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

UTTAR PRADESH

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Executive Summary

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

Biomass Availability and CBG Potential in Barabanki

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

- **Major Biomass Feedstocks**: Paddy Straw, Catte Dung, Sugarcane Leaves
- **High-Potential Zones**: Nawabganj, Ramsanehi Ghat and Fatehpur tehsils were identified as top biomass sources. Potential locations for CBG plants could be sited close to the paddy fields present in tehsils of Fatehpur, Nawabganj, Ramsanehi Ghat and Sirauli Ghauspur.
- **CBG Generation Potential**: The district has the potential to generate approximately 41 tonnes per day (TPD) of CBG from major feedstocks, such as paddy straw, sugarcane leaves and cattle dung, thereby contributing to the goal envisioned under the SATAT (Sustainable Alternative Towards Affordable Transportation) Scheme, which envisions installing 5,000 CBG plants by 2030.

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

Tehsil	Sugarcane Press mud	Paddy Straw	Cattle Dung	Sugarcane Leaves	Total
Fatehpur	1.3	0	3.84	1.59	6.73
Haidergarh	1.41	1.12	0	3.409	5.939
Nawabganj	1.84	0	4.5	3.196	9.536
Ram Nagar	0.88	0	0.96	1.45	3.29
Ramsanehi Ghat	1.96	0	3.42	4.451	9.831
Sirauli Ghauspur	1.79	0	3.2	0.74	5.73
Barabanki District	**9.18**	**1.12**	**15.92**	**14.836**	**41.056**

- **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 lead to a reduction in natural gas consumption and substantial carbon emission savings. To put it in figures, a total installed capacity of 41 TPD CBG plants can collectively abate 41,551.226 tonnes of CO_2 emissions annually[1].
  - In other words, 41 TPD of CBG can replace 41 TPD of CNG, corresponding to daily carbon emission savings of 113.839 tonnes of CO_2.
- **Supply Chain Considerations**: Efficient logistics and storage solutions are essential for sustainable biomass utilisation.

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

Recommendations

1. **Hybrid Feedstock Utilisation**
   - Encourage blending of paddy straw, 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) systems 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 globally, with consumption projected to triple from current levels by 2050.[2] With rising global energy demand, limited domestic fossil fuel reserves, and environmental concerns, renewable sources like solar, wind and biomass[3] are gaining prominence. Biomass energy not only helps meets this rising energy demand but also effectively manages organic waste - crop residues, animal waste, and municipal solid waste - reducing environmental degradation if left unaddressed. Currently, bioenergy accounts for 13 percent of India's total final energy consumption, with a projected growth rate of 45 percent between 2023 and 2030.[4] India's abundant biomass availability (See Figure 1 for 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

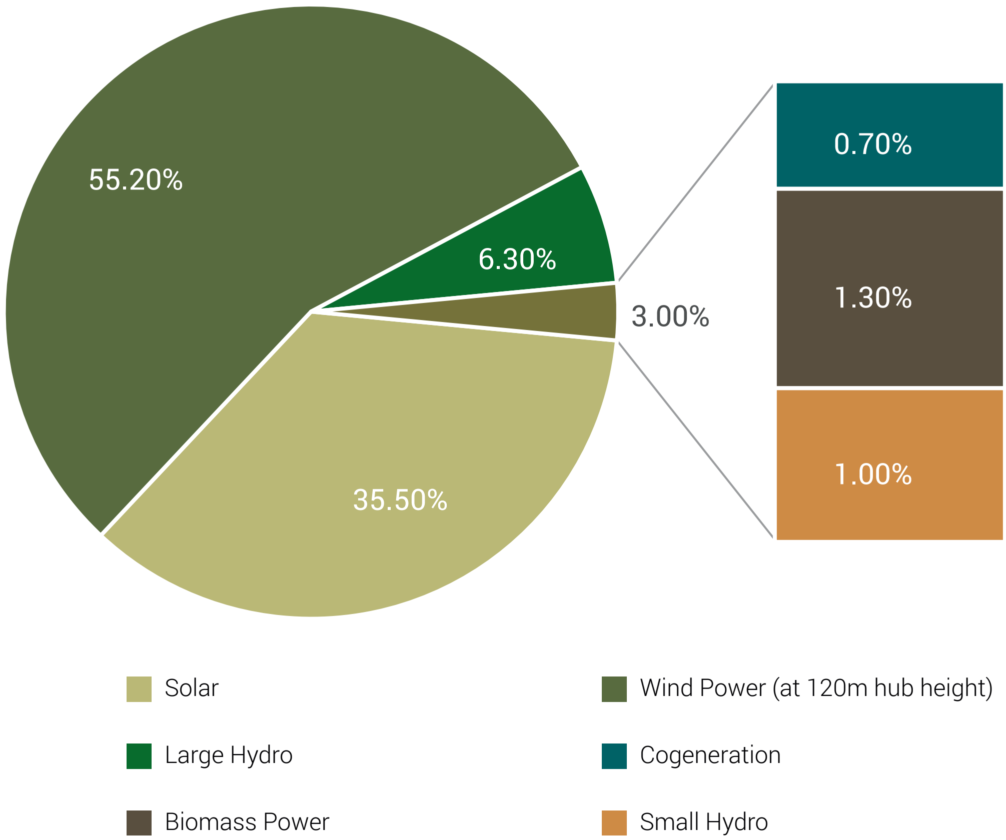


Figure 1: Source-wise renewable power potential in India, 2023[5,6]

India is the second largest agro-based economy and has 58 percent of its total land area available for agricultural purposes.[7] The country has a net cultivated area of around 219.16 million hectares and a cropping intensity[8,9] of 141.6 percent. 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] including approximately 234.5 MT of surplus residues[12] annually.

Uttar Pradesh, one of India's leading agrarian[13] states (See Figure 2), has the highest biomass power potential in the country (See Figure 3). The state 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)

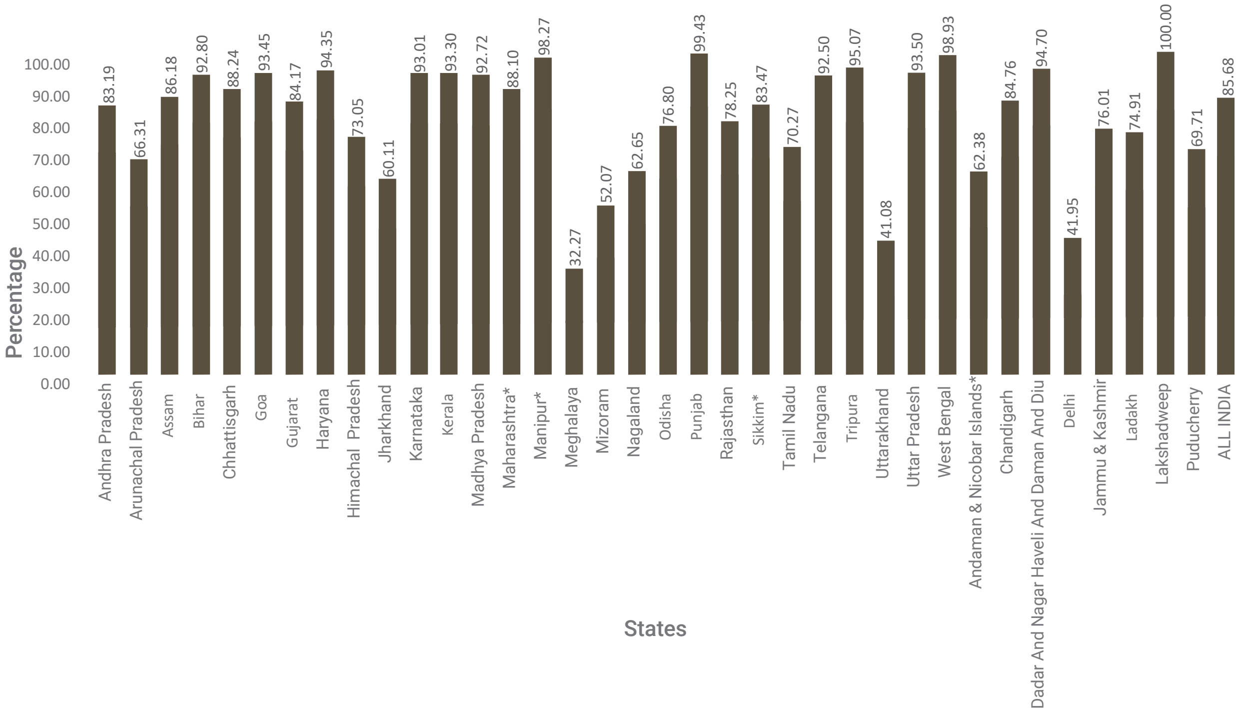


Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23[15]

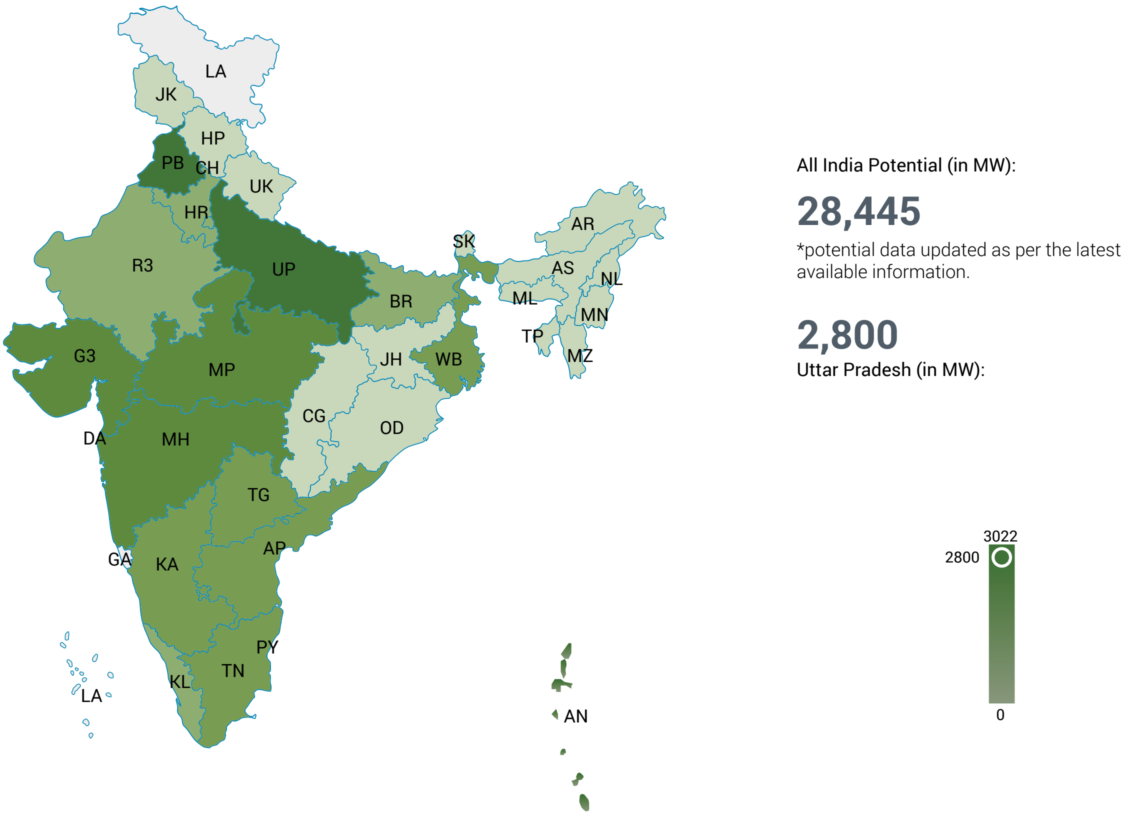


Figure 3: Biomass power potential in India[16]

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 residues 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 1:[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.

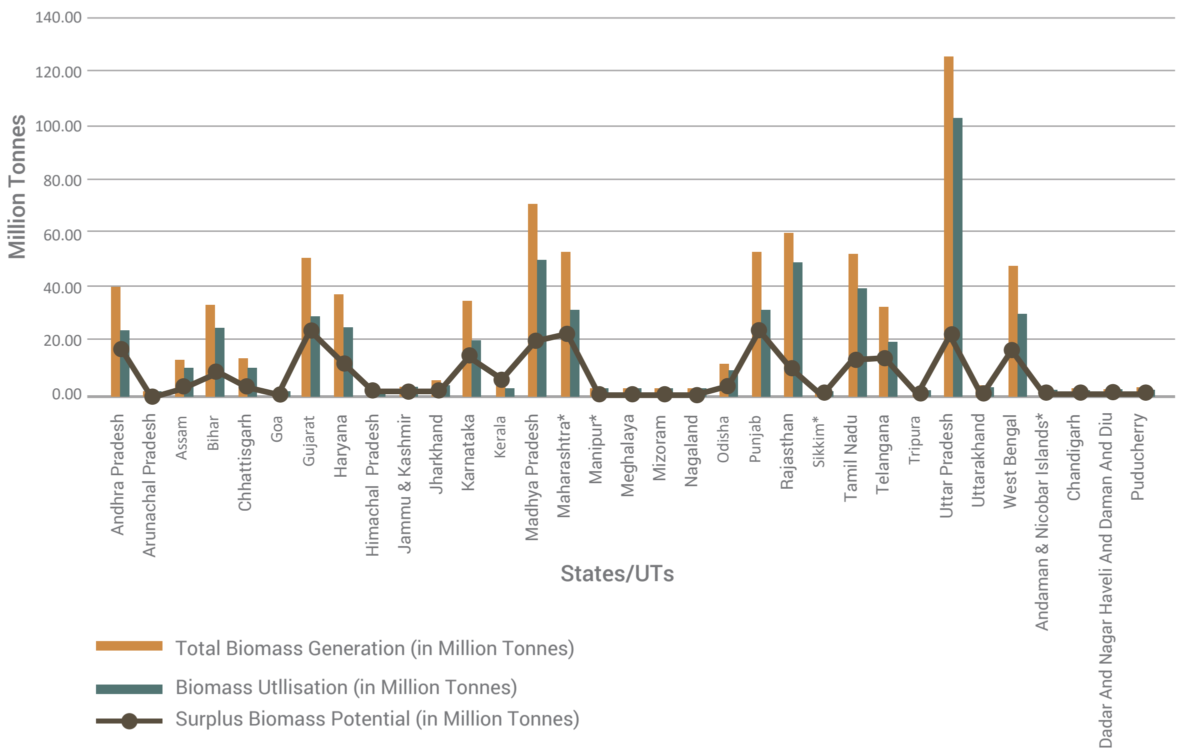


Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential[19]

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 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 Greenhouse Gas emissions is 30-35 percent greater compared to food-based biofuels.[22]

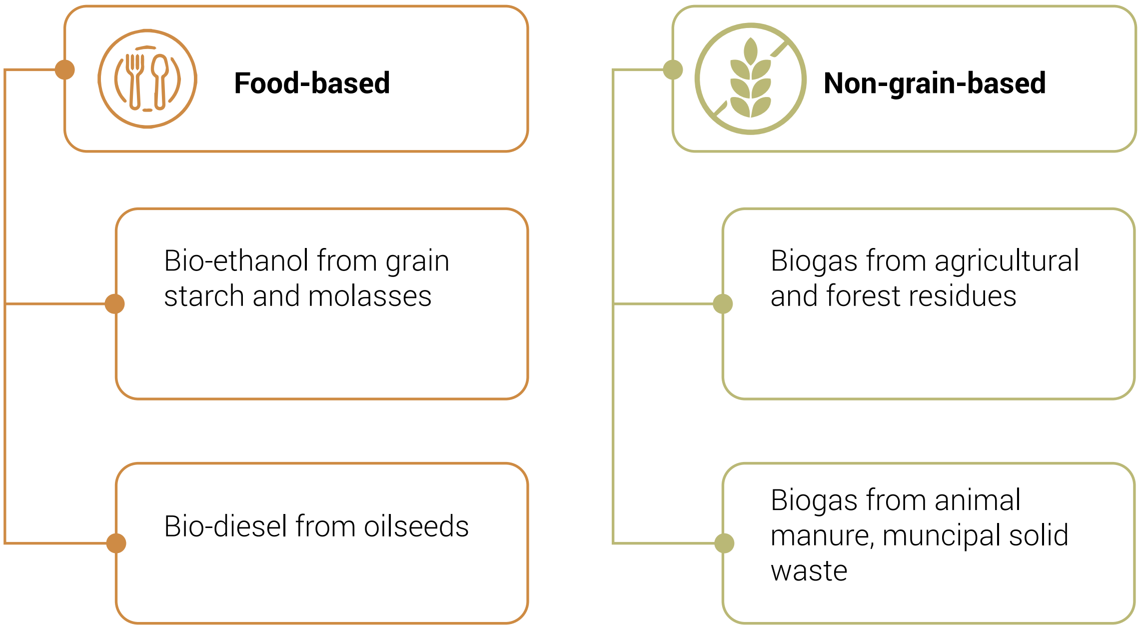


Figure 5: Classification of biofuels

2.1 Scope of the Study

This study aims to measure the net biomass residue production during 2023-24 across all six tehsils (administrative subdivisions) of Barabanki district in Uttar Pradesh. The resulting data will help determine the optimal 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, along with 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 certain feedstocks, which include forestry residues, municipal solid wastes, effluents and other wastes from industries such as paper and pulp, food processing, etc. It provides an *'as-is'* condition and excludes, the potential of biomass residues that can be generated by utilising barren, uncultured land or fallow lands, etc. The study also takes into consideration of the current biomass residue management practices and factors in the reduction jn available feedstock due to its use in existing or ongoing bioenergy projects at each tehsil.

It quantifies the net residue across two major cropping seasons (Kharif and Rabi) across all the tehsils. The crops selection was based on acreage and production levels 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 have been proven reliable and useful across various applications. For viable utilisation of biomass residues in energy generation, prior and precise database of residue distribution, seasonal fluctuations (including peak and lean periods 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, the adequacy, precision, reliability of data collected through traditional methods (secondary data collection or survey) are integrated with high-resolution spatial maps of crop production (one of the major agro residues) at the sub-d istrict level that can inform the potential plant capacity, annual feedstock availability for CBG production both, in terms of quantity and location specific procurement feasibility.

