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ASSESSING
BIOMASS AVAILABILITY AND COMPRESSED BIOGAS (CBG) POTENTIAL IN SHAMLI DISTRICT
UTTAR PRADESH

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Contents

List of Tables iv

List of Figures v

1. Executive Summary 1

2. Introduction 4

2.1 Scope of the Study 08

2.2 Importance of Biomass Quantification 09

2.3 Overview of Compressed Biogas (CBG) Industry 10

3. District Profile 15

3.1 Geographic Overview 15

3.2 Administrative Units (Tehsils/Blocks) 16

3.3 Climatic Conditions 17

3.4 Demographics (Urban/Rural) 20

3.5 Agricultural Overview 20

3.5.1 Total Agricultural Area 21

3.5.2 Major Crops and Cropping Patterns (Kharif, Rabi and Zaid) 21

3.5.3 Land Use Categories (Irrigated, Rainfed, etc.) 23

3.6 Forest Resources 23

3.6.1 Total Forest Area 23

3.6.2 Types of Forests and Residue Generated 23

3.7 Livestock Population 24

3.7.1 Cattle, Poultry, and Other Livestock Statistics 24

3.7.2 Manure and Waste Generation Potential 24

3.8 Industry and Processing Units 25

3.8.1 Existing Biomass-based Industries 25

4. Data Collection 27
4.1 Primary Data Collection 27
4.2 Secondary Data Collection 29
5. Stakeholder Mapping 33
5.1 Identification of Relevant Stakeholders 34
6. GIS-based Satellite Mapping 33
6.1 Cropping Pattern and Analysis 36
6.2 Land Use and Biomass Distribution Mapping 37
7. Methodology 38
7.1 Agricultural Residue 38
7.2 Livestock Residue 41
8. Biomass Category, Sources and Availability 43
8.1 Agricultural Residues 43
8.2 Animal Waste 47
8.3 Energy Crops 48
8.4 Other Types of Biomasses 48
9. Biomass Quantification Results 49
9.1 Total Biomass Availability by Category 51
9.2. Variations in Biomass Availability and Pricing 51
9.3 High-Potential Zones for Biomass Supply and CBG Production 53
10. Recommendations 59

List of Tables

Table 1: Tehsil-wise, feedstock-wise CBG Potential in TPD as per NIBE factors ... 2

Table 2: Potential availability of biomass in Uttar Pradesh ... 7

Table 3: Different feedstock and their biomass residues ... 9

Table 4: Chemical composition of raw biogas vs. CBG ... 11

Table 5: Composition of CBG as per IS 16087:2016 ... 11

Table 7: District agricultural and climate profile of Shamli ... 17

Table 8: Productivity of food grains in different agro-climatic zones of Uttar Pradesh ... 19

Table 9: Agricultural land area and cropping intensity in Shamli district ... 21

Table 10: Tehsil-wise cropped area of Rabi crops (in ha.) during 2023-24 ... 22

Table 11: Tehsil-wise production of Kharif crops (in ha.) during 2023-24 ... 22

Table 12: Sowing pattern for major Kharif and Rabi crops which are both irrigated and rainfed .. 23

Table 13: Total forest area (by classification) in Shamli ... 23

Table 14: Tehsil-wise livestock statistics and cattle in cowsheds ... 24

Table 15: Animal categories and their dung/litter generation potential ... 25

Table 16: Details of existing biomass-based industries in Shamli (both, completed and under-construction) ... 26

Table 17: Operating parameters and conversion factors for sugar mills ... 28

Table 18: Tehsil-wise sugar mills and their annual crushing capacity ... 29

Table 19: Residue-to-crop ratio and surplus fraction for various agricultural residue ... 30

Table 20: Biogas yield for various feedstocks as per NIBE estimates ... 31

Table 21: Conversion factor for surplus biomass residue calculation of animals ... 31

Table 22: Calorific values, for animal residue ... 31

Table 23: Tentative CBG yield from various feedstocks ... 32

Table 24: Stakeholders in bio-energy value chain ... 34

Table 25: Tehsil-wise land-use analysis for Shamli in ha. 37

Table 26: Tehsil-wise surplus biomass and potential CBG generation for various agricultural residue 44

Table 27: Tehsil-wise surplus biomass residue and potential CBG generation from various animal residues 47

Table 29: Potential daily generation of CBG as per NIBE and SATAT estimates 57

List of Figures

Figure 1: Source-wise renewable power potential in India, 2023, ... 5

Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23 6

Figure 3: Biomass power potential in India 6

Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential 7

Figure 5: Classification of biofuels 8

Figure 6: Bio-chemical process flow for biogas production 10

Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield 12

Figure 8: Process flow diagram for a compressed biogas plant 13

Figure 9: Location of Shamli district in Uttar Pradesh 16

Figure 10: District-wise climate vulnerability index 18

Figure 11: Agro-climatic zones in Uttar Pradesh 19

Figure 12: Agricultural land holdings in Shamli 20

Figure 13: Gross area sown during both the cropping seasons in Shamli 21

Figure 14: Crop yield during 2020-23 for major crops sown in Shamli during Kharif and Rabi 22

Figure 15: Traditional use of cow-dung as kitchen fuel and manure 25

Figure 16: Mapping the value chain of sugar industries 28
Figure 17: Location of sugar mills in Shamli district 29
Figure 18: Geographical spread of Kharif crops in tehsils of Shamli district during 2023-24 36
Figure 19: Geographical spread of Rabi crops in tehsils of Shamli district during 2023-24 36
Figure 20: Land cover analysis for tehsils of Shamli district during 2023-24 37
Figure 21: Flow diagram of the methodology used 39
Figure 22: Flow diagram for crop residue estimation 40
Figure 23: Crop residue management practices 41
Figure 24: Tehsil-wise annual availability of sugarcane leaves, paddy straw, press mud and cattle dung 50
Figure 25: Annual cane crushed in sugar mills during 2021-25 51
Figure 26: Annual press mud generated in sugar mills 51
Figure 27: YoY change in annual cane crushed and press mud generated during 2021-25 52
Figure 28: Press mud price variations 53
Figure 29: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, sugarcane leaves, cattle dung, and sugarcane press mud (as per NIBE estimates) 54
Figure 30: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, Sugarcane leaves, cattle dung, and sugarcane press mud (as per SATAT estimates) 55
Figure 31: CBG potential from major feedstocks (NIBE estimates) 56
Figure 32: Tehsil-wise CBG potential from cattle sheds 56
Figure 33: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants 57
Figure 34: Cane moved from the field to sugar mills for crushing 60

01

Executive Summary

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

Biomass Availability and CBG Potential in Shamli

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

- **Major Net Biomass Feedstocks:** Sugarcane Press Mud, Sugarcane Tops and Leaves, Paddy Straw and Cow Dung
- **High-Potential Zones:** Shamli and Unn tehsils emerged as top biomass sources. Potential locations for CBG plants could be sited close to the sugar mills or sugar farms in these tehsils
- **CBG Generation Potential:** The district has the potential to generate approximately 95 tonnes per day (TPD) of CBG from major feedstocks, such as sugarcane tops and leaves, press mud 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 as per NIBE factors

Tehsil	Sugarcane Leaves	Sugarcane Pressmud	Paddy Straw	Cattle Dung	Total
Kairana	17.77	0	0.95	6.27	24.99
Shamli	32.86	2.93	0.53	5.653	41.553
Unn	24.86	3.42	0.11	6.407	29.187
Shamli District	18.45	6.35	0.91	18.33	95.73

- **Emission Savings:** Compressed Biogas is a sustainable alternative to traditional natural gas and therefore can replace it as an automotive fuel or in city gas distribution networks. This replacement can result in reduction of natural gas consumption and save carbon emissions. To put it in figures, a total installed capacity of 95 TPD capacity CBG plants can collectively abate 95,356.25 T CO_2 emissions annually1.

In other words, 95 TPD of CBG can replace 95 TPD of CNG which will correspond to daily carbon emission savings of close to 261.25 T of CO_2.

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

1 Assuming combustion of 1 Kg of Methane produces 2.75 Kg of CO2 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 sugarcane leaves, pressmud mustard straw, Napier grass, and cattle dung to ensure year-round CBG production.
   - Diversified feedstocks stabilise biogas output and reduce supply fluctuations.
2. **Biomass Banks and Farmer Incentives**
   - Establish biomass banks managed by Farmer Producer Organisations (FPOs) to streamline biomass collection and distribution.
   - Introduce transparent pricing and payment mechanisms to encourage farmer participation.
3. **Strategic Siting of CBG Plants**
   - Identify barren lands near sugar mills (within 3-5 km radius) for setting up of CBG plants.
   - Locate plants close to cowsheds, poultry farms, and fuel stations to optimise feedstock procurement and CBG distribution.
4. **AgriPV for Fallow Land**
   - Install Agrivoltaics (AgriPV) on fallow land to create a favourable microclimate, enabling land reclamation for cultivation.
   - AgriPV helps conserve soil moisture, reduce evaporation, and provide shade, enhancing agricultural productivity.
5. **AgriPV in Horticulture Areas**
   - Deploy AgriPV systems in horticultural zones to improve crop yield and increase biomass availability.
   - Certain crops like leafy greens benefit from AgriPV, leading to higher biomass production for CBG generation.
6. **Promotion of Bio-Slurry Utilisation**
   - Encourage farmers to use bio-slurry from CBG plants as an organic fertiliser to improve soil health and crop productivity.
   - Develop training programs to educate farmers on the benefits and application techniques of bio-slurry.
7. **Advanced Biomass Storage Solutions**
   - Implement in-house and third-party storage facilities to manage seasonal fluctuations in biomass availability.
   - Utilise separate storage solutions for short-lived residues like press mud and long-lasting residues like paddy straw.

02

Introduction

India is expected to experience the largest increase in energy demand, tripling from current levels by 2050.[2] With rising global energy demand, limited local fossil fuel reserves, and environmental concerns, renewable sources like solar, wind and biomass[3] are gaining focus. Biomass energy not only meets the rising energy demand but also effectively manages organic waste - crop residues, animal waste, and municipal solid waste - reducing environmental problems if left unaddressed. Currently, India's bioenergy accounts for 13 percent of the total final energy consumption, with a projected growth rate of 45 percent between 2023 and 2030.[4] India's abundant biomass availability (*See Figure* 1 which describes the potential of biomass power in India), positions it well to meet this demand.

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

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

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

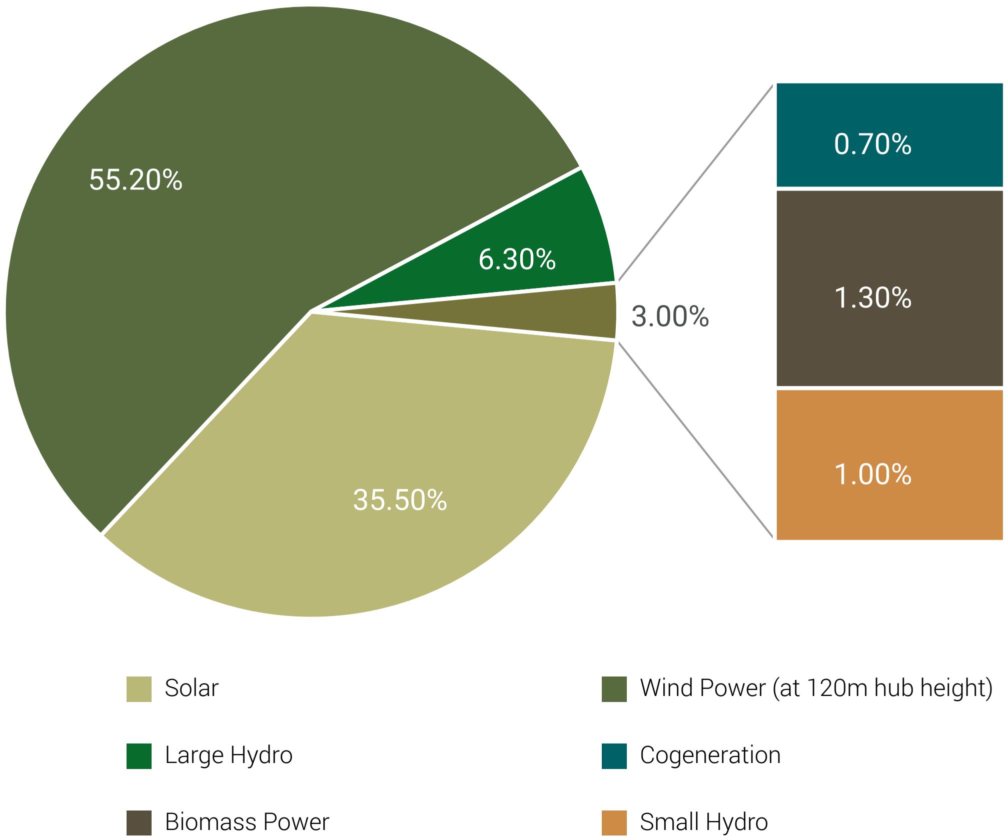


Figure 1: Source-wise renewable power potential in India, 2023[5,6]

