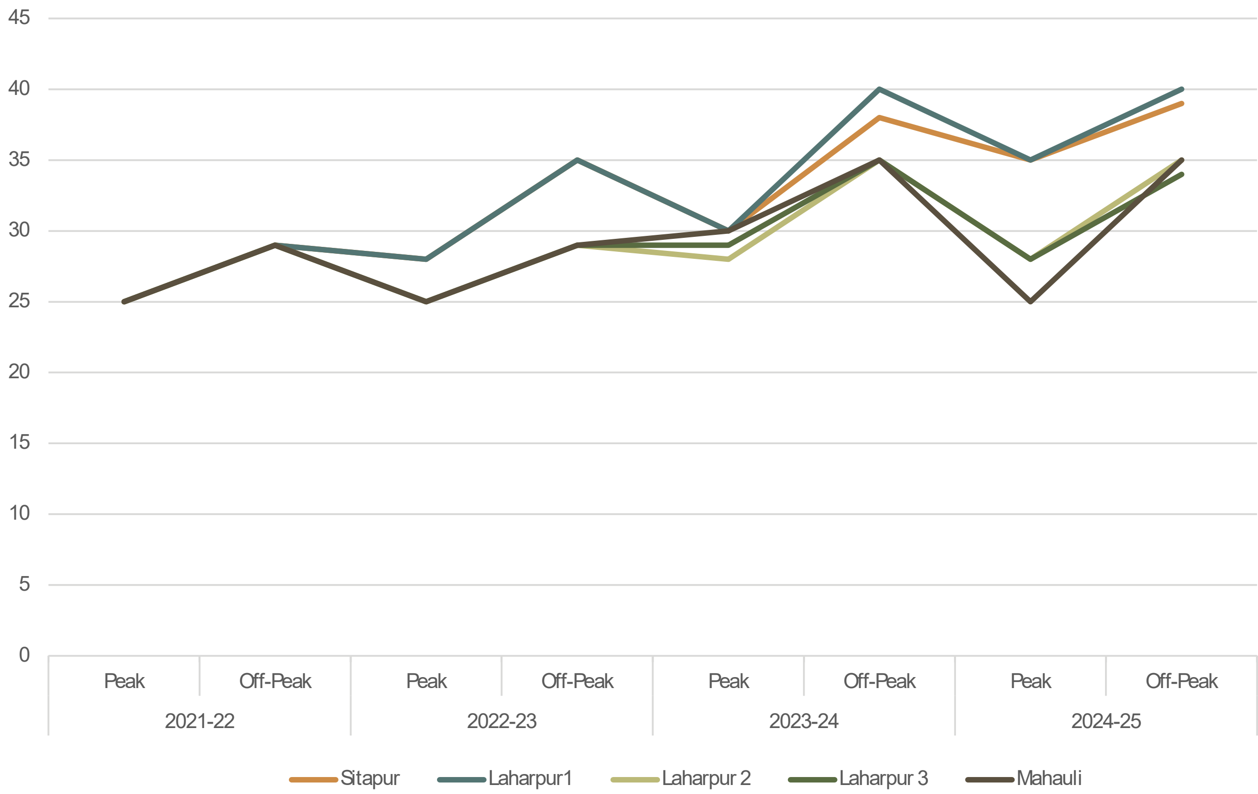


Figure 37: **Press mud price variations during 2021-25 (from medium sugar mills)**