Government agencies, industry developers or 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 correlate directly with greater biogas output. Additionally, the specific composition of the organic matter significantly impacts yield, with lipids exhibiting methanogenic potential compared to proteins or carbohydrates. The most common feedstocks utilised in existing CBG plants include animal waste, agricultural residue, organic fraction of municipal solid waste (MSW), and sewage sludge.

Biogas production constitutes an intricate biological process unfolding in four distinct phases:

- Hydrolysis (Phase 1): Fermentative bacteria break down complex biopolymers such as proteins, polysaccharides, and fats/oils into simpler monomers and oligomers like sugars, amino acids, and peptides.
- Acidogenesis (Phase 2): These simplified compounds are further transformed by fermentative bacteria into short-chain volatile organic acids, including propionate and butyrate.
- Acetogenesis (Phase 3): Intermediate products are transformed by acetogenic bacteria into acetate, hydrogen (H_2), and carbon dioxide (CO_2).
- Methanogenesis (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 primarily 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 by-product, 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 involves removing carbon dioxide (CO_2), H_2S, and moisture content, resulting in a fuel of higher calorific value. If the methane content of the upgraded product is above 90 percent, it can be used directly as the transportation fuel, replacing Compressed Natural Gas (CNG) or injected into gas grids as CBG, which should meet IS 16087:2016 specifications of Bureau of Indian Standards (BIS). Table 3 & 4 summarise the characteristics of raw biogas and Bio-CNG/CBG.

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

Table 4: Chemical composition of Raw Biogas vs. CBG

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

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

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

The wide variability in biogas substrates and raw materials often necessitates pretreatment processes, which can substantially enhance biogas yields. Figure 8 illustrates significant advantages that can be achieved through appropriate feedstock pretreatment. A single feedstock or a combination of feedstocks is fed into shredders (mechanical pretreatment) that make the substrate smaller or break open their cellular structure, increasing the specific surface area of the biomass (See Figure 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 digester.[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

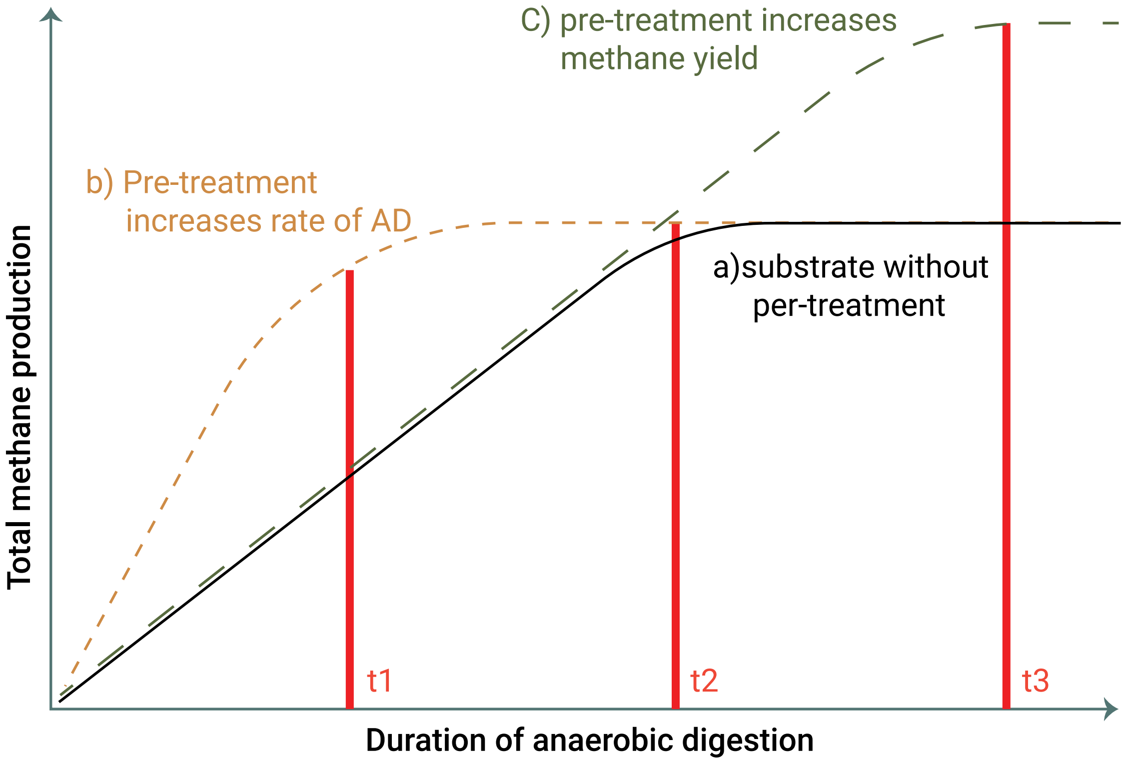


Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[28]

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

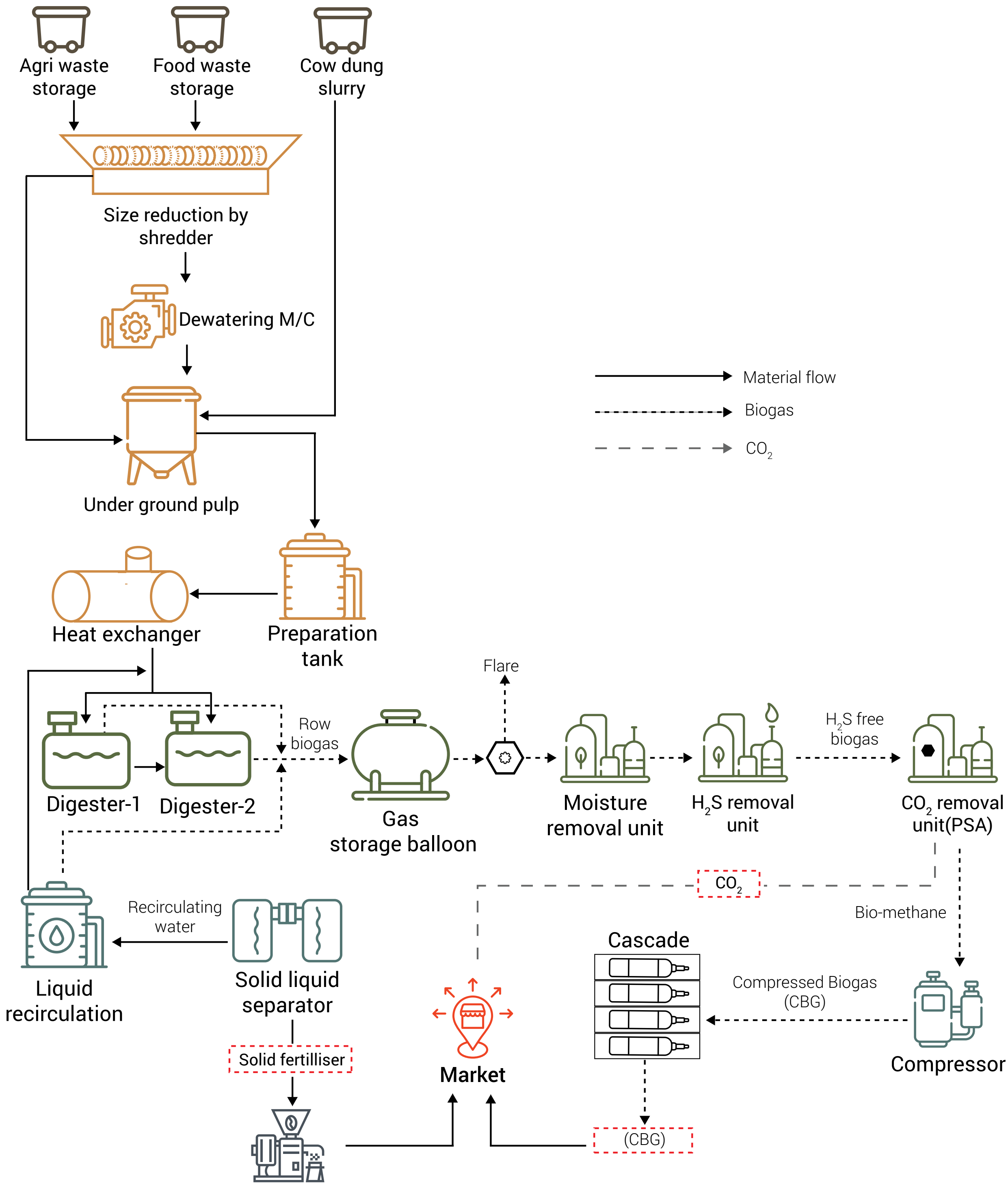


Figure 8: Process flow diagram for a Compressed Biogas plant[30]

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 at various stages of development. By 2030, CBG production could reach 0.8 bcm/yr. Realising this potential, Government of India, through various measures has 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 conversion of cattle dung, agricultural residues 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 phased mandatory blending of CBG in transport fuel 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 to the Fertiliser (Control) Order, 1985[34], provide 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], owing to its abundant organic feedstock availability.

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

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

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

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

03 District Profile

3.1 Geographic Overview

The district Barabanki[36] is situated in Faizabad Division which lies in central regions plain. To provide effective administration the district is administratively divided into 6 tehsils namely, Fatehpur, Ram Nagar, Nawabganj, Sirauli Ghauspur, Haidergarh, and Ramsanehi Ghat. It is situated in between Lucknow, the capital of the State and Faizabad, between the parallels of $26^{0}30'$ and $27^{0}19'$ north latitude and $81^{0}8'$ and $81^{0}56'$ east longitude. It is bounded in the north by Sitapur and Bahraich district while its south and south east boundaries formed by the district Rae Bareli, and Sultanpur respectively, in west Lucknow, in north east districts of Bahraich and Gonda, in east, Faizabad and Sultanpur are situated while Ghaghra forms north east boundary and Gomti makes its south west boundary. Total area of the district is 4402 sq. km. The district is well fed by rivers Ghaghra, Gomti, and Kalyani with their tributaries for major part of the year.

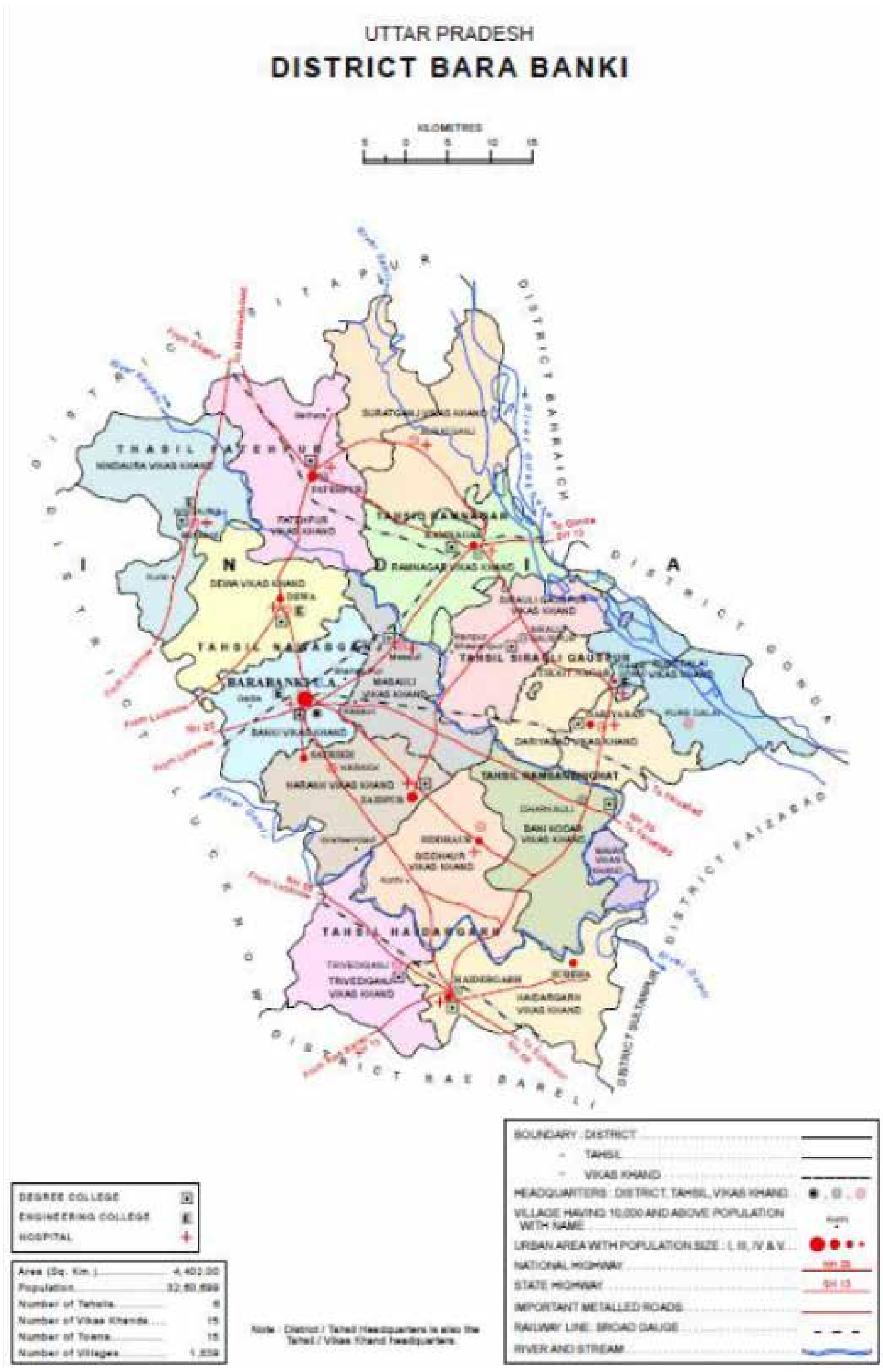


Figure 9: District map of Barabanki as per the 2011 Census[36]

In Barabanki, big and medium industries that are prominent include Reliance Ltd., U.P. State Spinning Mills, Balrampur Chini Mills, Somaya Organics, Indian Polyfibres, etc. The district is dependent on agriculture. Trade of the district depends on agriculture product, food grains, peppermint oil, etc.

3.2 Administrative Units (Tehsils/Blocks)

The district Barabanki is situated in Faizabad Division which lies in central regions plain. To provide efficient administration the district is divided into six tehsils. For implementation and monitoring of development schemes, the district is further divided into 15 development blocks. Rural area of the district overs 4337.1 sq. km. and urban recorded 64.9 sq. km. There are 1002 Gram Panchayats and 1845 revenue villages[36].

Table 6: Tehsil-wise revenue village count in Barabanki district[36]

Tehsil	Total Revenue Villages
Nawabganj	401
Fatehpur	401
Ram Nagar	241
Ramsanehi Ghat	267
Sirauli Ghauspur	189
Haidergarh	373
Total	**1845**

3.3 Climatic Conditions

The district lies in the eastern agro-climatic zone of the state. Its climatic condition is quite similar to the average climate condition of the plains. The district experience hot summers, cold winters and humid conditions during monsoon. Most of the rain occurs from June to September and often in November and January. The winter sets in November and continues till February end. The rainfall is erratic and distribution of rainfall is uneven.[36]

Table 7: District agricultural and climate profile of Barabanki

District Agricultural and Climate Profile				
Agro-Climatic Zone[37] (State Agricultural Profile[38])	Eastern Plain Zone/Upper Gangetic Plain Region			
Rainfall[39]				
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Southwest Monsoon (June-September)	883.3	49	2nd week of June	4th week of September

36 District Administration, Barabanki, https://barabanki.nic.in/about-district/administrative-setup/village-panchayats/

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

Post-monsoon (October-December)	54.8	10	-	-
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Winter (January-March)	44.4	8	-	-
Pre-monsoon (April-May)	120.2	-	-	-
Annual	1002.7	67	-	-
Temperature (in degree Celsius)[40]		42^0C (maximum)		4.6^0C (minimum)
Soil			Deep, loamy soils, slightly saline and moderately sodic	
Major Climate Contingency and Frequency		**Regular**	**Occasional**	**None**
Drought		x	x	√
Flood		x	√	x
Cyclone		x	x	√
Hailstorm		x	x	√
Heat wave		x	√	x
Cold wave		x	x	√
Frost		x	√	x

A report[41] assessing district-level climate vulnerabilities in India highlighted that Barabanki district in Uttar Pradesh falls under the moderately vulnerable category. The major drivers of vulnerability include

