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

UTTAR PRADESH

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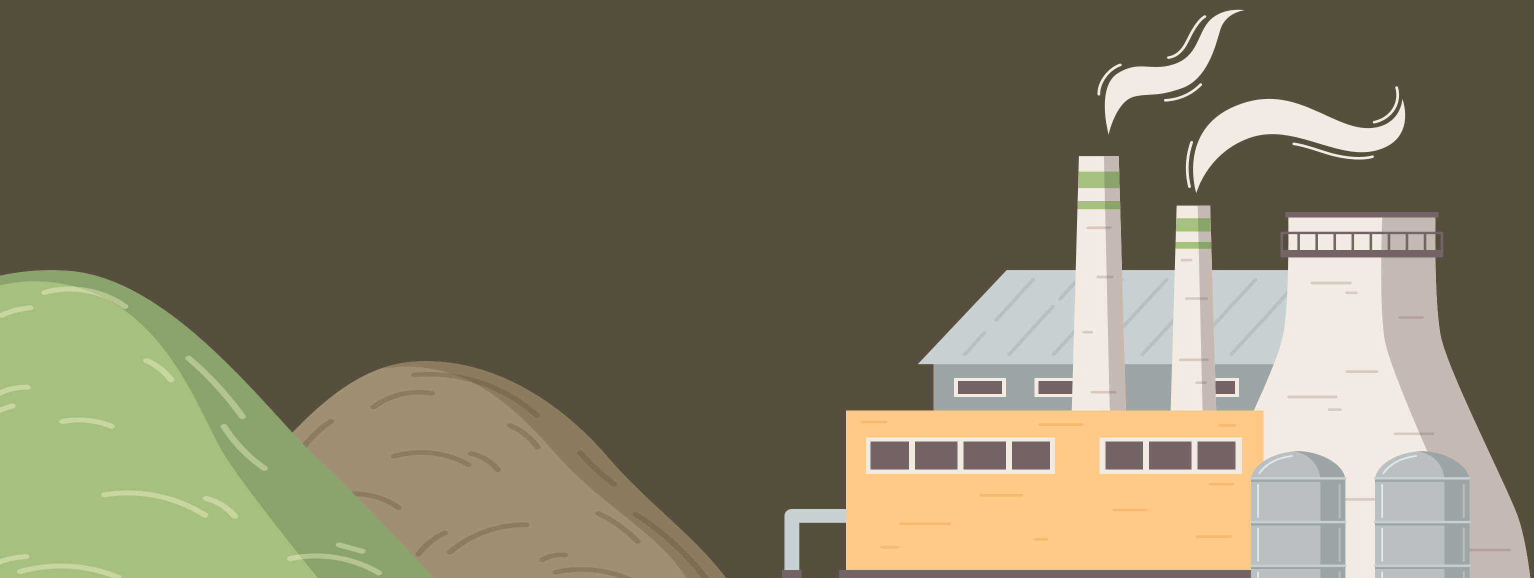

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Executive Summary

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 Lakhimpur Kheri 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 Lakhimpur Kheri

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

- **Major Biomass Feedstocks**: Sugarcane press mud, Sugarcane Leaves, Paddy Straw, and Cow Dung
- **High-Potential Zones**: Lakhimpur and Nighasan tehsils emerge as top biomass sources. Potential locations for CBG plants could be sited close to the sugar mills and sugar farms present in tehsils of Lakhimpur, Gola, Nighasan, Dhaurahara, or Palia, or in tehsils where paddy cultivation is high that includes tehsils of Gola and Mohammadi.
- **CBG Generation Potential**: The district has the potential to generate approximately 387 tonnes per day (TPD) of CBG from major feedstocks, such as sugarcane leaves, press mud, paddy straw, and

cattle dung, thereby contributing to the goal envisioned under the SATAT (Sustainable Alternative Towards Affordable Transportation) Scheme, which envisions installing 5,000 CBG plants by 2030.

Table 1: Tehsil-wise, feedstock-wise CBG potential in TPD

Tehsil	Sugarcane Leaves	Sugarcane Press mud	Paddy Straw	Cattle Dung	Total
Lakhimpur	51.45	43.36	0.52	6.32	101.65
Mohammadi	26.04	0	2.77	3.769	32.579
Gola Gokaran Nath	45.09	6.35	3.25	4.385	59.075
Nighasan	32.16	29.36	1.52	1.05	64.09
Dhaurahara	33.82	6.54	1.23	6.577	48.167
Palia	30.94	9.17	1.53	2.193	43.833
Mitauli	29.86	1.97	1.46	4.385	37.675
Lakhimpur Kheri district	249.36	96.75	12.28	28.679	**387.069**

- **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 387 TPD capacity CBG plants can collectively abate 3,88,451.25 T CO2 emissions annually[1].
  - In other words, 387 TPD of CBG can replace 387 TPD of CNG, which will correspond to daily carbon emission savings of 1064.25 T of CO2.
- **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, mustard straw, napier grass, and cattle dung to ensure year-round CBG production.
   - Diversified feedstocks stabilise biogas output and reduce supply fluctuations.

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

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

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

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

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

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

02

Introduction

India is expected to experience the largest increase in energy demand, tripling from current levels by 2050.[2] With rising global energy demand, limited local fossil fuel reserves, and environmental concerns, renewable sources like solar, wind and biomass[3] are gaining focus. Biomass energy not only meets the rising energy demand but also effectively manages organic waste - crop residues, animal waste, and municipal solid waste - reducing environmental problems if left unaddressed. Currently, India's bioenergy accounts for 13 percent of total final energy consumption, with a projected growth rate of 45 percent between 2023 and 2030.[4] India's abundant biomass availability (*See Figure1* which describes the potential of biomass power in India), positions it well to meet this demand.

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

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

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

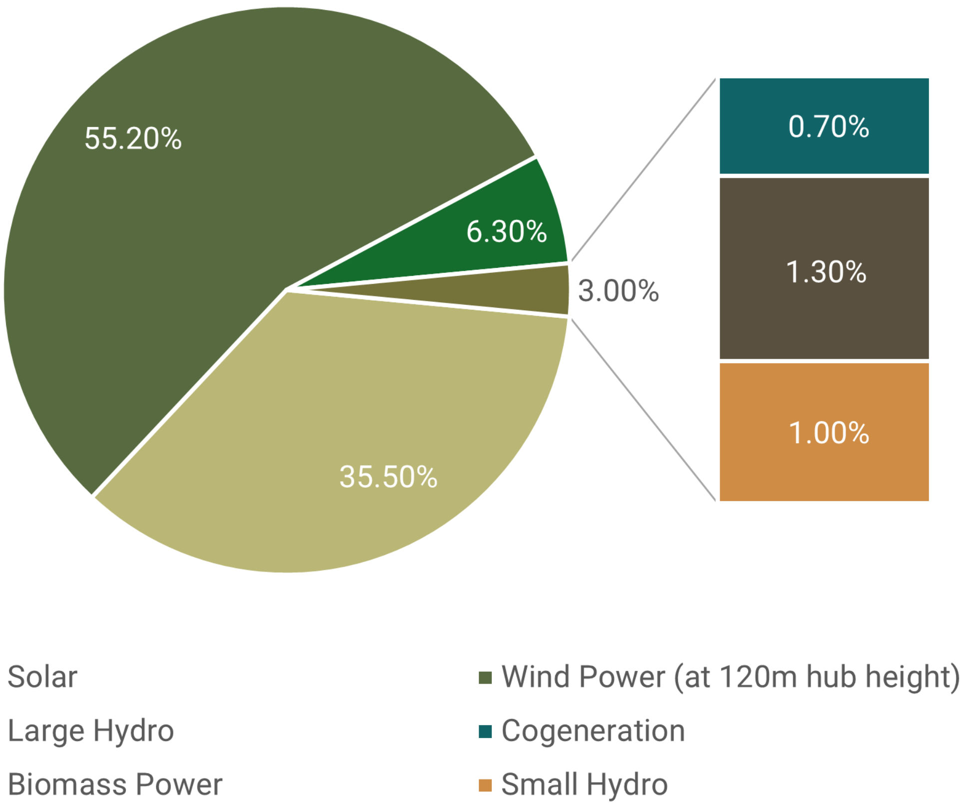

Figure 1: Source-wise renewable power potential in India, 2023[5,6]

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

In India, Uttar Pradesh is a leading agrarian[13] State (*See Figure 2*) and has the highest biomass power potential (See *Figure 3*). It is building a robust renewable biofuel economy in line with its Bio-energy Policy 2022. The main thrust of the policy is to promote the production of Biofuels such as Bio-CNG[14] and Bio-coal through waste-based enterprises.

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

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

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

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

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

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

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

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

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

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

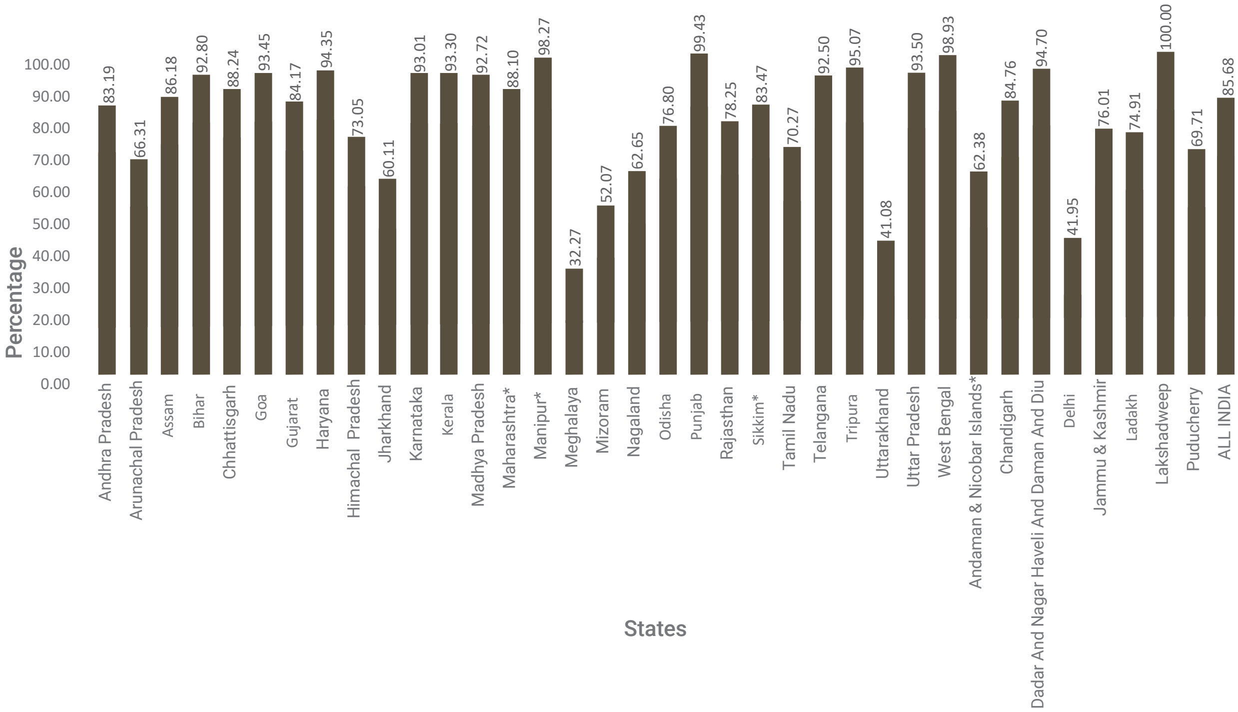

Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23[15]

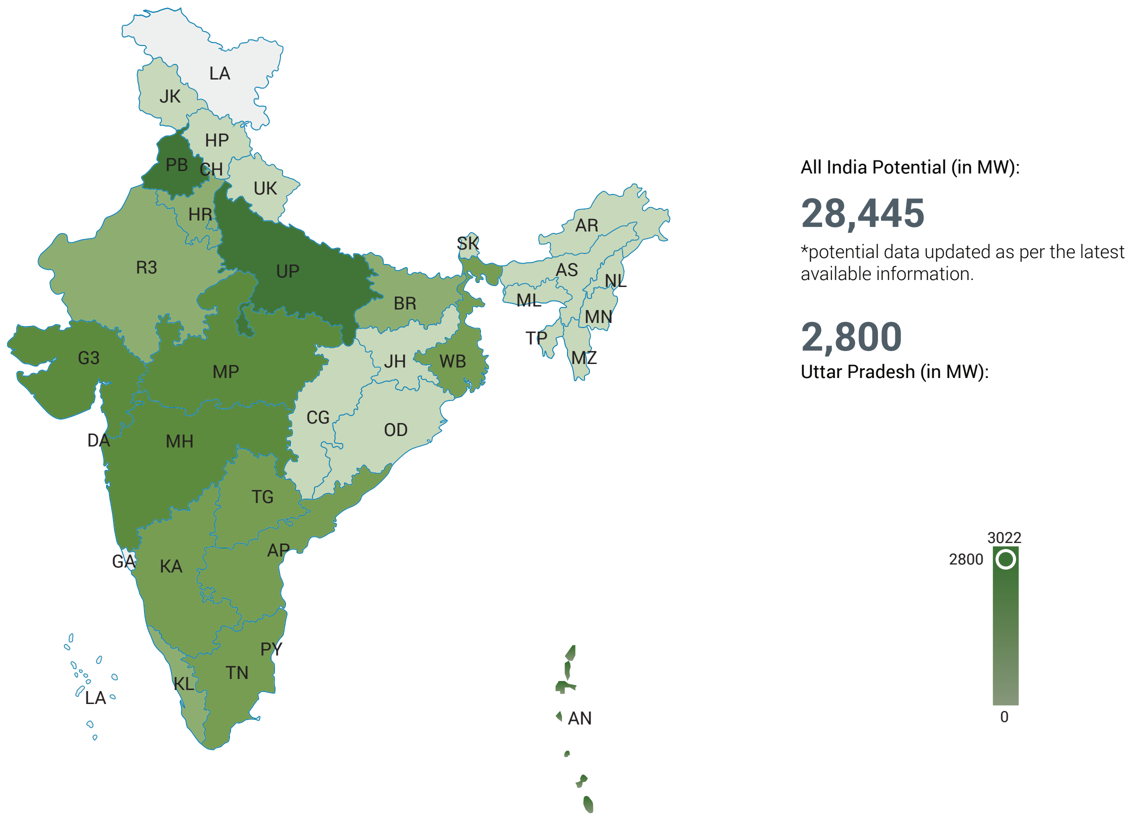

Figure 3: Biomass power potential in India[16]

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

16 India Climate and Energy Dashboard (ICED) 2025

Uttar Pradesh, among all other States, also has one of the highest total biomass and surplus biomass residue in India i.e., 124 MT and 21 MT,[17] respectively (See *Figure 4*). It has abundant biomass residue available which include bagasse, press mud, paddy straw, cattle dung, etc. which are potential feedstocks for Compressed Bio-Gas (CBG) production.

As per the 2022 Agricultural Statistics, State-wise potential availability of agriculture-based biomass (MT) is summarised in the table 2:[18]

Table 2: Potential availability of biomass in Uttar Pradesh

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

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

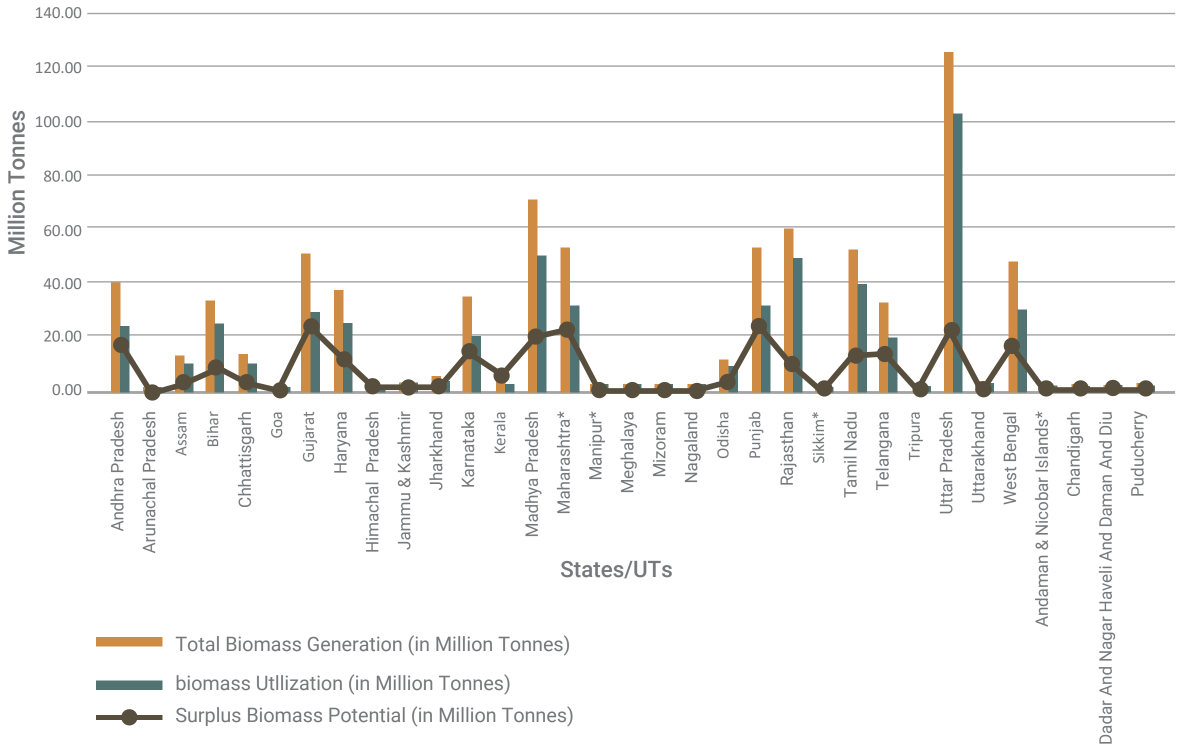

Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential[19]

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

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

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

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

- Agriculture and forestry residues that include – livestock residue and crop residue (includes non-edible plant parts that are left in the field after the crop is harvested, thrashed or left after pastures graze including stalk, stubbles, straws, bagasse, seed pods, and roots)[20]
- Industrial waste

In comparison to food-based, NGB biofuels do not compete with food and also not necessarily require land to cultivate for energy purposes, making it the most promising feedstock for energy generation[21]. Further, the contribution of NGB biofuels in reduction of GHG emissions is 30-35 percent greater compared to food-based biofuels.[22]