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

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

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

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

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

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

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

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

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

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

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

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

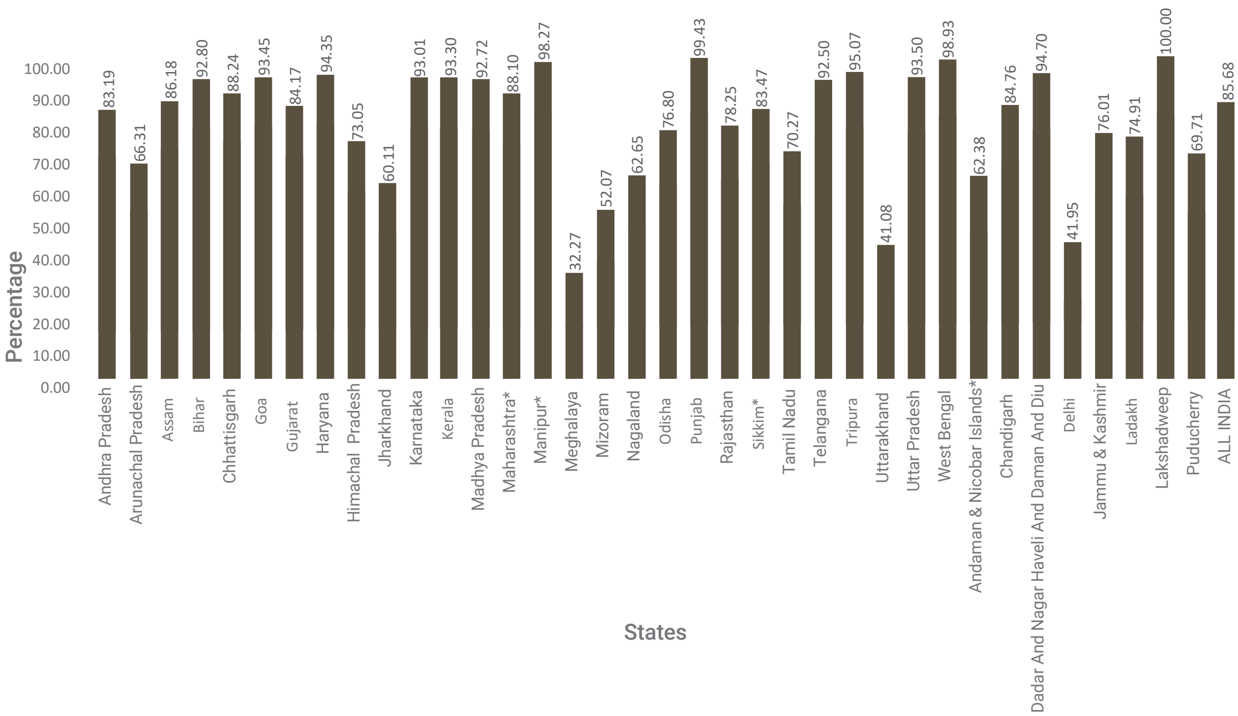


Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23[15]

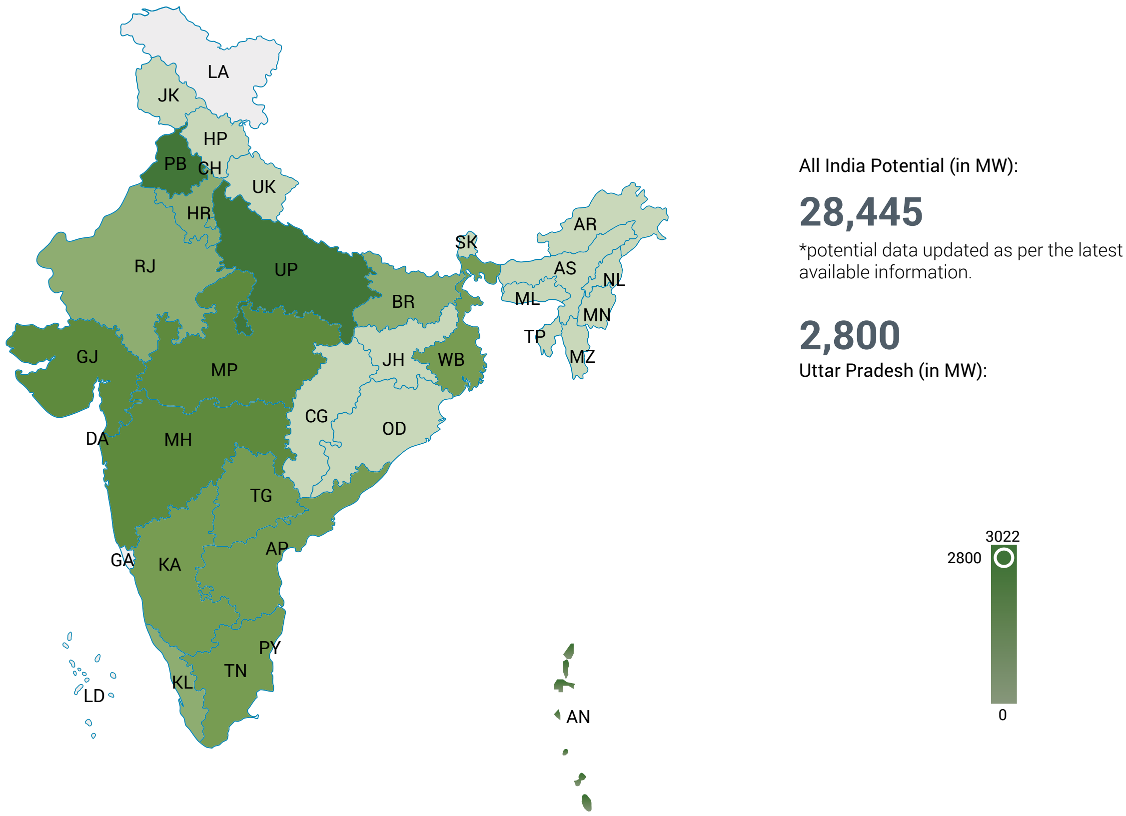


Figure 3: Biomass power potential in India[16]

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

16 India Climate and Energy Dashboard (ICED) 2025

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

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

Table 2: Potential availability of biomass in Uttar Pradesh

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

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

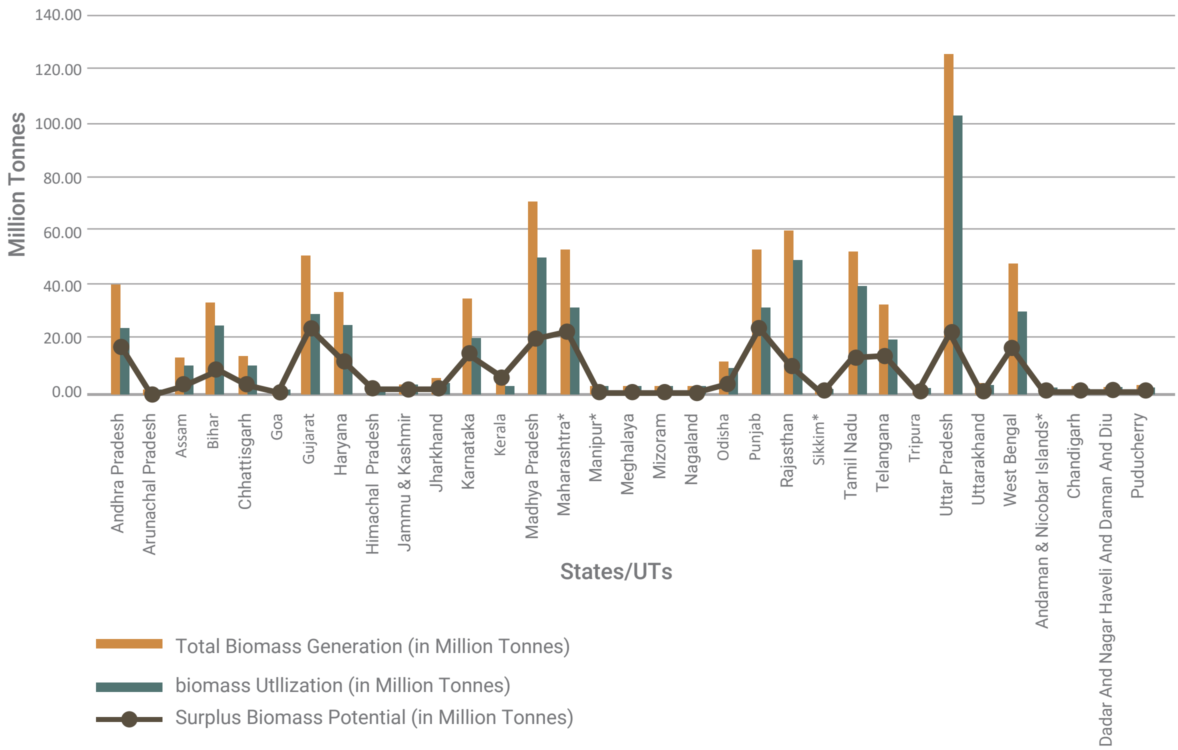


Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential[19]

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

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

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

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

- Agriculture and forestry residues that include – livestock 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]

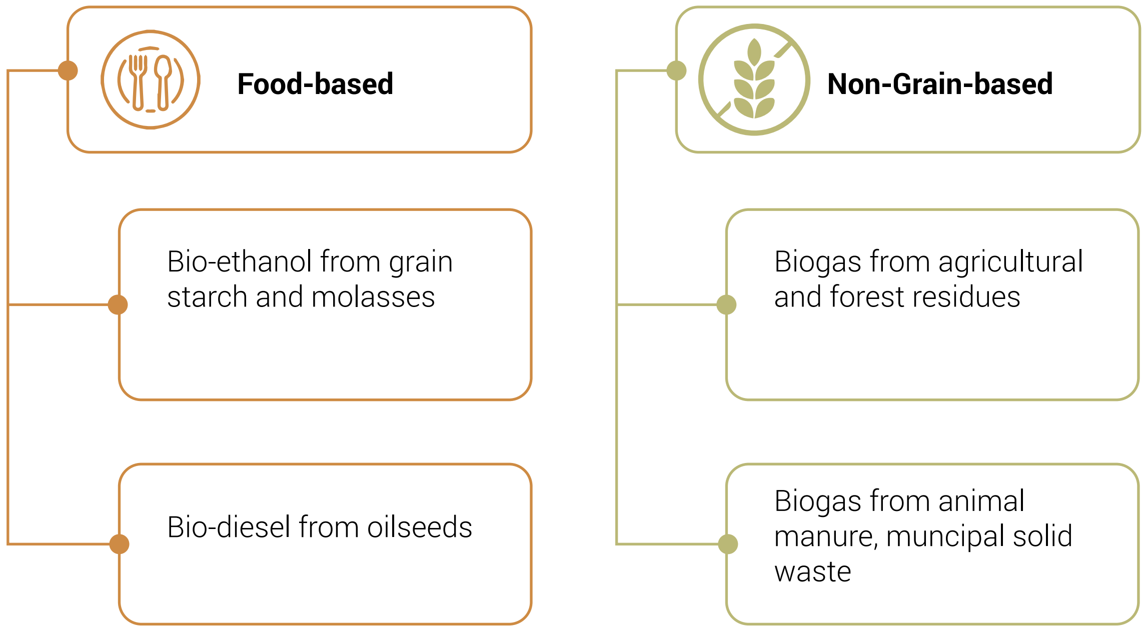


Figure 5: Classification of biofuels

2.1 Scope of the Study

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

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

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

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

Table 3: Different feedstock and their biomass residues

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

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

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

2.2 Importance of Biomass Quantification

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

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

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

2.3 Overview of Compressed Biogas (CBG) Industry

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

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

Figure 6: Bio-chemical process flow for biogas production

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

Additional processing of biogas is carried out by removing Carbon dioxide (CO_2), H_2S, and moisture content, resulting in a fuel of higher calorific value. If the methane content of the upgraded product is above 90 percent, it can be used directly as the transportation fuel to replace Compressed Natural Gas (CNG) or injected into gas grids as 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 7* illustrates significant advantages that can be achieved through appropriate feedstock pretreatment. A single feedstock or a combination of feedstocks is fed into shredders (mechanical pretreatment) that make the substrate smaller or break open their cellular structure, increasing the specific surface area of the biomass (*See Figure 8*).[25] This gives greater possibility for enzymatic attack and increase biogas yields. The substrate is then dewatered to remove excess moisture from biomass material thereby improving their thermal efficiency and storage stability.[26] After the substrate is homogenised and dewatered, it is preheated in a preparation tank before it is actually fed into a digestor.[27]