40 Krishi Vigyan Kendra, Barabanki, Agriculture Department, Government of Uttar Pradesh

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

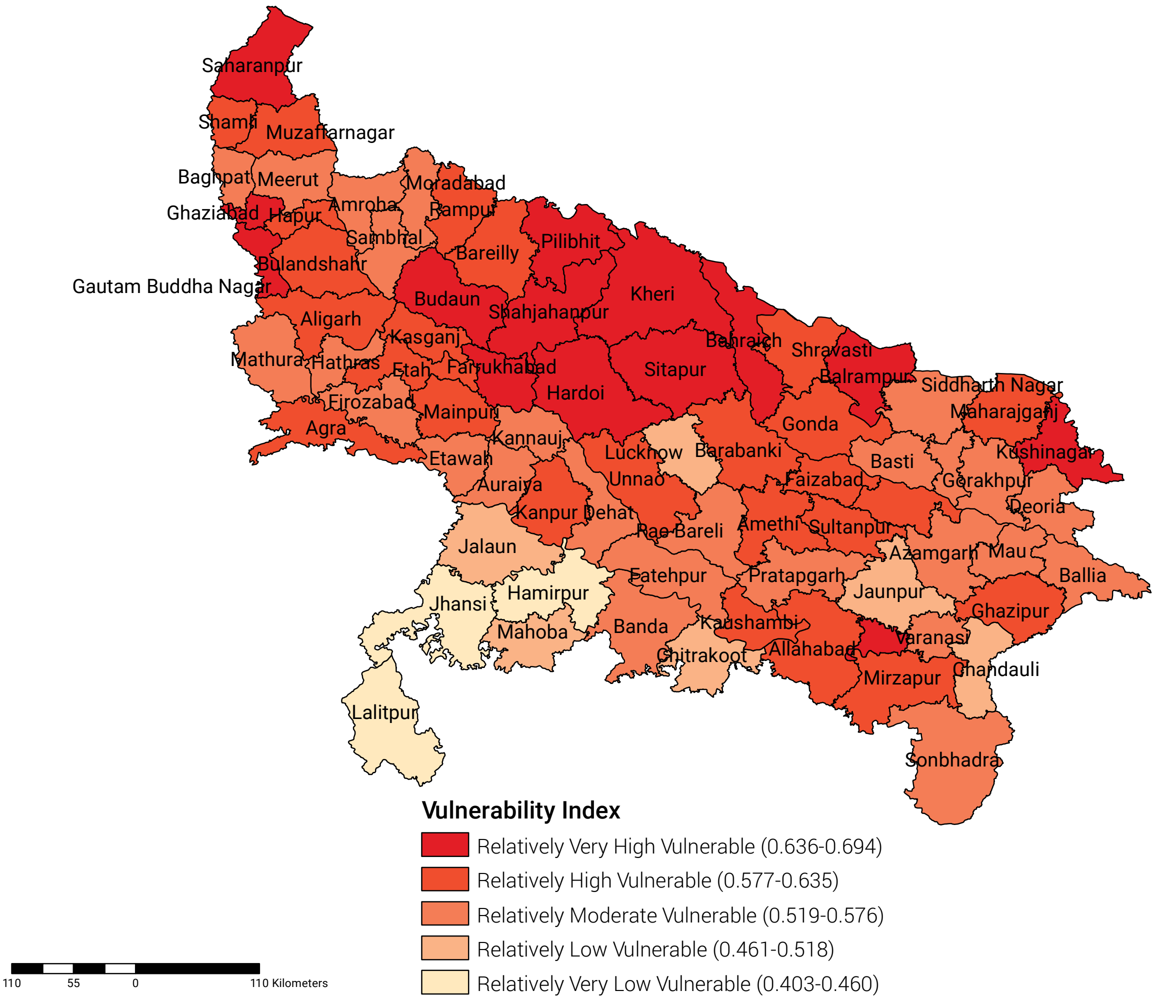


Figure 10: District-wise climate vulnerability index

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

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

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

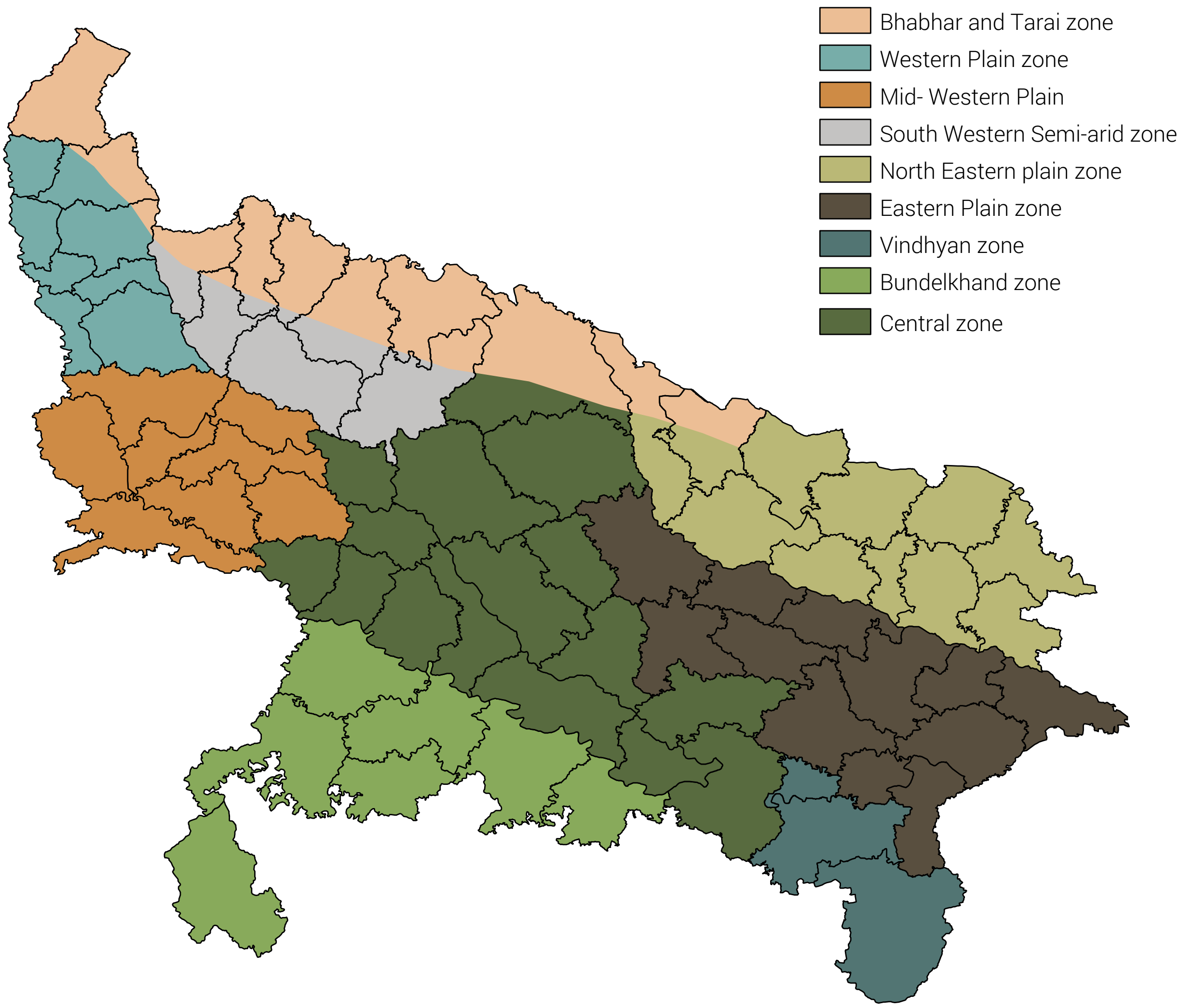


Figure 11: Agro-climatic zones in Uttar Pradesh[42]

3.4 Demographics (Urban/Rural)

Agriculture is the main economic source of the district with over 73 percent of the total workforce involved as agricultural workers.[36]

In terms of agricultural landholdings, over 53 percent of the holdings in the district were less than 1 hectare (ha.) while close to 25 percent of the holdings were 1-2 ha, approximately 14 percent of the holdings lie between 2-4 ha and 6 percent of the holdings were in the range of 4 ha. and above during 2015-16. In terms of agricultural income, during 2021-22[43] the gross value of agricultural produce per ha. of net area sown was INR 4,81,487.61.

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

43 District Wise Development Indicators, Uttar Pradesh 2023

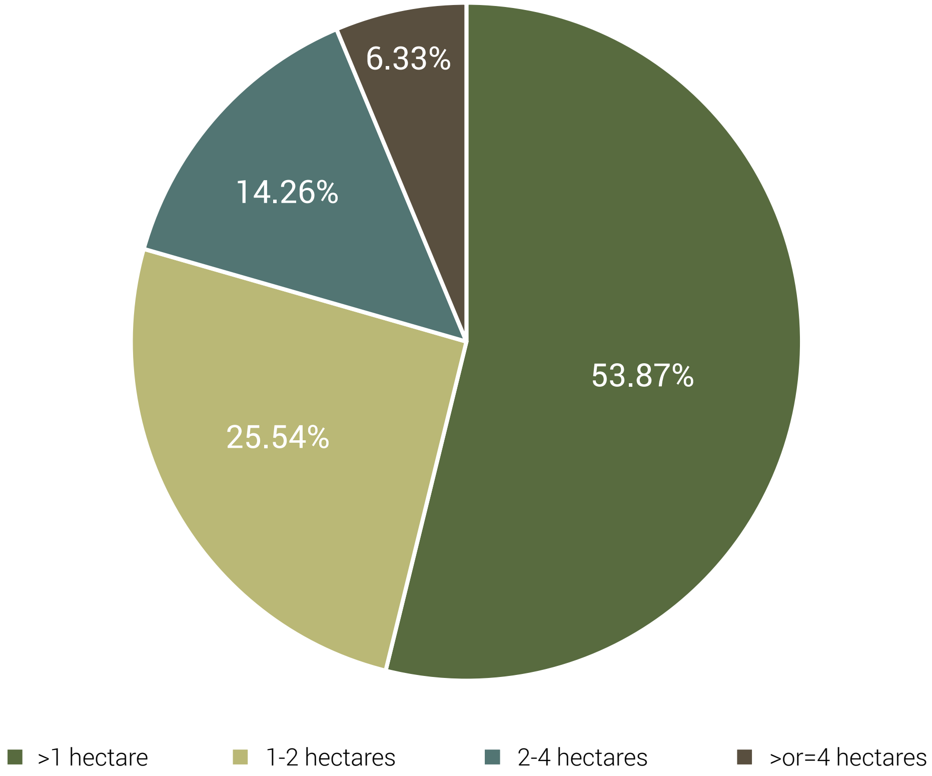


Figure 12: Agricultural land holdings in Barabanki[44]

3.5 Agricultural Overview

Barabanki has a significant agricultural economy. At the district-level, around 2.58 lakh hectares (ha.) of geographical area is sown with a cropping intensity of 196.9 percent.[40] Gross cropped area is approximately 5 lakh ha. with over 2.5 lakh ha. area sown more than once. The net irrigation area is around 2.34 lakh ha. out of which 24300 ha. are rainfed. Major sources of irrigation including bore wells (tube wells) and canals.

3.5.1 Total Agricultural Area

Table 9: Agricultural land area and cropping intensity in Barabanki district

Agricultural Land Use	Area ('000 ha)	Cropping Intensity (%)
Net sown area	258.4	196.9%
Area sown more than once	250.6	
Gross cropped area	509	

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

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

The dominant crops in the district are cereals mainly paddy and wheat, followed by pulses. Area under sugarcane is less in comparison to other districts in the state. Barabanki is one of the big potato producing areas in Uttar Pradesh. Wheat, rice, and maize are chief food crops of the district. Cash crops that are popularly sown in the district include opium, menthol oil, sugarcane, fruits, etc. Subsistence agriculture is practised in the district where farmers rotate up to five corps round the year.[45] Figure 13 describes the extent of land use in terms of gross area sown for Kharif and Rabi crops in Barabanki district during 2021-22.

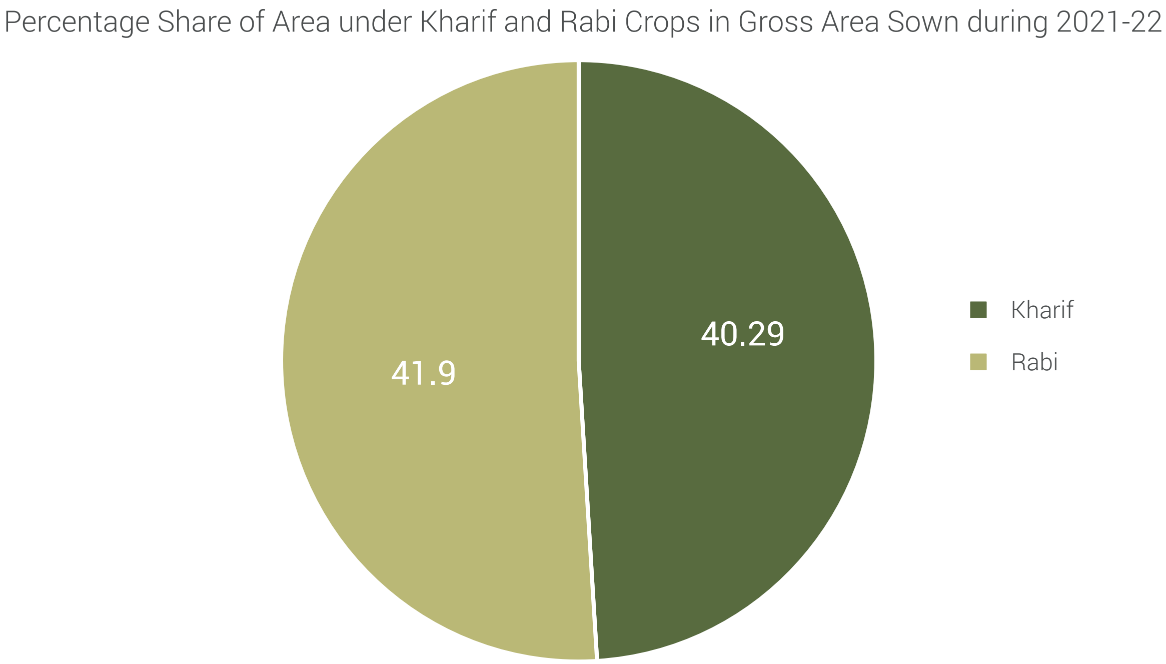


Figure 13: Gross Area Sown during both the cropping seasons in Barabanki[45]

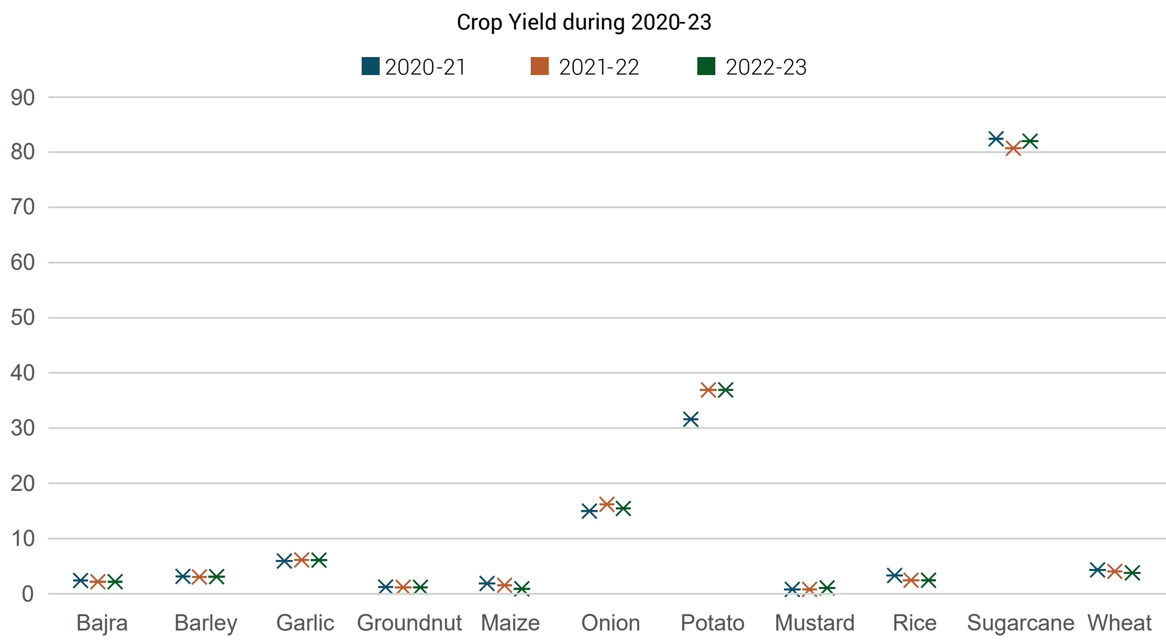


Figure 14: Crop yield during 2020-23 for major crops sown in Barabanki during Kharif and Rabi[46]

45 District Skill Development Plan of District Barabanki 2020, Uttar Pradesh Skill Development Mission

46 Area Production Statistics, Ministry of Agriculture and Farmers Welfare

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

Table 10: Tehsil-wise cropped area of Rabi crops (in ha.) during 2023-24[47]

Tehsil	Mustard	Wheat	Potato	Sugar-cane	Vege-table	Other Crops/ Grains	Total Crop Area (ha)
Fatehpur	10431.64	19147.74	6467.87	0.00	343.29	1292.53	37683.07
Haidergarh	8544.17	23113.30	1107.89	449.51	811.16	608.08	34634.11
Nawabganj	9510.66	21145.97	6575.67	0.00	121.20	3143.09	40496.60
Ram Nagar	4316.49	11774.17	2624.54	0.00	133.97	333.68	19182.84
Ramsanehi Ghat	4445.43	17482.88	320.90	1105.03	369.96	525.41	24249.61
Sirauli Ghauspur	2827.02	11440.05	766.51	1283.65	123.71	380.19	16821.14
Total	**40075.42**	**104104.12**	**17863.38**	**2838.18**	**1903.28**	**6282.98**	**173067.36**

During 2023-24, the prominent kharif crops in the district were maize and paddy, which together accounted for more than 93 percent of the total cropped area. Other kharif crops include barley and sugarcane that were sown and cultivated during the same period. Among all tehsils, Nawabganj had the highest share of paddy cultivation to the total cropped area followed by Haidergarh and Fatehpur. In comparison to other districts in the State, sugarcane cultivation is minimal and is cultivated the most in tehsils of Nawabganj, Fatehpur and Ramsanehi Ghat.

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

Tehsil	Agri_ plantation	Other Crops/ Grains	Paddy	Sugarcane	Total Area (ha)
Fatehpur	5090.89	1023.76	37604.86	1733.72	45453.24
Haidergarh	5827.13	874.69	38299.38	1422.12	46423.33
Nawabganj	6637.16	495.41	41885.50	2440.61	51458.68
Ram Nagar	2565.78	532.65	18895.91	1166.50	23160.84
Ramsanehi Ghat	5514.35	1643.02	22223.55	1501.44	30882.36
Sirauli Ghauspur	2786.25	93.17	20798.83	1101.81	24780.06
Total	**28421.57**	**4662.70**	**179708.03**	**9366.20**	**222158.51**

47 Analysis by Vasudha Foundation, 2025

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

In Barabanki, the percent of irrigated area to the area sown is 93.87 percent.[44] The gross irrigated area of the district is at 4.60 lakh ha.

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

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

3.6 Forest Resources

3.6.1 Total Forest Area

Table 13: Total forest area (by classification) in Barabanki[48]

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)
Barabanki	4402	3.58	5.71	94.70	103.99	3.99

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)

Forest area consists of Babul, Dhak, Neem, Sheesham, and Bamboo trees which are generally grown on scattered and barren land. In sandy areas, palm trees and thorny bushes are grown. In the Ganga region, there are moderately dense forests comprising of large trees and diverse vegetation. The district abounds in orchards, with mango trees grown in groves and along roadsides. Other varieties of trees include Banyan, Gular, Pakar, Fig, Vaska, etc.