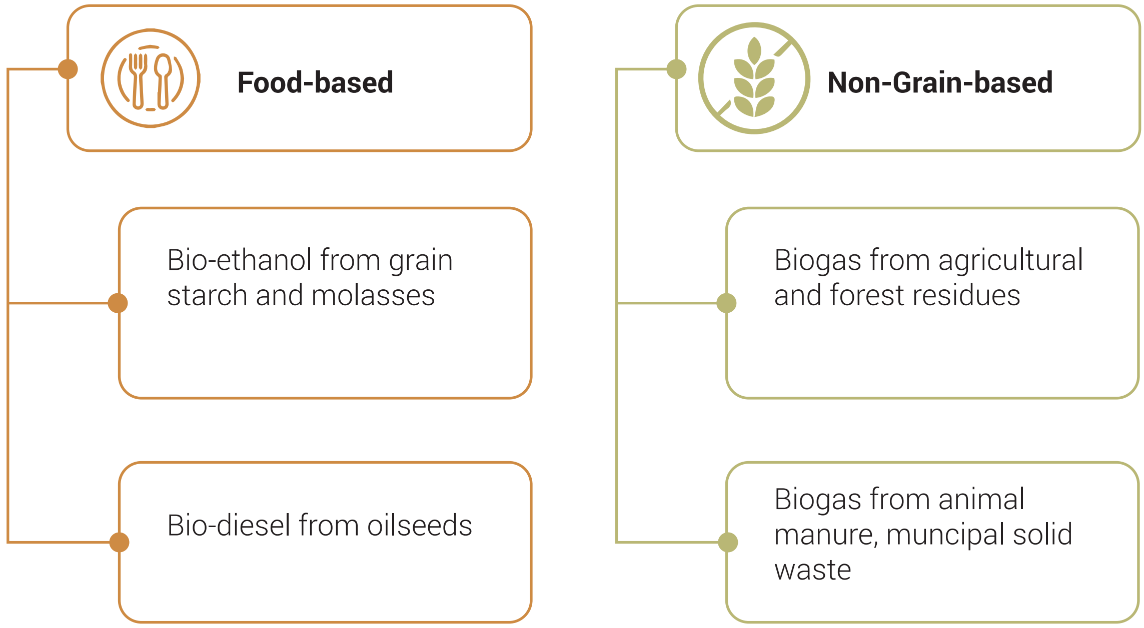

Figure 5: Classification of biofuels

2.1 Scope of the Study

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

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

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

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

Table 3: Different feedstock and their biomass residues

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

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

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

2.2 Importance of Biomass Quantification

Agro-residues are geographically distributed with variation in spatio-temporal availability. Agricultural statistics are fundamental datasets for assessing the general conditions of agricultural production and rural economy in India and are proven to be reliable and useful by various applications. For viable utilisation of biomass residue for energy generation, prior and precise database of residue distribution, seasonal fluctuation (peak and lean period of availability) is a pre-requisite.[23] Logistics such as residue harvest, collection, storage, transportation are spatially interlinked and need meticulous planning. In this study, adequacy, precision, reliability of data collected through traditional methods (secondary data collection or survey) is integrated with high-resolution spatial maps of crop production (one of the major agro residues) at the sub-district level that can inform the potential plant capacity, annual feedstock availability for CBG production (both, in terms of quantity and location from where it can be procured).

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

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

2.3 Overview of Compressed Biogas (CBG) Industry

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

Biogas production constitutes an intricate biochemical process unfolding in four distinct phases. The process begins with hydrolysis (Phase 1), where fermentative bacteria break down complex biopolymers such as proteins, polysaccharides, and fats/oils into simpler monomers and oligomers like sugars, amino acids, and peptides. In the acidogenesis phase (Phase 2), these simplified compounds are further transformed by fermentative bacteria into short-chain volatile organic acids, including propionate and butyrate. During acetogenesis (Phase 3), these intermediate products are transformed by acetogenic bacteria into acetate, hydrogen (H_2), and carbon dioxide (CO_2). Finally, in the methanogenesis phase (Phase 4), methanogenic microorganisms follow two pathways: acetolactic methanogens convert acetate into methane (CH_4) and CO_2, while CO_2-reducing methanogens utilise hydrogen to reduce carbon dioxide to methane. *Figure 6* shows this sequential breakdown of organic matter under anaerobic conditions, ultimately producing biogas.

Figure 6: Bio-chemical process flow for biogas production

Biogas is mostly composed of methane (40-60%) and carbon dioxide (30-35%), with small amounts of impurities such as Hydrogen Sulphide (H_2S), ammonia and moisture. This biogas can be used directly as cooking fuel or undergo additional processing. An important secondary benefit of biogas production is the digestate byproduct, which contains high concentrations of carbon and nitrogen compounds. Once dewatered, this digestate can be marketed as premium fertiliser.[24] This dual-product approach creates two distinct revenue streams from a single CBG plant operation.

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

24 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. *Figure 8* illustrates significant advantages that can be achieved through appropriate feedstock pretreatment. A single feedstock or a combination of feedstocks is fed into shredders (mechanical pretreatment) that make the substrate smaller or break open their cellular structure, increasing the specific surface area of the biomass (*See Figure 7*).[25] This gives greater possibility for enzymatic attack and increase biogas yields. The substrate is then dewatered to remove excess moisture from biomass material thereby improving their thermal efficiency and storage stability.[26] After the substrate is homogenised and dewatered, it is preheated in a preparation tank before it is actually fed into a digestor.[27]

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

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

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

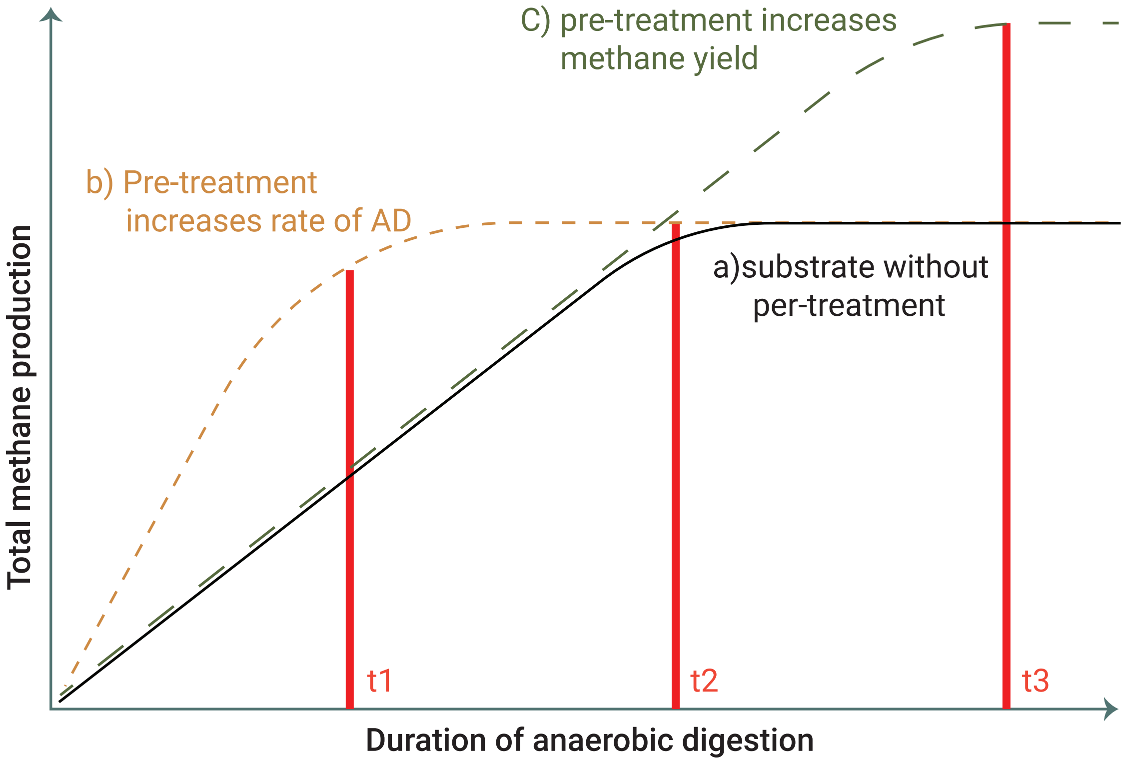

Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[28]

After the raw biogas exits digester, the moisture is removed using a dehumidifier or dryer as water vapour can not only decrease the heat value of the gas but also form condensates and accumulates in the downstream unit thereby forming plugs or hydraulic seals obstructing the transport of biogas.[29] This is followed by removal of hydrogen sulphide which not only contaminates the environment, but also minimises the useful life of downstream equipment by corrosion. Carbon dioxide is removed from the biogas stream using a Pressure Swing Adsorption technique which separates the two gases through selective adsorption. Purified gas is then compressed in a high-pressure compressor before getting deposited in a high-pressure compartment or cylindrical vessel.

28 IEA Bioenergy 2014

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

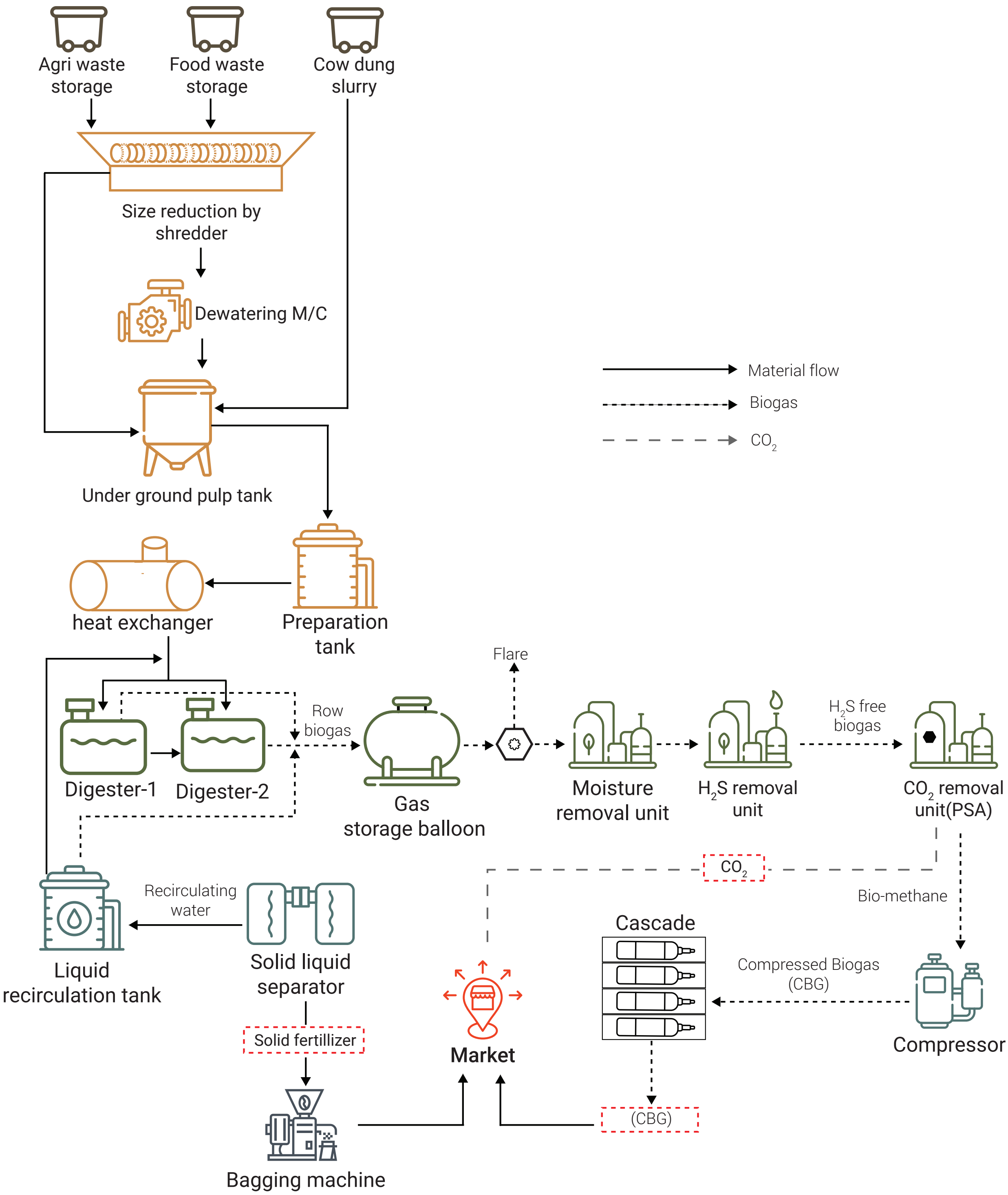

Figure 8: Processflow diagram for a Compressed Biogas plant[30]

India's CBG potential is estimated at approximately 87 bcm/yr[31], while the installed capacity currently represents less than 1 percent of this potential. As of September 2024, approximately 90 CBG plants were operational with an additional 508 plants under various stages of development. By 2030, CBG production could reach 0.8 bcm/yr. Realising this potential, Government of India through various measures have been promoting the production and use of CBG, which include:

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

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

- GOBARdhan (Galvanising Organic Bio-Agro Resources Dhan) which promotes converting cattle dung, agricultural residue and other organic waste into CBG and organic manure. The initiative has resulted in the installation of 110 community biogas plants and 21 CBG plants in Uttar Pradesh alone.[32]
- Under the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative, Government has introduced the phase-wise mandatory blending of CBG in CNG in transport and PNG (Petroleum Natural Gas) in City Gas Distribution network[33]
- Under the National Bioenergy Programme, government has been promoting energy generation from urban/industrial/agricultural residues.
- Market Development Assistance under GOBARdhan and amendments in the fertiliser (Control) Order of 1985[34], providing financial assistance to CBG developers, primarily for promotion of organic fertilisers, i.e., manure produced at CBG plants. This further enables farmers to get access to organic fertilisers, namely, Fermented Organic Manure (FOM), Liquid FOM, Phosphate Rich Organic Manure (PROM) at reasonable prices, addressing the organic carbon and micronutrients deficiency in Indian soil

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

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

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

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

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

03

District Profile

3.1 Geographic Overview[36]

Lakhimpur Kheri district is situated in northern most of Uttar Pradesh in Lucknow division and is situated in the Sub-Himalayan belt bordering the territory of Nepal It is bounded on the east by Bahraich district, separated by the Ghaghra River, and on the south by Sitapur district, and a short length by Hardoi district, on the west by the Shahjahanpur and Pilibhit districts and on the north by territory of Nepal. Its shape is roughly triangular. The district had an area of 7680 sq. km. ranking first in size in the division and occupies nearly 2.6 percent land area of the State.

The district is vast alluvial plain. The region is situated along the Ganga River and is formed of rocks of Alluvium and Dun gravels of recent age. The river Ganga flows along the boundary line of the district from north-west to south-east direction following the direction of slope of the area. There are number of small rivulets, which are mostly the left-out course of the river. Lakhimpur Kheri Tarai is situated in the northern part of the district, covering tehsils of Nighasan and Gola. This belt is flood-prone.

36 District Census Handbook, Lakhimpur Kheri, Part XX-A Series 10, Village and Town Directory, Directorate of Census Operations, Government of Uttar Pradesh

Figure 9: **District map of Lakhimpur Kheri as per the 2011 Census**

Sugar and the byproducts of the sugar industry, such as molasses, alcohol and other contents, are produced in large-scale units located at Palia Kalan, Sampoorna Nagar, Gola, Khamparia, Belraya, and Ajwapur. Sugar production being a seasonal industry, the mills operate between November to March. The Hindustan Sugar mill in Gola Gokaran Nath is the biggest mill in the district. Among small scale industries, there are several units of Khandsari, woodwork, general engineering, metalware, agricultural implements, oil farms, rice mils, hosiery, and metal casting

3.2 Administrative Units (Tehsils/Blocks)

The district is administratively divided into seven Tehsils, namely, Lakhimpur, Mohammadi, Gola Gokaran Nath, Nighasan, Dhaurahara, Palia, and Mitauli. For implementation and monitoring of development schemes, the district is further divided into 15 community development blocks. The rural area covers 7592 sq. km. and urban area recorded 88 sq. km. There are 995 Gram Panchayats and approximately 1794 Revenue villages with 1706 inhabited villages and 196 uninhabited villages in the district.

3.3 Climatic Conditions

The climate of the district, similar to that of the districts in the plains of central Uttar Pradesh is characterised by a dry hot summer and a pleasant, cold season. The year may be divided into four seasons. The cold season lasts from about the end of November to the end of February, followed by summer season. The air is very humid in the monsoon season. Winds are generally light throughout the year.

Table 6: District agricultural and climate profile of Lakhimpur Kheri

District Agricultural and Climate Profile				
Agro-Climatic Zone[37] (State Agricultural Profile[38])	Upper Gangetic Plain Region (Central Plain Zone)			
Rainfall[39]				
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Southwest Monsoon (June-September)	921.8	49	2nd week of June	3rd week of September
Post-monsoon (October-December)	55.5	10	-	-
Winter (January-March)	57.4	9	-	-
Pre-monsoon (April-May)	34	2	-	-
Annual	1068.7	49	-	-
Temperature (in degree Celsius)[40]	**Maximum** 32.3^{0}C – 44^{0}C		**Minimum** 4.2^{0}C - 15.6^{0}C	
Soil	Deep, fine soils moderately saline and sodic associated			
Major Climate Contingency and Frequency	**Regular**	**Occasional**		**None**
Drought	x	x		x
Flood	√	x		x

37 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.

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

39 Agriculture Contingency Plan for district: Lakhimpur Kheri, 2019, Department of Agriculture and Farmers' Welfare

40 Krishi Vigyan Kendra, Lakhimpur Kheri, Agriculture Department, Government of Uttar Pradesh

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

A report[41] which measured district-level climate vulneRabilities in India highlighted that Lakhimpur Kheri district falls under the moderately vulnerable category and the major drivers of vulneRability include high percent of marginal and small operational holders, low percent area covered under centrally funded crop insurance, lack of forest area per 1000 rural population, etc.