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

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

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

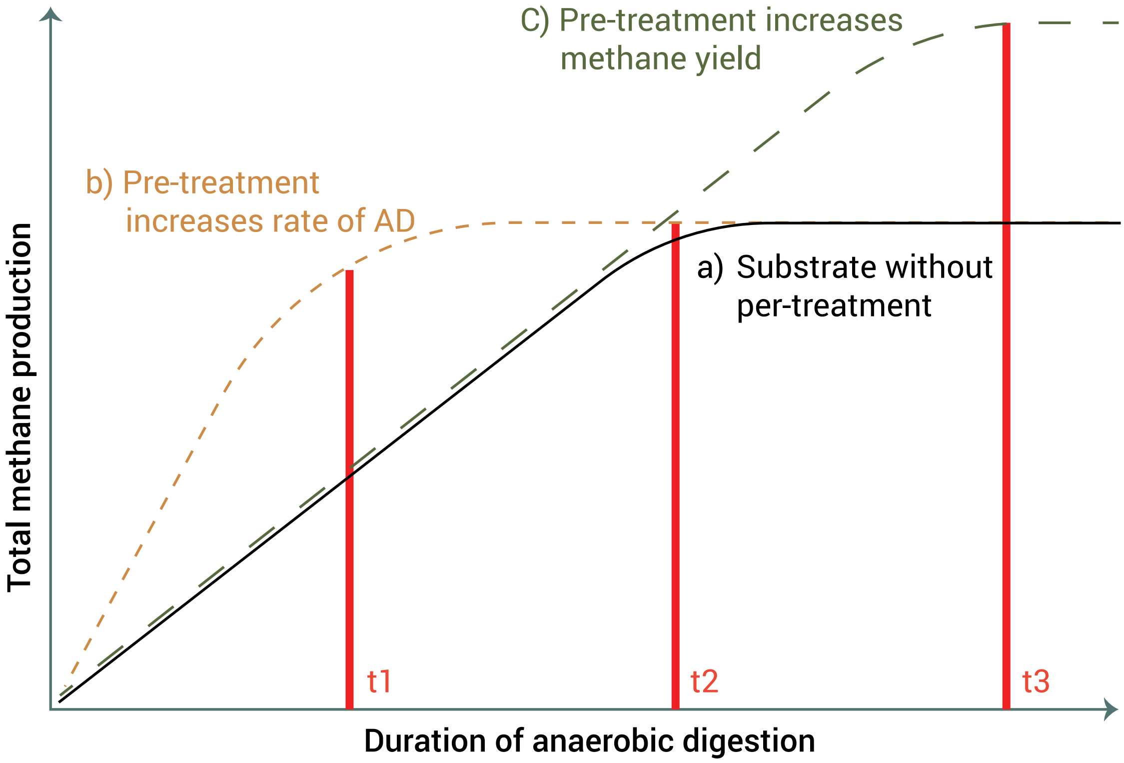


Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[28]

After the raw biogas exits digester, the moisture is removed using a dehumidifier or dryer as water vapour can not only decrease the heat value of the gas but also form condensates and accumulates in the downstream unit thereby forming plugs or hydraulic seals obstructing the transport of biogas.[29] This is followed by removal of hydrogen sulphide which not only contaminates the environment, but also minimizes 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

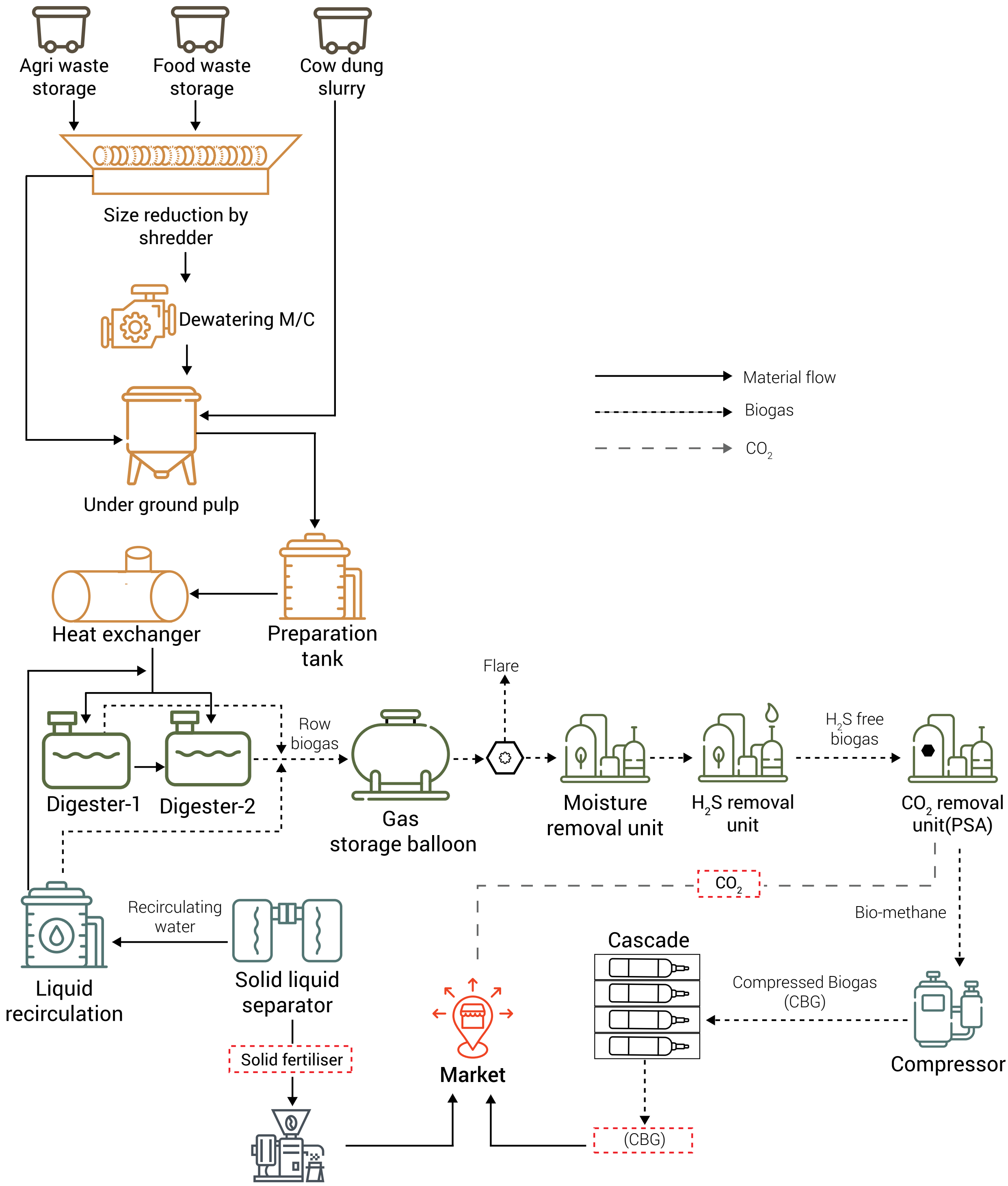


Figure 8: Process flow diagram for a compressed biogas plant[30]

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 under various stages of development. By 2030, CBG production could reach 0.8 bcm/yr. Realising this potential, Government of India through various measures have been promoting the production and use of CBG, which include:

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

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

- GOBARdhan (Galvanising Organic Bio-Agro Resources Dhan) which promotes converting cattle dung, agricultural residue and other organic waste into CBG and organic manure. The initiative has resulted in the installation of 110 community biogas plants and 21 CBG plants in Uttar Pradesh alone.[32]
- Under the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative, Government has introduced the phase-wise mandatory blending of CBG in transport and PNG (Petroleum Natural Gas) in City Gas Distribution network.[33]
- Under the National Bioenergy Programme, government has been promoting energy generation from urban/industrial/agricultural residues.
- Market Development Assistance under GOBARdhan and amendments in the Fertiliser (Control) Order of 1985[34], providing financial assistance to CBG developers, primarily for promotion of organic fertilizers i.e., manure produced at CBG plants. This further enables farmers to get access to organic fertilizers namely, Fermented Organic Manure (FOM), Liquid FOM, Phosphate Rich Organic Manure (PROM) at reasonable prices, addressing the organic carbon and micronutrients deficiency in Indian soil.
- Facilitating CBG offtake by financially supporting cost-effective pipeline transportation of CBG from production facilities to consumption centres (Scheme for Development of Pipeline Infrasturcture[35]) and price support for CBG gas under CBG-CGD Synchronisation scheme.[36]

Among all states, Uttar Pradesh accounts for 24 percent of the total CBG generation potential in India[37] due to abundant organic feedstock availability.

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

33 Under the Petroleum and Natural Gas Regulatory Board (PNGRB) Act 2006, CGD in a specified geographical area includes the following distinct segments:

i. Compressed Natural Gas predominantly used as auto-fuel

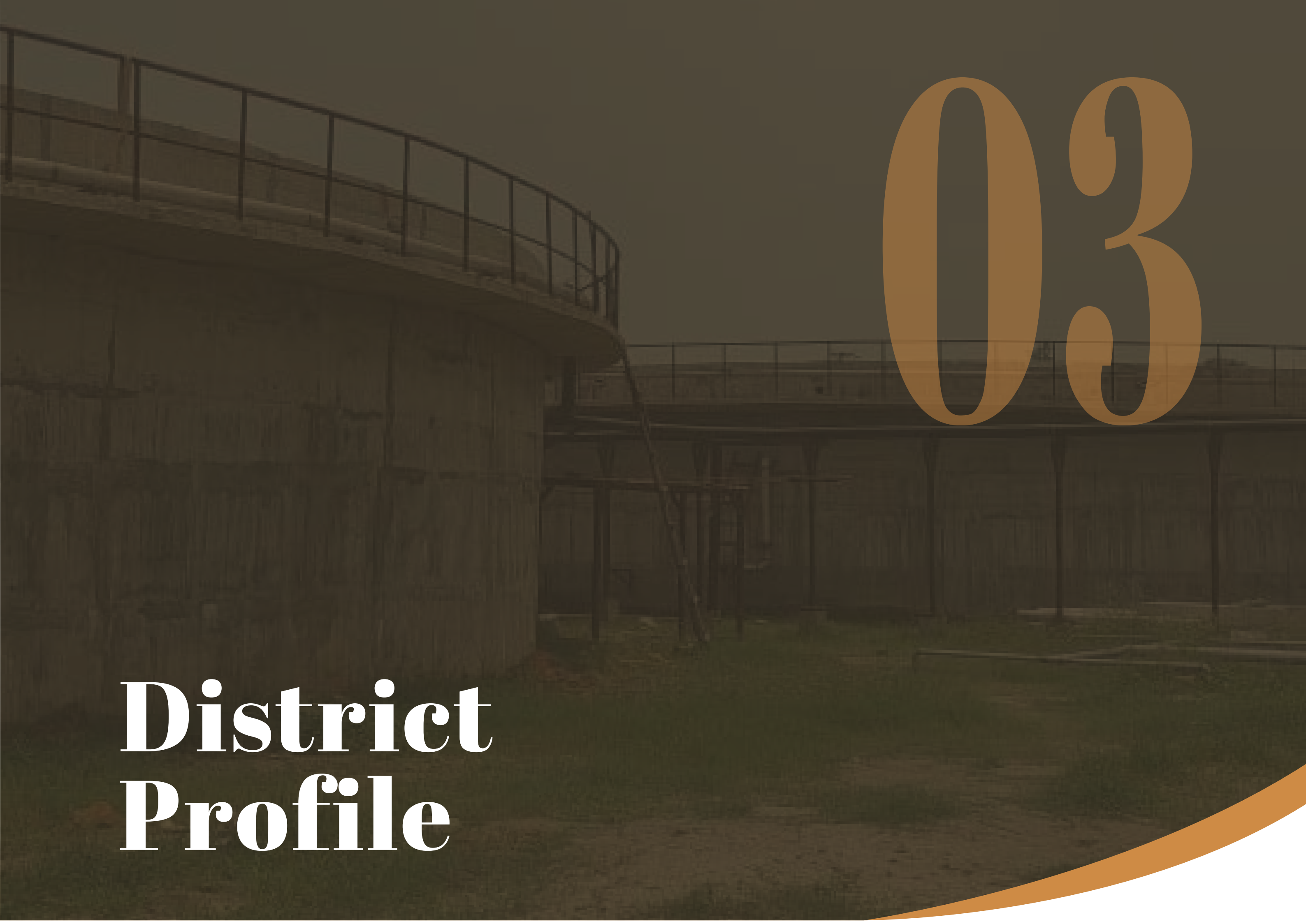
ii. Piped Natural Gas used in domestic, commercial, and industrial segments

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

35 Ministry of Petroleum and Natural Gas (MoPNG) (2024, 2025) Scheme Guideline for Development of Pipeline Infrastructure (DPI) for injection of Compressed Biogas (CBG) in City Gas Distribution (CGD) network, 2024 and 2025 Revisions

36 GAIL, MoPNG, 2025, Change in methodology and revision in price of Biogas/CBG under CBG-CGD Synchronization scheme

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



03

District Profile

3.1 Geographic Overview

Shamli district lies in the Shamli division of Western Uttar Pradesh. The district falls in Survey of India Toposheet No. 53G, covering north latitudes 29^{0}45′ 49.33″ and 29^{0}42′ 33.33″ and east longitude 77^{0}23′ 10.06″ and 78^{0}08′ 13.18″.[38] The district was carved out from Muzaffarnagar district on 28 September 2011 as Prabudh Nagar and awas renamed as Shamli and is within the National Capital Region of India. The district, covering an area of 1341 square kilometre lies in the north-west of Uttar Pradesh. It is bounded on the north by Shamli district, Bagpat district in the south and west in Haryana state.