3.6.2 Types of Forests and Residue Generated

Forestry residues consist of small trees, branches, leaves, bark, tops, and un-merchantable wood left in the forest after cleaning, thinning, or final felling. Woody biomass actually requires thermal gasification at high temperature in a low-oxygen environment to convert it into a mixture of gases, mainly, carbon monoxide, hydrogen and methane (syngas)[51]. To produce a stream of high-purity biomethane, this syngas is cleaned to remove any acidic and corrosive components. Therefore, woody biomass which consist of residues from forest management and wood processing must follow the gasification route, unlike other feedstocks like agriculture residue or Municipal Solid Wastes (MSW). Biomass such as paper, wood, dried leaves, wooden shavings, etc are generally high in lignin and cellulose. These substances are not suitable for 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 the animal population has also led to significant increase in livestock residues. Uttar Pradesh also has one of the highest number of livestock populations among all the states.

3.7.1 Cattle, Poultry, and Other Livestock Statistics

Table 14: Tehsil-wise livestock statistics and cattle in Cowsheds[54]

Tehsil	Cattle	Goat/Sheep	Swine	Poultry (Chicken)
Fatehpur	40537	56031	1026	4,56,901
Haidergarh	86695	39768	1931	2,44,980
Nawabganj	81274	82004	56031	4,56,901
Ram Nagar	36881	70767	19926	53
Ramsanehi Ghat	51543	39707	1208	25,410
Sirauli Ghauspur	18828	15589	404	2,037
Total	**315758**	**303866**	**80526**	**11,86,282**

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

Tehsil	Total Govansh
Fatehpur	2925
Haidergarh	6851
Nawabganj	4832
Ram Nagar	6051
Ramsanehi Ghat	3694
Sirauli Ghauspur	3981
Total	28334

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

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

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

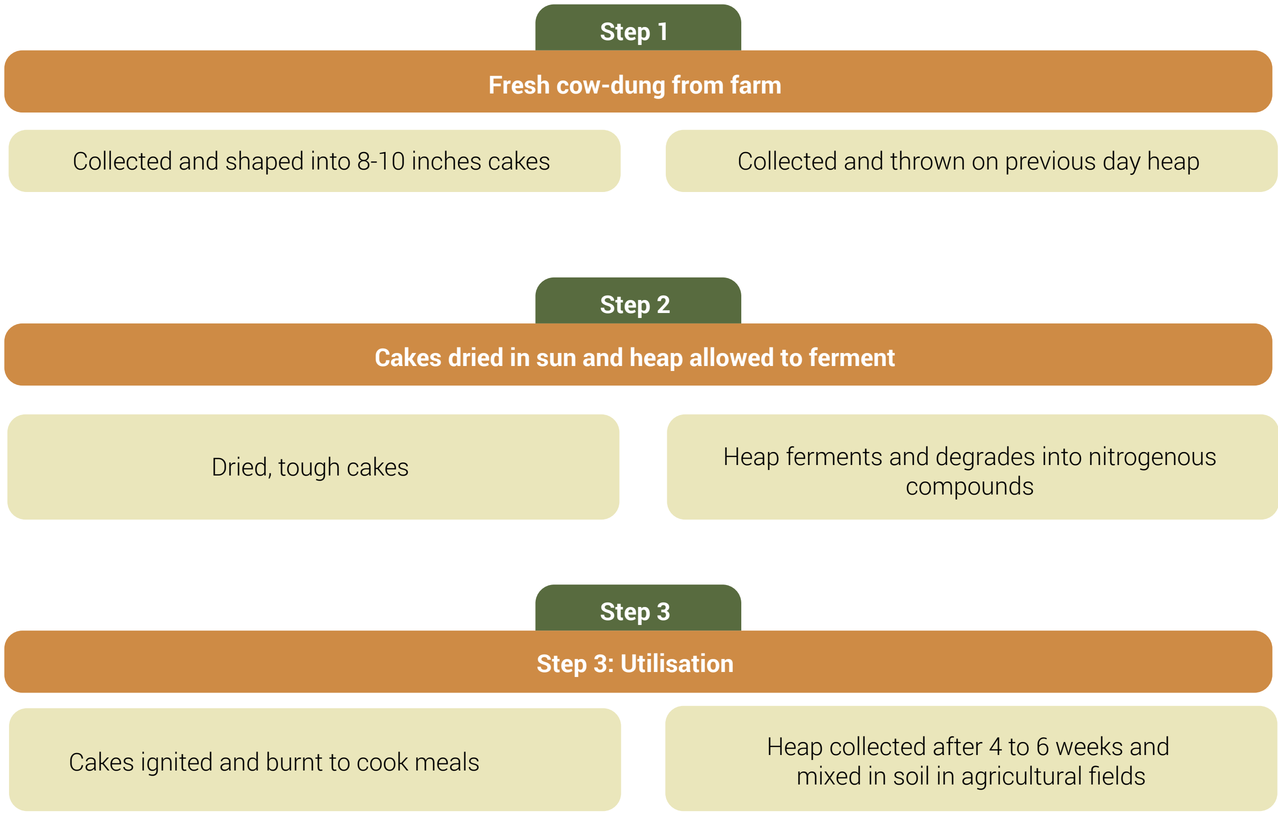


Figure 15: Traditional use of cow-dung as kitchen fuel and manure[59]

3.8 Industry and Processing Units

3.8.1 Existing Biomass-based Industries

There are two Compressed Biogas Plants, one in Nawabganj tehsil (commenced commercial operations) and the other in Haidergarh tehsil (under construction) and one large biogas plant in Haidergarh tehsil.

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

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

Plant Capacity and Tehsil	Feedstock/ Raw Material	By-Products	Off taker	Procurement Plan
20 TPD plant in Haidergarh tehsil (under construction)	Paddy Straw, Cattle Dung	CBG, FOM, LFOM	CBG would be captively used in their gas retail outlets	Plant is in construction phase and will tentatively start its operations starting from August 2025. Major feedstock that would plant would run on is paddy straw (75-80%) and cattle dung (20-25%). 50% of the paddy straw will be procured from tehsils of Haidergarh, Fatehpur, and Nawabganj and the rest 50% will be procured from neighbouring districts (Raebareli and Amethi). Cattle dung will be procured from a nearby cow shelter
20 TPD plant in Nawabganj tehsil	Paddy Straw, Cattle Dung	CBG, FOM, LFOM	CBG would be captively used in their gas retail outlets	Plant is in operation and procures 80% of paddy straw from tehsils of Nawabganj, Fatehpur, Haidergarh, and Ram Nagar and the rest from Raebareli, Amethi and Shahjahanpur districts. Cattle dung is procured from a nearby cow shelter run by the Government
45 m3 Per Day (MPD) in Haidergarh tehsil	Cattle Dung	Bio-slurry	Biogas used for heating purposes in cowshed	Commercial-scale biogas plant installed and functional inside a cowshed facility in Barabanki Tehsil (under GOBARdhan)

The feedstock procurement plan for both the CBG plants is described below:

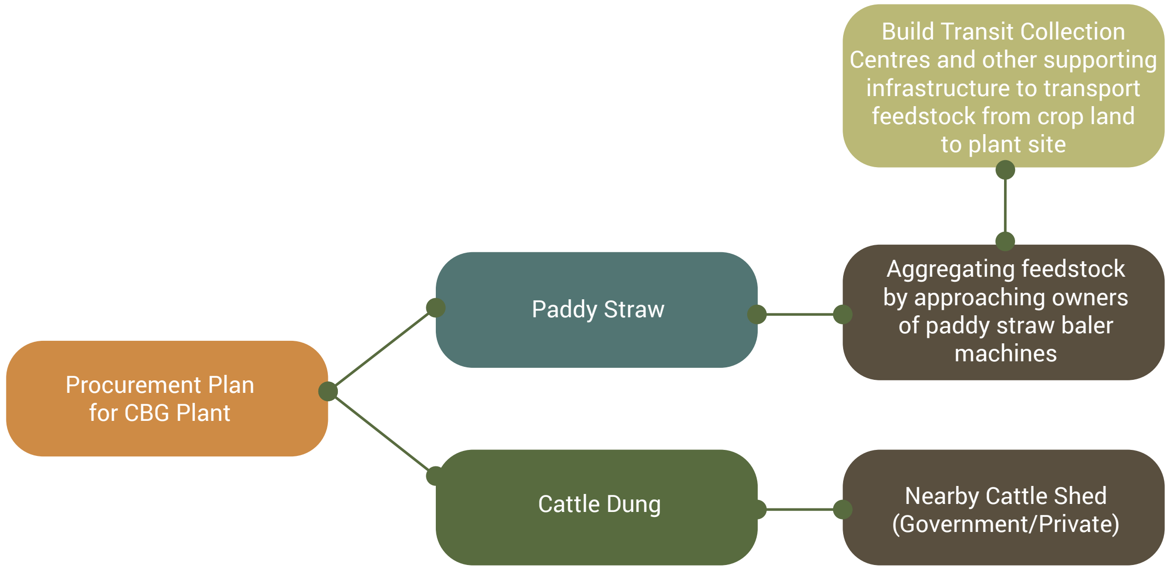


Figure 16: Feedstock procurement plan for existing CBG Plant[60]

60 Field visits and Analysis by Vasudha Foundation, 2025

04 Data Collection

4.1 Primary Data Collection

Primary datasets on land cover, usage, and cropping pattern of specified timeframe in each tehsil were studied. Crop mapping was conducted using high-resolution seasonal time series data and by extracting unique temporal signatures of different crop. The land cover map primarily describes the annual land use patterns in the district and all tehsils, distinguishing between built-up areas, agricultural land, fallow land, barren areas, scrubland, plantations and water bodies. Crop maps provide acreage estimations for 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 of sugar mills, we derived the following factors:

Table 17: Operating parameters and conversion factors for sugar mills

Parameter	Value
Conversion Factor (Sugarcane to Bagasse)	40% TCD[61]
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[62])	150 days
Number of Operating Days (Medium Sugar Mill[63])	150 days

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

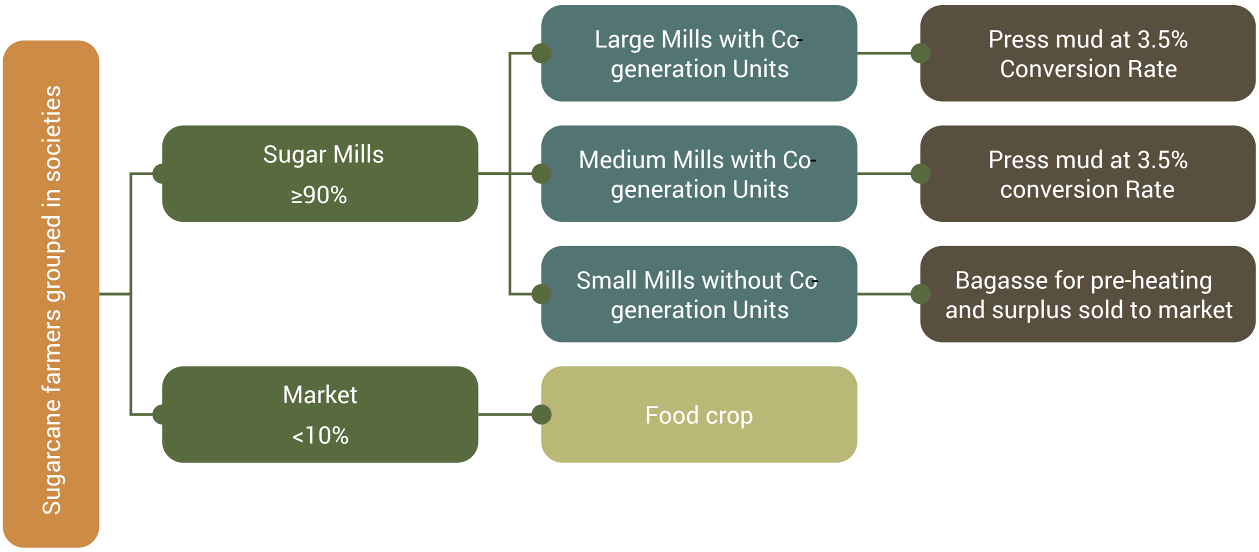


Figure 17: Mapping the value chain of sugar industries

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

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

63 Medium Sugar Mills use Horizontal Crushers to crush Sugarcane

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

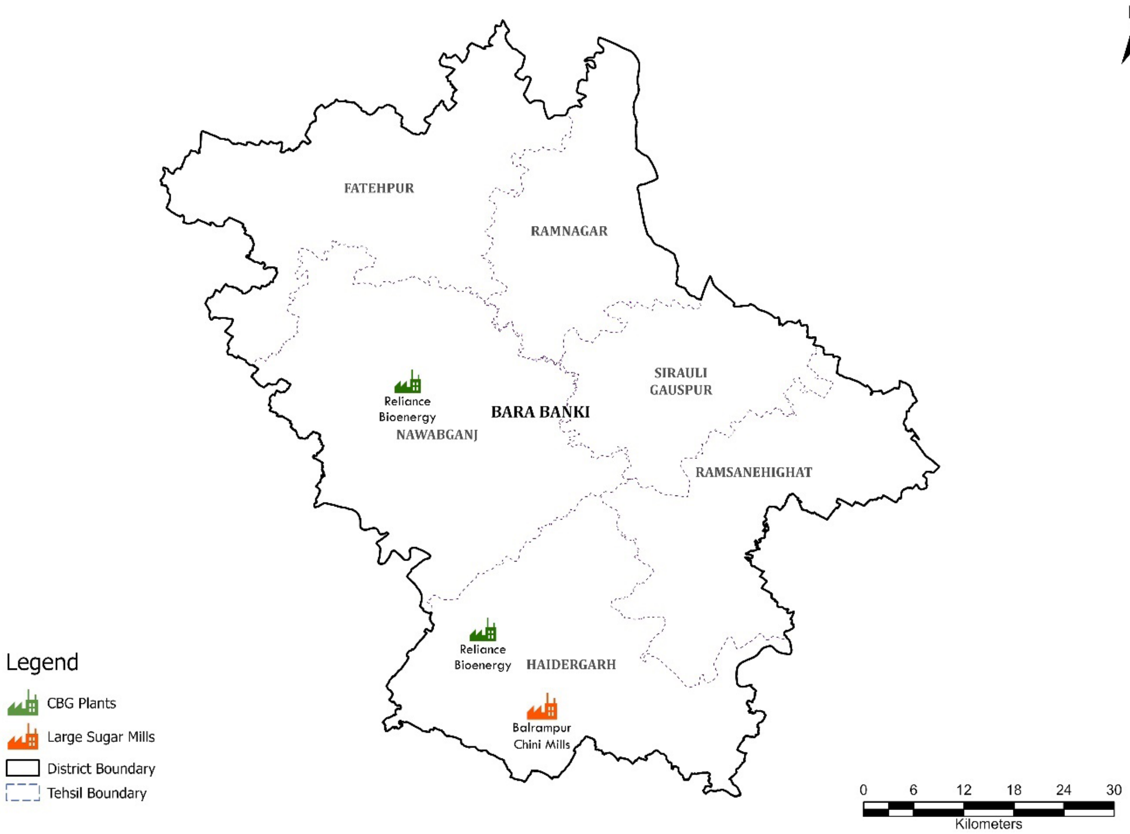


Figure 18: Location of sugar mills and CBG plants in Barabanki[64]

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

Tehsil	Cane Crushing Capacity in TCD		
	Large Mills	Medium Mills (Khandsari)	Small Mills (Vertical Crushers)
Haidergarh	5000	x	x

4.2 Secondary Data Collection

Major reliance was placed on secondary data that was shared by the Government at the central, state, district, and sub-district level. Crop yield data was collected from the Crop Production Statistics published by the Ministry of Agriculture and Farmers Welfare for three-year period (2021-24) to arrive at an average. Further, the crop-to-residue ratio (on dry weight basis) was borrowed from the latest National Biomass Atlas[65] which is described as under:

64 Analysis by Vasudha Foundation, 2025

65 National Biomass Atlas of India, 2023

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

Crop	Residue	Residue to Crop Ratio	Surplus Fraction
Wheat	Straw	1.5	0.2
	Husk	0.3	0.2
Paddy	Straw	1.5	0.17
		0.2	0.17
Sugarcane	Tops and leaves	0.05	1
Maize	Stalks	2	0.01
	Cobs	0.3	0.01
	Leaves	0.12	0.01
Mustard	Stalks	1.8	1
Pulses	Stalks	2.5	1
Potato	Stalks	0.1	1
Vegetable	Stalks	0.1	1
Barley	Straw	1.3	1
Bajra	Stalks	2	1
	Husk	0.3	1
	Cobs	0.33	1

Biogas yield for different crops/raw materials was shared by National Institute of Bioenergy (NIBE). For crops with unavailable crop-specific conversion factors, a standardised average conversion ratio (calculated on a dry weight basis) was applied to estimate biogas yield potential. This approach accounts for moisture content variations and ensures consistency in quantifying energy generation capacity from residual biomass.[66]

66 As per the NIBE's approximations

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

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

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

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

Category	Animal	Collectable Dung (Kg/day)	Total Solids	Availability Coefficient	Biogas in m^3	Multiplication Factor[67]
Large	Cows, Buffalo	22.5	25%	70%	0.6	4.76086
Small	Sheep, Goat	1.6	29%	20%	0.4	4
Swine	Pigs	2.7	29%	60%	0.4	4
Poultry	Broiler, Layer, and Other	0.045	29%	60%	0.8	4.71428

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

Table 22: Calorific values[68,69] for animal residue

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

67 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 Pressmud) Across India.