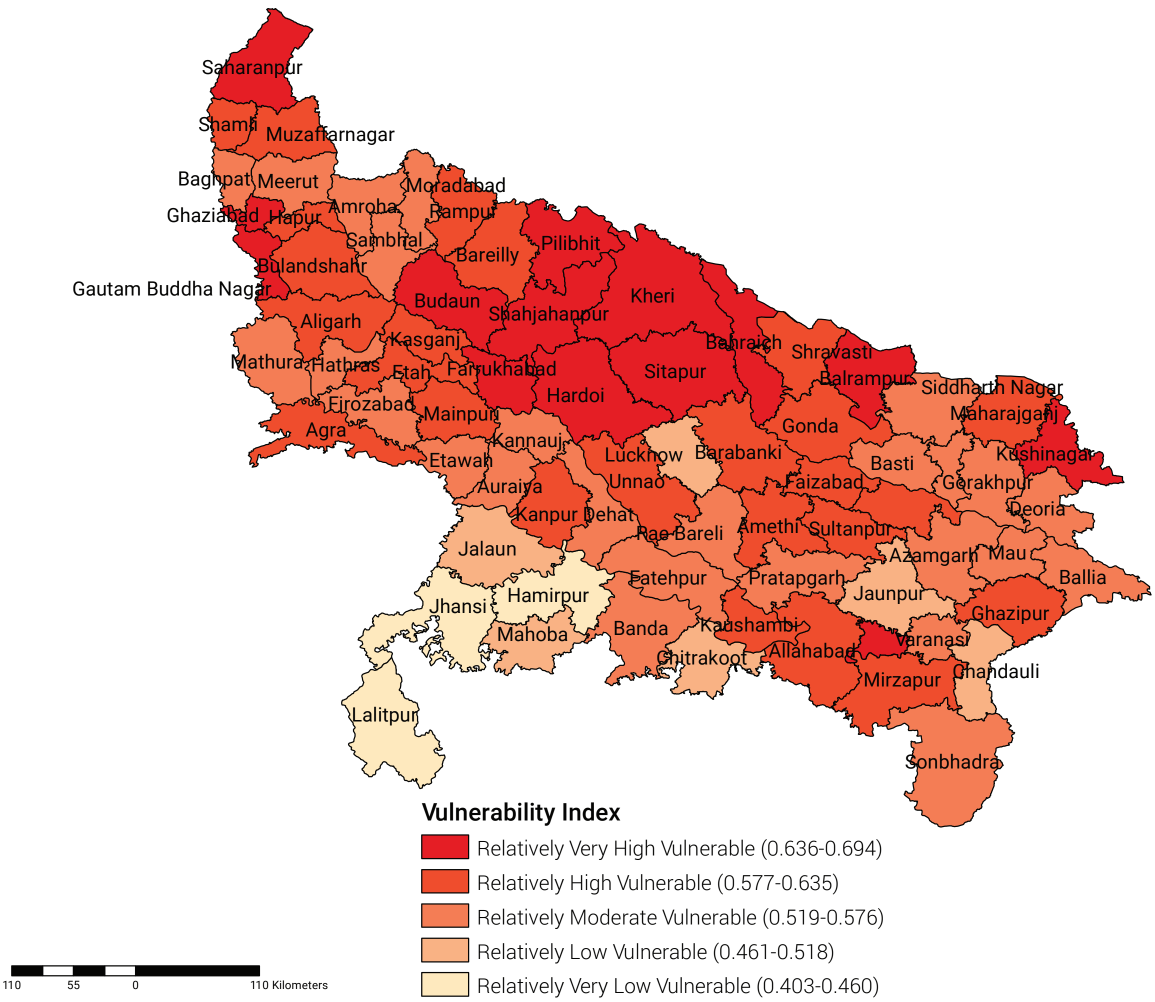

Figure 10: District-wise climate vulneRability index

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

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

Table 7: Productivity of food grains in different agro-climatic zones of Uttar Pradesh

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

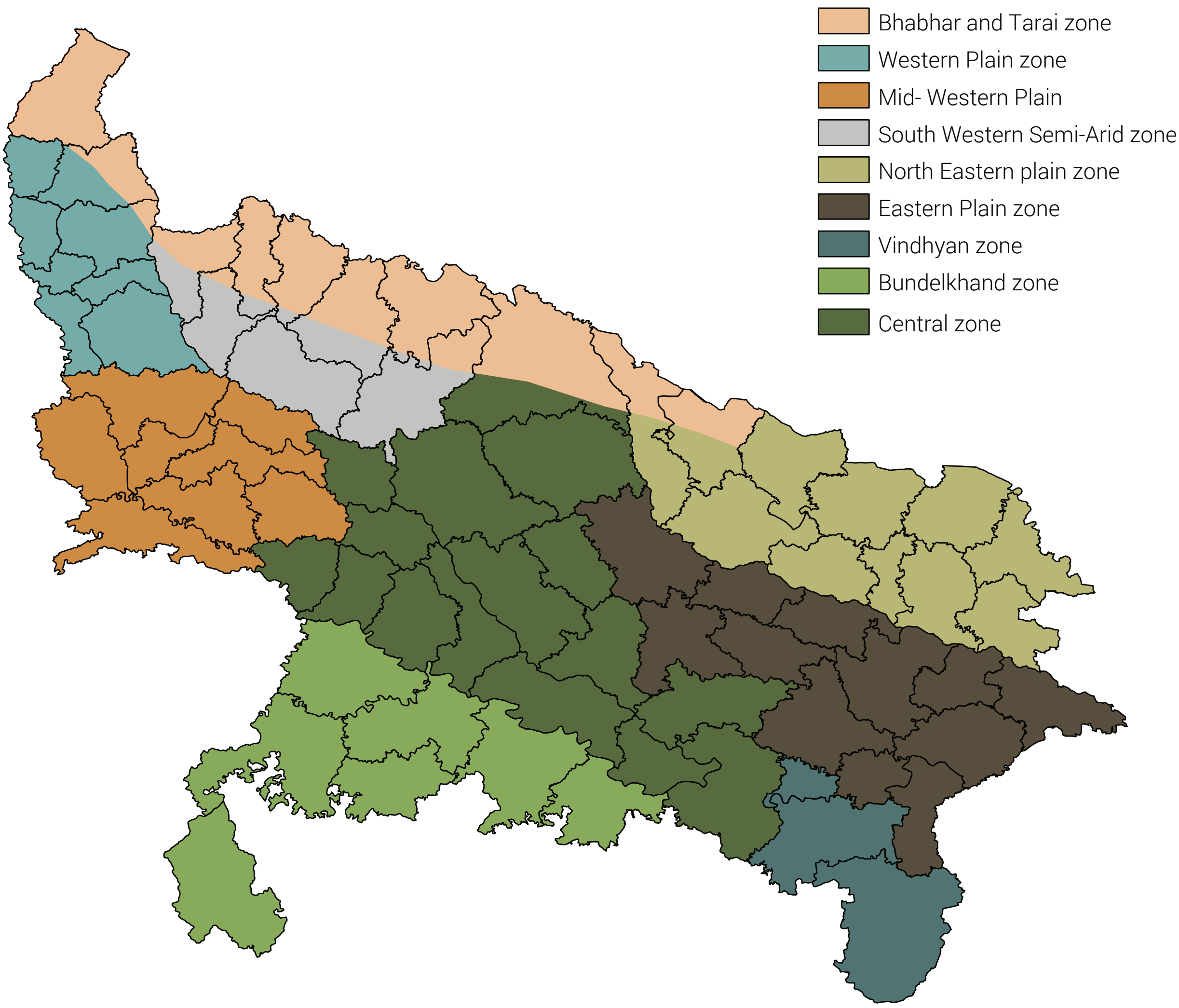

Figure 11: Agro-climatic zones in Uttar Pradesh[42]

42 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

3.4 Demographics (Urban/Rural)

Agriculture is the primary occupation in the district with over 75 percent of the total workforce involved either as cultivators or agriculture labourers.

In terms of agricultural landholdings, nearly 79 per cent of the holdings in the district were less than 1 hectare (ha.) while 13 percent of the holdings were 1-2 ha, close to 6 per cent of the holdings lie between 2-4 ha and less than2 percent of the holdings were between above 4 ha during 2015-16. In terms of agricultural income, during 2018-19 the gross value of agricultural produce per ha. of net area sown was INR 3,61,615.71.

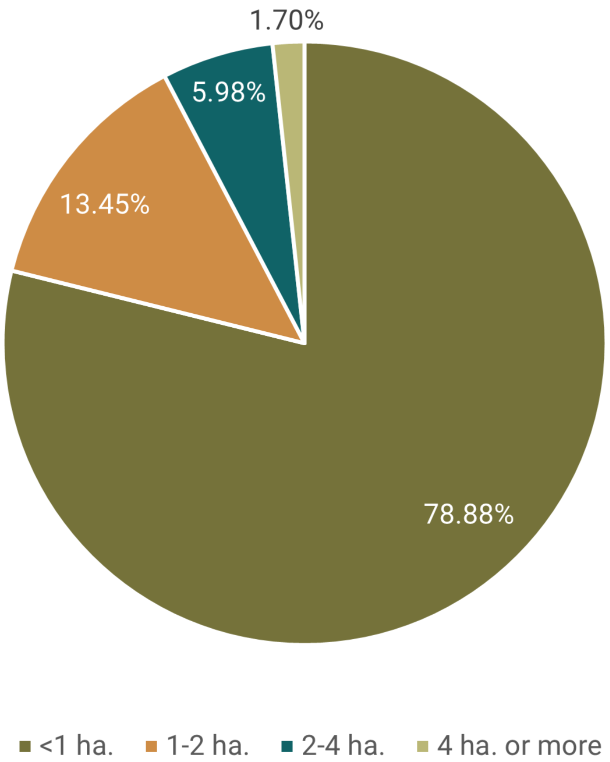

Figure 12: Agricultural land holdings in Lakhimpur Kheri[43]

3.5 Agricultural Overview

Lakhimpur Kheri has a significant agricultural economy. At the district-level, around 4.97 lakh hectares (ha.) of geographical area is sown with a cropping intensity of 149.1 percent.39 Gross cropped area is approximately 7.14 lakh ha. with over 2.35 lakh ha. area sown more than once. The net irrigation area is around 4.08 lakh ha. out of which 70900 ha. are rain fed. Major sources of irrigation including bore wells (tube wells) and canals.

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

3.5.1 Total Agricultural Area[44]

Table 8: Agricultural land area and cropping intensity in Lakhimpur Kheri district

Agricultural Land Use	Area ('000 ha)	Cropping Intensity (%)
Net sown area	479.7	149.1[45]
Areas own more than once	235.3	
Gross cropped area	714.9	

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

Major agricultural crops by production in the district include wheat, gram, moong, barley, pea, sugarcane, jowar, mustard, potato and horticulture crops during Rabi season and jowar, millet, bajra, maize, paddy, and pulses (*tur/arhar*) during Kharif season. Zaid are intermediate harvest and is of little significance. Cash crops that are popularly sown in the Ddstrict include sugarcane, potato, etc. At times, double cropping is practised in the district to obtain more yield. Figure 13 describes the extent of land use in terms of gross areas sown for Kharif and Rabi crops in Lakhimpur Kheri during 2021-22.

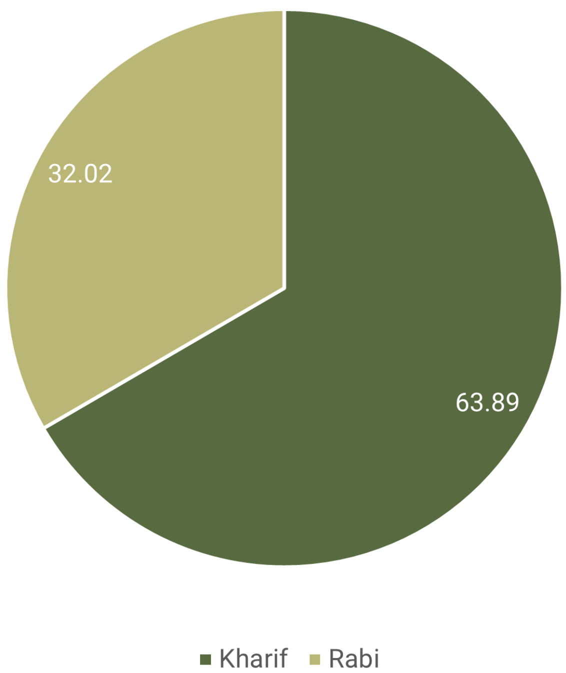

Figure 13: Gross area sown during both the cropping seasons in Lakhimpur Kheri

44 District Profile, Krishi Vigyan Kendra, Kheri

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

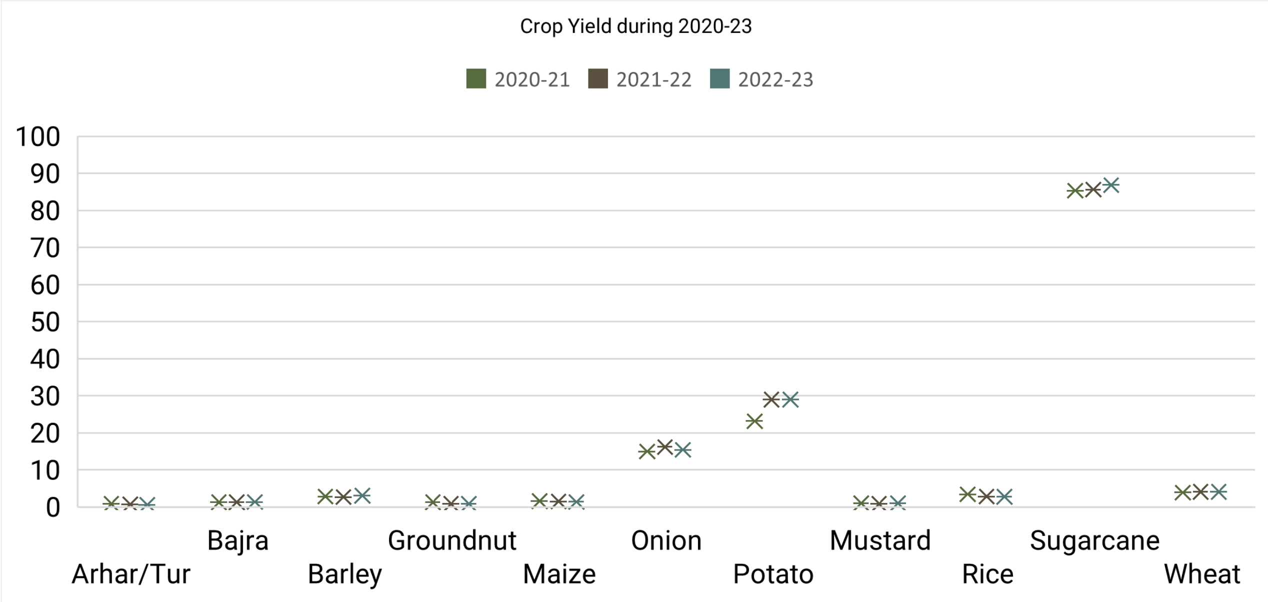

Figure 14: Crop yield during 2020-23 for major crops sown in Lakhimpur Kheri during *Kharif* and *Rabi*[46]

Rabi crops are sown around mid-November and harvested during spring (April to June) while Kharif crops are sown during the first week of June to mid-July and are harvested during September to October. During 2023-24, the prominent Rabi crops were wheat, mustard, and barley where wheat alone occupied more than 60 percent of the total cropped area. Other Rabi crops include potato, other vegetables, etc.

46 Area Production Statistics, Ministry of Agriculture and Farmers Welfare

Table 9: Tehsil-wise cropped area of *Rabi* crops (in ha.) during 2023-24

Tehsil	Mustard	Other Crop	Potato	Pulses	Sugarcane	Vege-table	Wheat	Total
Dhaura-hara	6273.45	439.85	98.27	381.30	3795.13	69.46	8848.73	19906.18
Gola gokaran nath	5323.99	498.64	119.57	432.67	2492.81	68.63	20102.33	29038.65
Lakhimpur	6475.79	684.19	121.36	567.81	3528.05	90.55	17072.42	28540.16
Mitauli	3547.33	424.97	63.90	226.93	2334.85	45.38	12207.48	18850.85
Moham-mdi	3425.12	345.19	53.60	208.20	2309.82	38.12	19357.68	25737.73
Nighasan	4051.04	312.05	67.08	281.90	2805.33	45.76	8750.86	16314.02
Palia	3151.73	187.95	54.48	180.39	3405.38	34.00	7729.66	14743.60
Total	**32248.46**	**2892.84**	**578.25**	**2279.21**	**20671.38**	**391.90**	**94069.16**	**153131.19**

During 2023-24, the prominent *Kharif* crops in Lakhimpur Kheri were sugarcane and paddy where together they comprised more than 80 percent of the total cropped area. Other major *Kharif* crops include oil seeds, maize, barley, and bajra that were sown and cultivated during the same period. Among all tehsils, Aonla had the highest share of cropped area for paddy, while Baheri, Nawabganj and Meerganj dominated in cultivation of sugarcane, followed by Kheri and Faridpur.

Table 10: **Tehsil-wise production of *Kharif* crops (in ha.) during 2023-24**

Tehsil	Agri-plantation	Bajra	Fallow	Paddy	Sugar-cane	Pulses	Vegeta-ble	Total
Dhaura-hara	2073.76	13284.35	7140.41	733.37	37233.76	60465.64	178.83	57583.54
Gola go-karan nath	828.79	982.39	18865.29	1561.17	52205.90	74443.53	59.01	51795.47
Lakhimpur	2475.27	3948.90	12863.96	2994.27	58896.05	81178.45	98.35	39485.45
Mitauli	2028.90	1170.97	8498.33	920.88	33889.40	46508.47	6.86	36258.38
Mohammdi	1403.29	2441.36	16103.09	2345.72	29277.38	51570.83	157.49	28636.21
Nighasan	450.26	2697.04	8822.92	1824.67	36212.10	50006.99	98.02	32235.70
Palia	278.33	2869.83	8917.12	2491.72	34133.66	48690.67	98.02	32235.70
Total	**9538.60**	**27394.82**	**81211.13**	**12871.80**	**281848.24**	**412864.58**	**598.56**	**245994.77**

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

In Lakhimpur Kheri, the percent of irrigated area to the total cultivable area is 90.77[47]. The gross irrigated area of the district is at 4.91 lakh ha.

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

Sowing window for major field crops	Rice	Sugarcane	Groundnut	Wheat	Potato	Mustard
Kharif – Rainfed	-	-	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	-	1st week of October to last week of October	-	2nd week of November to 2nd week of December	-	-

3.6 Forest Resources

3.6.1 Total Forest Area[48]

Table 12: Total forest area (by classification) in Lakhimpur Kheri

District	Calculated Area (km^2)	Very Dense Forest (km^2)	Moderate Dense Forest (km^2)	Open Forest[49] (km^2)	Total (km^2)	Scrub[50] (km^2)
Lakhimpur Kheri	7680.44	805.14	157.70	271.29	1234.13	8.22

Forest area consists of Babul, Dhak, Neem, Sheesham, and Bamboo trees which are grown in scattered and barren land. In sandy areas, palm trees and thorny bushes grow. 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 varieties of

47 District Census Handbook for Lakhimpur Kheri, 2011

48 Forest Survey of India, India State of Forest Report 2023 Vol. II p.300

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

50 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)

trees include Banyan, Gular, Pakar, Fig, Vaska, etc.