According to 2011 census, Shamli district has a population of 13,13,650. The district has a population density of 1125 inhabitants per square kilometre. Shamli district is demarcated by rivers Yamuna in the west and Krishni in the east. The district occupies the northern part of Ganga basin and Yamuna sub-basin.[38]

38 Report on Aquifer Mapping and Ground Water Management Plan, Shamli District, Uttar Pradesh, Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation

Figure 9: Location of Shamli district in Uttar Pradesh[39]

3.2 Administrative Units (Tehsils/Blocks)

For administrative convenience, the district has been sub-divided into 3 tehsils and 5 development blocks. According to 2011 census, Shamli has 352 census villages and 230 village panchayats.

39 Maps of India, Muzaffarnagar Tehsil Map, https://www.mapsofindia.com/maps/uttarpradesh/tehsil/muzaffarnagar.html

3.3 Climatic Conditions

The climate of the district is sub-humid and it is characterized by general dryness except in the brief period during monsoon season. Summer is hot and winter is pleasant and cold. May is the hottest month. The mean daily temperature is about 40^{0}C, mean daily minimum temperature is about 24^{0}C. The air is dry during major parts of the year.

The loamy soils of the area are very fertile. About 80% of the total geographical area of the district is cultivated area. The maximum irrigational needs of the district are met by ground water. The total groundwater contribution in the district is 94.43%.

The entire district is a flat terrain falling in middle Yamuna plain. The district is underlain by alluvium deposited by Ganga and Yamuna River system.

A report[40] which measured district-level climate vulnerabilities in India highlighted that Shamli district in Uttar Pradesh fall is placed under relatively moderate vulnerable category and the major drivers of vulnerability include high percent of marginal and small operational holders, low percent area covered under centrally funded crop insurance, lack of forest area per 1000 rural population, etc.

Table 7: District agricultural and climate profile of Shamli[41]

District Agricultural and Climate Profile				
Agro-Climatic Zone[42] (State Agricultural Profile[43])	Northern Plain, Agro-climate zone: Upper Gangetic Plain (Planning Commission) and Mid-Western Plain Zone (NARP)			
Rainfall[44]				
Season	Average Annual Rainfall (mm)	Normal Rainy Days (no.)	Normal Onset	Normal Cessation
Southwest Monsoon (June-September)	855.9	47	4th week of June	2nd week of September
Post-monsoon (October-December)	49.4	12	3rd week of December	2nd week of January
Winter (January-March)	42.3	13	-	-
Pre-monsoon (April-May)	16.5	7	-	-
Annual	964	-	-	-

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

41 Agriculture Contingency Plan for Muzaffarnagar, ICAR-Central Research Institute for Dryland Agriculture

42 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.

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

44 Agriculture Contingency Plan for District: Shamli, 2019, Department of Agriculture and Farmers' Welfare

Temperature (in degree Celsius)	38.6^{0} C (Max)	6.7^{0} C(Min)	
Soil	Sandy loam and clay loam soils		
Major Climate Contingency and Frequency	Regular	Occasional	None
Drought		√	
Flood			√
Cyclone			√
Hailstorm		√	
Heat wave		√	
Cold wave		√	
Frost		√	

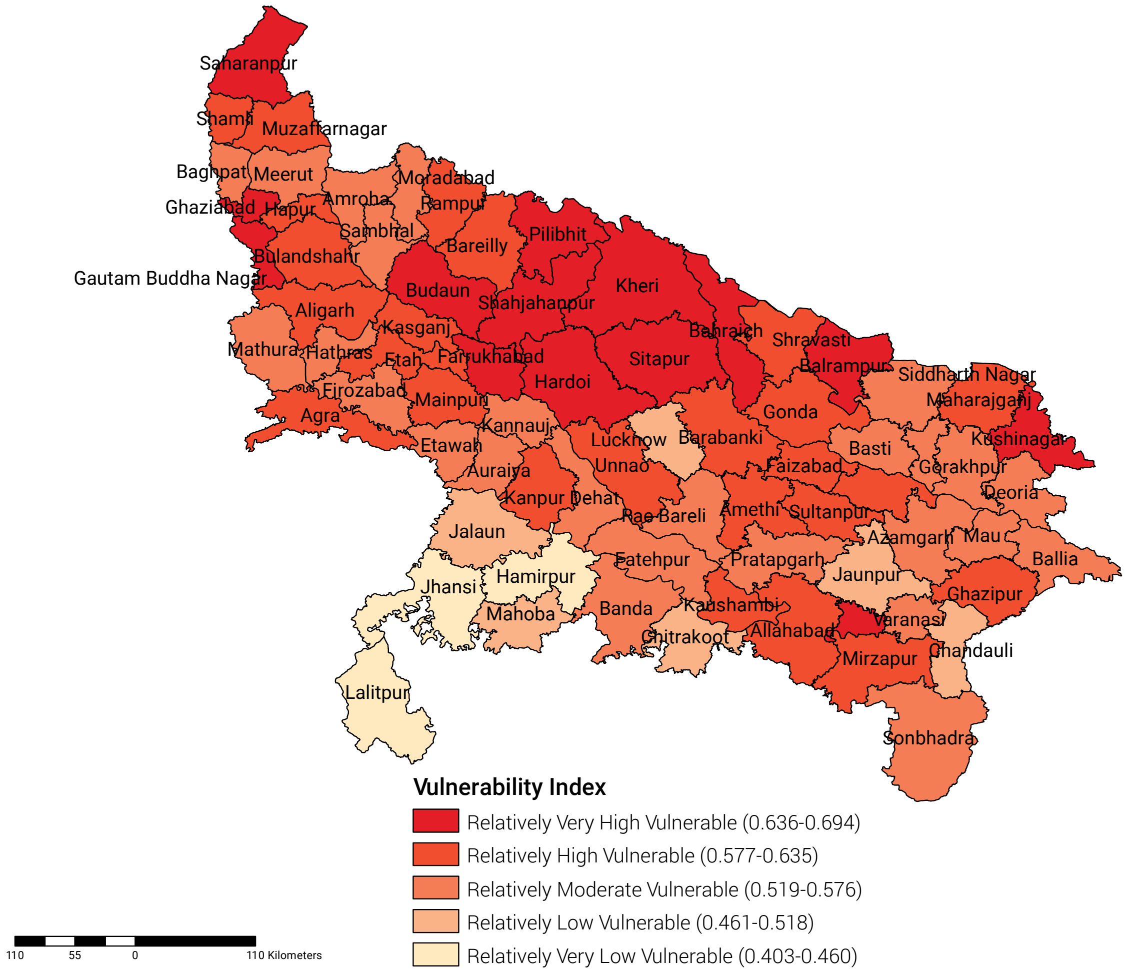


Figure 10: District-wise climate vulnerability index

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

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

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

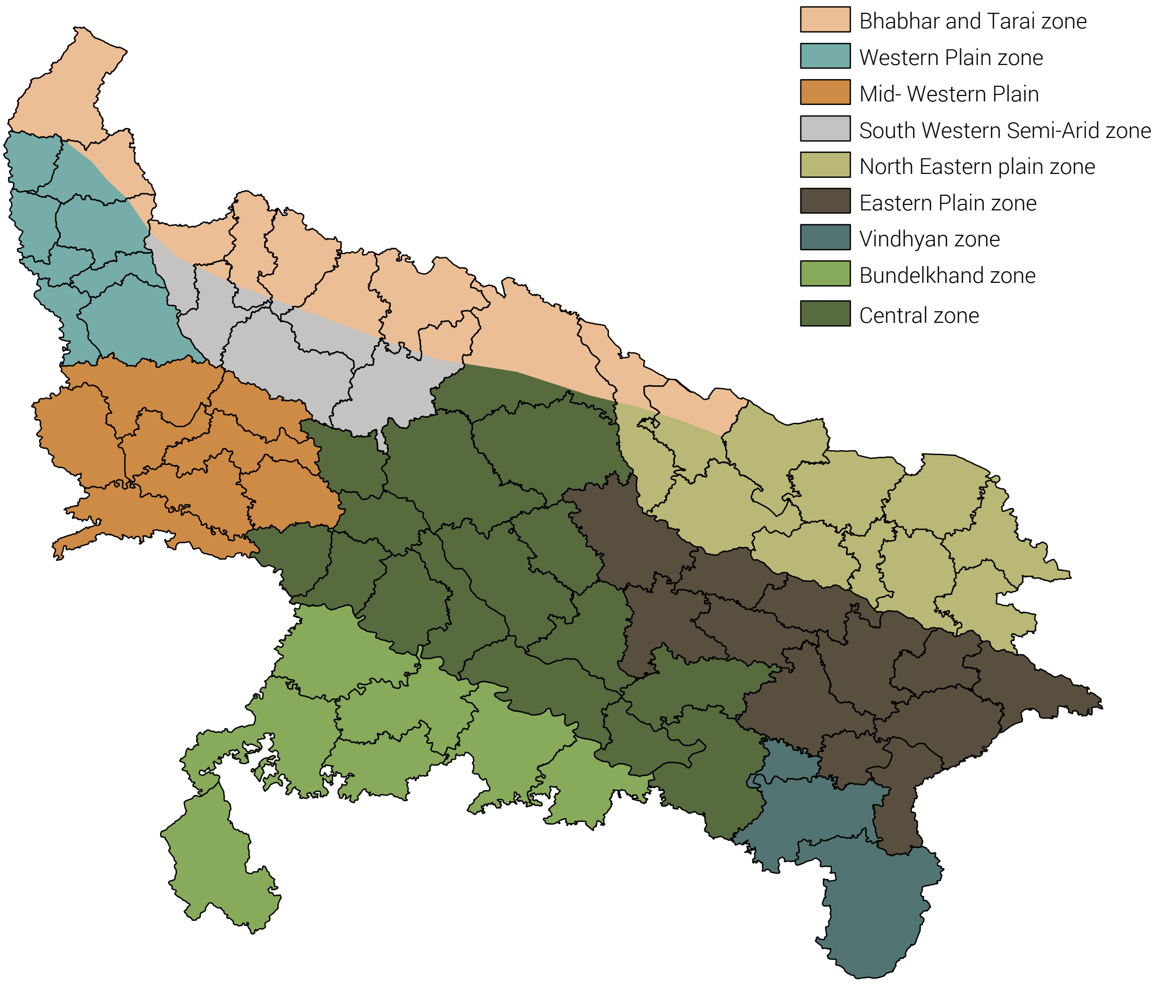


Figure 11: Agro-climatic zones in Uttar Pradesh[45]

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

3.4 Demographics (Urban/Rural)

Shamli is located in the extremely fertile Doab region with Eastern Yamuna canal as the irrigation source. Agriculture is the primary occupation and sugarcane is the major crop as Shamli provides ideal conditions for sugarcane cultivation. The economy is therefore primarily driven by sugarcane production and processing.