68 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

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

To understand which feedstock is best for CBG production, we used SATAT data published by the Ministry of Petroleum and Natural Gas (MoPNG)[70]. The tentative yield of various feedstocks is tabulated as under:

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

Feedstock	CBG Production (T)	Feedstock Requirement
Agriculture Residue	1	10 T
Pressmud	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

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

05

Stakeholder Mapping

5.1 Identification of Relevant Stakeholders

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

Table 24: Stakeholders in Bio-energy value chain

Sector	Stakeholder	Data
Central Government	National Institute of Bioenergy	Clarification on surplus factors (the proportion of agricultural/industrial residues available beyond existing uses) and the conversion factor used to translate surplus biomass residues (in 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 Barabanki District
Private	Sugar Mills – Large, Medium and Small	Annual cane crushing capacity, press mud market and management, Conversion factor for bagasse and press mud in a sugar mill, Bagasse generating capacity for small-sized informal sugar mills
	Under-construction CBG Plant	Plant Capacity, feedstock mix, raw material procurement plan, stocking and reserves, land area, contingency planning

06

GIS-based Satellite Mapping

6.1 Cropping Pattern and Analysis

It can be observed from the Kharif crop map that sugarcane cultivation was almost negligent while paddy was prominently cultivated almost in all tehsils. Among them, Sirauli Ghauspur, Nawabganj, Haidergarh and Fatehpur were the leading paddy cultivators.

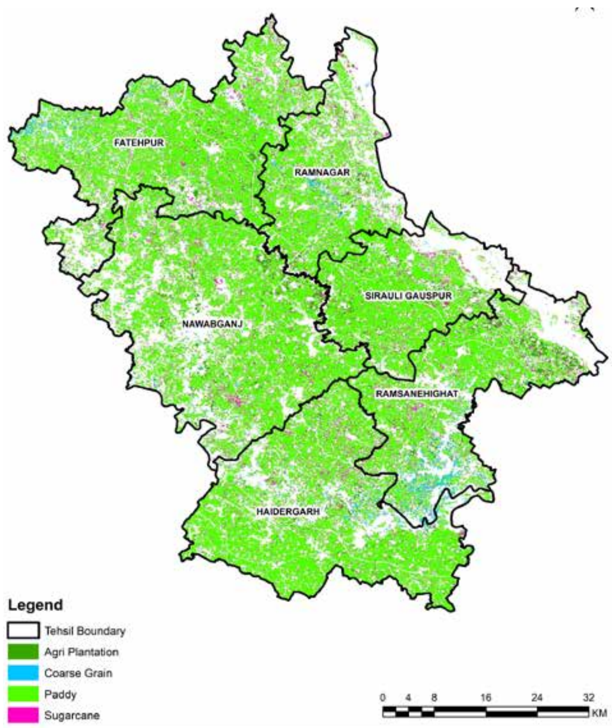


Figure 19: **Geographical spread of Kharif crops in tehsils of Barabanki during 2023-24**[71]

During the Rabi season of 2023-24, wheat was prominently cultivated in almost all the tehsils. Other Rabi crops include potato which was grown in tehsils of Fatehpur, Nawabganj and Ram Nagar.

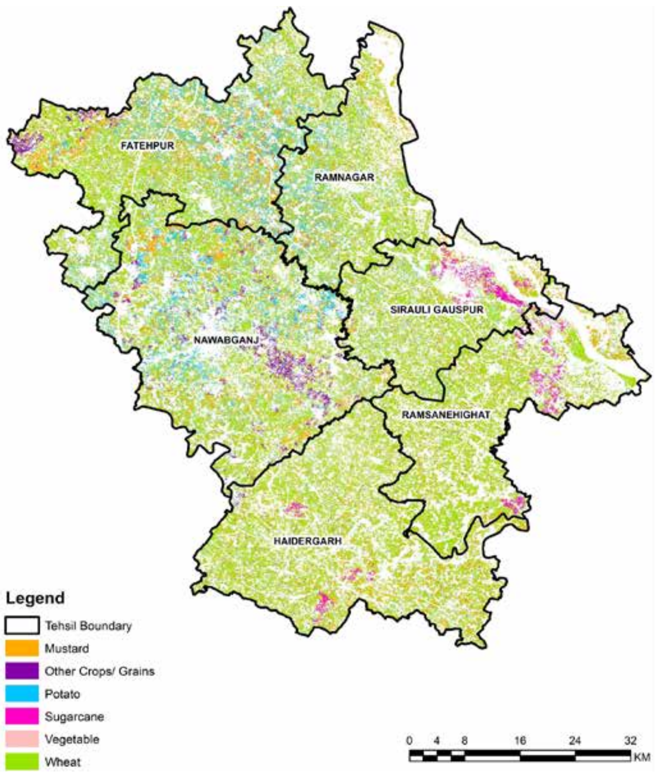


Figure 20: **Geographical spread of Rabi crops in t ehsils of Barabanki during 2023-24**[72]

71 Analysis by Vasudha Foundation, 2025

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

Table 25: Tehsil-wise land-use analysis for Barabanki in ha.

Tehsil	Agri Planta-tion	Bare/ Sparse Vege-tation	Barren/ Waste land	Built-Up	Crop land	Scrub land	Water-bodies	Water-logged	Total Area (ha)
Fatehpur	58.09	176.97	2027.56	2799.20	57399.10	10719.52	368.22	0.00	73548.66
Haidergarh	3216.76	212.49	3261.12	3476.82	51727.73	14317.92	163.02	0.00	76375.87
Nawabganj	2469.25	262.92	4478.15	5511.77	65188.42	14541.96	137.79	105.00	92695.26
Ram Nagar	250.08	446.52	1572.59	1425.66	33630.01	6221.86	1536.44	0.00	45083.15
Ramsanehi Ghat	3449.18	426.52	2465.73	2120.18	37202.80	10872.30	2039.12	0.00	58575.83
Sirauli Ghauspur	447.86	508.46	1526.80	1371.14	27600.83	7996.94	2232.48	0.00	41684.52
Total	**9891.22**	**2033.88**	**15331.96**	**16704.77**	**272748.89**	**64670.51**	**6477.06**	**105.00**	**387963.29**

It can be observed from the land use analysis[73] that nearly 70 percent of the total geographical area of the district was under cultivation during 2023-24.

73 Analysis by Vasudha Foundation, 2025

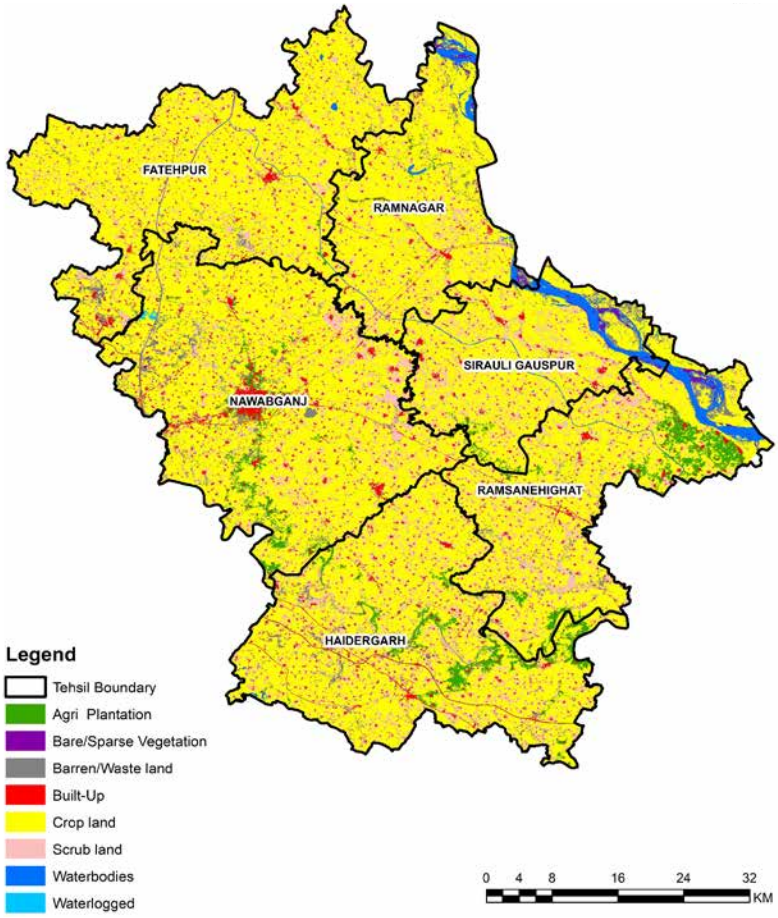


Figure 21: **Land cover analysis for tehsils of Barabanki during 2023-24**[74]

74 Analysis by Vasudha Foundation, 2025

07 Methodology

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

7.1 Agricultural Residue

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

Crop acreage estimation was conducted using the Support Vector Machine (SVM)[75] algorithm, a supervised machine learning method trained on ground-truth data to classify satellite imagery into distinct crop categories. This approach enabled precise mapping of Kharif and Rabi cultivation zones

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

by assigning pixel-level classifications. After determining crop-specific acreage, the study incorporated existing district- and tehsil-level agricultural statistics—such as yield per hectare—to calculate total production. By integrating 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.

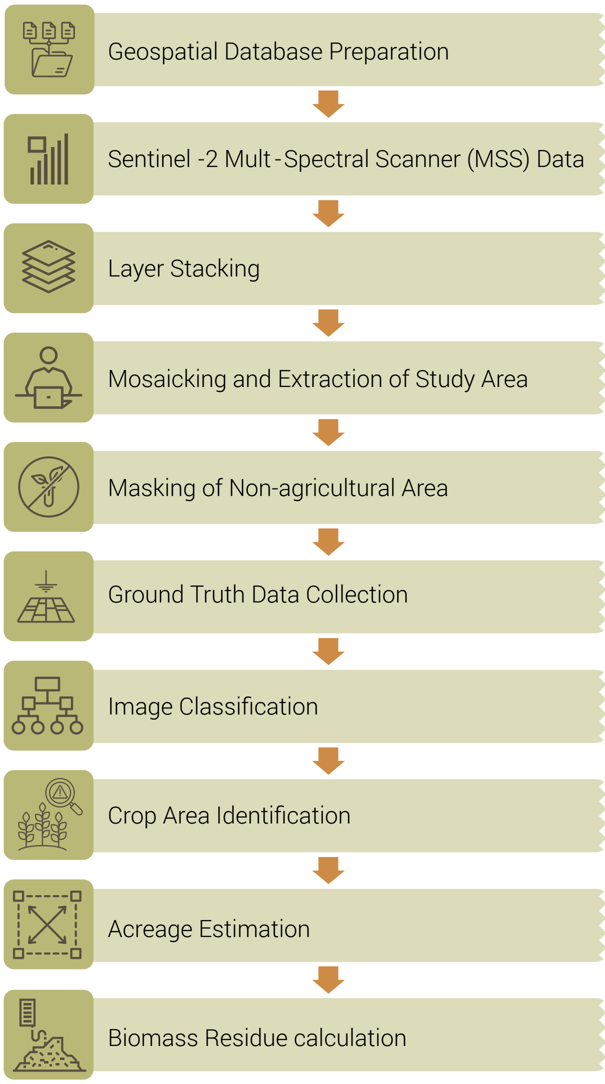


Figure 22: Flow diagram of the methodology used

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

Gross crop residue[76] is 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 the crop grain and the dry matter of its crop residue.[77,78] 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.

76 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.

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

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

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

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

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

The surplus crop residue of particular crop represents the amount of crop residues that are available for energy production after all the other competing uses such as cooking fuel, cattle feed, roof thatching, composting, animal bedding, and others are taken into consideration (as described in Figure 16).[79]

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

***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.[80,81]

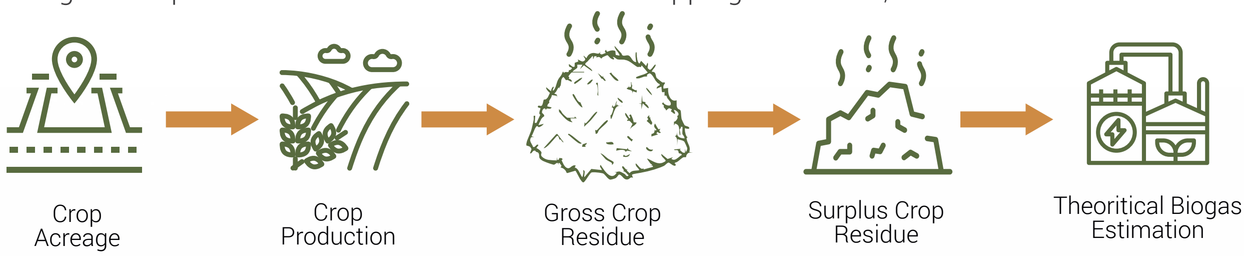


Figure 23: Flow diagram for crop residue estimation

79 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

80 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

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

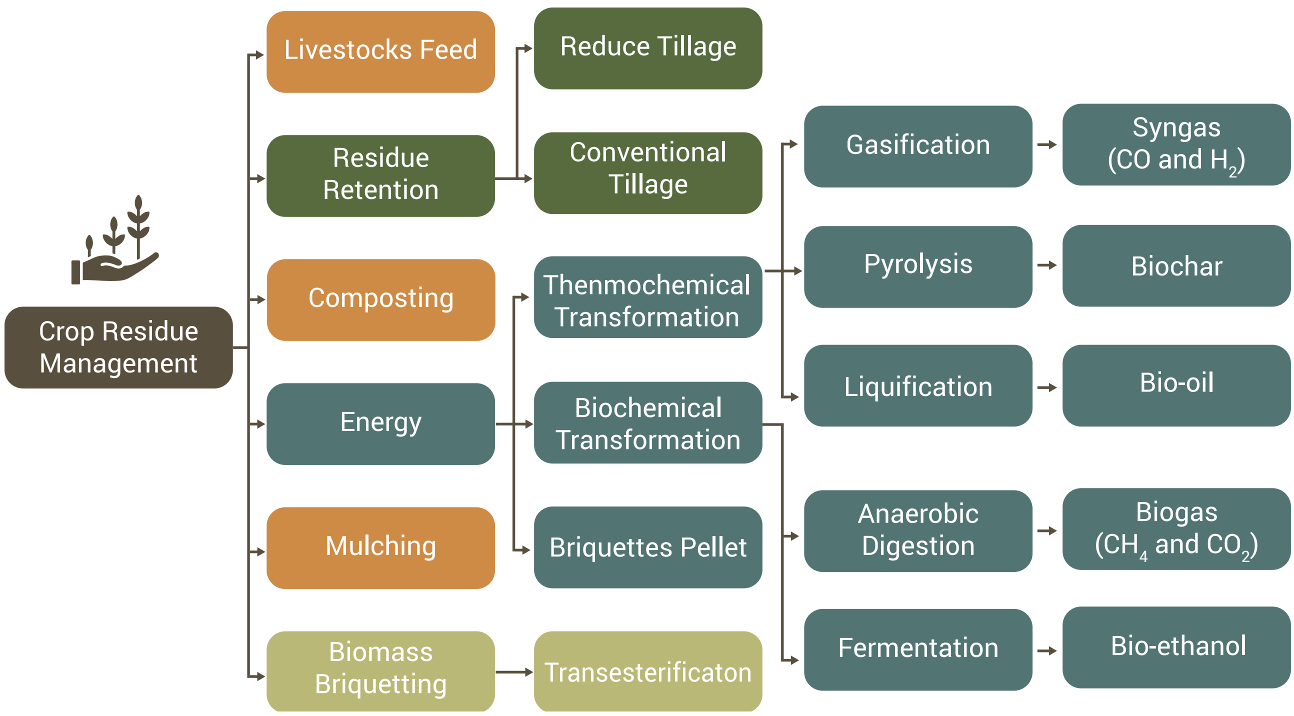


Figure 24: Crop residue management practices[82]

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.

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

08

Biomass Category, Sources and Availability

The results for Biomass Assessment are tabulated in Table 25. It describes for each Tehsil, the feedstock-wise annual biomass production during 2023-24 and corresponding gross residue and surplus residue that is available for CBG production. For agricultural crops, residue-to-crop ratios and corresponding surplus fractions for various crops are listed in Table 18. Similarly, the surplus animal dung/ litter and biogas yield for various biomass residues are described in Table 26 and 20 respectively. *Equations 1-6* were applied to arrive at the biogas yield results. We have two distinct results for CBG potential for majority of the the feedstocks because of the difference in residue-to-crop ratio as is the case for paddy straw, and different biogas yield ratios prescribed by NIBE and SATAT Scheme.