3.6.2 Types of Forests and Residue Generated

Forestry residue consists of small trees, branches, leaves, bark, tops, and un-merchantable wood left in the forest after cleaning, thinning, or final felling. Woody biomass requires thermal gasification at high temperature in a low-oxygen environment to convert it into a mixture of gases, mainly carbon monoxide, hydrogen and methane (syngas)[51]. 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 agricultural residue or Municipal Solid Wastes (MSW). Biomass such as paper, wood, dried leaves, wooden shavings, etc are generally high in lignin and cellulose. These substances are not suitable for the commercial biogas generation.[52]

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

3.7.1 Cattle, Poultry, and Other Livestock Statistics

Table 13: Tehsil-wise livestock statistics have been collected, and their manure and waste generation potential[54]

Tehsil	Cattle	Goat/Sheep	Swine	Poultry (Chicken)	Total Gov-ansh
Lakhimpur	160764	97302	932	1,11,051	7272
Mohammadi	167271	97299	910	1,11,005	4235
Gola Go-karan Nath	111514	64866	600	73,990	4570
Nighasan	111517	64867	621	74,030	5445
Dhaurahara	167263	97297	931	111047	4191
Palia	55757	32433	310	37014	2200
Mitauli	111515	44324	624	74031	7200
Total	885601	498388	4928	592168	35113

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

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

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

54 Animal Husbandry Department, Government of Uttar Pradesh

3.7.2 Manure and Waste Generation Potential

The high population of cattle and other livestock has resulted in higher quantities of cattle dung and poultry litter. Common practices for managing dung and litter include composting for manure production, forming cattle dung cakes to be used as fuel, and as feedstock for small biogas plants. Based on the existing literature[55,56,57,58] around dung/litter yield from the respective livestock, the following figures are derived:

Table 14: Animal categories and their dung/litter generation potential

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

Step 1

Fresh cow-dung from farm

- Collected and shaped into 8-10 inches cakes
- Collected and thrown on previous day heap

Step 2

Cakes dried in sun and heap allowed to ferment

- Dried, tough cakes
- Heap ferments and degrades into nitrogenous compounds

Step 3

Step 3: Utilisation

- Cakes ignited and burnt to cook meals
- Heap collected after 4 to 6 weeks and mixed in soil in agricultural fields

Figure 15: Traditional use of cow-dung as kitchen fuel and manure[59]

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55 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

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

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

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

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

3.8 Industry and Processing Units

3.8.1 Existing Biomass-based Industries

There are two operational Compressed Biogas Plants, in Mohammadi tehsil and one large biogas plant in Lakhimpur tehsil. Both the CBG plants are located in close proximity to two large sugar mills from where they procure press mud.

Table 15: Details of existing biomass-based industries in Lakhimpur Kheri

Plant Capacity	Feedstock/ Raw Material	By-Products	Off taker	Procurement Plan
12 TPD plant in Mohammadi tehsil	Sugarcane press mud, [60] Cattle dung	CBG, FOM, LFOM (FOM is distributed to farmers at free of cost)	CBG is being supplied to Jio-BP	Plant has started its commercial operations in February 2025 and has signed a long-term press mud procurement agreement with one large sugar mill in the tehsil. No other feedstock is blended or used for round-the-year operations
10.6 TPD plant in Mohammadi tehsil	Sugarcane Press mud, Cattle dung	CBG, FOM, LFOM (FOM is distributed to farmers at free of cost)	CBG is being supplied to BPCL and HPCL	Plant has started its commercial operations in March 2024 and has entered into a long-term press mud procurement agreement with one large sugar mill in the tehsil. No other feedstock is blended or used for round-the-year operations
140 m^3 Per Day (MPD) in Lakhimpur tehsil	Cattle Dung	Bio-slurry	Biogas used for heating purposes in cowshed	Commercial-scale biogas plant installed and functional inside a cowshed facility in Lakhimpur Tehsil (under GOBARdhan)

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

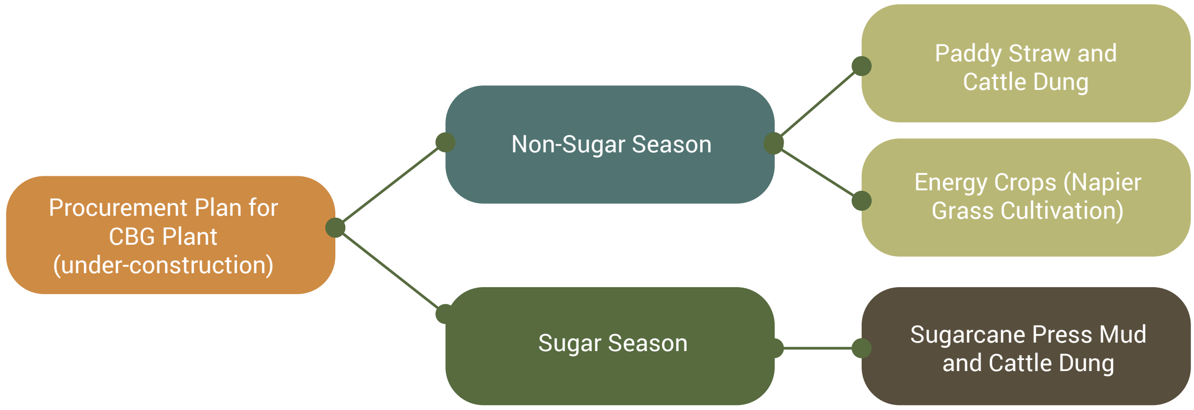


Figure 16: Feedstock procurement plan for existing CBG plant[61]

60 Press mud, also known as filter cake or press cake, is a residual byproduct in the sugar industry

61 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

04 Data Collection

4.1 Primary Data Collection

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

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

(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)

Table 16: Operating parameters and conversion factors for sugar mills

Parameter	Value
Conversion Factor (Sugarcane to Bagasse)	40% TCD[62]
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[63])	150 days
Number of Operating Days (Medium Sugar Mill[64])	150 days

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

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

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

64 Medium Sugar Mills use Horizontal Crushers to crush Sugarcane

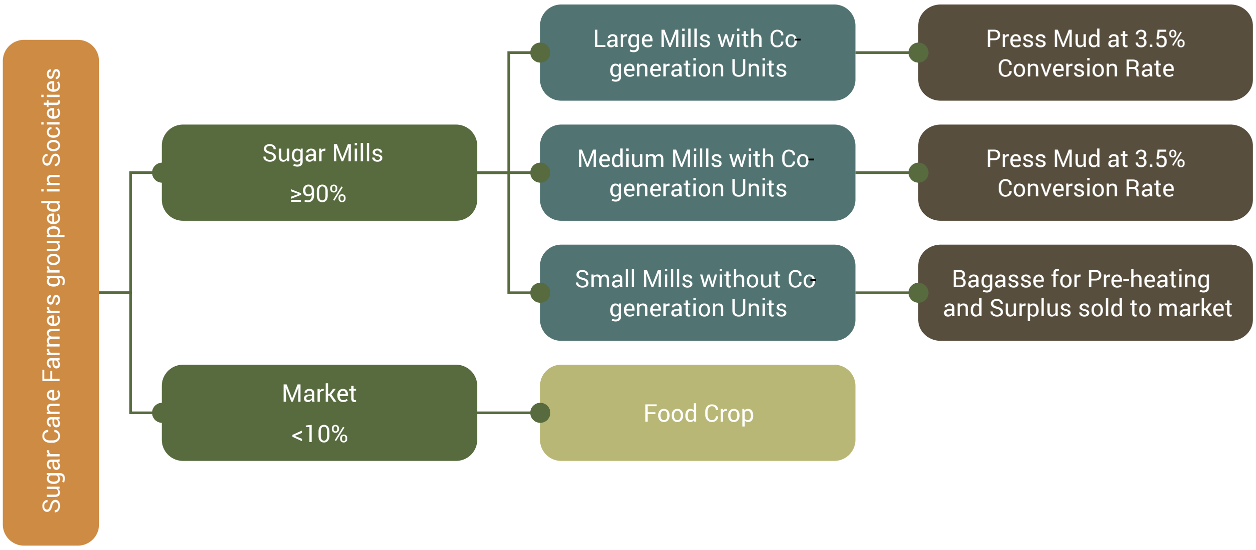


Figure 17: Mapping the value chain of sugar industries

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

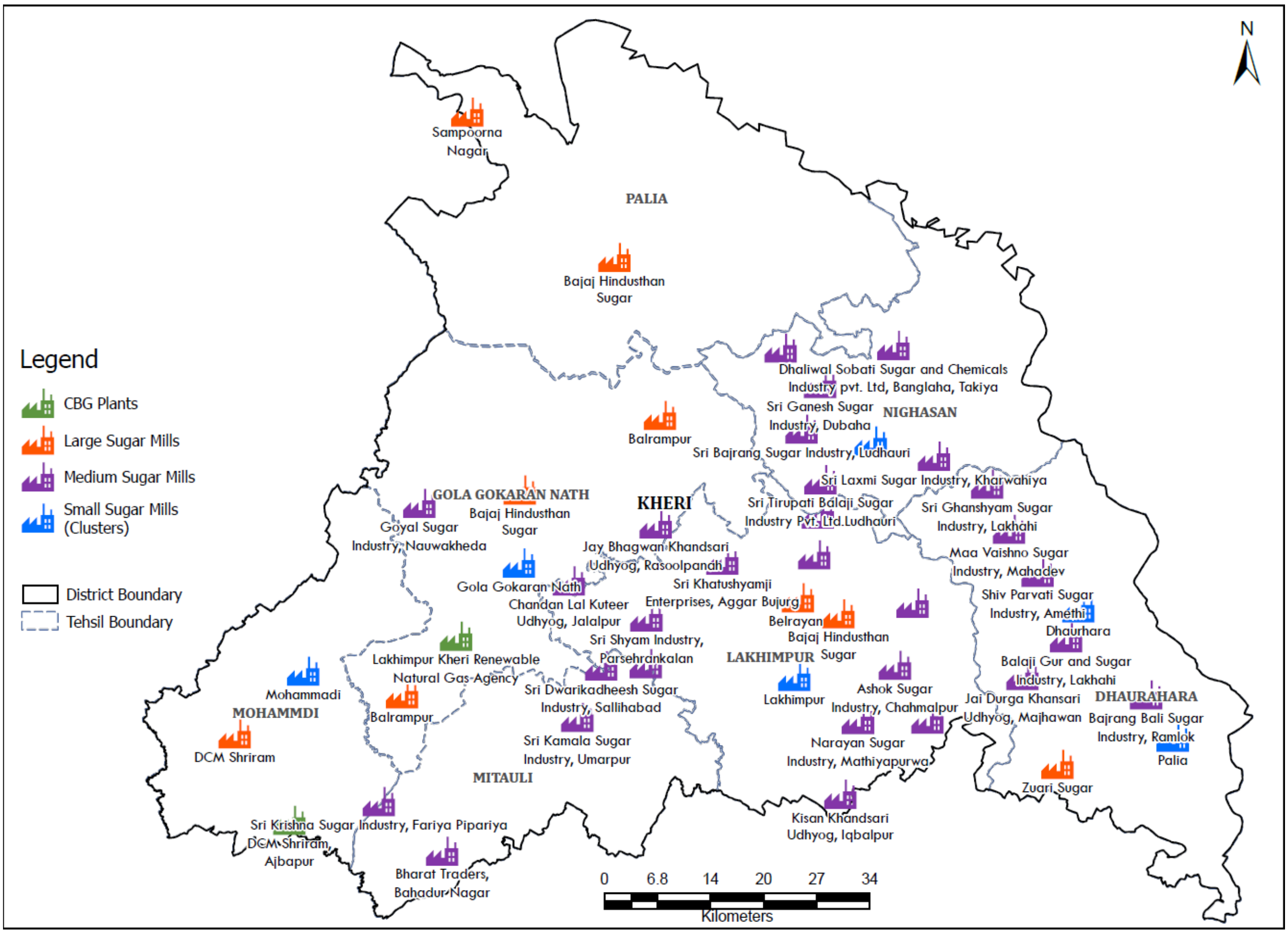


Figure 18: Location of sugar mills in Lakhimpur Kheri district[65]

65 Analysis by Vasudha Foundation, 2025

Table 17: Tehsil-wise sugar mills and their annual crushing capacity

Tehsil	Cane Crushing Capacity in TCD		
	Large Mills	Medium Mills	Small Mills (Vertical Crushers)
Gola	13000	7400 (2 Mills)	11 (134 Mills)
Palia	21000 (3 Mills)	-	11 (70 Mills)
Lakhimpur	18000 (2 Mills)	55000 (8 Mills)	11 (139 Mills)
Dhaurahara	10000	24700 (5 Mills)	11 (91 Mills)
Mohammadi	23500 (2 Mills)	-	11 (183 Mills)
Nighasan	-	46200 (7 mills)	11 (95 Mills)
Mitauli	-	38000 (6 mills)	11 (193 Mills)

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 levels. Crop Yield data was collected from the Crop Production Statistics published by the Ministry of Agriculture and Farmers' Welfare for three-year period (2021-24) to arrive at an average. Further, the residue-to-crop ratio (on a dry weight basis) was borrowed from the latest National Biomass Atlas[66] which is described as under:

Table 18: Residue-to-crop ratio and surplus fraction for various agricultural residue

Crop	Residue	Residue to Crop Ratio	Surplus Fraction
Wheat	Straw	1.5	0.2
	Husk	0.3	0.2
Paddy	Straw	1.5	0.17
		0.2	0.17
Sugarcane	Tops and leaves	0.05	1
Maize	Stalks	2	0.01
	Cobs	0.3	0.01
	Leaves	0.12	0.01
Mustard	Stalks	1.8	1
Pulses	Stalks	2.5	1

66 National Biomass Atlas of India, 2023

Potato	Stalks	0.1	1
Vegetable	Stalks	0.1	1
Barley	Straw	1.3	1
Bajra	Stalks	2	1
	Husk	0.3	1
	Cobs	0.33	1

Biogas Yield for different crops/raw materials was shared by National Institute of Bioenergy (NIBE). For crops with unavailable crop-specific conversion factors, a standardised average conversion ratio (calculated on a dry weight basis) was applied to estimate biogas yield potential. This approach accounts for moisture content variations and ensures consistency in quantifying energy generation capacity from residual biomass.[67]

Table 19: Biogas yield for various feedstocks as per NIBE estimates

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

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

Table 20: Conversion factor for surplus biomass residue calculation of animals

Category	Animal	Collectable Dung (Kg/day)	Total Solids	Availability Coefficient	Biogas in m^3	Multiplication Factor[68]
Large	Cows, Buffalo	22.5	25%	70%	0.6	4.76086
Small	Sheep, Goat	1.6	29%	20%	0.4	4

67 As per the NIBE's approximations

68 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.

Swine	Pigs	2.7	29%	60%	0.4	4
Poultry	Broiler, Layer, and Other	0.045	29%	60%	0.8	4.71428

Alternatively, we also know from various studies, that, 0.04 m^3 of biogas can be generated from 1 kg of cattle dung.

Table 21: Calorific values[69,70] for animal residue

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

To understand which feedstock is best for CBG production, we used SATAT data published by the Ministry of Petroleum and Natural Gas (MoPNG)[71]. The tentative yield of various feedstocks is tabulated in Table 22.

Table 22: Tentative CBG yield from various feedstocks[80]

Feedstock	CBG Production (T)	Feedstock requirement
Agriculture residue	1	10 T
Press mud	1	25 T
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

69 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

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

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

05

Stakeholder Mapping

5.1 Identification of Relevant Stakeholders

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

Table 23: Stakeholders in bio-energy value chain

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

06

GIS-based Satellite Mapping

6.1 Cropping Pattern and Analysis

It can be observed from the Kharif crop map that while sugarcane was cultivated across the district, they are prominent crops in tehsils of Gola, Mohammadi, Mitauli and Lakhimpur. Paddy can be seen cultivated in parts of Mohammadi, Gola, and Palia.

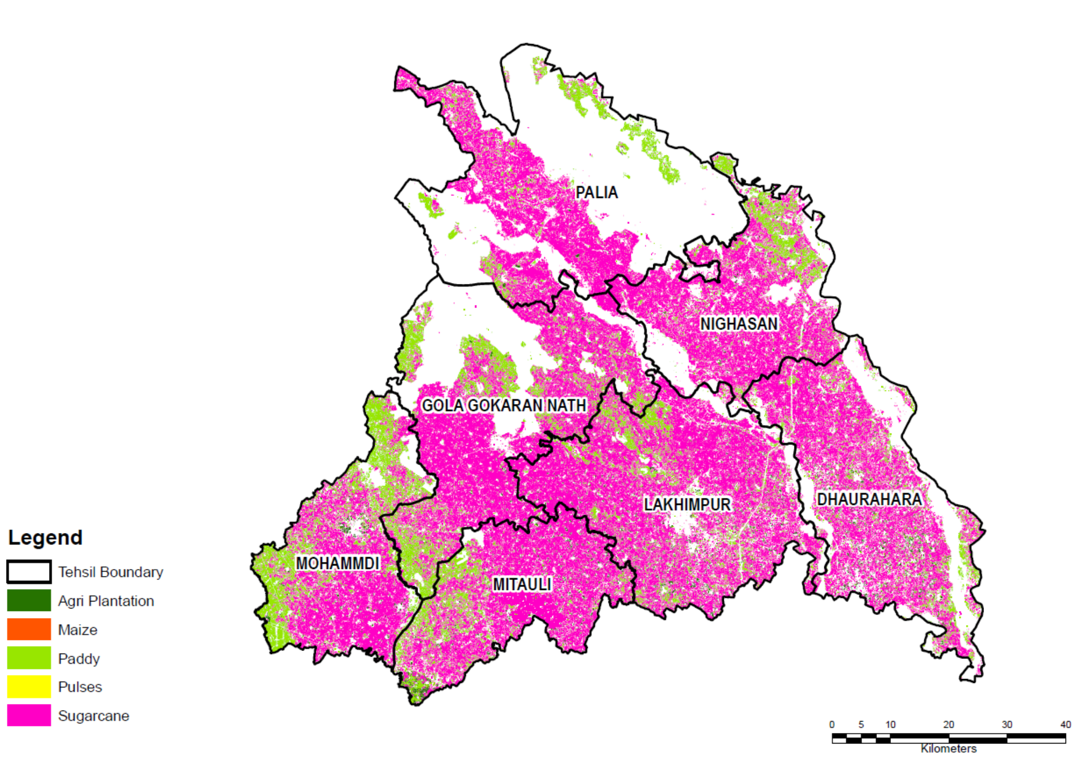


Figure 19: Geographical spread of *Kharif* crops in tehsils of Lakhimpur Kheri district during 2023-24[72]

During the Rabi season of 2023-24, wheat was cultivated across the district in tehsils of Nighasan, Gola, Mohammadi and Mitauli.