In terms of agricultural landholdings, 72.11 percent of the holdings in the district were less than 1 hectare (ha.) while 16.84 percent of the holdings were 1-2 ha, 8.76 percent of the holdings lie between 2-4 ha and 2.29 percent of the holdings were 4 ha or more during 2015-16. In terms of agricultural income, during 2021-22, the gross value of agricultural produce per ha. of net area sown was INR 4,18,018.[46]

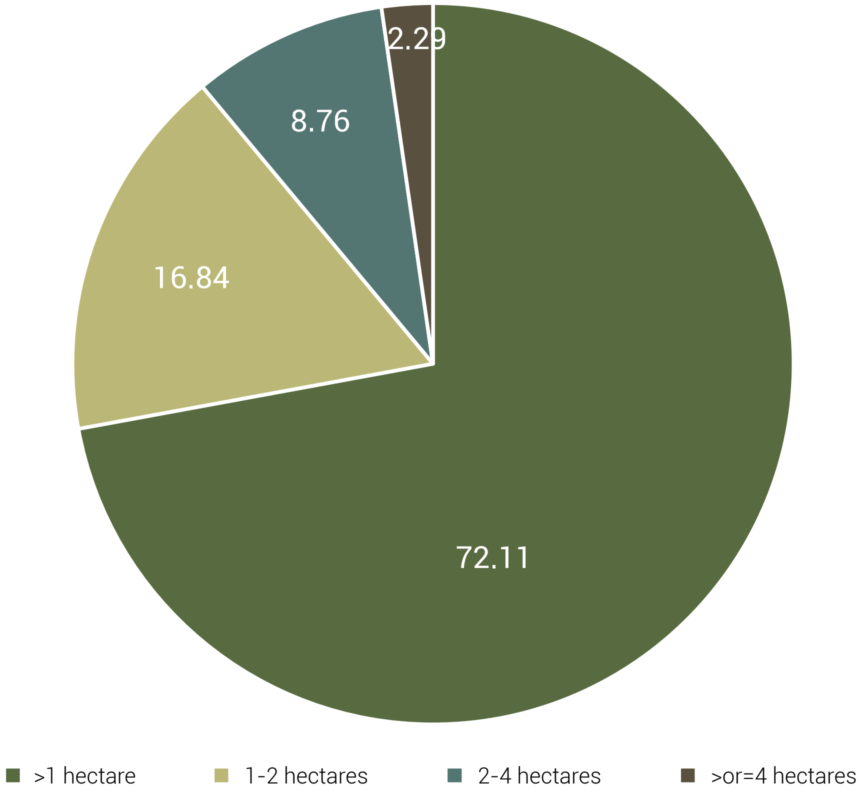


Figure 12: Agricultural land holdings in Shamli[46]

3.5 Agricultural Overview

Shamli is predominantly an agricultural district in Uttar Pradesh. The loamy soils of the area are very fertile. About 80% of the total geographical area of the district is cultivated area. The main rabi crops are wheat and oil seeds while paddy and pulses are the main kharif crops. The abundantly produced sugarcane is a perennial crop. At the district-level, cultivable area of around 2.50 lakh hectares (ha.) with a cropping intensity of 153.60 percent.[41] Gross cropped area is approximately 2.98 lakh ha. with over 1.04 lakh ha. area sown more than once. The net irrigation area is around 1.73 lakh ha. and an area of 20,000 ha. is rain-fed. Other major sources of irrigation include canals and bore wells.

46 District Wise Development Indicators Uttar Pradesh 2024

3.5.1 Total Agricultural Area

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

Agricultural Land Use	Area ('000 ha)	Cropping Intensity (%)
Net sown area	194.1	
Area sown more than once	104	153.60
Gross cropped area	298.1	

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

Major agricultural crops by production in the district include wheat, sugarcane, mustard and vegetable crops during Rabi season and maize, jowar, other coarse grains, paddy, sugarcane, bajra, etc. during Kharif season. Zaid are intermediate harvest and is of little significance. Cash crops that are popularly sown in the district include sugarcane, etc. At times, double cropping is practised in the district to obtain more yield. *Figure 13* describes the extent of land use in terms of gross area sown for Kharif and Rabi crops in Shamli district during 2021-22.

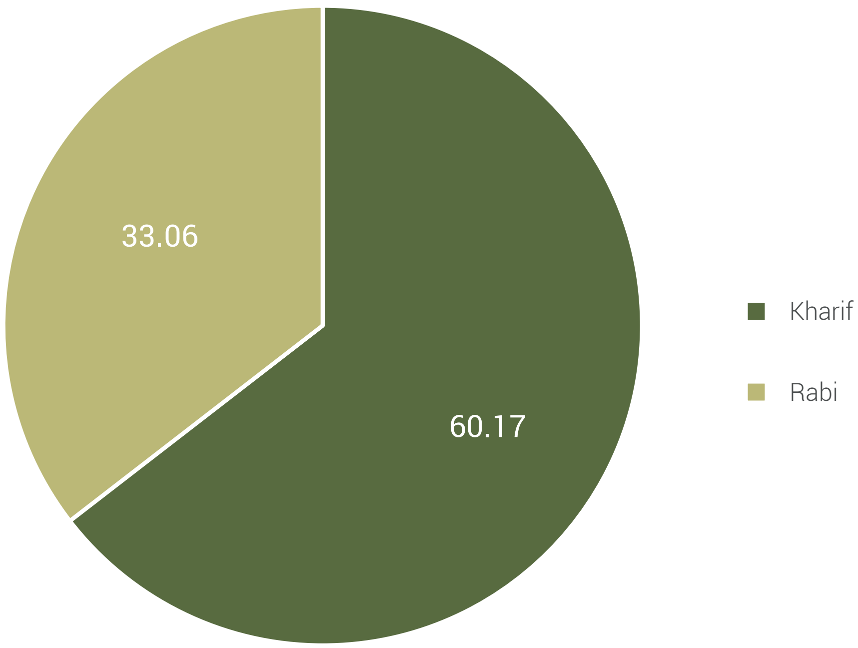


Figure 13: Gross area sown during both the cropping seasons in Shamli[46]

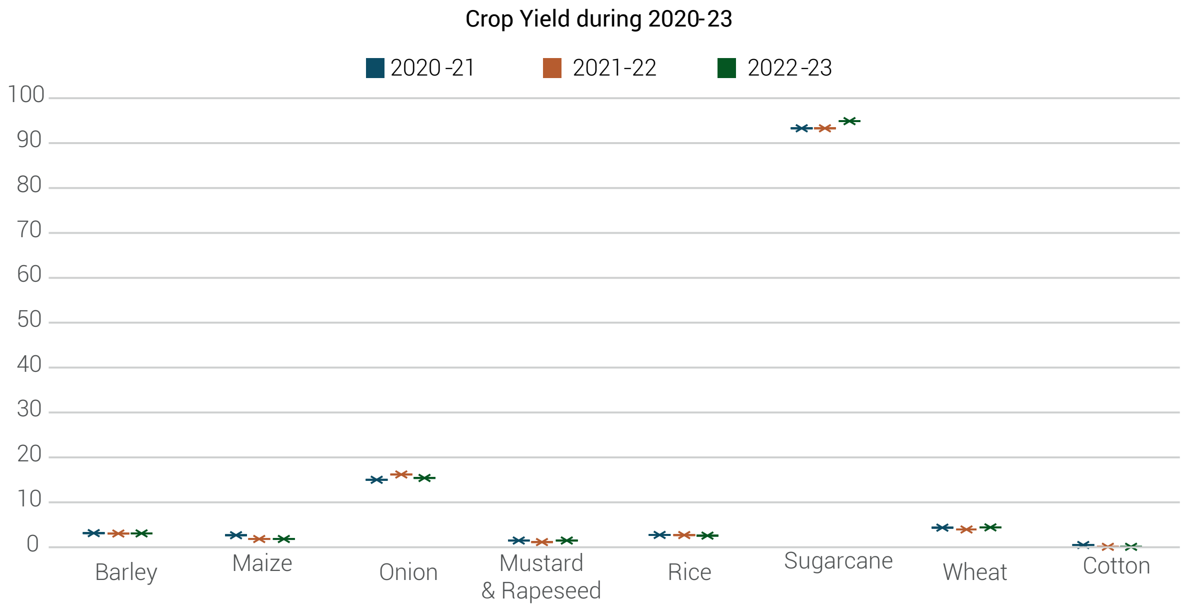


Figure 14: Crop yield during 2020-23 for major crops sown in Shamli during Kharif and Rabi[47]

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 crop was wheat it occupied close to 54 percent of the total cropped area. Other major rabi crops include mustard, sugarcane, vegetables, etc.

Table 10:Tehsil-wise cropped area of Rabi crops (in ha.) during 2023-24[48]

Tehsil	Mustard	Other Crop	Sugarcane	Vegetables	Wheat	Grand Total
KAIRANA	1047.47	1235.74	6903.36	126.84	16434.07	**25747.48**
SHAMLI	1600.25	2320.94	14895.14	306.57	11350.38	**30473.28**
UNN	1742.57	470.20	6499.40	3.93	15097.62	**23813.71**

During 2023-24, the prominent Kharif crops in Shamli were paddy and sugarcane where together they comprised 81 percent of the total cropped area. Other major kharif crops vegetables, maize and other coarse grains that were sown and cultivated during the same period. Among all tehsils, Shamli had the highest share of cropped area for sugarcane and paddy followed by Kairana and Unn.

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

Tehsil	Mustard	Other Crop	Sugarcane	Vegetables	Wheat	Grand Total
KAIRANA	1047.47	1235.74	6903.36	126.84	16434.07	**25747.48**
SHAMLI	1600.25	2320.94	14895.14	306.57	11350.38	**30473.28**
UNN	1742.57	470.20	6499.40	3.93	15097.62	**23813.71**

47 Area Production Statistics, Ministry of Agriculture and Farmers Welfare

48 Analysis by Vasudha Foundation, 2025

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

In Shamli, the percent of gross irrigated area to the gross area sown was 99.77 during 2022-23.[46]

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

Sowing window for major field crops	Rice	Wheat	Maize	Black gram	Green gram
Kharif – Rainfed	-	-	June	June-July	June-July
Kharif – Irrigated	June-July	-	June	June-July	June-July
Rabi – Rainfed	-	November-December	-	-	-
Rabi – Irrigated	-	November-December	-	-	-

3.6 Forest Resources

3.6.1 Total Forest Area

Table 13: Total forest area (by classification) in Shamli[49]

District	Calculated Area (km^2)	Very Dense Forest (km^2)	Moderate Dense Forest (km^2)	Open Forest[50] (km^2)	Total (km^2)	Scrub[51] (km^2)
Shamli	1257.46	0	3.96	20.43	24.39	1.21

3.6.2 Types of Forests and Residue Generated

Forests cover practically the whole of hilly range of the Shiwalik. This is generally covered with trees and coarse grass which is in itself of considerable economic value and also useful for grazing. Forestry residue consists of small trees, branches, leaves, bark, tops, and un-merchantable wood left in the forest after cleaning, thinning, or final felling. Woody biomass actually requires thermal gasification at high temperature in a low-oxygen environment to convert them into a mixture of gases, mainly, carbon monoxide, hydrogen and methane (syngas)[52]. To produce a stream of biomethane of high purity, this syngas is cleaned to remove any acidic and corrosive components. Therefore, woody biomass which consist of residues from forest management and wood processing has to follow the gasification route unlike other feedstocks like agriculture residue or Municipal Solid Wastes (MSW). Biomass such as paper, wood, dried leaves, wooden shavings, etc are generally high in lignin and cellulose. These substances are not suitable for the commercial biogas generation.[53]

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

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

51 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)

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

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

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

3.7.1 Cattle, Poultry, and Other Livestock Statistics

Table 14: Tehsil-wise livestock statistics and cattle in cowsheds[55]

Tehsil	Cattle	Goat/Sheep	Swine	Poultry (Chicken)
Kairana	159518	8082	1523	2,00,126
Shamli	143751	9208	1758	46,046
Unn	185799	7111	1840	50,254
Shamli District	489068	24401	5121	296426

Tehsil	Total Govansh
Kairana	489
Shamli	1234
Unn	1043
Shamli District	2766

3.7.2 Manure and Waste Generation Potential

The high population of cattle and other livestock has resulted in higher quantities of cattle dung and poultry litter. Common practices for managing dung and litter include composting for manure production, forming cattle dung cakes to be used as fuel, and as feedstock for small biogas plants. Based on the existing literature[56,57,58,59] around dung/litter yield from the respective livestock, the following figures are derived:

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

55 Animal Husbandry Department, Government of Uttar Pradesh

56 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

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

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

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

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

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

Step 1

Fresh cow-dung from farm

Collected and shaped into 8-10 inches cakes

Collected and thrown on previous day heap

Step 2

Cakes dried in sun and heap allowed to ferment

Dried, tough cakes

Heap ferments and degrades into nitrogenous compounds

Step 3

Step 3: Utilisation

Cakes ignited and burnt to cook meals

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

Figure 15: Traditional use of cow-dung as kitchen fuel and manure[60]

3.8 Industry and Processing Units

3.8.1 Existing Biomass-based Industries

There are two CBG plants in the district, both of which is one will be operational from November 2025 and are located in Shamli and Unn tehsils.