8.1 Agricultural Residues

Table 26: **Tehsil-wise surplus Biomass and Potential CBG Generation (in TPD) for Various Agricultural Residue**

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	**Yield** (T/ha)	**Total Production** (T)						
Fatehpur	Wheat	19147.74	4.05	77548.35	Straw	116322.52	23264.50	23264.50	4.61	6.37
					Husk	23264.50	4652.90	4652.90	0.92	1.27
	Paddy	37604.86	2.71	101909.17	Straw	152863.76	25986.84	17226.84	**3.84**	**19.94**
					Husk	20381.83	3464.91	3464.91	0.77	
	Sugarcane	1733.72	78.43	135975.66	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Large)		0.00		**0.00**	**0.00**
					Press Mud (Medium)		0.00		**0.00**	**0.00**
					Leaves	6798.78	6798.78	6798.78	**1.30**	1.30
	Agri Plantation (Maize)	5090.89	1.42	7229.06	Stalks	14458.13	144.58	144.58	0.04	0.04
					Cobs	2168.72	21.69	21.69	0.01	0.01
					Leaves	867.49	8.67	8.67	0.00	0.00
	Mustard	10431.64	0.87	9075.53	Leaves	16335.95	16335.95	16335.95	4.48	4.48
	Potato	5467.87	35.14	192140.95	Stalks	19214.10	19214.10	19214.10	5.26	5.26

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	**Yield** (T/ha)	**Total Production** (T)						
Haidergarh	Vegetables	343.29	15.55	5338.16	Stalks	533.82	533.82	533.82	0.15	0.15
	Other Crops (Barley)	1292.53	3.08	3980.99	Straw	5175.29	5175.29	5175.29	1.42	1.42
	Bajra	1023.76	2.23	2282.98	Stalks	4565.97	4565.97	4565.97	1.25	1.25
					Husk	684.90	684.90	684.90	0.19	0.19
					Cobs	753.38	753.38	753.38	0.21	0.21
	Wheat	23113.30	4.05	93608.87	Straw	140413.30	28082.66	28082.66	5.56	7.69
					Husk	28082.66	5616.53	5616.53	1.11	1.54
	Paddy	38299.38	2.71	103791.32	Straw	155686.98	26466.79	0.00	**0.00**	**14.35**
					Husk	20758.26	3528.90	3528.90	0.79	
	Sugarcane	1871.63	78.43	146791.94	Bagasse (Small)		0.00		**0.00**	**0.00**
					Press Mud (Large)		8214.50		**0.89**	**0.90**
					Press Mud (Medium)		2065.60		**0.22**	**0.23**
					Leaves	7339.60	7339.60	7339.60	**1.41**	**1.41**

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ha)	Total Production (T)						
	Agri Plantation (Maize)	5827.13	1.42	8274.52	Stalks	16549.05	165.49	165.49	0.05	0.05
					Cobs	2482.36	24.82	24.82	0.01	0.01
					Leaves	992.94	9.93	9.93	0.00	0.00
	Mustard	8544.17	0.87	7433.43	Leaves	13380.17	13380.17	13380.17	3.67	3.67
	Potato	1107.89	35.14	38931.25	Stalks	3893.13	3893.13	3893.13	1.07	1.07
	Vegetables	811.16	15.55	12613.54	Stalks	1261.35	1261.35	1261.35	0.35	0.35
	Other Crops (Barley)	608.08	3.08	1872.89	Straw	2434.75	2434.75	2434.75	0.67	0.67
	Bajra	874.69	2.23	1950.56	Stalks	3901.12	3901.12	3901.12	1.07	1.07
					Husk	585.17	585.17	585.17	0.16	0.16
					Cobs	643.68	643.68	643.68	0.18	0.18
Nawabganj	Wheat	11774.17	4.05	47685.3885	Straw	128461.77	25692.35	25692.35	5.09	7.04
					Husk	25692.35	5138.47	5138.47	1.02	1.41
	Paddy	18895.91	2.71	51207.9161	Straw	170264.56	28944.97	20184.97	4.50	22.48
					Husk	22701.94	3859.33	3859.33	0.86	

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	**Yield** (T/ha)	**Total Production** (T)						
	Sugarcane	1166.5	78.43	91488.595	Bagasse (Small)		0.00		**0.00**	**0.00**
					Press Mud (Large)		0.00		**0.00**	**0.00**
					Press Mud (Medium)		0.00		**0.00**	**0.00**
					Leaves	9570.85	9570.85	9570.85	**1.84**	**1.84**
	Agri Plantation (Maize)	2565.78	1.42	3643.4076	Stalks	18849.53	188.50	188.50	0.05	0.05
					Cobs	1225.22	12.25	12.25	0.00	0.00
					Leaves	1130.97	11.31	11.31	0.00	0.00
	Mustard	4316.49	0.87	3755.3463	Leaves	992.91	992.91	992.91	0.27	0.27
	Potato	2624.54	35.14	92226.3356	Stalks	23106.90	23106.90	23106.90	6.33	6.33
	Vegetables	133.97	15.55	2083.2335	Stalks	188.47	188.47	188.47	0.05	0.05
	Other Crops (Barley)	333.68	3.08	1027.7344	Straw	12584.93	12584.93	12584.93	3.45	3.45
	Bajra	532.65	2.23	1187.8095	Stalks	2209.53	2209.53	2209.53	0.61	0.61
					Husk	331.43	331.43	331.43	0.09	0.09
					Cobs	364.57	364.57	364.57	0.10	0.10

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	**Yield** (T/ha)	**Total Production** (T)						
Ram Nagar	Wheat	11774.17	4.05	47685.3885	Straw	71528.08	14305.62	14305.62	2.83	3.92
					Husk	14305.62	2861.12	2861.12	0.57	0.78
	Paddy	18895.91	2.71	51207.9161	Straw	76811.87	13058.02	4298.02	**0.96**	**8.82**
					Husk	10241.58	1741.07	1741.07	0.39	
	Sugarcane	1166.5	78.43	91488.595	Bagasse (Small)		0.00		**0.00**	**0.00**
					Press Mud (Large)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		**0.00**	**0.00**
					Leaves	4574.43	4574.43	4574.43	**0.88**	**0.88**
	Agri Plantation (Maize)	2565.78	1.42	3643.4076	Stalks	7286.82	72.87	72.87	0.02	0.02
					Cobs	1093.02	10.93	10.93	0.00	0.00
					Leaves	437.21	4.37	4.37	0.00	0.00
	Mustard	4316.49	0.87	3755.3463	Leaves	6759.62	6759.62	6759.62	1.85	1.85
	Potato	2624.54	35.14	92226.3356	Stalks	9222.63	9222.63	9222.63	2.53	2.53
	Vegetables	133.97	15.55	2083.2335	Stalks	208.32	208.32	208.32	0.06	0.06

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ha)	Total Production (T)						
Ramsanehi Ghat	Other Crops (Barley)	333.68	3.08	1027.7344	Straw	1336.05	1336.05	1336.05	0.37	0.37
	Bajra	532.65	2.23	1187.8095	Stalks	2375.62	2375.62	2375.62	0.65	0.65
					Husk	356.34	356.34	356.34	0.10	0.10
					Cobs	391.98	391.98	391.98	0.11	0.11
	Wheat	17482.88	4.05	70805.664	Straw	69498.30	13899.66	13899.66	4.16	5.82
					Husk	13899.66	2779.93	2779.93	0.83	1.16
	Paddy	22223.55	2.71	60225.82	Straw	84547.24	14373.03	14373.03	**3.42**	**13.20**
					Husk	11272.97	1916.40	1916.40	0.46	
	Sugarcane	2606.47	78.43	204524.44	Bagasse (Small)		0.00		**0.00**	**0.00**
					Press Mud (Large)		0.00		**0.00**	**0.00**
					Press Mud (Medium)		0.00		**0.00**	**0.00**
					Leaves	9354.58	9354.58	9354.58	**1.96**	**1.96**

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	**Yield** (T/ha)	**Total Production** (T)						
	Agri Plantation (Maize)	5514.35	1.42	7830.38	Stalks	7912.95	79.13	79.13	0.04	0.04
					Cobs	1186.94	11.87	11.87	0.01	0.01
					Leaves	474.78	4.75	4.75	0.01	0.01
	Mustard	4445.43	0.87	3867.5241	Leaves	4427.11	4427.11	4427.11	1.91	1.91
	Potato	320.9	35.14	11276.426	Stalks	2693.52	2693.52	2693.52	0.31	0.31
	Vegetables	369.96	15.55	5752.878	Stalks	192.37	192.37	192.37	0.16	0.16
	Other Crops (Barley)	525.41	3.08	1618.2628	Straw	1522.28	1522.28	1522.28	0.58	0.58
	Bajra	1643.02	2.23	3663.9346	Stalks	415.54	415.54	415.54	2.01	2.01
					Husk	62.33	62.33	62.33	0.30	0.30
					Cobs	68.56	68.56	68.56	0.33	0.33
Sirauli Ghauspur	Wheat	11440.05	4.05	46332.20	Straw	69498.30	13899.66	13899.66	2.75	3.81
					Husk	13899.66	2779.93	2779.93	0.55	0.76
	Paddy	20798.83	2.71	56364.83	Straw	84547.24	14373.03	14373.03	**3.20**	**12.35**
					Husk	11272.97	1916.40	1916.40	0.43	

Tehsil	Name	Production			Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (NIBE)	CBG Potential (SATAT)
		Area (ha)	**Yield** (T/ha)	**Total Production** (T)						
	Sugarcane	2385.46	78.43	187091.63	Bagasse (Small)		0.00		**0.00**	**0.00**
					Press Mud (Large)		0.00		**0.00**	**0.00**
					Press Mud (Medium)		0.00		**0.00**	**0.00**
					Leaves	9354.58	9354.58	9354.58	**1.79**	**1.79**
	Agri Plantation (Maize)	2786.25	1.42	3956.48	Stalks	7912.95	79.13	79.13	0.02	0.02
					Cobs	1186.94	11.87	11.87	0.00	0.00
					Leaves	474.78	4.75	4.75	0.00	0.00
	Mustard	2827.02	0.87	2459.51	Leaves	4427.11	4427.11	4427.11	1.21	1.21
	Potato	766.51	35.14	26935.16	Stalks	2693.52	2693.52	2693.52	0.74	0.74
	Vegetables	123.71	15.55	1923.69	Stalks	192.37	192.37	192.37	0.05	0.05
	Other Crops (Barley)	380.19	3.08	1170.99	Straw	1522.28	1522.28	1522.28	0.42	0.42
	Bajra	93.17	2.23	207.77	Stalks	415.54	415.54	415.54	0.11	0.11
					Husk	62.33	62.33	62.33	0.02	0.02
					Cobs	68.56	68.56	68.56	0.02	0.02

8.2 Animal Waste

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

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

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Poten-tial (MW)	CBG Poten-tial	CBG Poten-tial (SATAT)
Fatehpur	Cattle	40537.00	221940075.00	55485018.75	38839513.13	38839.51	633767639.37	0.33	**1.59**	**2.128**
	Goat/ Sheep	56031.00	32722104.00	9489410.16	1897882.03	1897.88	23822215.27	0.03	0.10	0.149
	Swine	1026.00	1011123.00	293225.67	175935.40	175.94	3149243.70	0.00	0.01	0.014
	Poultry (Chicken)	456901.00	7504598.93	2176333.69	1305800.21	1305.80	20892803.41	0.02	0.09	0.143
Haidergarh	Cattle	86695	474655125	118663781.3	83064646.88	83064.65	1355415681.85	0.72	**3.41**	**4.55**
	Goat/ Sheep	39768	23224512	6735108.48	1347021.70	1347.02	16907816.33	0.02	0.07	0.11
	Swine	1931	1903000.5	551870.145	331122.09	331.12	5927085.36	0.00	0.02	0.03
	Poultry (Chicken)	244980	4023796.5	1166900.985	700140.59	700.14	11202249.46	0.01	0.05	0.08

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Poten-tial (MW)	CBG Poten-tial	CBG Poten-tial (SATAT)
Nawabganj	Cattle	81274	444975150	111243787.50	77870651.25	77870.65	1270662138.84	0.67	**3.20**	**4.27**
	Goat/ Sheep	56031	32722104	9489410.16	1897882.03	1897.88	23822215.27	0.03	0.10	0.15
	Swine	1026	1011123	293225.67	175935.40	175.94	3149243.70	0.00	0.01	0.01
	Poultry (Chicken)	456901	7504598.925	2176333.69	1305800.21	1305.80	20892803.41	0.02	0.09	0.14
Ram Nagar	Cattle	36881.00	201923475.00	50480868.75	35336608.13	35336.61	576608636.74	0.30	1.45	**1.94**
	Goat/ Sheep	70767.00	41327928.00	11985099.12	2397019.82	2397.02	30087392.83	0.03	0.13	0.19
	Swine	19926.00	19637073.00	5694751.17	3416850.70	3416.85	61161627.57	0.04	0.17	0.27
	Poultry (Chicken)	53.00	870.53	252.45	151.47	0.15	2423.54	0.00	0.00	0.00

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Poten-tial (MW)	CBG Poten-tial	CBG Poten-tial (SATAT)
Ramsanehi Ghat	Cattle	51543.00	282197925.00	70549481.25	49384636.88	108458.04	805838750.67	0.93	**4.45**	**2.71**
	Goat/ Sheep	39707.00	23188888.00	6724777.52	1344955.50	1344.96	16881881.49	0.02	0.07	0.11
	Swine	1208.00	1190484.00	345240.36	207144.22	207.14	3707881.47	0.00	0.01	0.02
	Poultry (Chicken)	25410.00	417359.25	121034.18	72620.51	72.62	1161928.15	0.00	0.01	0.01
Sirauli Ghauspur	Cattle	18828.00	103083300.00	25770825.00	18039577.50	18039.58	294362609.81	0.16	**0.74**	**0.99**
	Goat/ Sheep	15589.00	9103976.00	2640153.04	528030.61	528.03	6627840.19	0.01	0.03	0.00
	Swine	404.00	398142.00	115461.18	69276.71	69.28	1240053.07	0.00	0.00	0.01
	Poultry (Chicken)	2037.00	33457.73	9702.74	5821.64	5.82	93146.31	0.00	0.00	0.00

8.3 Energy Crops

Poplar Trees, Willow, Jatropha

These crops were not identified in our GIS Crop Maps. As per the State Agriculture Department, there are no such crops grown and cultivated for energy purposes in Barabanki 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.[83]

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

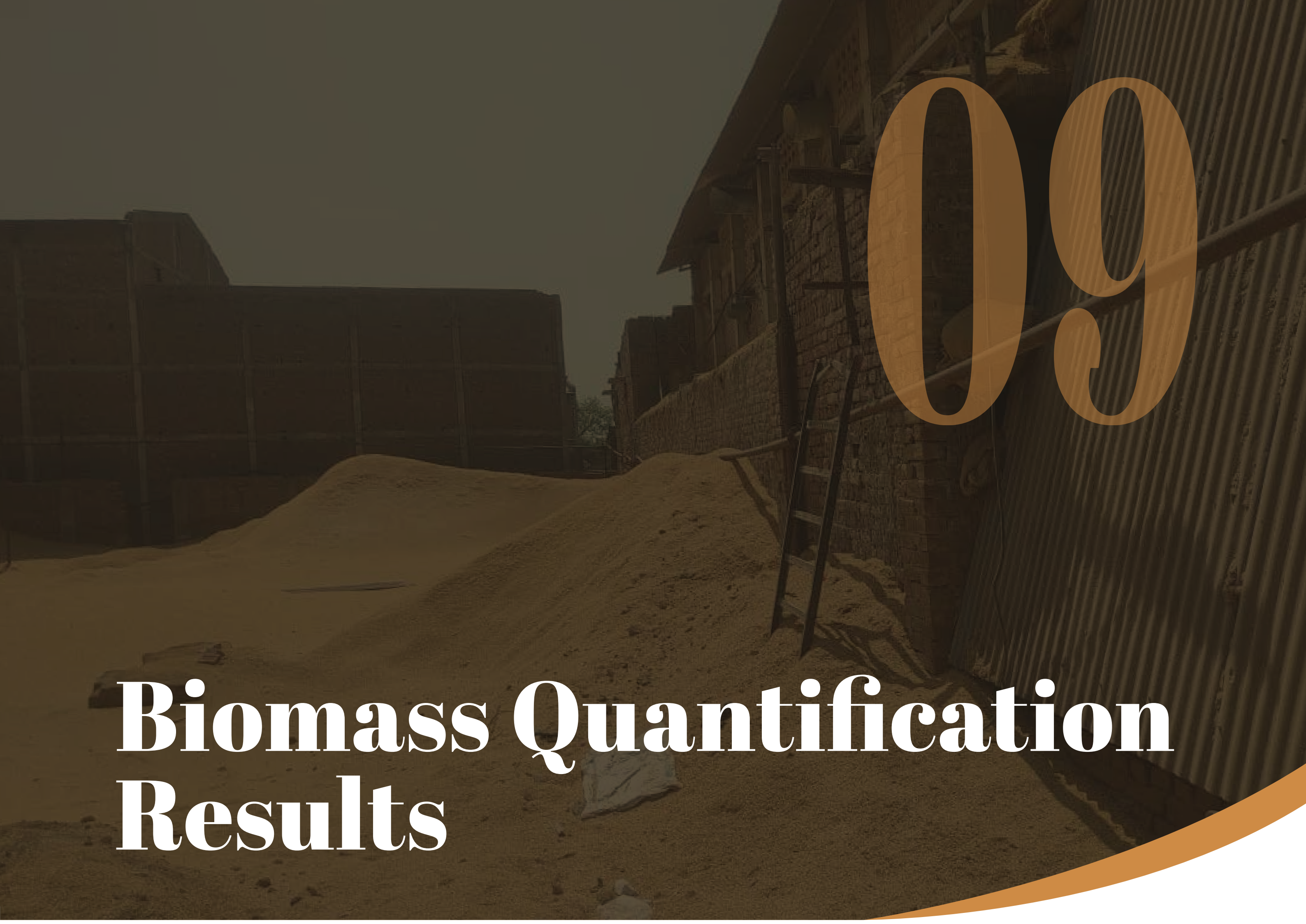
8.4.2 Groundnut Shell

Groundnut is sown and harvested during the Kharif season and yields groundnut shells as residue. During 2022-24[48], as per the Crop Production Statistics, groundnut was not cultivated in 24 ha of land with a total crop production of 28 T and a crop yield of 1.17 T/ha.

8.4.3 Sugarcane Bagasse

There are no small sugar mills in the district and hence, there is no bagasse available in the district.