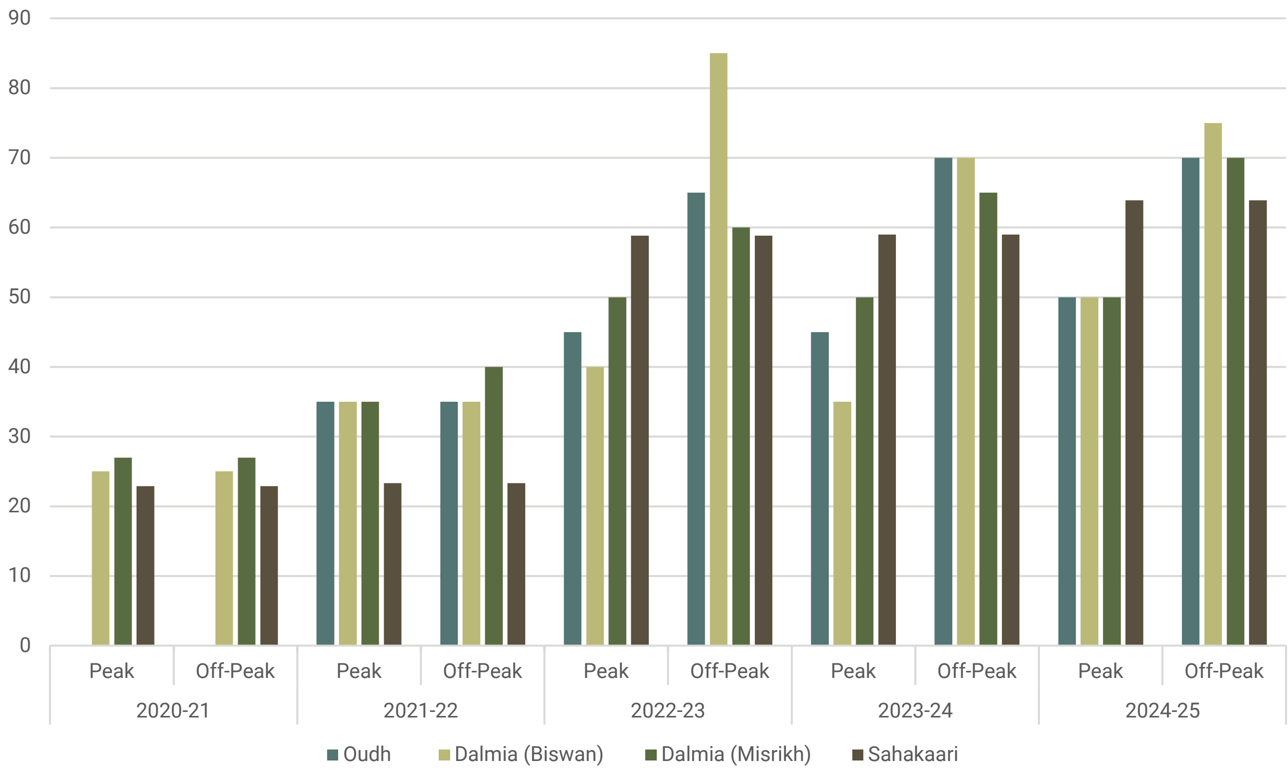


Figure 38: **Press mud price variations during peak and off-peak season**

9.3 High-Potential Zones for Biomass Supply and CBG Production

It can be observed that tehsils of Sitapur has the highest annual press mud availability followed by Biswan and Misrikh. Mahmudabad and Laharpur also have significant press mud available. However, there are no sugar mills located within the Sidhauli tehsil. Among all tehsils, Mahmudabad has the highest paddy straw availability, while the rest of them have comparable stock as agricultural residue. All tehsils of Sitapur, excluding Maholi 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, in Tonne per day (TPD) was estimated for each feedstock in each tehsil which are described in the charts below:

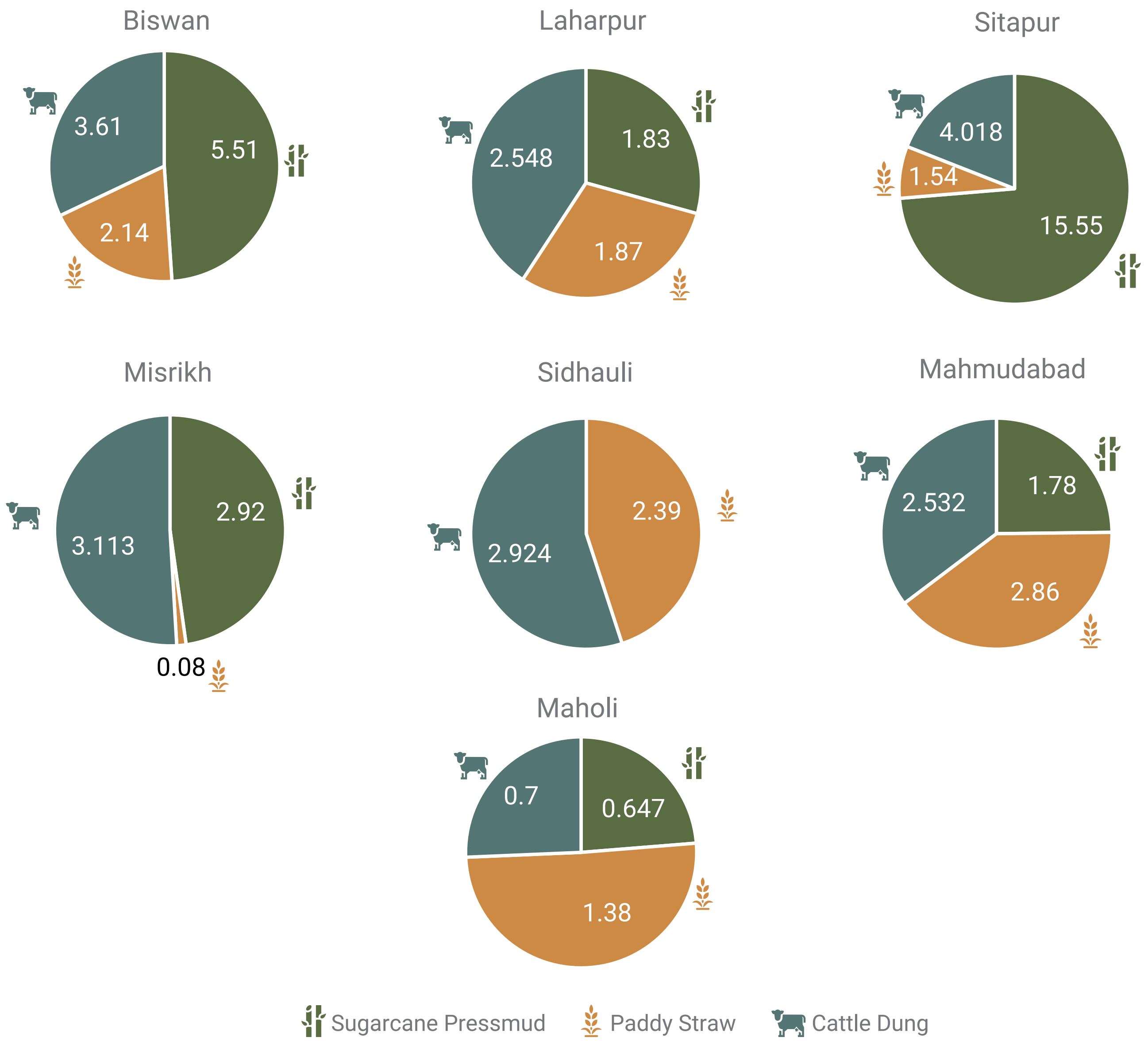


Figure 39: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per NIBE estimates)