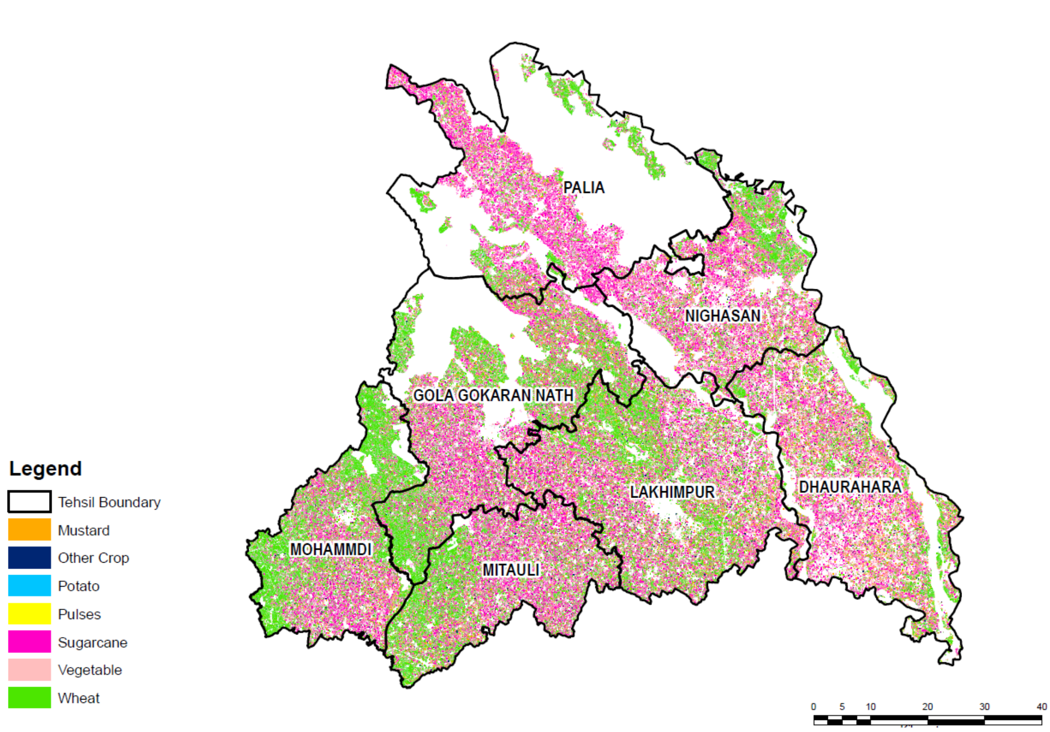


Figure 20: Geographical spread of *Rabi* crops in tehsils of Lakhimpur Kheri district during 2023-24[73]

72 Analysis by Vasudha Foundation, 2025

73 Analysis by Vasudha Foundation, 2025

6.2 Land Use and Biomass Distribution Mapping

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

Table 24: Tehsil-wise land-use analysis for Lakhimpur Kheri[74]

Tehsil	Barren/ Waste land	Built-Up	Crop land	Grass land	Scrub	Waterbodies	Wetland	Total
Dhaurahara	6739.73	5061.98	89936.45	4009.54	1773.43	4362.14	119521.46	81755.87
Gola gokaran nath	2337.65	7218.50	93565.32	37604.21	4210.23	729.88	147275.39	84267.21
Lakhimpur	2435.38	10248.94	116761.04	3670.34	1062.23	1773.70	137903.20	73019.86
Mitauli	9.35	4163.21	70374.34	841.51	391.77	278.71	76141.45	63811.57
Mohammdi	162.66	4737.39	71068.19	4088.75	1365.64	347.09	81809.46	52830.65
Nighasan	3231.33	4636.58	68622.07	25912.90	4975.24	3063.77	111858.85	57637.51
Palia	4581.70	3552.08	61738.23	83793.43	10028.39	1558.70	167242.53	57637.51
Total	**19497.80**	**39618.69**	**572065.63**	**159920.68**	**23806.93**	**12113.98**	**841752.34**	**413322.68**

It can be observed from the land use analysis that nearly 67 percent of the total geographical area of the district was under cultivation during 2023-24.

74 Analysis by Vasudha Foundation, 2025

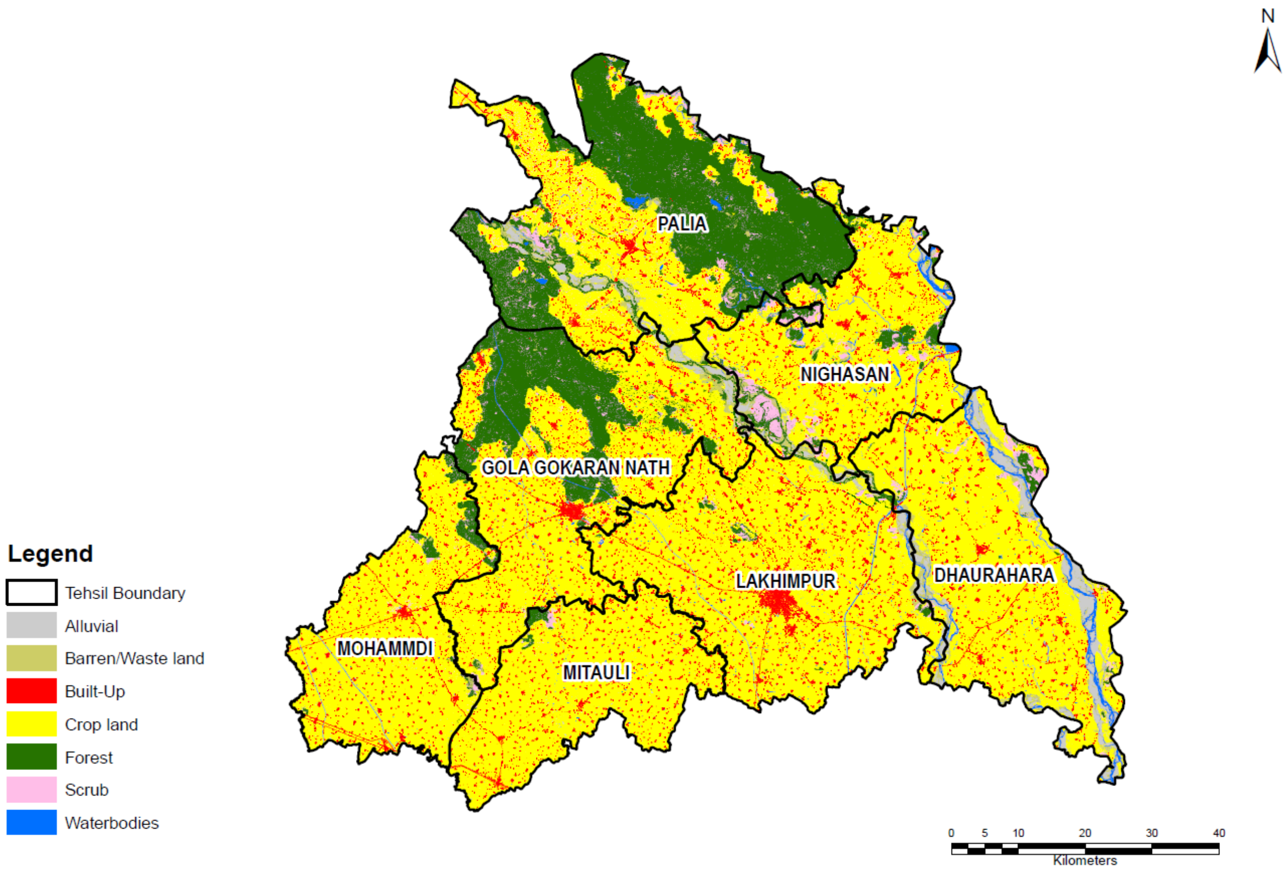


Figure 21: **Land cover analysis for tehsils of Lakhimpur Kheri district during 2023-24**[75]

75 Analysis by Vasudha Foundation, 2025

07

Methodology

This study estimates annual net biomass residue availability in all 7 Tehsils of Kheri district in Uttar Pradesh. It takes into account the competing uses of the biomass in the respective tehsil and generates a net value of the residue and corresponding theoretical value of Compressed Biogas (TPD) that can be generated out of it. The following approach was adopted for various feedstocks in consideration:

7.1 Agricultural Residue

The study integrated Geographic Information System (GIS) tools and seasonal satellite imagery to analyse spatial and temporal trends in crop residues. Sentinel-2 satellite data was processed to estimate the cultivated area of Kharif and Rabi crops. The workflow began with layer stacking and mosaicking of satellite images, followed by spatial subset to focus on Lakhimpur Kheri district and its seven tehsils using administrative boundaries. A district-level land use/land cover 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)[76], a supervised machine learning algorithm trained on ground-truth data to classify satellite imagery into distinct crop categories. This approach enabled precise mapping of Kharif and Rabi cultivation zones by assigning

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

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

Figure 22: Flow diagram of the methodology used

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

Gross crop residue[77] 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.[78] [79] It is determined based on three important parameters, such as: area occupied by the particular crop, crop yield and Residue Production Ratio value for that crop.

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

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

77 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.

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

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

Here, CRg(j) denotes the gross crop residue for n number of crops at jth state, in tonnes; and A(i,j) denotes the area covered by ith crop at jth state, in hectares; Y(i,j) denotes the yield of the ith crop at jth state, in tonnes/hectare, and RPR(i,j) denotes the residue to product ratio for the given ith crop at jth 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 Figure16).[80]

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

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.[81][82]

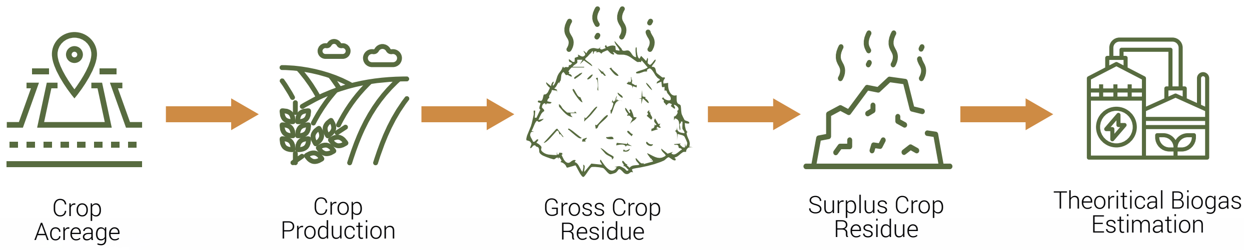


Figure 23: Flow diagram for crop residue estimation

80 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

81 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

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

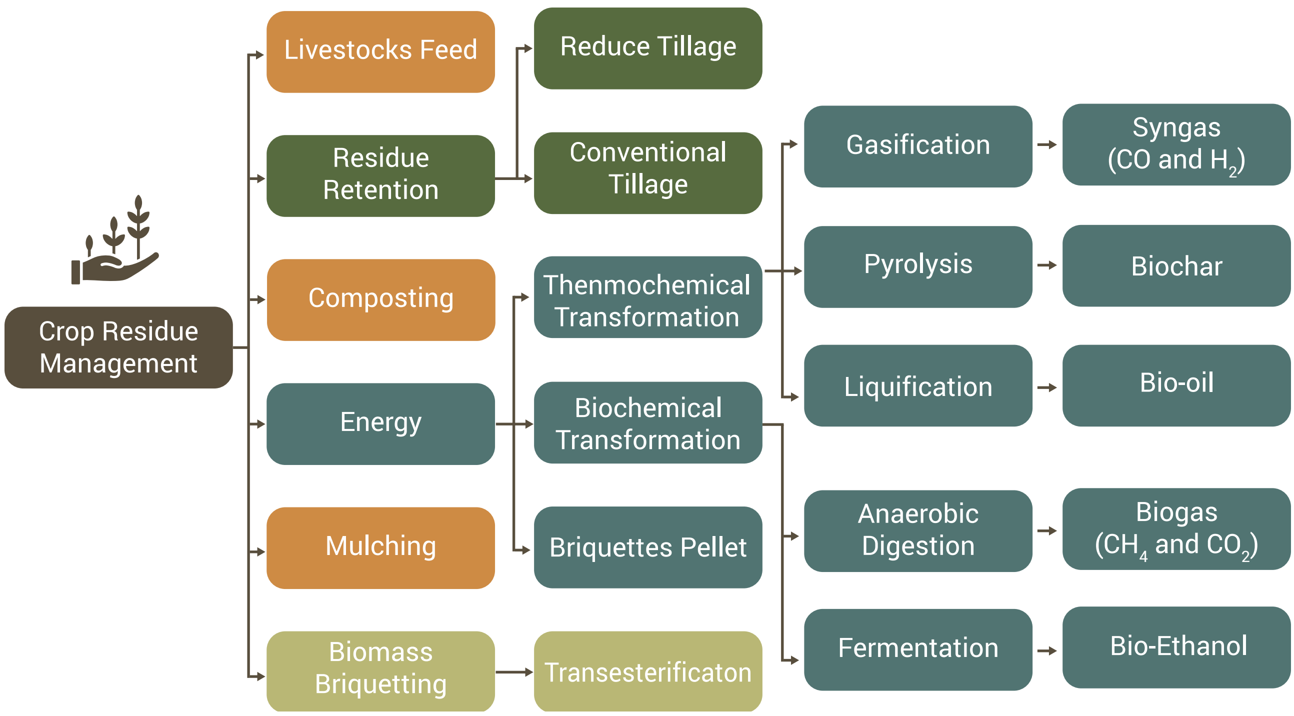


Figure 24: Crop residue management practices[83]

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

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

7.2 Livestock Residue

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

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

***Equation 5:* Theoretical CBG Estimation from Livestock Residues**

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

08

Biomass Category, Sources and Availability

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

8.1 Agricultural Residues

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

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
Lakhimpur	Wheat	17072.42	4.04	68972.58	Straw	103458.87	20691.77	20691.77	4.10	5.67
					Husk	20691.77	4138.35	4138.35	0.82	1.13
	Paddy	2994.27	3.03	9072.64	Straw	13608.96	2313.52	2313.52	0.52	1.99
					Husk	1814.53	308.47	308.47	0.07	
	Sugarcane	62424.1	85.96	5365975.64	Bagasse (Small)		38688.00		3.27	10.60
					Press Mud (Large)		82271		8.96	9.02
					Press Mud (Medium)		315910		34.40	34.62
					Leaves	268298.78	268298.78	268298.78	51.45	51.45
	Maize	3948.9	1.51	5962.84	Stalks	11925.68	119.26	119.26	0.03	0.03
					Cobs	1788.85	17.89	17.89	0.00	0.00
					Leaves	715.54	7.16	7.16	0.00	0.00
	Mustard	6475.79	0.98	6346.27	Stalks	11423.29	11423.29	11423.29	3.13	3.13
	Pulses (Tur/Arhar)	3562.08	0.72	2564.70	Stalks	6411.74	6411.74	6411.74	1.76	1.76

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Potato	121.36	27.06	3284.00	Stalks	328.40	328.40	328.40	0.09	0.09
	Vegetables	90.55	15.56	1408.96	Stalks	140.90	140.90	140.90	0.04	0.04
	Barley	684.19	2.87	1963.63	Straw	2552.71	2552.71	2552.71	0.70	0.70
	Bajra	2475.27	1.32	3267.36	Stalks	6534.71	6534.71	6534.71	1.79	1.79
					Husk	980.21	980.21	980.21	0.27	0.27
					Cobs	1078.23	1078.23	1078.23	0.30	0.30
Moham-madi	Wheat	19357.68	4.04	78205.03	Straw	117307.54	23461.51	23461.51	4.65	6.43
					Husk	23461.51	4692.30	4692.30	0.93	1.29
	Paddy	16103.09	3.03	48792.363	Straw	73188.54	12442.05	12442.05	2.77	10.69
					Husk	9758.47	1658.94	1658.94	0.37	
	Sugarcane	31587.2	85.96	2715235.7	Bagasse (Small)		21040.00		1.78	5.76
					Press Mud (Large)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
						118617.53	118617.53	118617.53	22.75	22.75

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
2441.36	1.51	3686.4536	Stalks	7372.91	73.73	73.73	0.02	0.02	0.01	0.01
					Cobs	1105.94	11.06	11.06	0.00	0.00
					Leaves	442.37	4.42	4.42	0.00	0.00
3425.12	0.98	3356.6176	Stalks	6041.91	6041.91	6041.91	1.66	1.66	3.92	3.92
2553.92	0.72	1838.8224	Stalks	4597.06	4597.06	4597.06	1.26	1.26	0.98	0.98
53.6	27.06	1450.416	Stalks	145.04	145.04	145.04	0.04	0.04	0.06	0.06
38.12	15.56	593.1472	Stalks	59.31	59.31	59.31	0.02	0.02	0.17	0.17
345.19	2.87	990.6953	Straw	1287.90	1287.90	1287.90	0.35	0.35	0.84	0.84
1403.29	1.32	1852.3428	Stalks	3704.69	3704.69	3704.69	1.01	1.01	1.41	1.41
					Husk	555.70	555.70	555.70	0.15	0.15
					Cobs	611.27	611.27	611.27	0.17	0.17

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
Gola Gokaran Nath	Wheat	20102.33	4.04	81213.413	Straw	121820.12	24364.02	24364.02	4.82	6.68
					Husk	24364.02	4872.80	4872.80	0.96	1.34
	Paddy	18865.29	3.03	57161.829	Straw	85742.74	14576.27	14576.27	3.25	12.53
					Husk	11432.37	1943.50	1943.50	0.43	
	Sugarcane	54698.71	85.96	4701901.1	Bagasse (Small)		26704.00		2.26	7.32
					Press Mud (Large)		54012.00		5.88	5.92
					Press Mud (Medium)		4340.00		0.47	0.48
					Leaves	235095.06	235095.06	235095.06	45.09	45.09
	Maize	982.39	1.51	1483.4089	Stalks	2966.82	29.67	29.67	0.01	0.01
					Cobs	192.84	1.93	1.93	0.00	0.00
					Leaves	178.01	1.78	1.78	0.00	0.00
	Mustard	5323.99	0.98	5217.5102	Stalks	626.10	626.10	626.10	0.17	0.17
	Pules (Tur/ Arhar)	1993.84	0.72	1435.5648	Stalks	3588.91	3588.91	3588.91	0.98	0.98
	Potato	119.57	27.06	3235.5642	Stalks	323.56	323.56	323.56	0.09	0.09
	Vegetables	68.63	15.56	1067.8828	Stalks	106.79	106.79	106.79	0.03	0.03