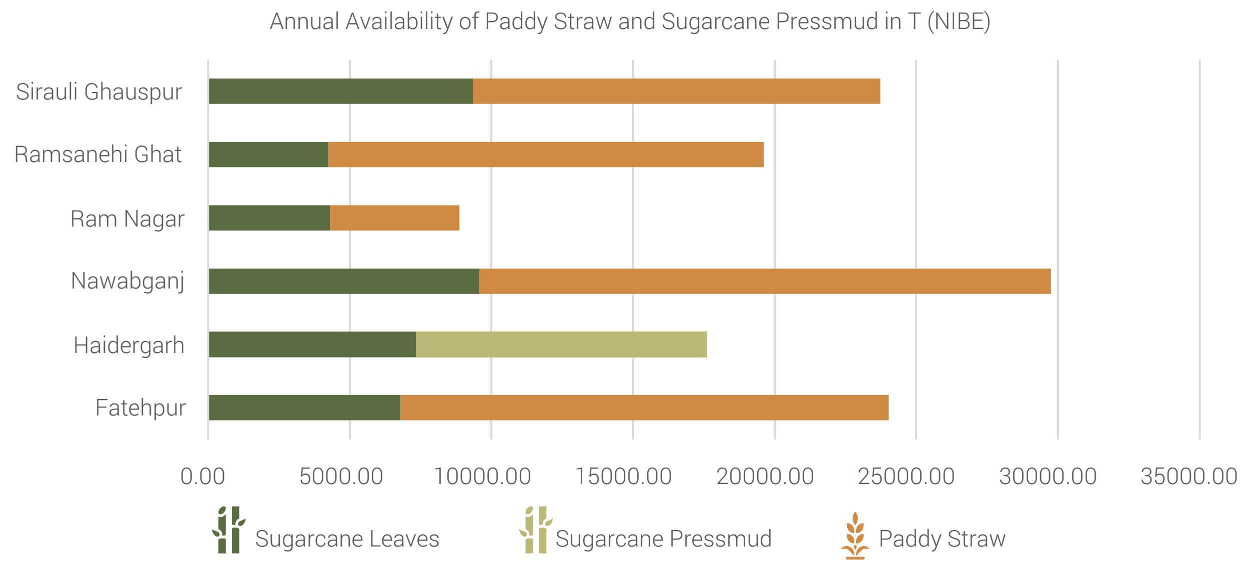
83 Pandey K.C. and Roy A.K., 2011. p.23, Forage Crops Varieties, Indian Grassland and Fodder Research Institute (IGFRI)

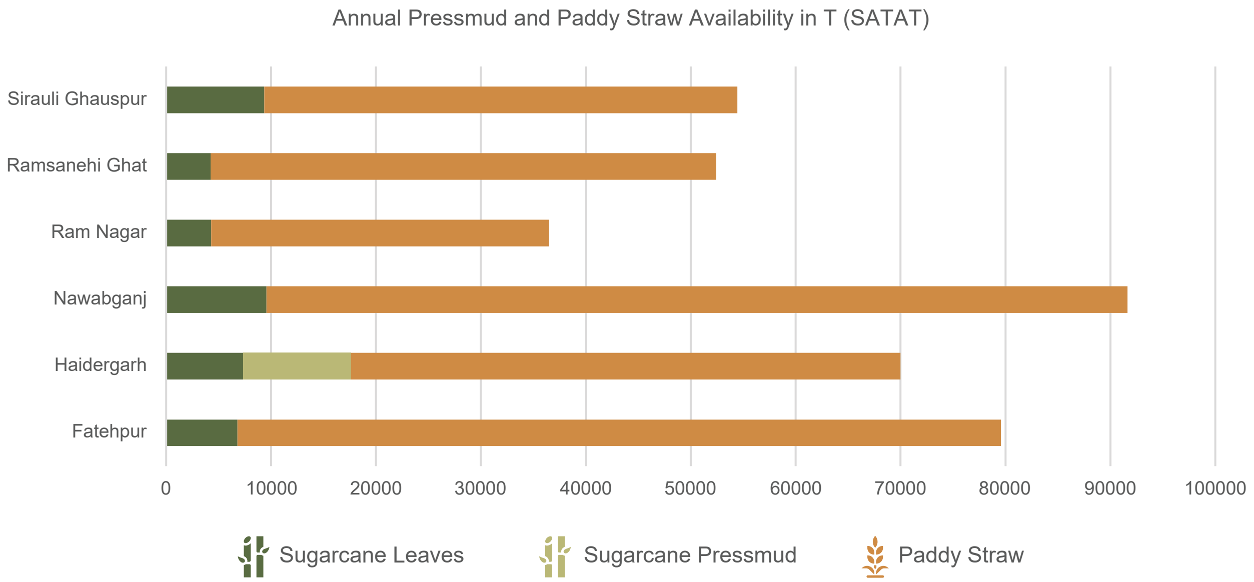


09 Biomass Quantification Results

9.1 Total Biomass Availability by Category

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





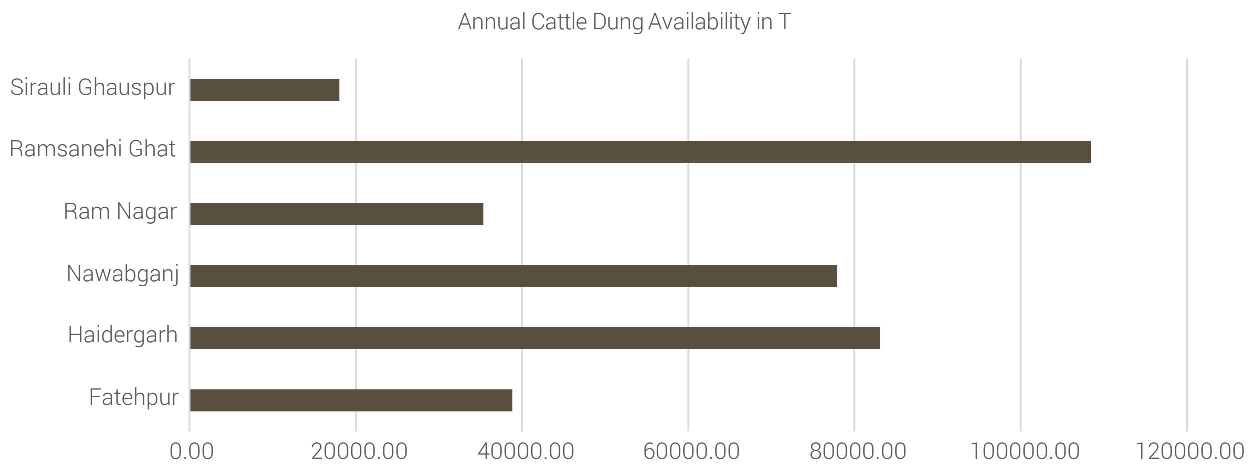


Figure 25: Tehsil-wise annual availability of paddy straw, sugarcane leaves, press mud, and cattle dung

9.2 Variations in Biomass Availability and Pricing

The availability and generation of sugarcane pressmud has been varying over the years. From the Figure 28 & Figure 29, the variation in availability of pressmud in the sugar mill can be attributed to the varying quantities of sugarcane crushed annually. Figure 30 depicts the year-on-year change in pressmud that is generated. The reasons that can be attributed to varying production could be due to adverse weather conditions (drought and excessive rainfall), crop diseases, etc. This condition is prevalent across the state. This can affect the pricing of the press mud. Based on the data that was shared by the Cane Commissioner, the average cost of press mud for all sugar mills hovered between INR 15 to 60 per quintal during 2022-25.

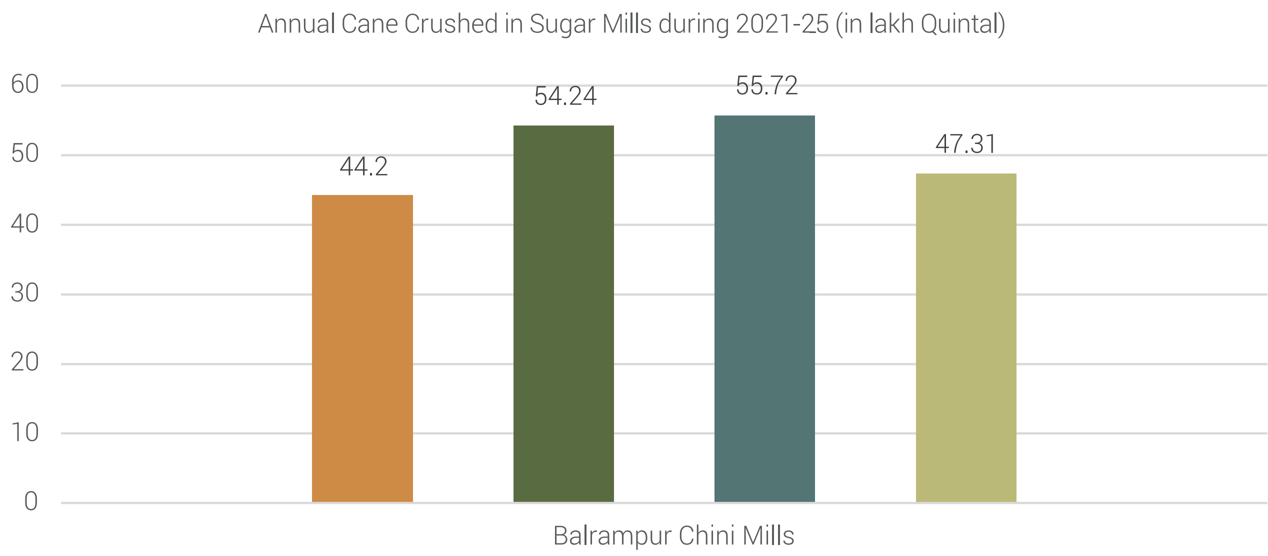


Figure 26: Annual cane crushed in sugar mill during 2021-25[84]

Figure 27: Annual press mud generated in sugar mill during 2021-25

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

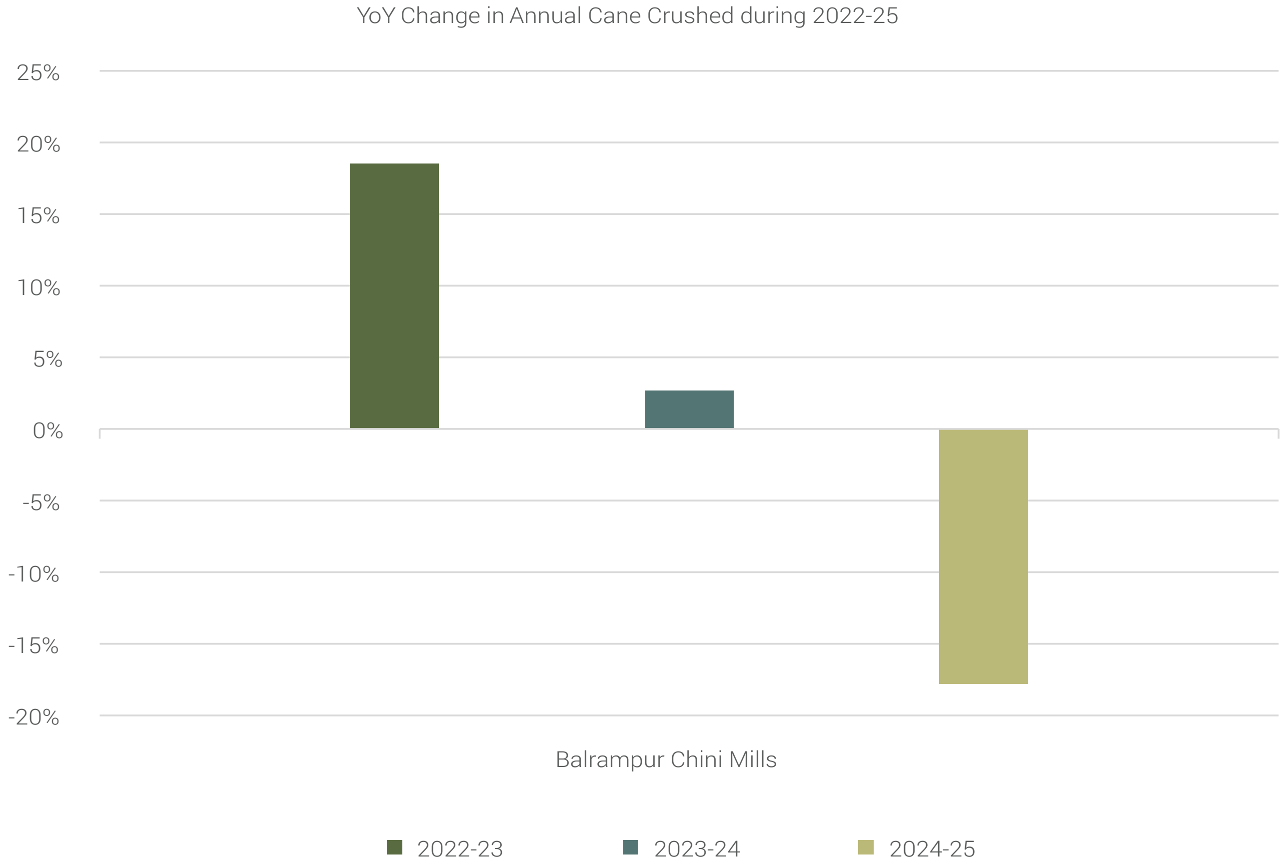


Figure 28: YoY change in annual cane crushed and press mud generated during 2022-25

It can be observed from Figure 37 that pressmud price vary significantly throughout the 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 pressmud is usually lowest in the year. As we move into the non-sugar or off-peak season, the price for pressmud spikes. For instance, the prices of sugarcane pressmud increased to 48 percent during 2023-24 between peak and off-peak periods and the reasons for the spike include: high demand for supply of press mud, shortage in availability of coal, high temperature, etc. As temperature rises, quality of pressmud improves due to low moisture content. In interactions with sugar mill operators, the following reasons were identified for fluctuations in pressmud prices during the year 2020-25:

- Price varies from plant to plant based on the operating efficiency, cane crushing capacity, quality of Pressmud 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, pressmud is captively used for cogeneration which reduces the surplus pressmud.
- Prices also vary between sugar and non-sugar season in a particular year. Usually, it remains lower in winter and increases as the temperature rises.

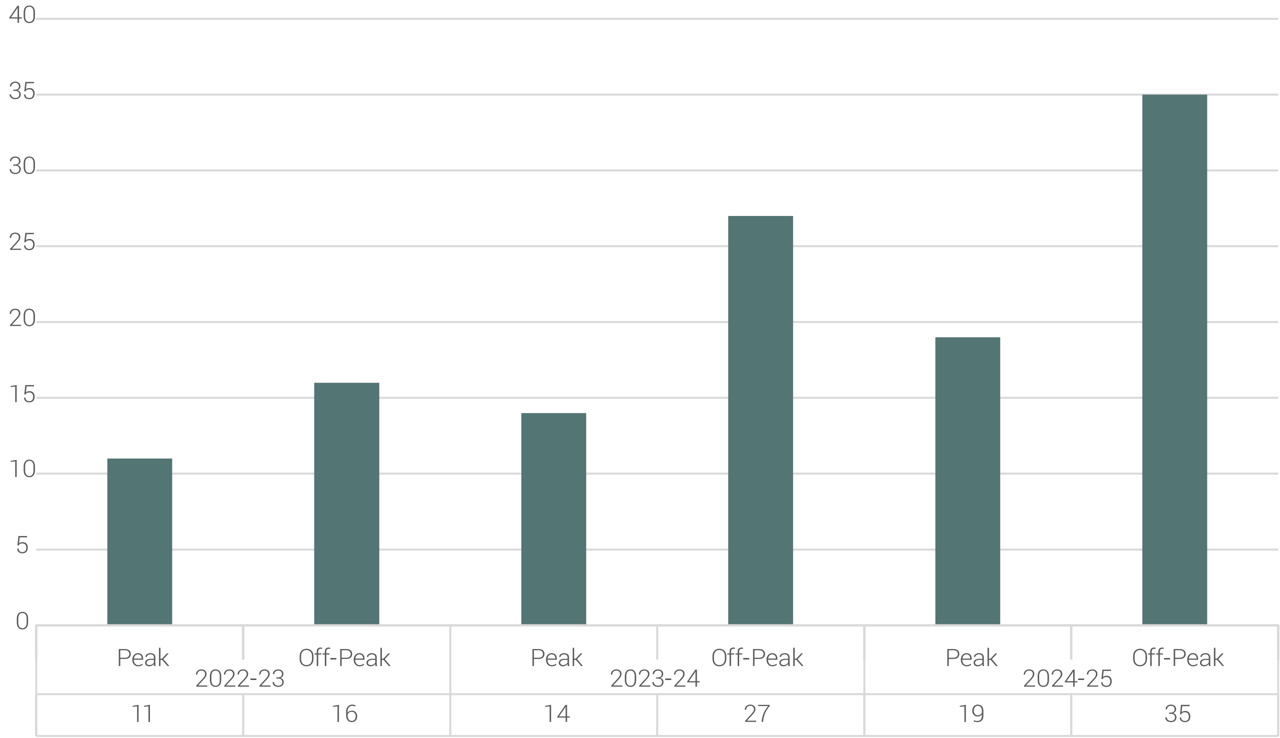


Figure 29: Pressmud price variations during peak and off-peak season in large sugar mill

9.3 High-Potential Zones for Biomass Supply and CBG Production

It can be observed that Nawabganj has the highest paddy straw availability, followed by tehsils of Ramsanehi Ghat and Sirauli Ghauspur. Considering the current consumption by existing CBG plants, there is no net paddy straw availability in Haidergarh tehsil. Tehsils of Nawabganj, Haidergarh and Sirauli Ghauspur lead in the production of sugarcane leaves while Haidergarh has net sugarcane press mud that is available. Tehsils of Sirauli Ghauspur, Ramsanehi Ghat and Nawabganj have rich cattle dung availability which can be used as a combination feedstock with agricultural residue for CBG production. We can also see the variation in the availability of paddy straw in particular based on the different residue to crop ratios that were used.