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

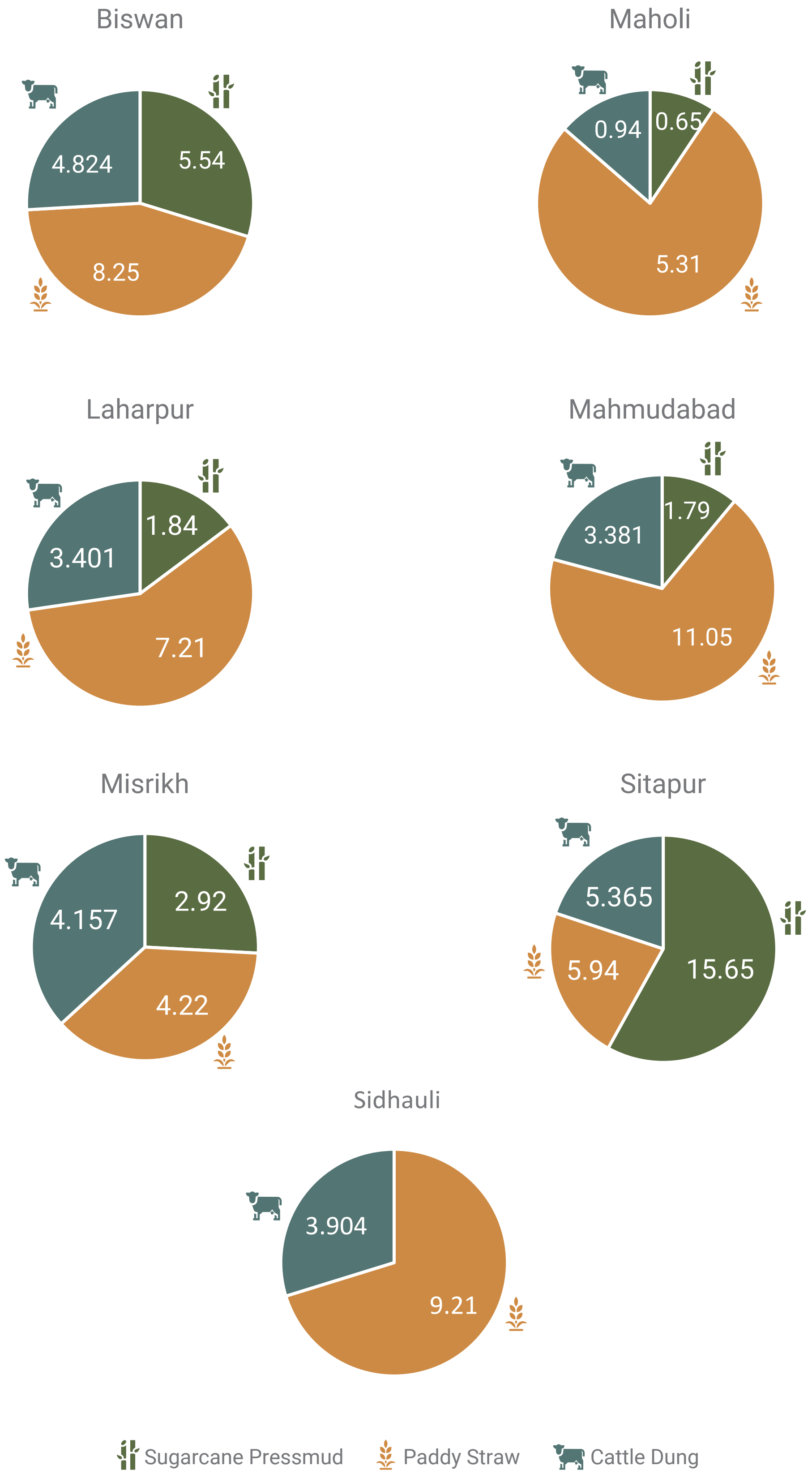


Figure 40: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per SATAT estimates)