60 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 Shamli (both, completed and under-construction)

Plant Capacity and Tehsil	Feedstock/Raw Material	By-Products	Procurement Plan
5 TPD in Shamli tehsil	Pressmud, Paddy straw	CBG, Bio-Fertilizer	Combination feedstock comprising of 80% of sugarcane press mud and 20% of paddy straw, procuring 120 TPD of press mud at INR 125 per quintal
10 TPD in Unn tehsil	Napier grass, Paddy straw	CBG, Bio-Fertilizer	Combination feedstock comprising of 80% of Napier grass and 20% of Paddy straw, procuring 60 TPD of cattle dung and 100 TPD of Napier grass

04 Data Collection

4.1 Primary Data Collection

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

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

Table 17: Operating parameters and conversion factors for sugar mills

Parameter	Value
Conversion Factor (Sugarcane to Bagasse)	40% TCD[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 press mud or bagasse for CBG generation described below:

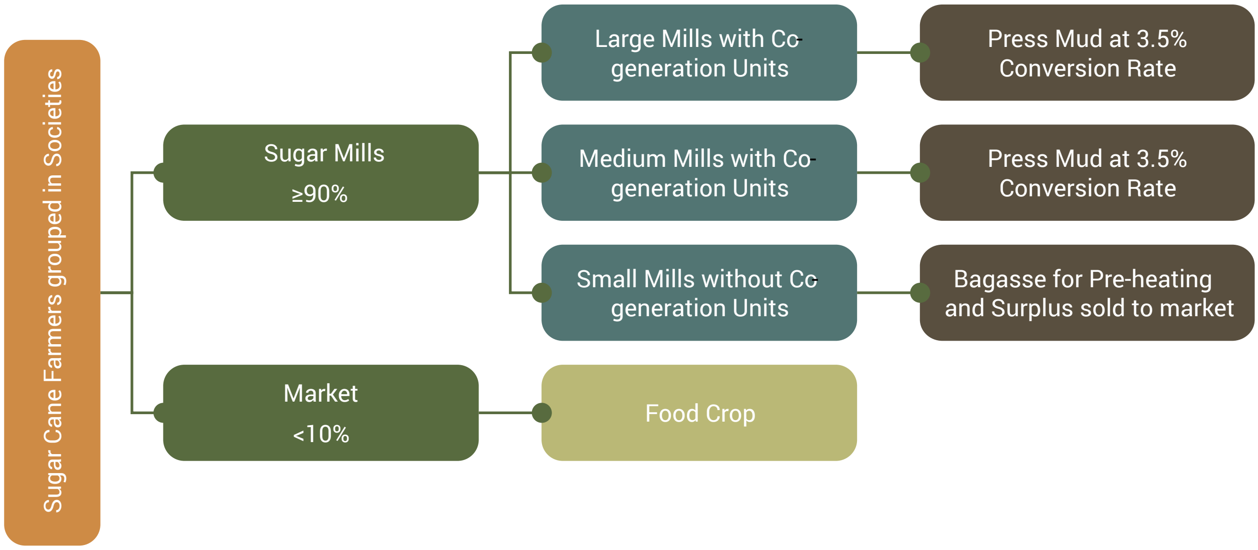


Figure 16: Mapping the value chain of sugar industries

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

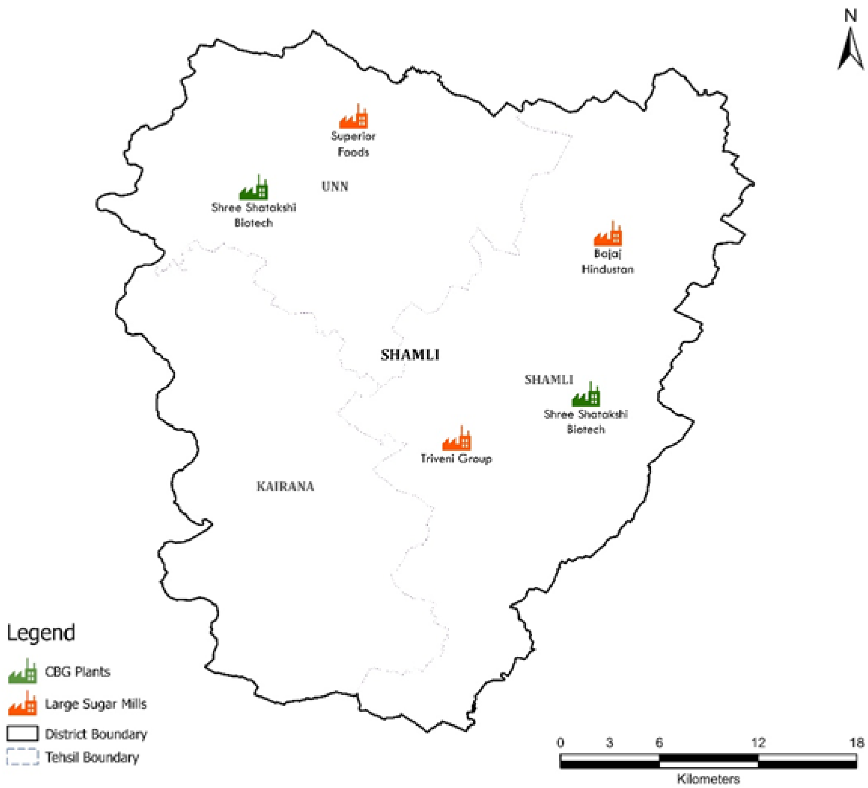


Figure 17: Location of sugar mills in Shamli district[64]

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

Tehsil	Cane Crushing Capacity in TCD		
	Large Mills	Medium Mills	Small Mills (Vertical Crushers)
Shamli	7500x1, 9000x1	x	275x15 TCD per plant
Unn	7200x1	x	136x9 TCD per plant

4.2 Secondary Data Collection

Major reliance was placed on secondary data that was shared by the Government at the Central, State, District, and sub-District level. Crop Yield data was collected from the Crop Production Statistics published by the Ministry of Agriculture and Farmer's Welfare for three-year period (2021-24) to arrive at an average. Further, the Crop-to-Residue Ratio (on dry weight basis) was borrowed from the latest National Biomass Atlas[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	15	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 Press Mud) 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
Press Mud	1	25 T
Spent Wash	1	10 KL
Bagasse	1	10 T
Municipal Solid Waste	1	20 T
Cow Dung	1	50 T
Chicken Litter	1	25 T
Forest Residue	1	15 T
Napier Grass	1	10 T
Sewage Waste	1	15 MLD

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

05

Stakeholder Mapping

5.1 Identification of Relevant Stakeholders

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

Table 24: Stakeholders in bio-energy value chain

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

06

GIS-based Satellite Mapping

6.1 Cropping Pattern and Analysis

It can be observed from the Kharif crop map that sugarcane is cultivated across in all the tehsils with Shamli and Unn having the highest cultivation. Unn and Shamli also have large paddy cultivations in their respective tehsils. Kairana tehsil cultivate large share of bajra, barley and other coarse grains besides paddy and sugarcane.

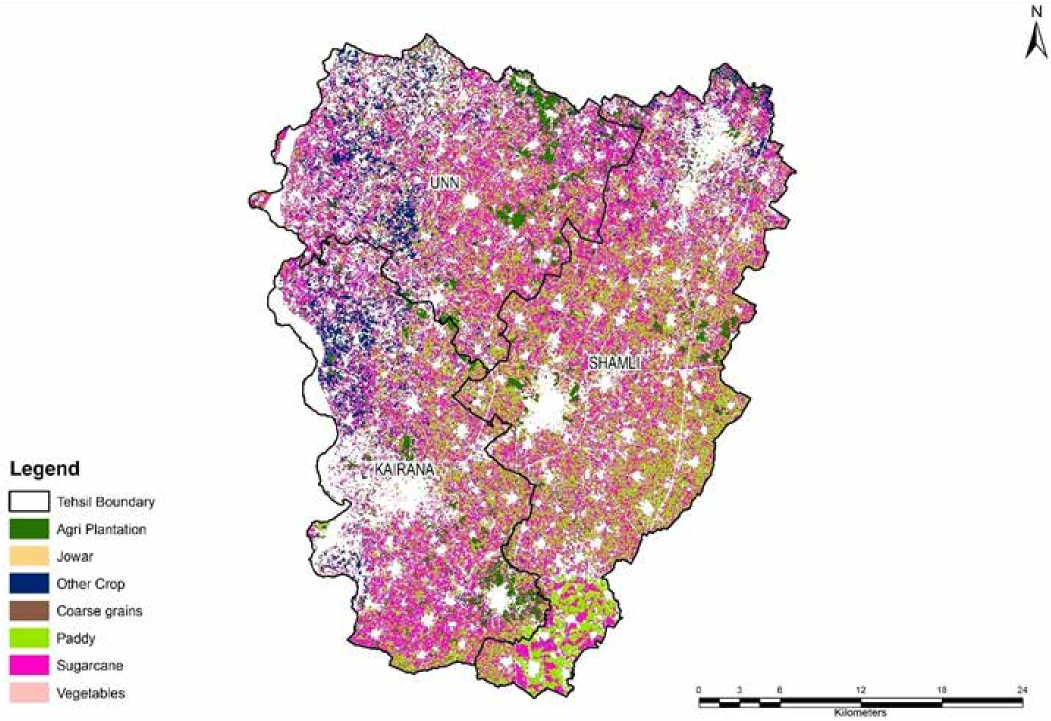


Figure 18: Geographical spread of Kharif crops in tehsils of Shamli district during 2023-24[71]

During Rabi season, wheat is predominantly grown across in Shamli and Unn tehsils with traces of mustard and vegetables, etc.

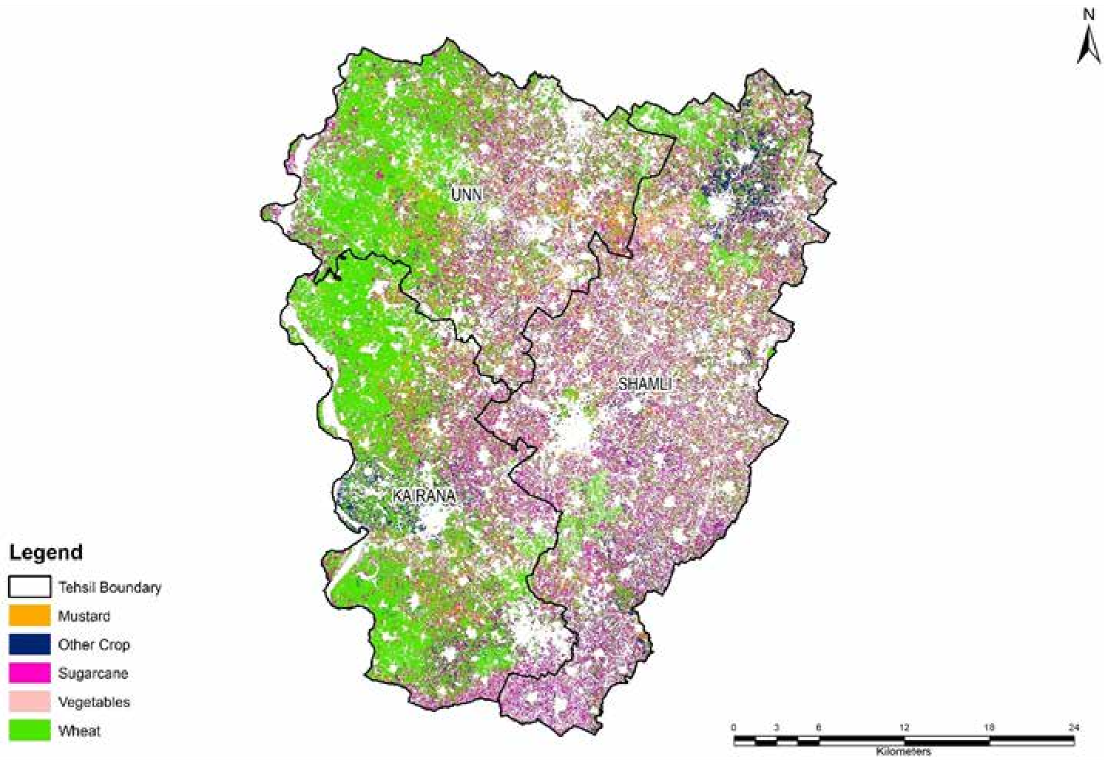


Figure 19: Geographical spread of Rabi crops in tehsils of Shamli district during 2023-24[72]

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

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

Tehsil	Barren/ Waste land	Built-Up	Crop land	Grass land	Scrub	Water-bodies	Wetland	Grand Total
KAIRANA	348.15	2051.42	33377.69	824.70	248.04	607.60	21.82	37479.42
SHAMLI	201.32	3468.55	50382.02	1305.78	278.79	13.02	0.31	55649.79
UNN	92.73	1634.55	34904.27	370.60	175.59	210.26	1.52	37389.52

It can be observed from the Land Use analysis[73] that nearly 90% percent of the total geographical area of the district was under cultivation during 2023-24.