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Barley	498.64	2.87	1431.0968	Straw	1860.43	1860.43	1860.43	0.51	0.51
	Bajra	828.79	1.32	1094.0028	Stalks	2188.01	2188.01	2188.01	0.60	0.60
					Husk	328.20	328.20	328.20	0.09	0.09
					Cobs	361.02	361.02	361.02	0.10	0.10
Nighasan	Wheat	8750.86	4.04	35353.474	Straw	53030.21	10606.04	10606.04	2.10	2.91
					Husk	10606.04	2121.21	2121.21	0.42	0.58
	Paddy	8822.92	3.03	26733.448	Straw	40100.17	6817.03	6817.03	1.52	5.86
					Husk	5346.69	908.94	908.94	0.20	
	Sugarcane	39017.43	85.96	3353938.3	Bagasse (Small)		16192.00		1.37	4.44
					Press Mud (Large)		269605.00		29.36	29.55
					Press Mud (Medium)		0.00		0.00	0.00
					Leaves	167696.91	167696.91	167696.91	32.16	32.16
	Maize	2697.04	1.51	4072.5304	Stalks	8145.06	81.45	81.45	0.02	0.02
					Cobs	1221.76	12.22	12.22	0.00	0.00
					Leaves	488.70	4.89	4.89	0.00	0.00

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Mustard	4051.04	0.98	3970.0192	Stalks	7146.03	7146.03	7146.03	1.96	1.96
	Pules (Tur/ Arhar)	2106.57	0.72	1516.7304	Stalks	3791.83	3791.83	3791.83	1.04	1.04
	Potato	67.08	27.06	1815.1848	Stalks	181.52	181.52	181.52	0.05	0.05
	Vegetables	45.76	15.56	712.0256	Stalks	71.20	71.20	71.20	0.02	0.02
	Barley	312.05	2.87	895.5835	Straw	1164.26	1164.26	1164.26	0.32	0.32
	Bajra	450.26	1.32	594.3432	Stalks	1188.69	1188.69	1188.69	0.33	0.33
					Husk	178.30	178.30	178.30	0.05	0.05
					Cobs	196.13	196.13	196.13	0.05	0.05
Dhaura-hara	Wheat	8848.73	4.04	35748.869	Straw	53623.30	10724.66	10724.66	2.10	2.94
					Husk	10724.66	2144.93	2144.93	0.42	0.59
	Paddy	7140.41	3.03	21635.442	Straw	32453.16	5517.04	5517.04	1.23	4.74
					Husk	4327.09	735.61	735.61	0.16	

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Sugarcane	41028.89	85.96	3526843.4	Bagasse (Small)		39680.00		3.36	10.87
					Press Mud (Large)		13391.00		1.46	1.47
					Press Mud (Medium)		46662.00		5.08	5.11
					Leaves	176342.17	176342.17	176342.17	33.82	33.82
	Maize	13284.35	1.51	20059.369	Stalks	40118.74	401.19	401.19	0.11	0.11
					Cobs	6017.81	60.18	60.18	0.02	0.02
					Leaves	6017.81	60.18	60.18	0.02	0.02
	Mustard	6723.45	0.98	6588.981	Stalks	11860.17	11860.17	11860.17	3.25	3.25
	Pulses (Tur/Arhar)	1114.67	0.72	802.5624	Stalks	2006.41	2006.41	2006.41	0.55	0.55
	Potato	98.27	27.06	2659.1862	Stalks	265.92	265.92	265.92	0.07	0.07
	Vegetables	69.46	15.56	1080.7976	Stalks	108.08	108.08	108.08	0.03	0.03
	(Barley)	439.85	2.87	1262.3695	Straw	1641.08	1641.08	1641.08	0.45	0.45

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Bajra	2073.76	1.32	2737.3632	Stalks	5474.73	5474.73	5474.73	1.50	1.50
					Husk	821.21	821.21	821.21	0.22	0.22
					Cobs	903.33	903.33	903.33	0.25	0.25
Palia	Wheat	7729.66	4.04	31227.826	Straw	46841.74	9368.35	9368.35	1.85	2.57
					Husk	9368.35	1873.67	1873.67	0.37	0.51
	Paddy	8917.12	3.03	27018.874	Straw	40528.31	6889.81	6889.81	1.53	5.92
					Husk	5403.77	918.64	918.64	0.20	
	Sugarcane	37539.04	85.96	3226855.9	Bagasse (Small)		8144.00		0.69	2.23
					Press Mud (Large)		84238.00		9.17	9.23
					Press Mud (Medium)		0.00		0.00	0.00
					Leaves	161342.79	161342.79	161342.79	30.94	30.94
	Maize	2869.83	1.51	4333.4433	Stalks	8666.89	86.67	86.67	0.02	0.02
					Cobs	1300.03	13.00	13.00	0.00	0.00
					Leaves	520.01	5.20	5.20	0.00	0.00
	Mustard	3151.73	0.98	3088.6954	Stalks	5559.65	5559.65	5559.65	1.52	1.52

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Pules (Tur/ Arhar)	2672.11	0.72	1923.9192	Stalks	4809.80	4809.80	4809.80	1.32	1.32
	Potato	54.48	27.06	1474.2288	Stalks	147.42	147.42	147.42	0.04	0.04
	Vegetables	34	15.56	529.04	Stalks	52.90	52.90	52.90	0.01	0.01
	Barley	187.95	2.87	539.4165	Straw	701.24	701.24	701.24	0.19	0.19
	Bajra	278.33	1.32	367.3956	Stalks	734.79	734.79	734.79	0.20	0.20
					Husk	110.22	110.22	110.22	0.03	0.03
					Cobs	121.24	121.24	121.24	0.03	0.03
Mitauli	Wheat	12207.48	4.04	49318.219	Straw	73977.33	14795.47	14795.47	2.93	4.05
					Husk	14795.47	2959.09	2959.09	0.59	0.81
	Paddy	8498.33	3.03	25749.94	Straw	38624.91	6566.23	6566.23	1.46	5.64
					Husk	5149.99	875.50	875.50	0.20	

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Sugarcane	36224.25	85.96	3113836.5	Bagasse (Small)		23856.00		2.02	6.54
					Press Mud (Large)		18112.50		1.97	1.98
					Press Mud (Medium)		0.00		0.00	0.00
					Leaves	155691.83	155691.83	155691.83	29.86	29.86
	Maize	1170.97	1.51	1768.1647	Stalks	3536.33	35.36	35.36	0.01	0.01
					Cobs	530.45	5.30	5.30	0.00	0.00
					Leaves	212.18	2.12	2.12	0.00	0.00
	Mustard	3547.33	0.98	3476.3834	Stalks	6257.49	6257.49	6257.49	1.71	1.71
	Pulses (Tur/Arhar)	1147.81	0.72	826.4232	Stalks	2066.06	2066.06	2066.06	0.57	0.57
	Potato	63.9	27.06	1729.134	Stalks	172.91	172.91	172.91	0.05	0.05
	Vegetables	45.38	15.56	706.1128	Stalks	70.61	70.61	70.61	0.02	0.02
	(Barley)	424.97	2.87	1219.6639	Straw	1585.56	1585.56	1585.56	0.43	0.43
	Agri-Plantation (Bajra)	2028.9	1.32	2678.148	Stalks	5356.30	5356.30	5356.30	1.47	1.47
					Husk	803.44	803.44	803.44	0.22	0.22
					Cobs	883.79	883.79	883.79	0.24	0.24

8.2 Animal Waste

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

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

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG Potential	CBG Potential (SATAT)
Lakhimpur	Cattle	160764	880182900	220045725	154032.0075	2513432686	1.327862134	6.32	8.44
	Goat/ Sheep	97302	56824368	16479066.72	3295.813344	41369049.09	0.043944178	0.18	0.26
	Swine	932	918486	266360.94	159.816564	2860716.496	0.001997707	0.01	0.01
	Poultry (Chicken)	111051	1824012.675	528963.6758	317.3782055	5078051.287	0.004721887	0.02	0.03
Mohammadi	Cattle	111514	610539150	152634787.5	91844.35125	1743443386	0.791761649	3.77	5.03
	Goat/ Sheep	64866	37881744	10985705.76	2197.141152	27578515.74	0.029295215	0.12	0.26
	Swine	600	591300	171477	102.8862	1841662.98	0.001286078	0.01	0.01
	Poultry (Chicken)	73990	1215285.75	352432.8675	211.4597205	3383355.528	0.003146053	0.01	0.03

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG Potential	CBG Potential (SATAT)
Gola Gokaran Nath	Cattle	111514	610539150	152634787.5	106844.3513	1743443386	0.921071994	4.39	5.85
	Goat/ Sheep	64866	37881744	10985705.76	2197.141152	27578515.74	0.029295215	0.12	0.17
	Swine	600	591300	171477	102.8862	1841662.98	0.001286078	0.01	0.01
	Poultry (Chicken)	73990	1215285.75	352432.8675	211.4597205	3383355.528	0.003146053	0.01	0.02
Nighasan	Cattle	111517	610555575	152638893.8	25573.92	1743490289	0.220464828	1.05	1.40
	Goat/ Sheep	64867	37882328	10985875.12	2197.175024	27578940.9	0.029295667	0.12	0.17
	Swine	621	611995.5	177478.695	106.487217	1906121.184	0.00133109	0.01	0.01
	Poultry (Chicken)	74030	1215942.75	352623.3975	211.5740385	3385184.616	0.003147754	0.01	0.02
Dhaurahara	Cattle	167263	915764925	228941231.3	160258.8619	2615040005	1.381541913	6.58	8.78
	Goat/ Sheep	97297	56821448	16478219.92	3295.643984	41366923.29	0.04394192	0.18	0.26
	Swine	931	917500.5	266075.145	159.645087	2857647.057	0.001995564	0.01	0.02

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG Potential	CBG Potential (SATAT)
	Poultry (Chicken)	111047	1823946.975	528944.6228	317.3667737	5077868.378	0.004721716	0.02	0.03
Palia	Cattle	55757	305269575	76317393.75	53422.17563	871721693	0.460535997	2.19	2.93
	Goat / Sheep	32433	18940872	5492852.88	1098.570576	13789257.87	0.014647608	0.06	0.09
	Swine	310	305505	88596.45	53.15787	951525.873	0.000664473	0.00	0.00
	Poultry (Chicken)	37014	607954.95	176306.9355	105.7841613	1692546.581	0.001573835	0.01	0.01
Mitauli	Cattle	111515	610544625	152636156.3	106845.3094	1743459020	0.921080253	4.39	5.85
	Goat / Sheep	44324	25885216	7506712.64	1501.342528	18844851.41	0.0200179	0.08	0.12
	Swine	624	614952	178336.08	107.001648	1915329.499	0.001337521	0.01	0.01
	Poultry (Chicken)	74031	1215959.175	352628.1608	211.5768965	3385230.343	0.003147797	0.01	0.02
	Poultry (Chicken)	37014	607954.95	176306.9355	105.7841613	1692546.581	0.001573835	0.01	0.01

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 Lakhimpur Kheri district.

8.4 Other Types of Biomasses

8.4.1 Napier Grass

Napier Grass, also known as Elephant Grass or Uganda Grass is a species native to the tropical grasslands of Africa. It has a very high productivity, both as a forage grass for livestock and as a biofuel crop. It is most susceptible to frost and grows best in high-rainfall areas (in excess of 1500 mm/year), but its deep root system allows it to survive in drought times. Pusa Giant Napier, developed by IARI provides high yield (250-300 t/ha/year) of green matter under irrigated condition.[84]

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 not cultivated in the district.

Table 28: Surplus bagasse generated from small sugar mills cluster

Crop	Area (ha.)	Yield (T/ ha.)	Production (T)	Crop-to-Residue Groundnut Shell	Residue (T)	CBG Potential (TPD) (SATAT)
Ground-nut	7836	0.83	6488	0.3	1946.4	0.533

8.4.3 Sugarcane Bagasse

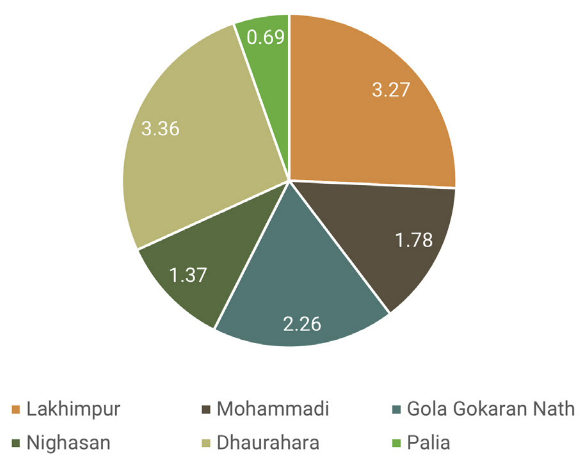
Apart from large sugar mills, generally, there are small sugar mills (without a bagasse co-generation unit) that operate with vertical crushers in Uttar Pradesh. There were around 250-320 small sugar mill units that operate in different tehsils including Nawabganj, Faridpur and Baheri. These units produce only bagasse as they do not have the facility to filter and process the liquid residue. The fibrous residue, i.e. bagasse is used for captive process heating and some portion of it are also sold to third parties like swine farms for feeding pigs at the rate of INR 50-80 per quintal. The conversion ratio from sugarcane to bagasse in these units is 40%.

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

Table 29: **Surplus bagasse generated from small sugar mills cluster**

Tehsil	Crushing Capacity in TCD	Number of Units	Surplus Bagasse (T)
Dhaurahara	12	91	39680
Gola Gokaran Nath	12	134	26704
Lakhimpur	12	139	38688
Mohammadi	12	183	21040
Nighasan	12	95	16192
Palia	12	70	8144

Figure 25 describes the corresponding CBG potential that can be generated from sugarcane bagasse as per NIBE and SATAT.



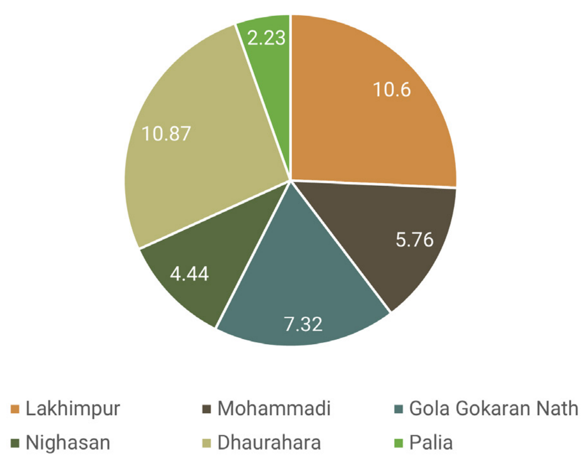
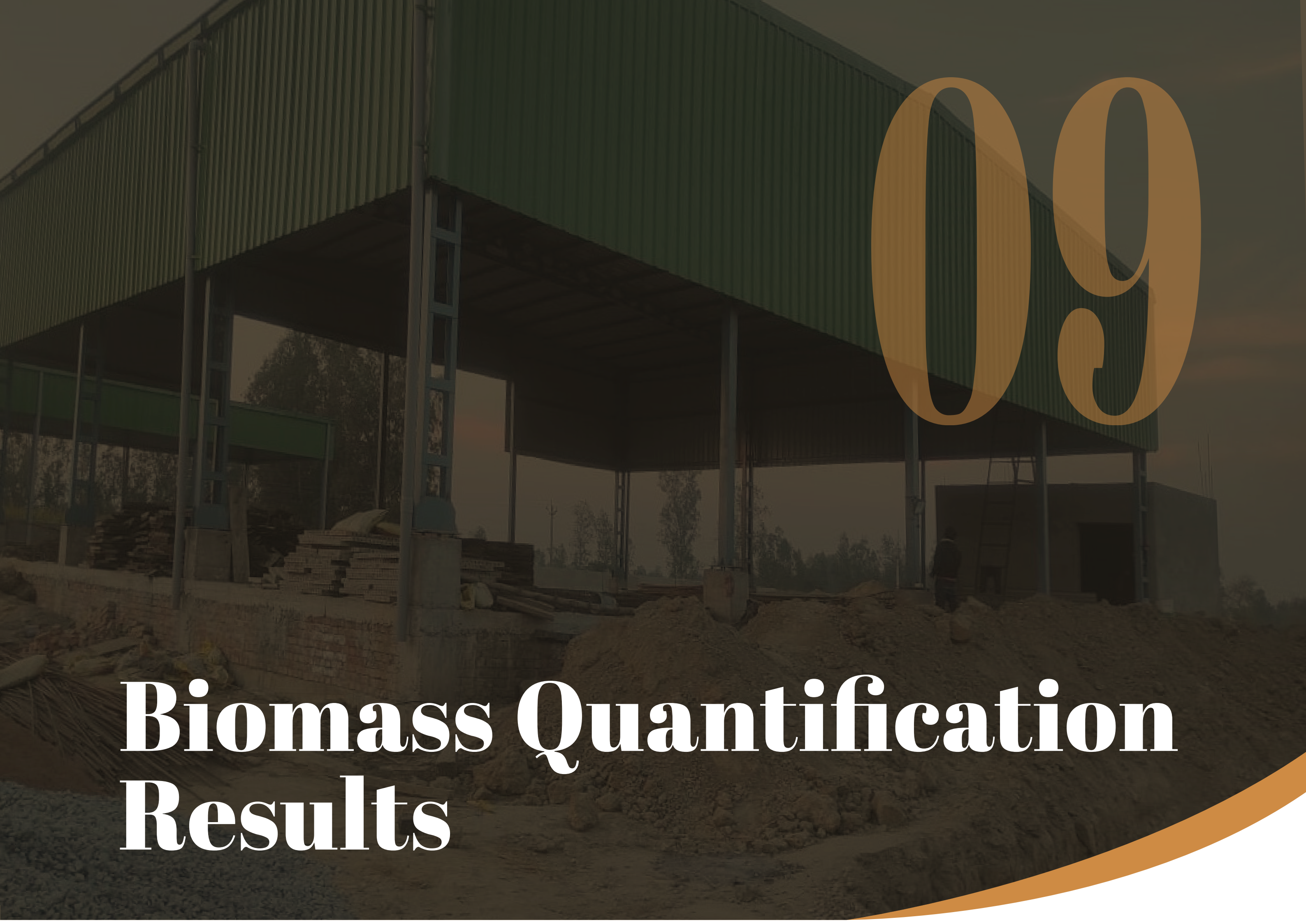