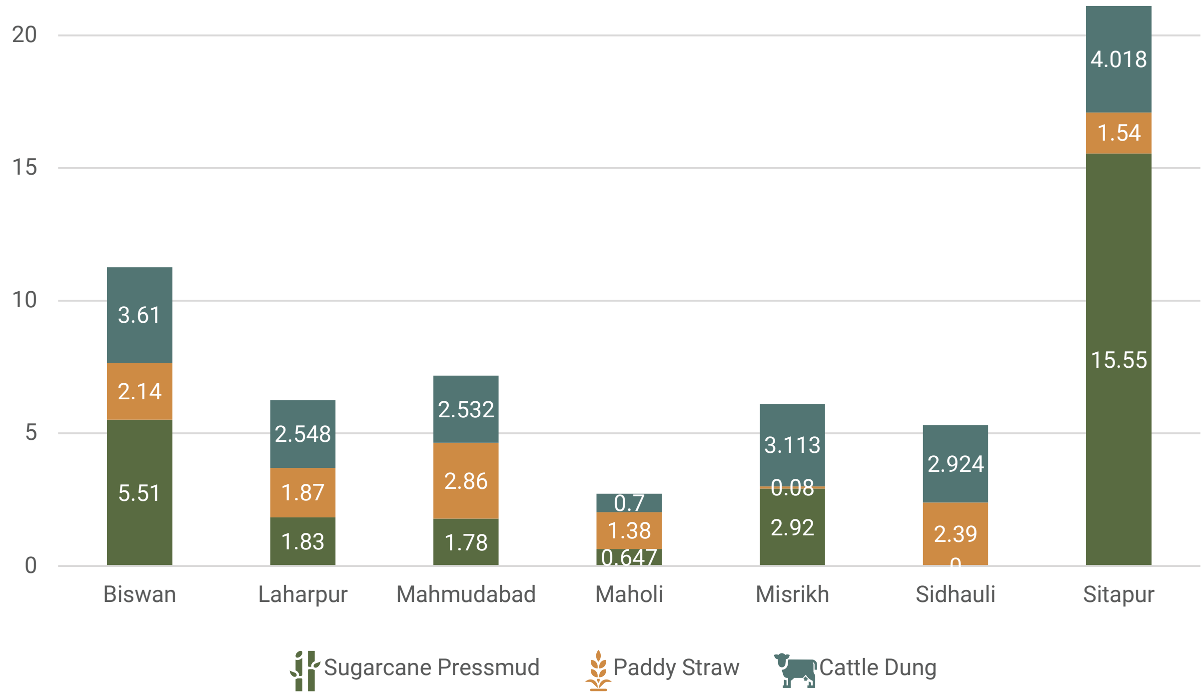


Figure 41: CBG potential from major feedstocks

While the CBG capacity from various feedstocks has been outlined, it's essential to recognise that CBG plants often operate on a mix of feedstocks rather than a single type. The sizing and design of these plants depend on a comprehensive set of factors (as captured in the Fig 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.

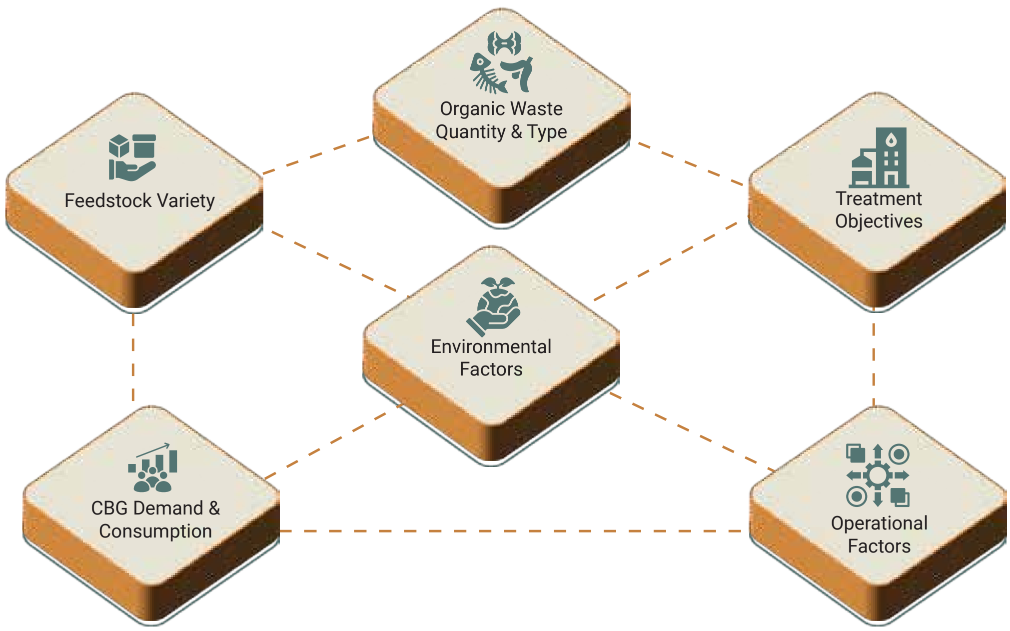


Figure 42: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

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

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

NIBE – CBG potential (in TPD) feedstock-wise in each tehsil				
Tehsil	**Sugarcane Pressmud**	**Paddy Straw**	**Cattle Dung**	**Total**
Biswan	5.51	2.14	3.61	11.26
Laharpur	1.83	1.87	2.548	6.248
Mahmudabad	1.78	2.86	2.532	7.172
Maholi	0.647	1.38	0.70	2.727
Misrikh	2.92	0.08	3.113	6.113
Sidhauli	0	2.39	2.924	5.314
Sitapur	15.55	1.54	4.018	21.108
Total	28.237	12.268	19.445	59.942

SATAT – CBG potential (in TPD) feedstock-wise in each tehsil				
Tehsil	**Sugarcane Pressmud**	**Paddy Straw**[100]	**Cattle Dung**	**Total**
Biswan	5.54	8.25	4.824	18.614
Laharpur	1.84	7.21	3.401	12.451
Mahmudabad	1.79	11.05	3.381	16.221
Maholi	0.65	5.31	0.94	6.9
Misrikh	2.92	4.22	4.157	11.297
Sidhauli	0	9.21	3.904	13.114
Sitapur	15.65	5.94	5.365	26.955
Total	28.39	51.199	25.988	105.552

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, where according to UPNEDA, 0.40 percent of the gross crop residue is surplus.