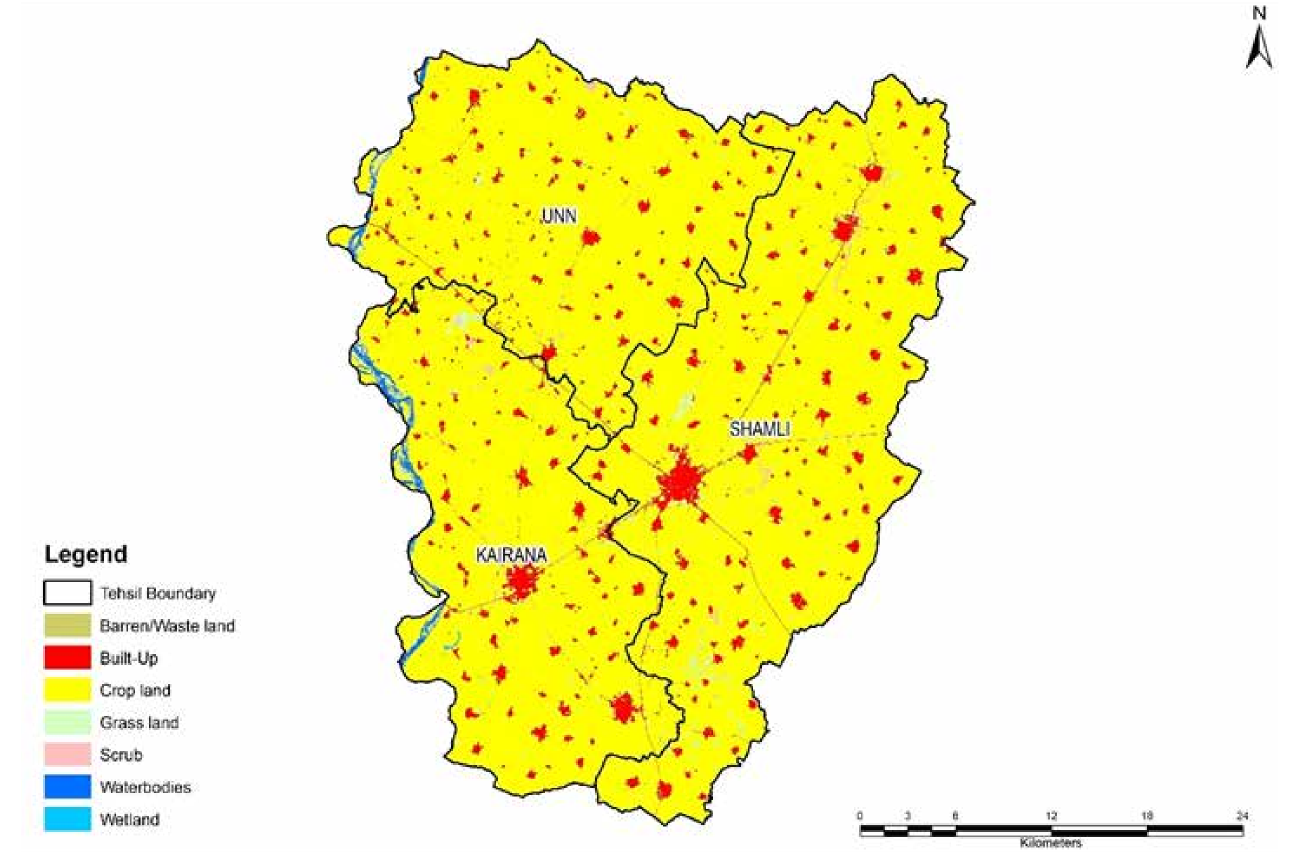


Figure 20: Land cover analysis for tehsils of Shamli district during 2023-24[74]

73 Analysis by Vasudha Foundation, 2025

74 Analysis by Vasudha Foundation, 2025

07

Methodology

This study estimates annual net biomass residue availability in all the three tehsils of Shamli 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 Shamli 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], a supervised machine learning algorithm trained on ground-truth data to classify satellite imagery into distinct crop

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

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

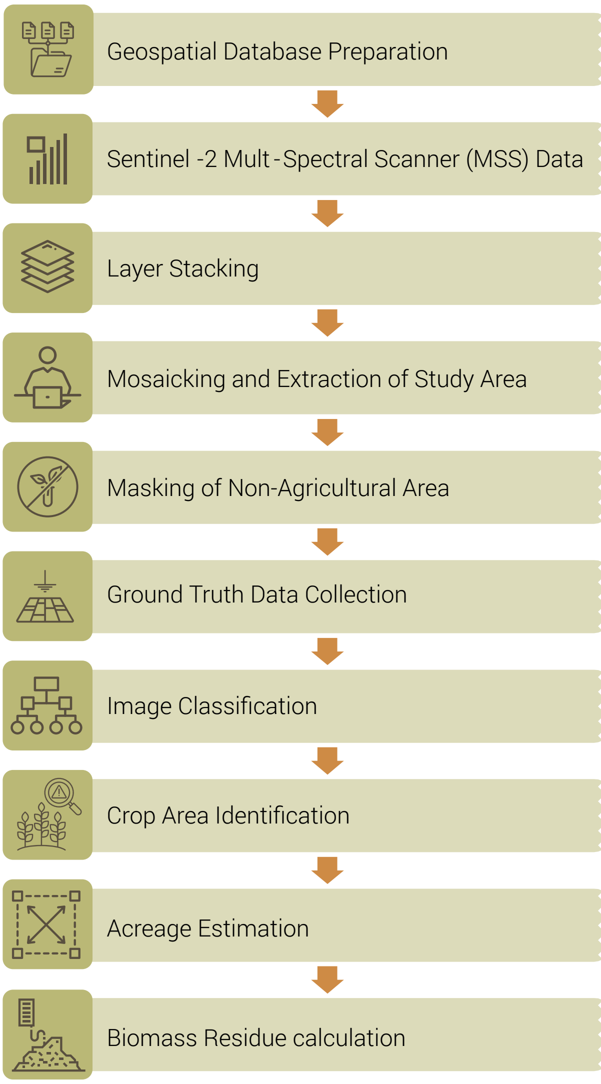


Figure 21: Flow diagram of the methodology used

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

Gross crop residue76 can be defined as the sum total of crop residues produced for a particular crop. In general, there is a 1:1 grain-to-residue relationship between the dry matter of crop grain and the dry matter of crop residues.[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 *Fig.15*).[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]

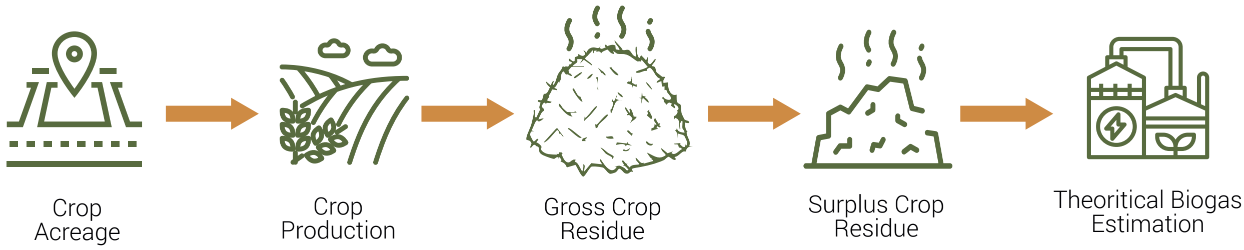


Figure 22: Flow diagram for crop residue estimation

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

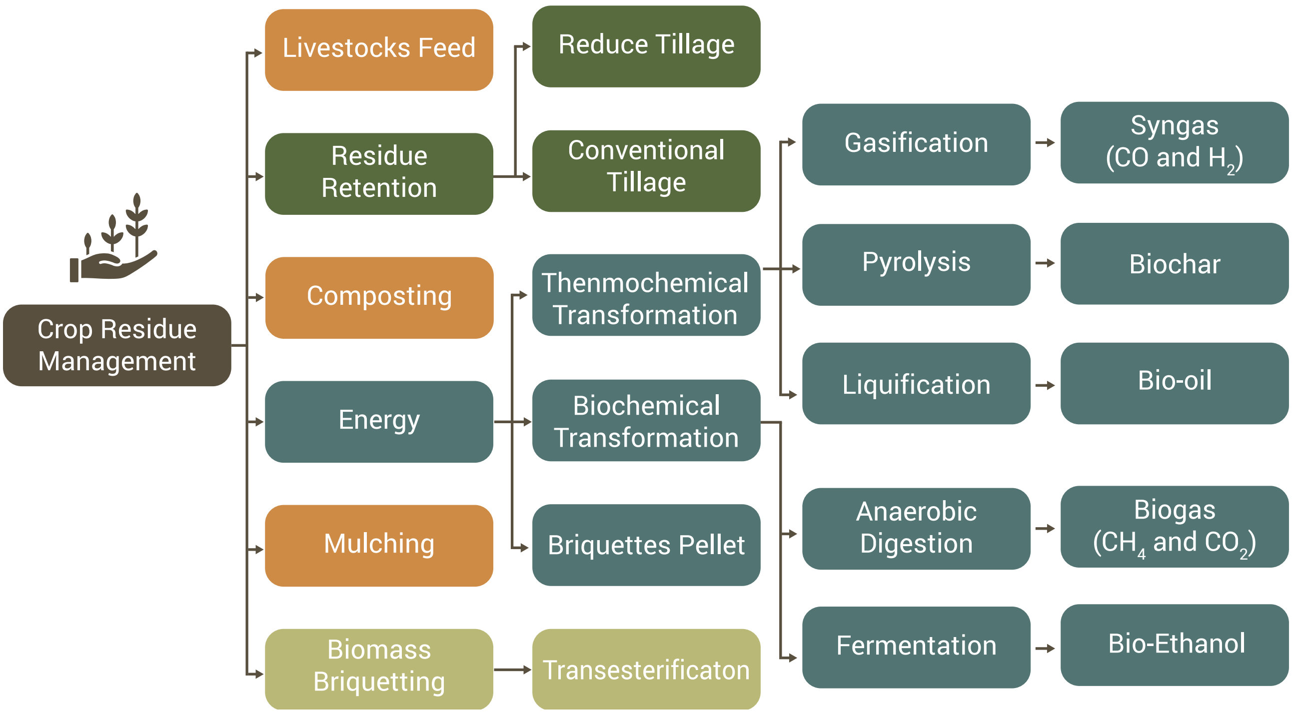


Figure 23: Crop residue management practices[82]