Figure 25: **CBG Potential from bagasse generated from small sugar mills**

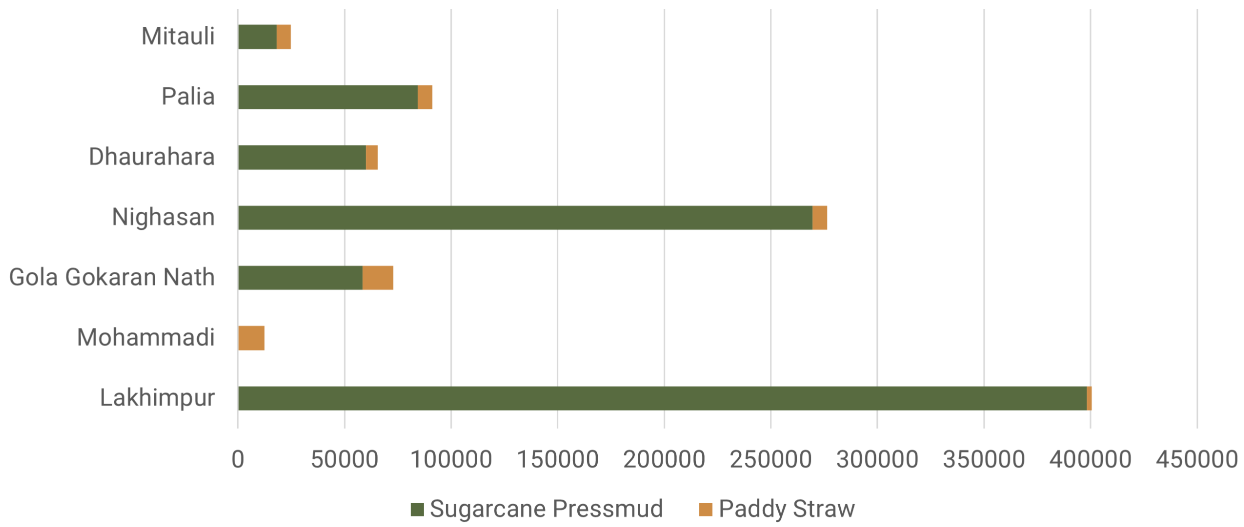


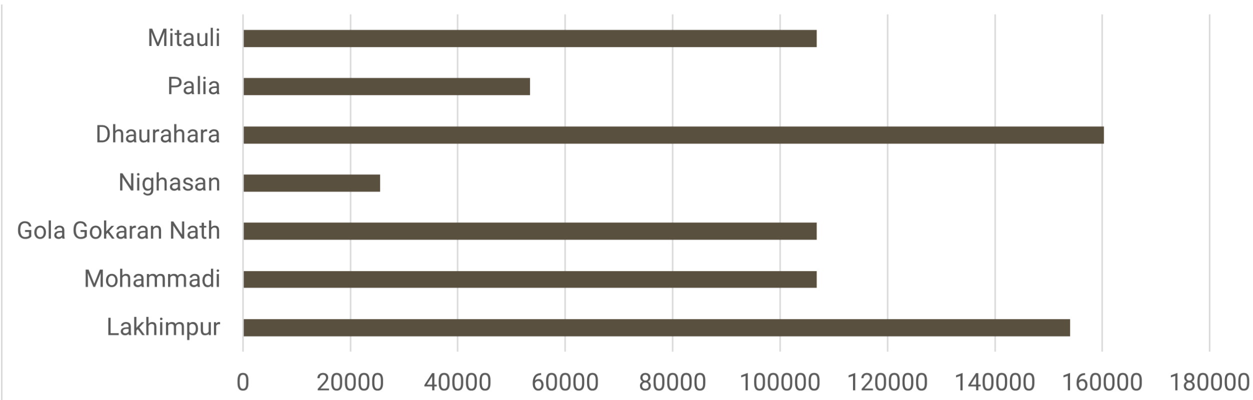
09

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 of the tehsil in Lakhimpur Kheri.





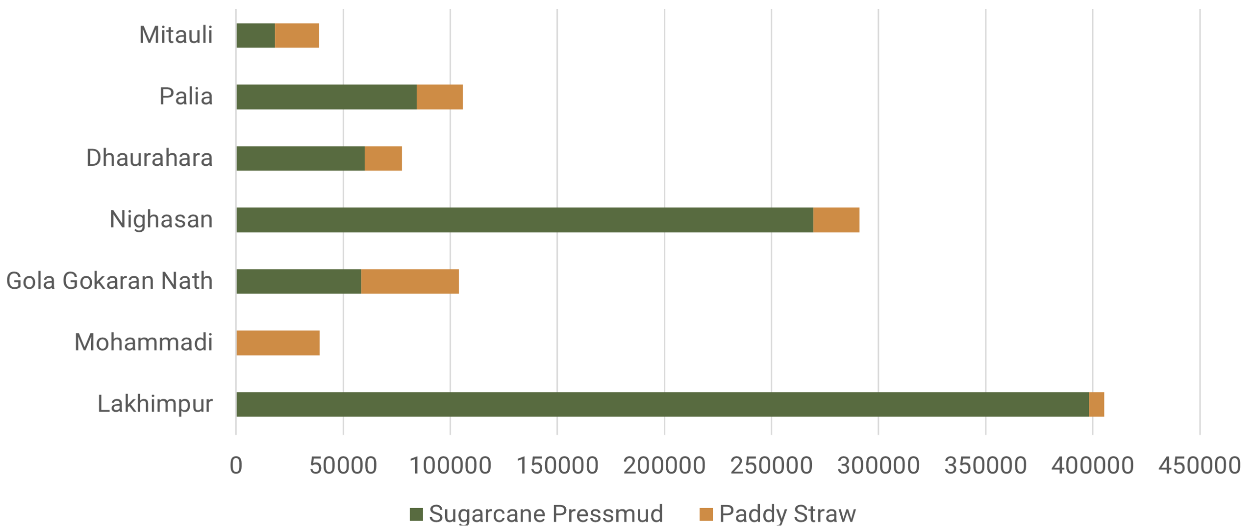


Figure 26: Tehsil-wise annual availability of paddy straw, press mud and cattle dung

9.2 Variations in Biomass Availability and Pricing

The availability and generation of sugarcane press mud has been varying over the years. From the Figure 27 & Figure 28, the variation in availability of press mud in all the sugar mills can be attributed to the varying quantities of sugarcane crushed annually in these mills. Figure 29 depicts the year-on-year change in press mud that is generated. The reasons that can be attributed to varying production could be due to adverse weather conditions (drought and excessive rainfall), crop diseases, etc. This condition is prevalent across the State. This can affect the pricing of the press mud. Based on the data that was shared by the Cane Commissioner, the average cost of press mud for all sugar mills hovered between INR 15 to 60 per quintal during 2022-25.

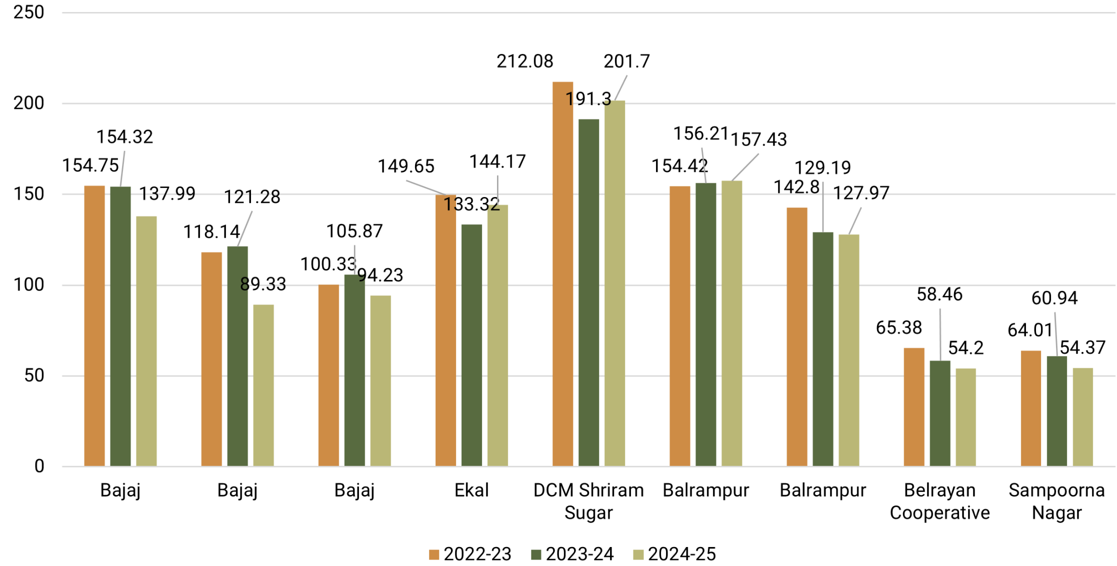


Figure 27: Annual cane crushed in sugar mills during 2021-25[85]

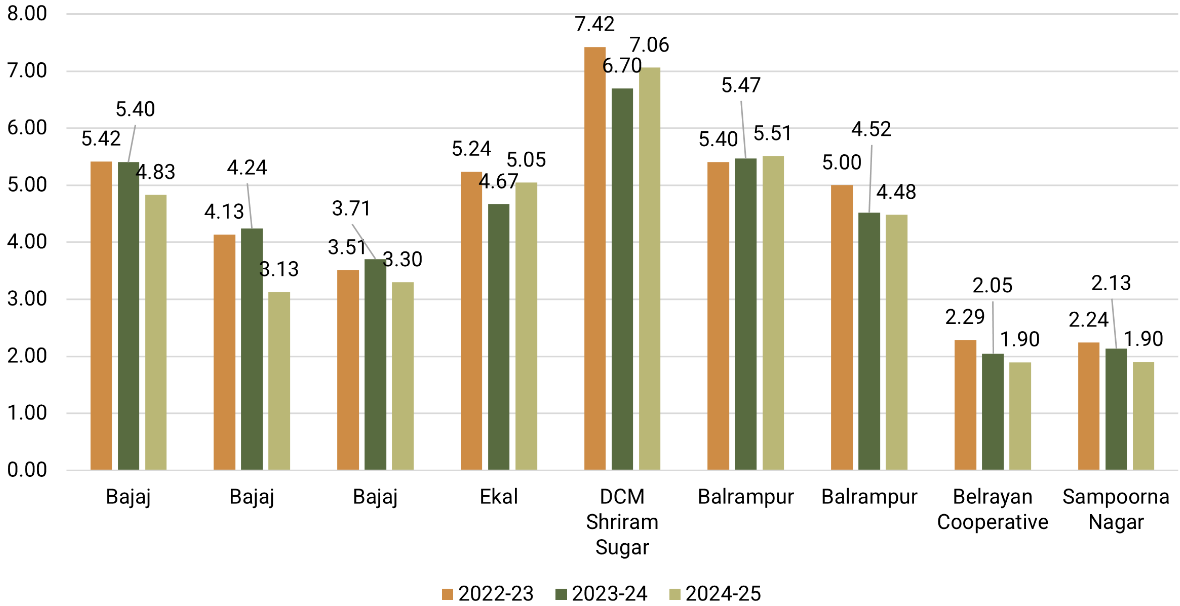


Figure 28: Annual press mud generated in sugar mills

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

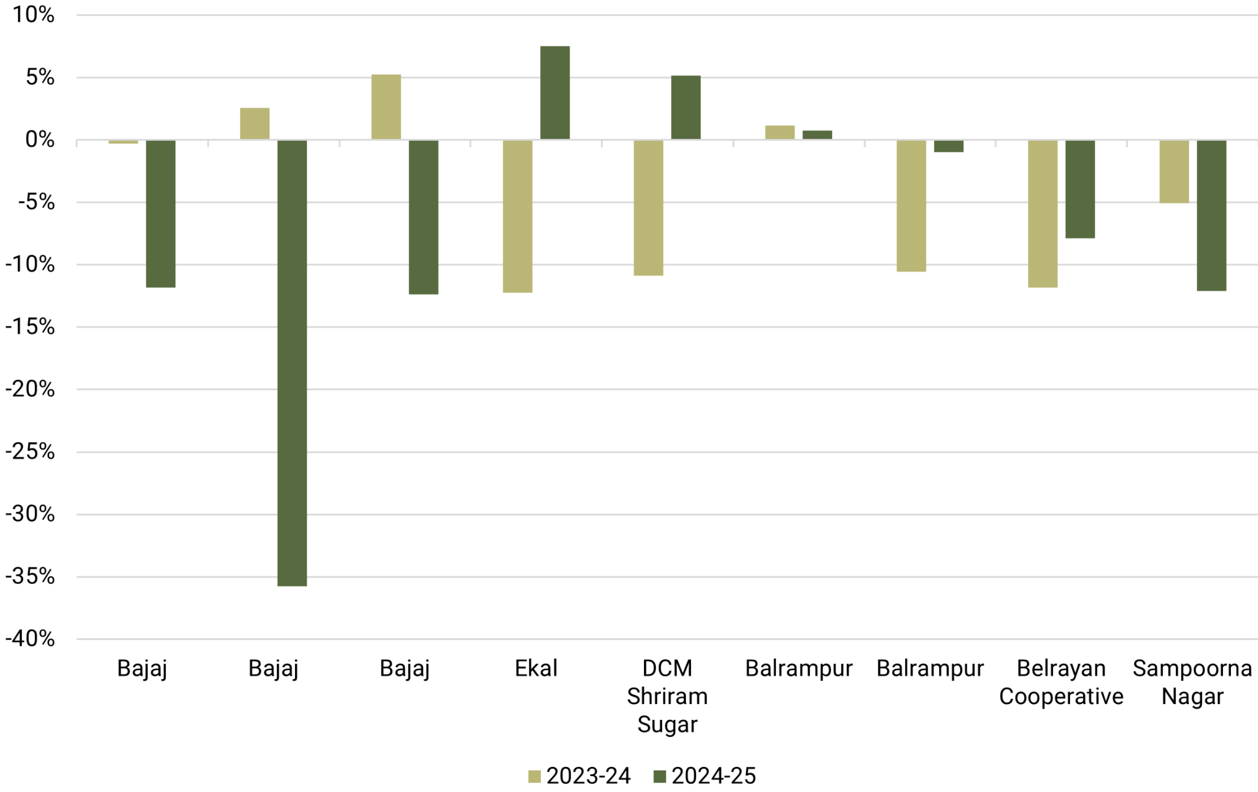


Figure 29: YoY change in annual cane crushed and press mud generated during 2021-25

It can be observed from Figure 30 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 of press mud spikes. For instance, the prices of sugarcane press mud increased to 50% during 2023-24 between peak and off-peak periods in one of the sugar mills in Faridpur tehsil and the reasons for the spike include: high demand for supply of press mud, shortage in availability of coal, high temperature, etc. As temperature increases, quality of press mud increases due to low moisture content. Similarly, a 40 percent increase in price of press mud was observed during the same year in one o the medium sugar mills in Baheri tehsil. 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 press mud
- Price also varies between sugar and non-sugar seasons in a particular year. Usually, it remains low in winter and increases as the temperature increases

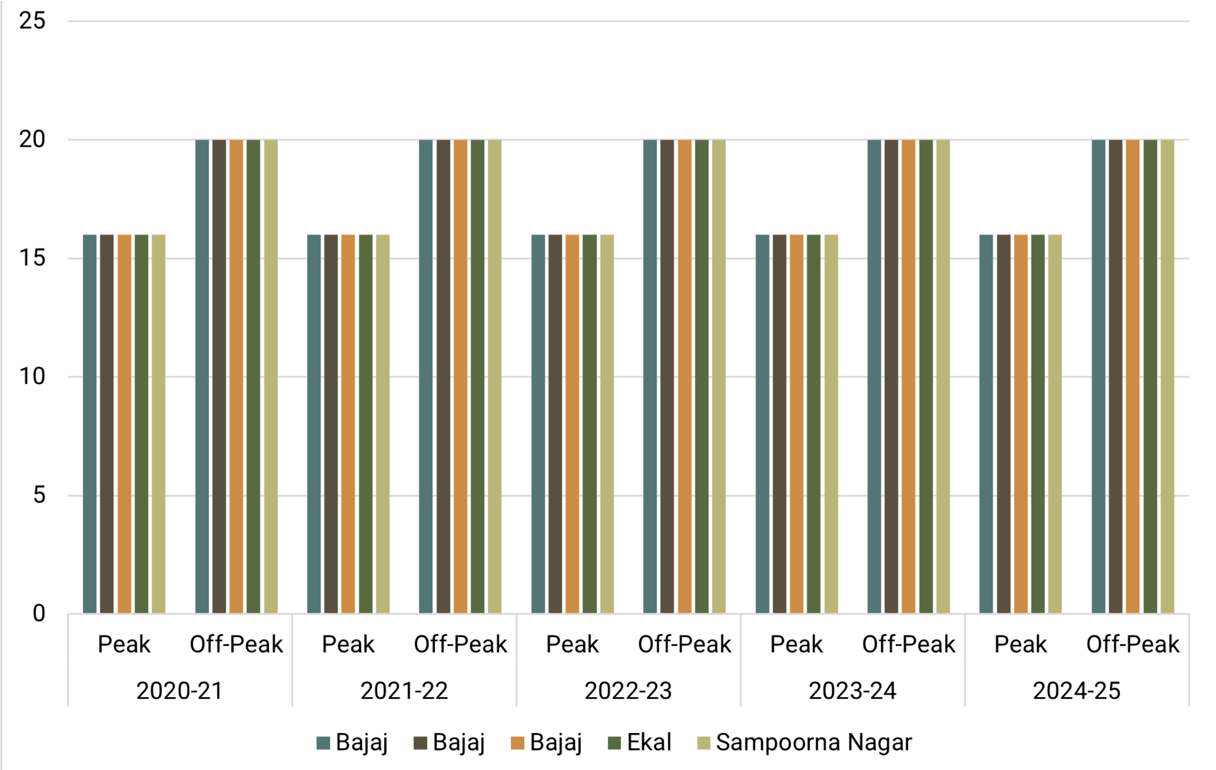


Figure 30: Press mud price variations during 2021-25 (from medium sugar mills)

9.3 High-Potential Zones for Biomass Supply and CBG Production

It can be observed that Baheri had the highest annual press mud availability and sugarcane leaves. There are no sugar mills in Aonla tehsil, however, the tehsil has abundant paddy straw available for use. A CBG plant which is running in Baheri tehsil, almost consumes the entire press mud that is available with the private sugar mill in the same tehsil. The same case applies to the CBG plant running in Faridpur tehsil. All tehsils of Lakhimpur Kheri have low to moderate cattle dung availability which can be used as a combination feedstock with agricultural residue for CBG production. We can also see the variation in the availability of paddy straw in particular, based on the different residue-to-crop ratios that were used.