As per the estimates, theoretically, Sitapur district has a CBG potential of approximately 60 TPD based on the biomass available during the year 2023-24. Out of all the Tehsils, Sitapur has the highest potential CBG capacity with sugarcane press mud contributing to the range between 50-75 percent of the total raw material. Biswan leads after Sitapur on the potential CBG capacity with both sugarcane

100 In this case, 40% of the Gross Paddy Straw Residue is considered surplus with Residue-to-Crop ratio of 2.0

pressmud and paddy straw both 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

1. Sitapur has a high theoretical potential for CBG with 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.[101]
3. A beneficial, reliable, and transparent pricing and payment mechanism can incentivise collection and availability of biomass. This would establish a biofuel-led economy that can offer unique opportunities for farmers, enhance their regular incomes by turning waste into wealth. This additional stream of income can be particularly beneficial during times of market volatility or poor harvests of traditional crops and continue to drive economic growth at grassroot level.
4. Encourage farmers to use bio-slurry from CBG plants as an organic fertiliser to improve soil health and crop productivity. Implement comprehensive training programs to educate farmers on its benefits and proper application methods. Additionally, provide hands-on demonstrations and success stories to encourage adoption. Establish support networks and incentives to facilitate widespread usage and long-term sustainability.

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

5. CBG/Bio-fuel plant has to be designed, and tailor-made based on the crop residues for which the long-term availability is guaranteed based on forecasting and observing past trends. [102]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 43: Cane moved from the field to sugar mills for crushing

102 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)