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

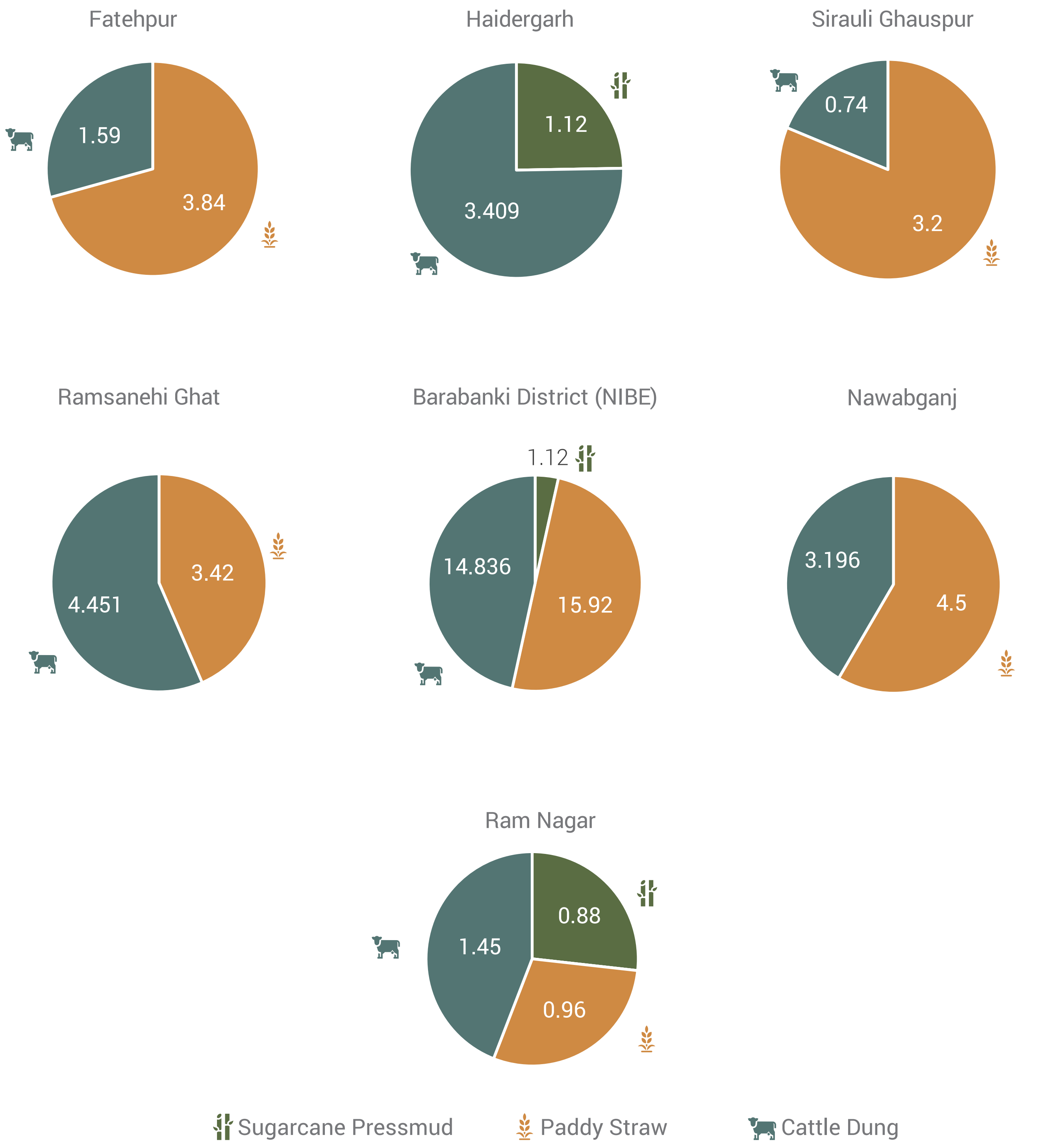


Figure 30: Tehsil-wise daily CBG generation potential for major feedstocks: Sugarcane leaves, paddy straw, cattle dung, and sugarcane pressmud (as per NIBE estimates)

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

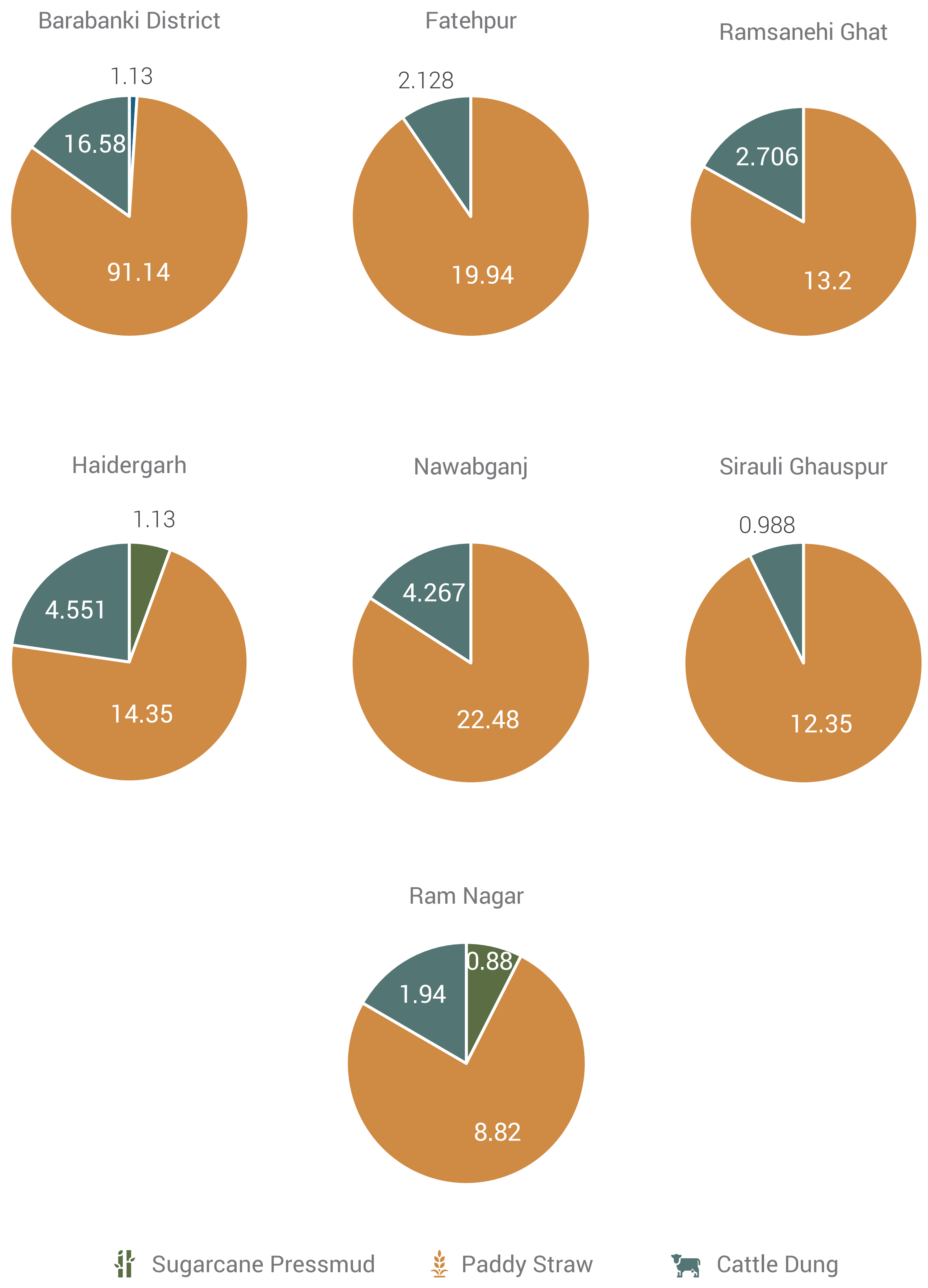


Figure 31: Tehsil-wise Daily CBG generation potential for major feedstocks: Sugarcane leaves, paddy straw, cattle dung, and sugarcane pressmud (as per SATAT estimates)

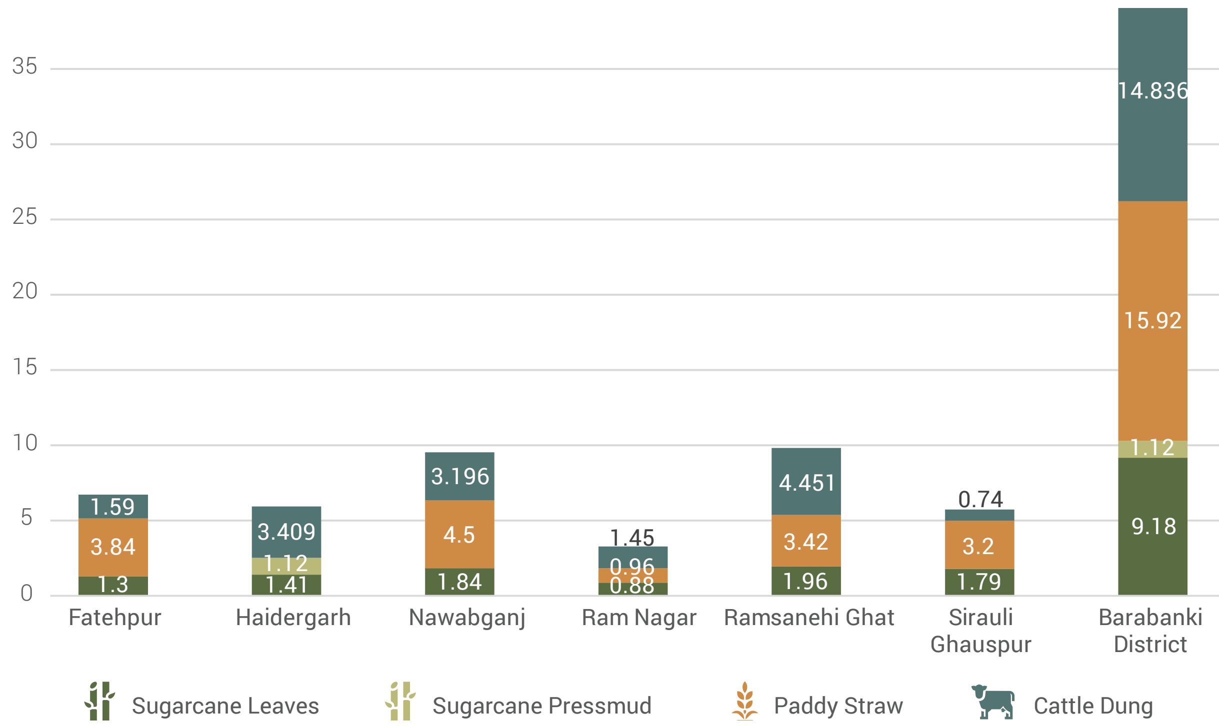


Figure 32: CBG potential from major feedstocks (NIBE Estimates)

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

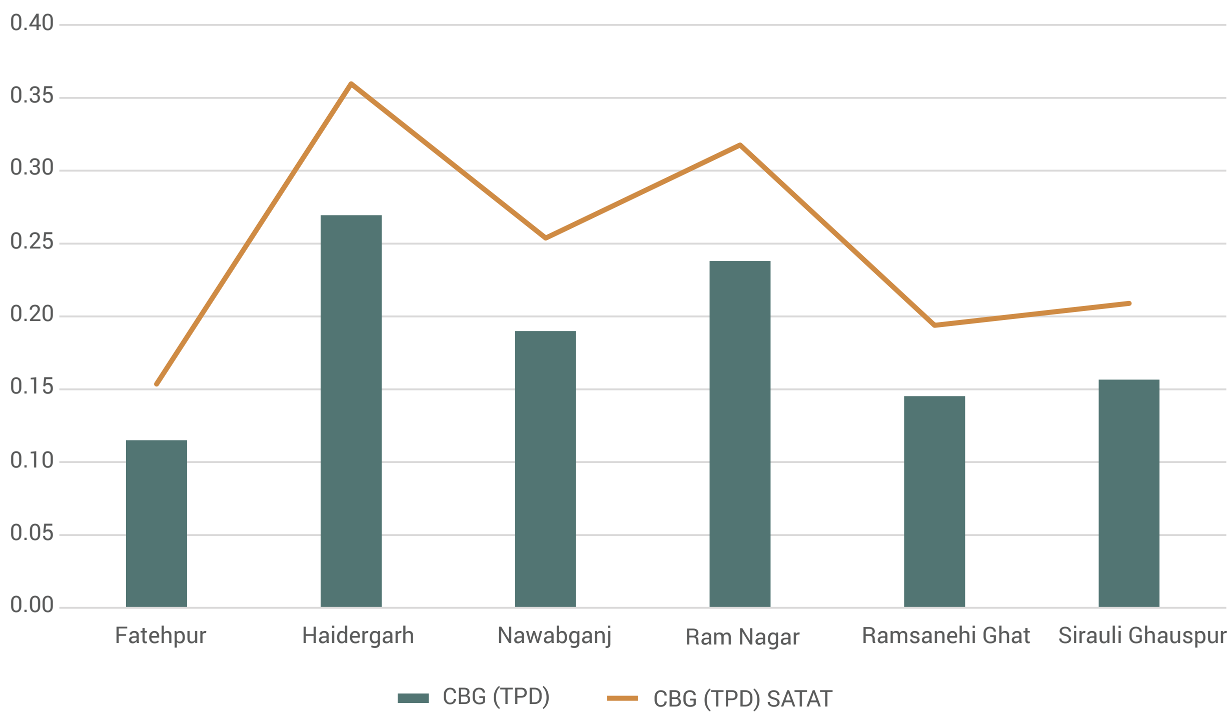


Figure 33: Tehsil-wise CBG potential from cattle sheds

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

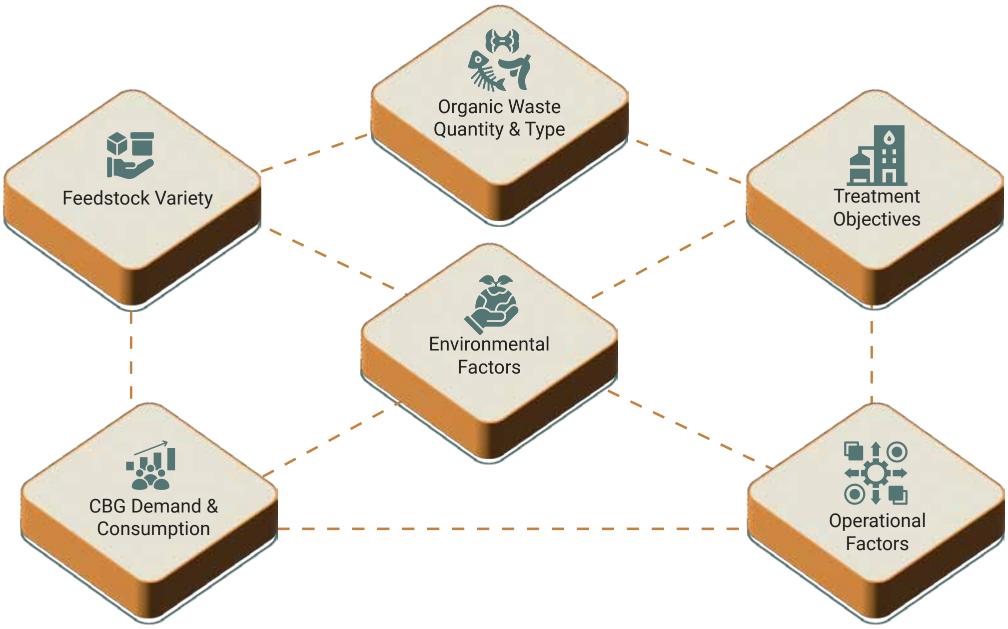


Figure 34: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

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

Table 28: Potential Daily Generation of CBG as per NIBE and SATAT Estimates

NIBE					
Tehsil	**Sugarcane Leaves**	**Sugarcane Pressmud**	**Paddy Straw**	**Cattle Dung**	**Total**
Fatehpur	1.3	0	3.84	1.59	6.73
Haidergarh	1.41	1.12	0	3.409	5.939
Nawabganj	1.84	0	4.5	3.196	9.536
Ram Nagar	0.88	0	0.96	1.45	3.29
Ramsanehi Ghat	1.96	0	3.42	4.451	9.831
Sirauli Ghauspur	1.79	0	3.2	0.74	5.73
Barabanki District	9.18	1.12	15.92	14.836	**41.056**

SATAT					
Tehsil	**Sugarcane Leaves**	**Sugarcane Pressmud**	**Paddy Straw**	**Cattle Dung**	**Total**
Fatehpur	1.3	0	19.94	2.128	23.368
Haidergarh	1.41	1.13	14.35	4.551	21.441
Nawabganj	1.84	0	22.48	4.267	28.587
Ram Nagar	0.88	0	8.82	1.94	11.64
Ramsanehi Ghat	1.96	0	13.2	2.706	17.866
Sirauli Ghauspur	1.79	0	12.35	0.988	15.128
Barabanki District	9.18	1.13	91.14	16.58	**108.85**

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, Barabanki district has a CBG potential of approximately 41 TPD based on the net biomass available during the year 2023-24 and consumption of biomass by existing CBG plants as of May 2025. Among all the tehsils, Ramsanehi Ghat has the highest potential for CBG production with paddy straw and cattle dung contributing a little over 90 percent of the total feedstock. Nawabganj and Haidergarh tehsils follow Ramsanehi Ghat with paddy straw as their major feedstock alongside sugarcane leaves. 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 and investors to consider these multiple factors to maximise CBG yield.

10 Recommendations

1. Tehsils of Ramsanehi Ghat and Nawabganj have a high theoretical potential for CBG, with paddy straw, sugar cane leaves and cattle dung as its major feedstocks. It is important to ensure that CBG plants are designed to handle combination feedstocks, including Napier grass and cattle dung, to support year-round plant operations and maximises biogas yield. Among the feedstocks considered in the study, for a given quantity of biomass residue, pressmud has the highest CBG yield.
2. Availability of appropriate biomass and reliable supply chain are indispensable for sustainability and financial feasibility of a CBG plant. Harvestable crop residues per unit of land also depend on region-specific crop production practices. Farmer's willingness to collect crop residues depend critically on the yields and the prices offered in the market.[85]
3. A beneficial, reliable, and transparent pricing and payment mechanism can incentivise collection and availability of biomass. This would help establish a biofuel-led economy offering unique opportunities for farmers, enhance their regular incomes by turning waste into wealth. This additional stream of income can be particularly beneficial during times of market volatility or poor harvests of traditional crops and continue to drive economic growth at grassroot level.
4. Encourage farmers to use bio-slurry from CBG plants as an organic fertiliser to improve soil health and crop productivity. Implement comprehensive training programs to educate farmers on its benefits and proper application methods. Additionally, provide hands-on demonstrations and success stories to encourage adoption. Establish support networks and incentives to facilitate widespread usage and long-term sustainability.

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

5. CBG/Bio-fuel plant must be custom-designed based on the crop residues for which long-term availability is guaranteed based on forecasting and observing past trends. [86]Sugarcane and paddy, dominant Kharif crops over the years, are expected to remain key contributors. According to Agriculture Production Statistics, 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 shows 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 careful consideration of local biodiversity concerns.

Figure 35: Cane moved from the field to sugar mills for crushing

9. Dedicated biomass banks can be established either through a third-party agency or by leveraging existing institutions such as FPOs that can ensure collection and storage of residues after harvest. Considering the seasonal nature 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 disasters. Such disruptions can sever supply chains and leave the plant operations stranded. To

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

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 cannot be stored for more than 60 days and should be maintained in live storage, whereas paddy straw, which has a longer shelf life, can be 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.

Figure 36: **Storage of paddy straw in silages**

NOTES

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