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

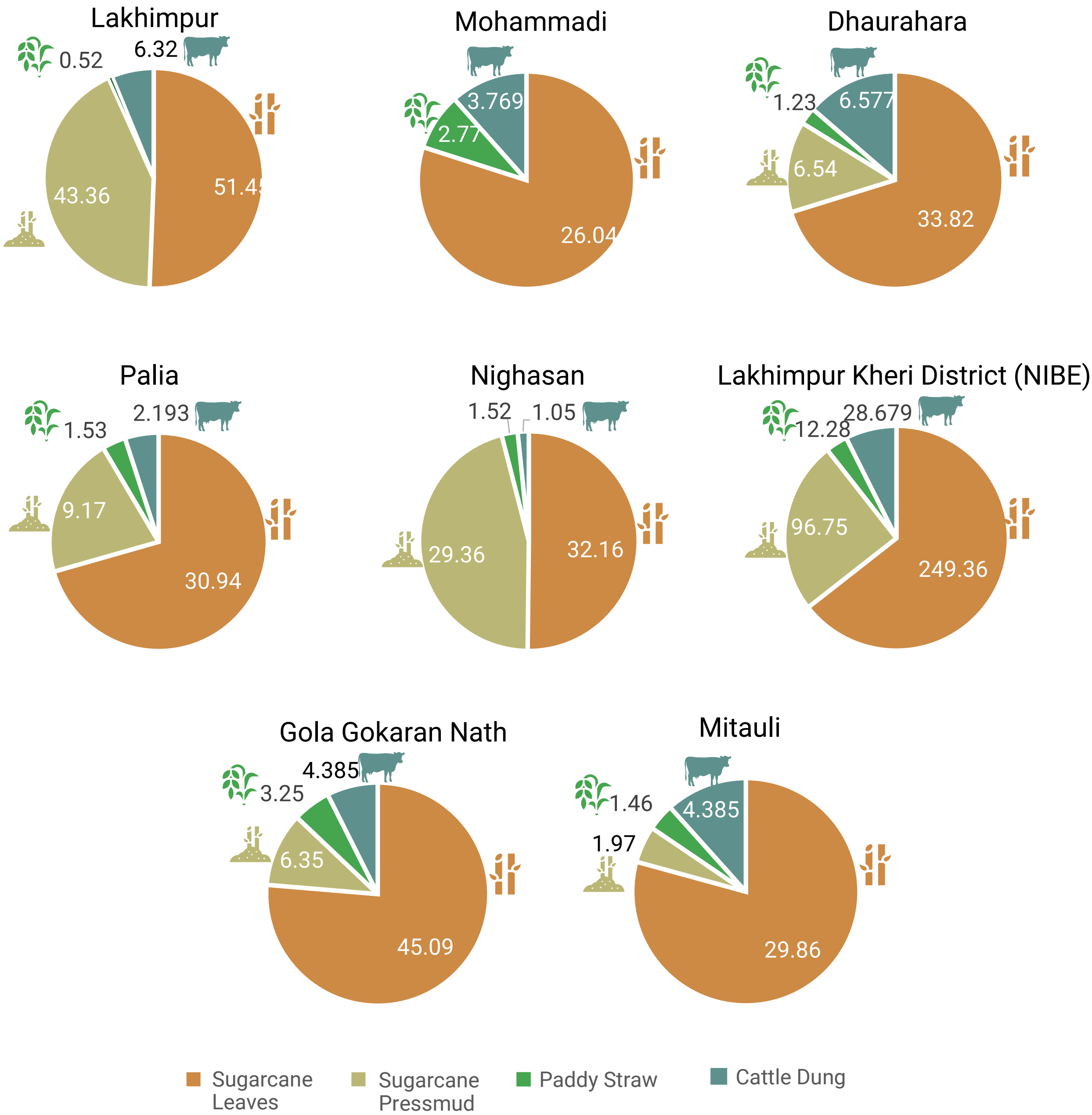


Figure 31: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per NIBE estimates)

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

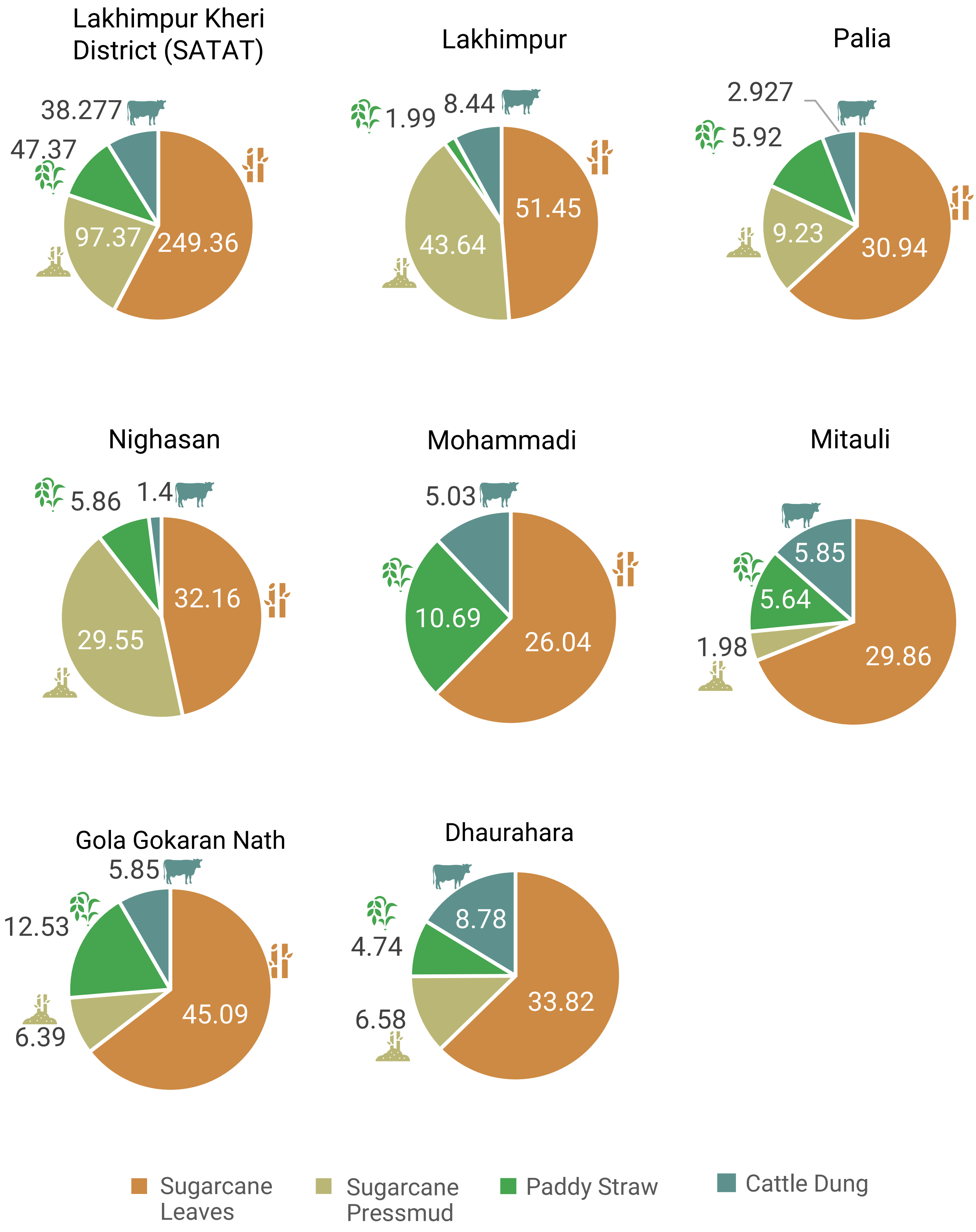


Figure 32: **Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per SATAT estimates)**

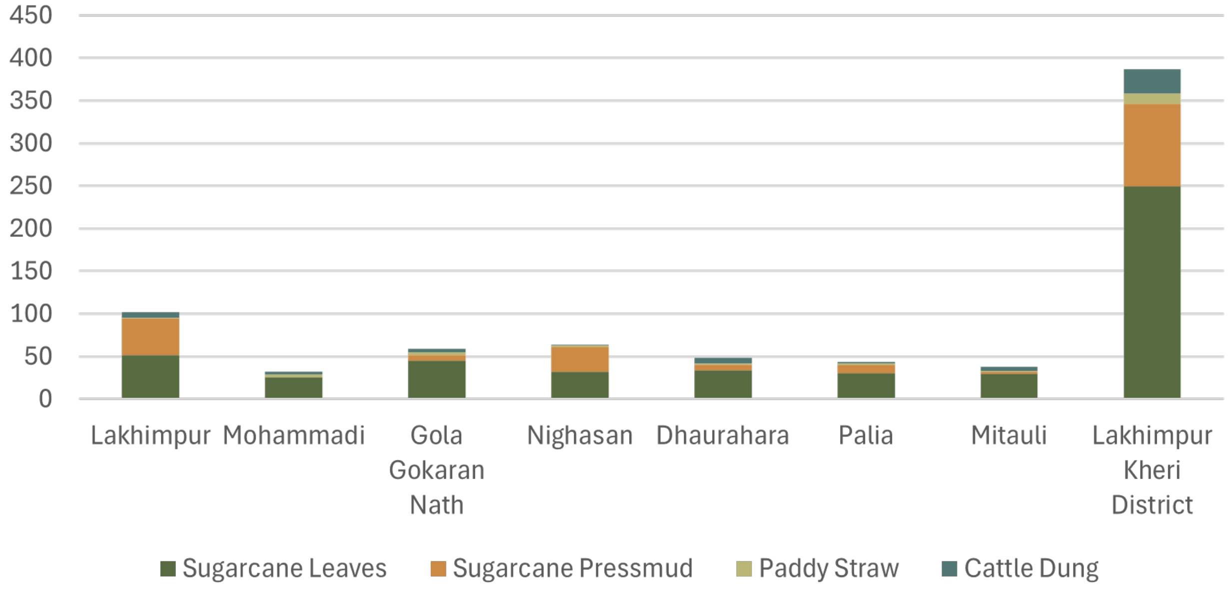


Figure 33: CBG potential from major feedstocks (NIBE estimates)

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

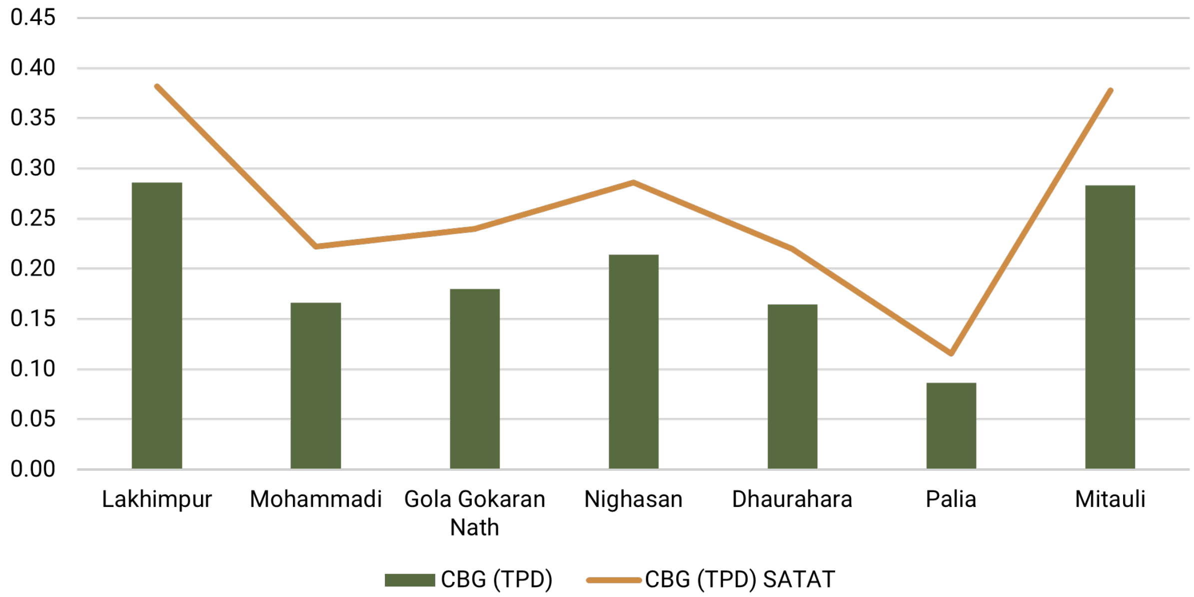


Figure 34: Tehsil-wise CBG potential from cattle sheds

While the CBG capacity from various feedstocks has been outlined, it's essential to recognise that CBG plants often operate on a mix of feedstocks rather than a single type. The sizing and design of these plants depend on a comprehensive set of factors (as captured in the Figure 35), including the quantity and variety of organic waste to be processed, the primary objective of waste treatment, demand for CBG, consumption patterns, local environmental conditions such as soil type and groundwater levels, regional climate factors like temperature and seasonal wind patterns, and the expertise level of the operational staff. This multifaceted approach ensures that CBG plants are optimised for efficiency, sustainability, and adaptability to local conditions.

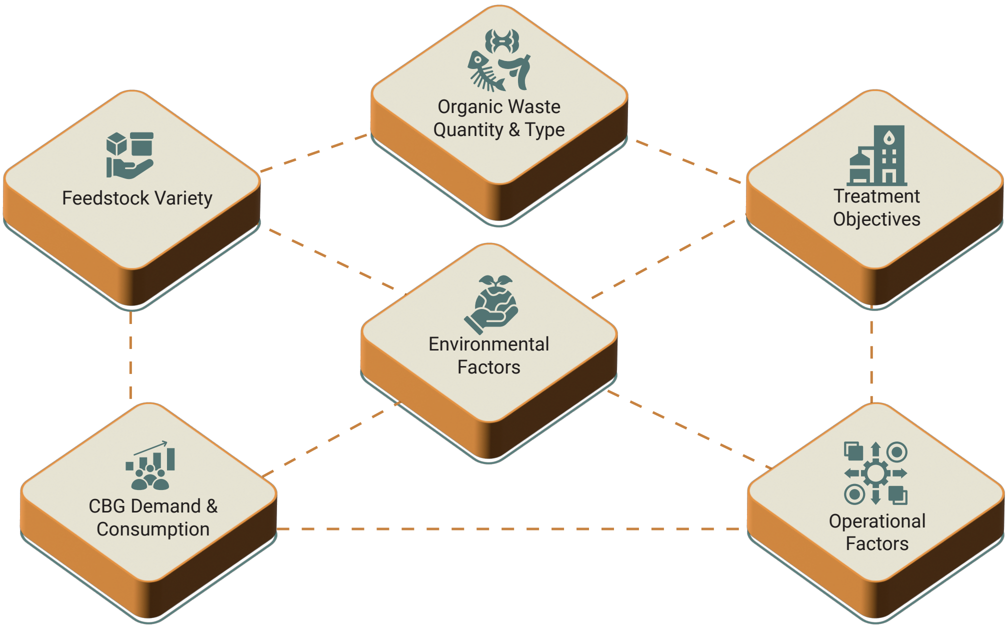


Figure 35: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

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

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

NIBE – CBG potential (in TPD) feedstock-wise in each tehsil					
Tehsil	**Sugarcane Leaves**	**Sugarcane Press mud**	**Paddy Straw**	**Cattle Dung**	**Total**
Lakhimpur	51.45	43.36	0.52	6.32	101.65
Mohammadi	26.04	0	2.77	3.769	32.579
Gola Gokaran Nath	45.09	6.35	3.25	4.385	59.075
Nighasan	32.16	29.36	1.52	1.05	64.09
Dhaurahara	33.82	6.54	1.23	6.577	48.167
Palia	30.94	9.17	1.53	2.193	43.833
Mitauli	29.86	1.97	1.46	4.385	37.675
Lakhimpur Kheri District	249.36	96.75	12.28	28.679	387.069
SATAT – CBG potential (in TPD) feedstock-wise in each tehsil					

Tehsil	Sugarcane Leaves	Sugarcane Press mud	Paddy Straw	Cattle Dung	Total
Lakhimpur	51.45	43.64	1.99	8.44	105.52
Mohammadi	26.04	0	10.69	5.03	41.76
Gola Gokaran Nath	45.09	6.39	12.53	5.85	69.86
Nighasan	32.16	29.55	5.86	1.4	68.97
Dhaurahara	33.82	6.58	4.74	8.78	53.92
Palia	30.94	9.23	5.92	2.927	49.017
Mitauli	29.86	1.98	5.64	5.85	43.33
Lakhimpur Kheri District (SATAT)	249.36	97.37	47.37	38.277	432.377

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

As per the estimates, theoretically, Lakhimpur Kheri district has a CBG potential of approximately 114 TPD based on the biomass available during the year 2023-24. Out of all the Tehsils, Baheri has the highest potential for CBG production with sugarcane press mud and leaves contributing a little over 80% of the total feedstock. Nawabganj and Meerganj tehsils follow Baheri with potential CBG capacity from sugarcane leaves, press mud and paddy straw contributing as the major feedstocks. Aonla tehsil had the highest paddy straw availability. 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. Lakhimpur has a high theoretical potential for CBG with sugarcane leaves, press mud and paddy straw as its major feedstock. It is important to ensure that CBG plants are designed to handle a combination of feedstocks with paddy straw, Napier grass and cattle dung that can support year-round plant operation and maximise 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 a reliable supply chain is indispensable for sustainability and financial feasibility of a CBG plant. Harvestable crop residues per unit of land also depend on region-specific crop production practices. Farmer's willingness to collect crop residues depends critically on the yields and on the biomass, prices provided in the market.
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, enhancing 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.

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

Figure 36: Cane moved from the field to sugar mills for crushing

Figure 37: **Storage of Paddy Straw in Silages[86]**

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 live storage, while paddy straw which can sustain longer, can go into a dead storage. Feedstocks like paddy straw involves careful handling to preserve its energy value and prevent degradation due to microbial activity, moisture, or fire hazards.

86 Analysis by Vasudha Foundation, 2025

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