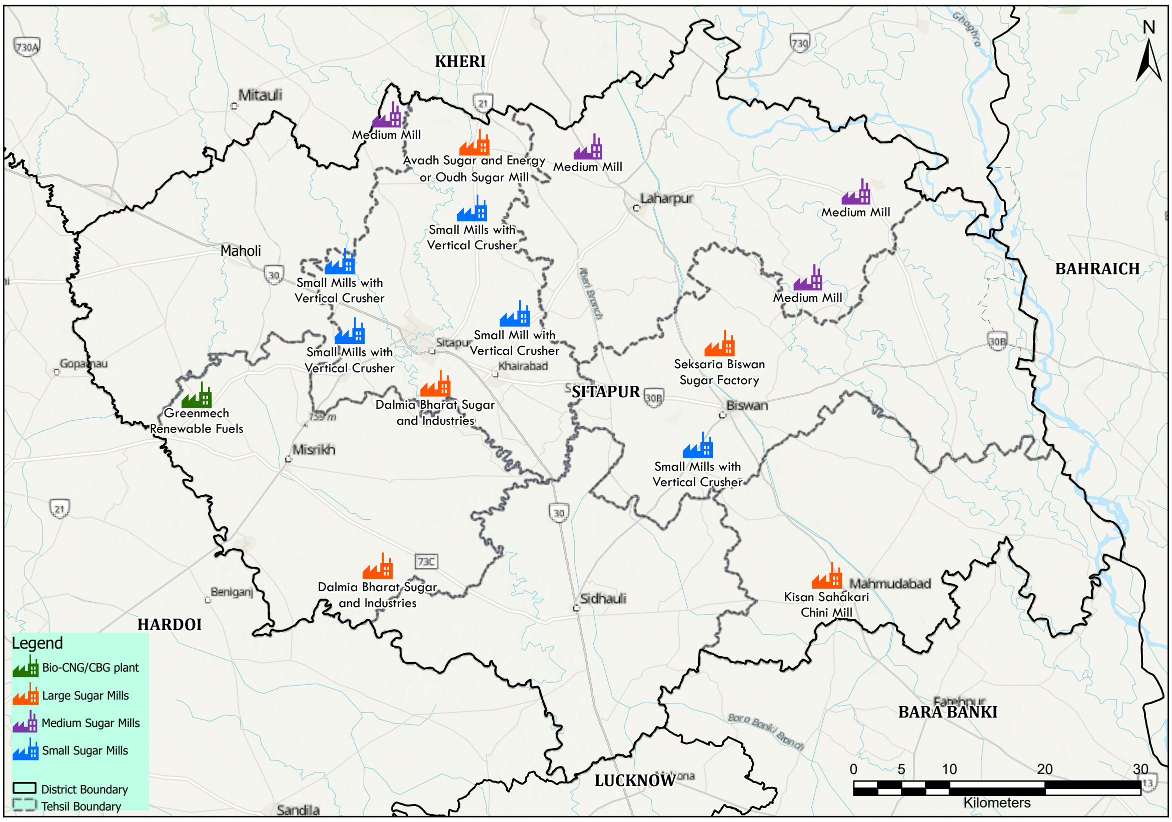


Figure 44: Location of sugar mills in Sitapur District[103]

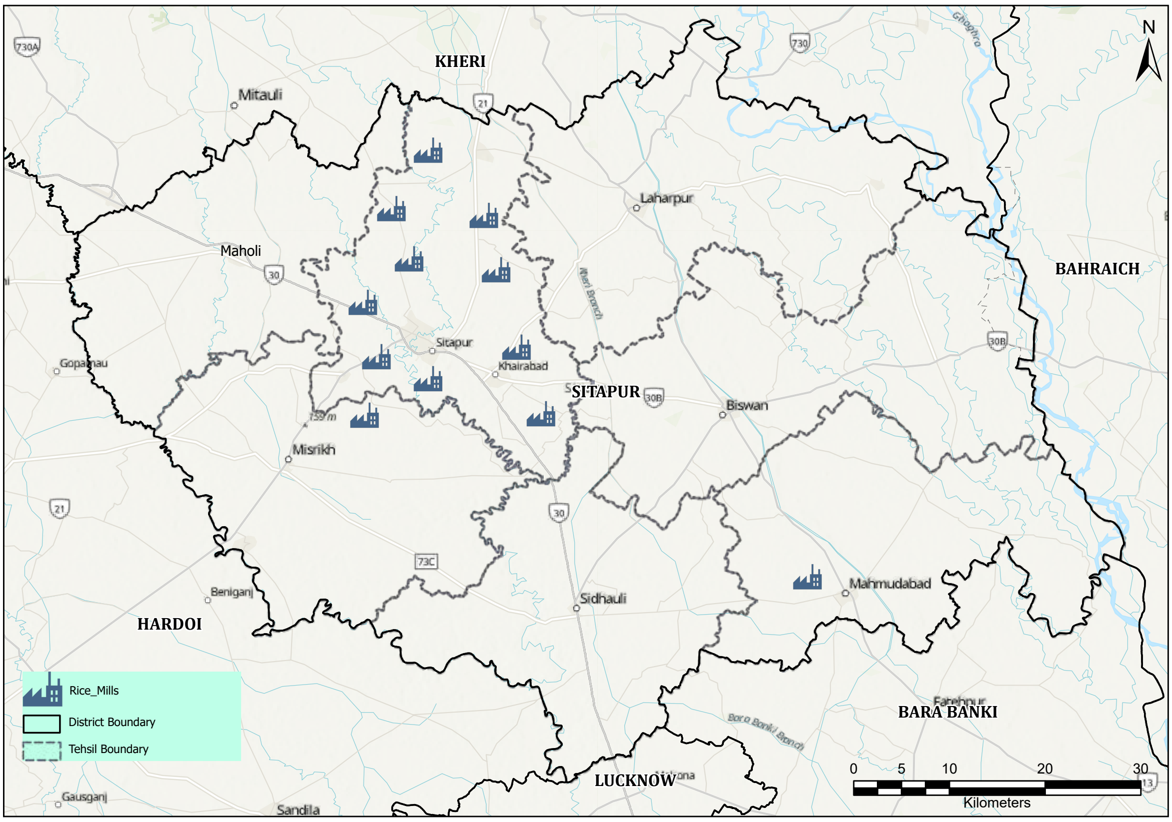


Figure 45: Location of rice mills in Sitapur District

103 Analysis by Vasudha Foundation, 2025

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

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