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

7.2 Livestock Residue

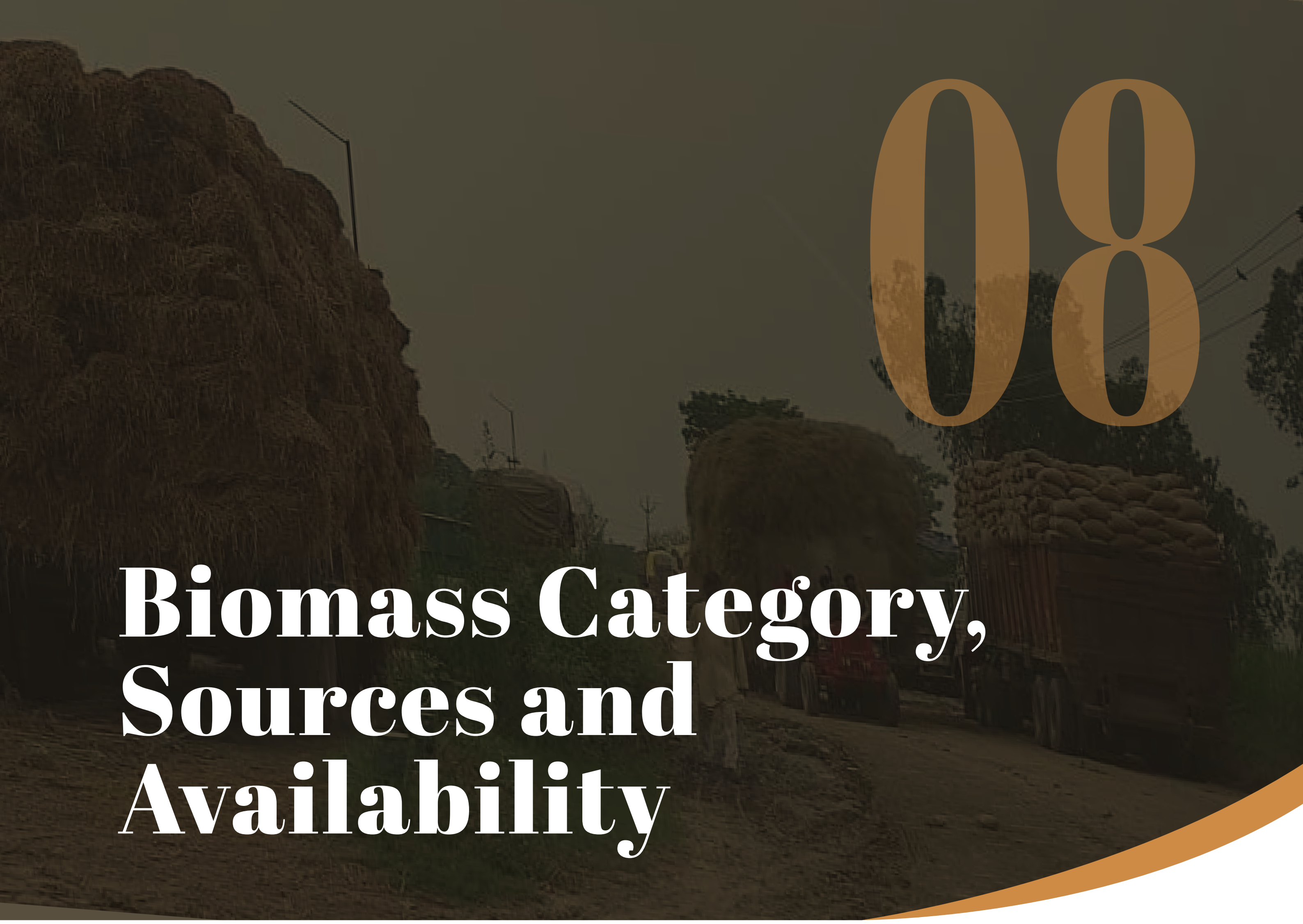
The data on livestock population at the district level and tehsil level are used to estimate the total dung/ litter that could be generated.

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

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

Equation 5: Theoretical CBG estimation from livestock residues

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



08

Biomass Category, Sources and Availability

8.1 Agricultural Residues

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..

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

Tehsil	Name	Production		Total Production (T)	Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ha)								
Kairana	Wheat	16434.07	4.68	76911.4476	Straw	115367.17	23073.43	23073.43	1667.52	4.57	6.32
					Husk	23073.43	4614.69	4614.69	333.50	0.91	1.26
	Paddy	5817.75	2.86	16638.765	Straw	24958.15	4242.89	4242.89	344.96	0.95	3.65
					Husk	3327.75	565.72	565.72	45.99	0.13	
	Sugarcane	18264.7	101.45	1852953.815	Bagasse (Small)		0.00		0.00	0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00	0.00
					Tops and Leaves	92647.69	92647.69	92647.69	6485.34	17.77	17.77
	Mustard	1047.47	1.74	1822.5978	Stalks	3280.68	3280.68	3280.68	328.07	0.90	0.90
	Tur/Arhar	0	0	0	Stalks	0.00	0.00	0.00	0.00	0.00	0.00
	Potato	0	0	0	Stalks	0.00	0.00	0.00	0.00	0.00	0.00
	Vegetables	275.12	15.55	4278.116	Stalks	427.81	427.81	427.81	42.78	0.12	0.12
	Barley	3800.32	3.08	11704.9856	Stalks	15216.48	15216.48	15216.48	1521.65	4.17	4.17
	Jowar	297.91	2.01	598.7991	Stalks	1017.96	1017.96	1017.96	101.80	0.28	0.28
					Husk/ Leaves	119.76	119.76	119.76	11.98	0.03	0.03
					Cobs	299.40	299.40	299.40	29.94	0.08	0.08
	Coarse Grains (Maize/ Ragi)	672.73	2.01	1352.1873	Stalks	2704.37	2704.37	2704.37	270.44	0.74	0.74
					Cobs	405.66	405.66	405.66	40.57	0.11	0.11
					Leaves	162.26	162.26	162.26	16.23	0.04	0.04
	Bajra	1726.84	2.01	3470.9484	Stalks	6941.90	6941.90	6941.90	694.19	1.90	1.90
					Husk	1041.28	1041.28	1041.28	104.13	0.29	0.29
					Cobs	1145.41	1145.41	1145.41	114.54	0.31	0.31

Tehsil	Name	Production		Total Production (T)	Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ha)								
Shamli	Wheat	11350.38	4.68	53119.78	Straw	79679.67	15935.93	15935.93	1151.69	3.16	4.37
					Husk	15935.93	3187.19	3187.19	230.34	0.63	0.87
	Paddy	15720.03	2.86	44959.29	Straw	67438.93	11464.62	514.62	41.84	0.11	9.85
					Husk	8991.86	1528.62	1528.62	124.28	0.34	
	Sugarcane	33779.33	101.45	3426913.03	Bagasse (Small)	79200.00			2446.92	6.70	6.70
					Press Mud (Large)	26865.00			1067.84	2.93	2.94
					Press Mud (Medium)	0.00			0.00	0.00	0.00
					Tops and Leaves	171345.65	171345.65	171345.65	11994.20	32.86	32.86
	Mustard	1600.25	1.74	2784.44	Stalks	5011.98	5011.98	5011.98	501.20	1.37	1.37
	Tur/Arhar	0	0	0.00	Stalks	0.00	0.00	0.00	0.00	0.00	0.00
	Potato	0	0	0.00	Stalks	0.00	0.00	0.00	0.00	0.00	0.00
	Vegetables	324.99	15.55	5053.59	Stalks	505.36	505.36	505.36	50.54	0.14	0.14
	Barley	3451.72	3.08	10631.30	Stalks	13820.69	13820.69	13820.69	1382.07	3.79	3.79
	Jowar	577.43	2.01	1160.63	Stalks	1973.08	1973.08	1973.08	197.31	0.54	0.54
					Husk/ Leaves	232.13	232.13	232.13	23.21	0.06	0.06
					Cobs	580.32	580.32	580.32	58.03	0.16	0.16
	Coarse Grains (Maize/ Ragi)	862.85	2.01	1734.33	Stalks	3468.66	3468.66	3468.66	346.87	0.95	0.95
					Cobs	520.30	520.30	520.30	52.03	0.14	0.14
					Leaves	208.12	208.12	208.12	20.81	0.06	0.06
	Bajra	1757.41	2.01	3532.39	Stalks	7064.79	7064.79	7064.79	706.48	1.94	1.94
					Husk	1059.72	1059.72	1059.72	105.97	0.29	0.29
					Cobs	1165.69	1165.69	1165.69	116.57	0.32	0.32

Tehsil	Name	Production		Total Production (T)	Gross Residue Total Production (T)*Crop-to-Residue Ratio		Surplus Residue Gross Residue (T)*Surplus Fraction	Net Residue (T)	CBG Potential (TPA)	CBG Potential (TPD)	CBG Potential (SATAT)
		Area (ha)	Yield (T/ha)								
Unn	Wheat	15097.62	4.68	70656.86	Straw	105985.29	21197.06	21197.06	1531.91	4.20	5.81
					Husk	21197.06	4239.41	4239.41	306.38	0.84	1.16
	Paddy	5586.92	2.86	15978.59	Straw	23967.89	4074.54	4074.54	331.28	0.91	3.50
					Husk	3195.72	543.27	543.27	44.17	0.12	
	Sugarcane	18964.06	101.45	1923903.89	Bagasse (Small)	23500.80			726.07	1.99	1.99
					Press Mud (Large)	31409.00			1248.46	3.42	3.44
					Press Mud (Medium)	0.00			0.00	0.00	0.00
					Tops and Leaves	96195.19	96195.19	96195.19	6733.66	18.45	18.45
	Mustard	1742.57	1.74	3032.07	Stalks	5457.73	5457.73	5457.73	545.77	1.50	0.10
	Tur/Arhar	0	0	0.00	Stalks	0.00	0.00	0.00	0.00	0.00	0.00
	Potato	0	0	0.00	Stalks	0.00	0.00	0.00	0.00	0.00	0.00
	Vegetables	247.2	15.55	3843.96	Stalks	384.40	384.40	384.40	38.44	0.11	0.11
	Barley	3771.68	3.08	11616.77	Stalks	15101.81	15101.81	15101.81	1510.18	4.14	4.14
	Jowar	104.26	2.01	209.56	Stalks	356.26	356.26	356.26	35.63	0.10	0.10
					Husk/ Leaves	41.91	41.91	41.91	4.19	0.01	0.01
					Cobs	104.78	104.78	104.78	10.48	0.03	0.03
	Coarse Grains (Maize/ Ragi)	890.38	2.01	1789.66	Stalks	3579.33	3579.33	3579.33	357.93	0.98	0.98
					Cobs	536.90	536.90	536.90	53.69	0.15	0.15
					Leaves	214.76	214.76	214.76	21.48	0.06	0.06
	Bajra	1840.02	2.01	3698.44	Stalks	7396.88	7396.88	7396.88	739.69	2.03	2.03
					Husk	1109.53	1109.53	1109.53	110.95	0.30	0.30
					Cobs	1220.49	1220.49	1220.49	122.05	0.33	0.33

8.2 Animal Waste

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

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

Tehsil	Animal	Population	CollectableDung/ Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy (MW)	CBG in TPD (NIBE)	CBG in TPD (SATAT)
Kairana	Cattle	159518	873361050	218340262.5	152838183.8	152838.18	2493952347.16	1.31757	6.27	8.375
	Goat/Sheep	8082	4719888	1368767.52	273753.504	273.75	3436153.98	0.0037	0.01	0.021
	Swine	1523	1500916.5	435265.785	261159.471	261.16	4674754.53	0.00326	0.01	0.020
	Poultry (Chicken)	2,00,126	3287069.55	953250.1695	571950.1017	571.95	9151201.63	0.00851	0.04	0.06268
Shamli	Cattle	143751	787036725	196759181.3	137731426.9	137731.43	2247446331.18	1.18734	5.653	7.547
	Goat/Sheep	9208	5377472	1559466.88	311893.376	311.89	3914885.66	0.00416	0.02	0.024
	Swine	1082	1066311	309230.19	185538.114	185.54	3321132.24	0.00232	0.0093	0.0145
	Poultry (Chicken)	46,046	756305.55	219328.6095	131597.1657	131.60	2105554.65	0.00195788	0.0092	0.0144
Unn	Cattle	185799	1017249525	254312381.3	156118666.9	156118.67	2547481958.60	1.34585	6.407	8.554
	Goat/Sheep	7111	4152824	1204318.96	240863.792	240.86	3023322.32	0.00321	0.01	0.019
	Swine	1840	1813320	525862.8	315517.68	315.52	5647766.47	0.00394	0.0158	0.0247
	Poultry (Chicken)	50,254	825421.95	239372.3655	143623.4193	143.62	2297974.71	0.00213680	0.0101	0.0157

8.3 Energy Crops

Poplar Trees, Willow, Jatropha

These crops were not identified in our GIS Crop Maps.

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 usually sown and harvested during the kharif season and yields groundnut shells as residue. During 2022-23, as per the Crop Production Statistics, there was no data on groundnut cultivation in the district.

8.4.3. Sugarcane Bagasse

Apart from large sugar mills, generally, there are small sugar mills (without a bagasse co-generation unit) that operate with vertical crushers in Uttar Pradesh. There are close to 411 sugar mills in both Shamli and Unn tehsils of the district with individual capacities of 15 and 9 TCDs. These together contribute to approximately 102,700 T of bagasse generation in a year which corresponds to 10.12 TPD of CBG. However, bagasse is used captively for heating in the sugar and is sold for other secondary purposes.

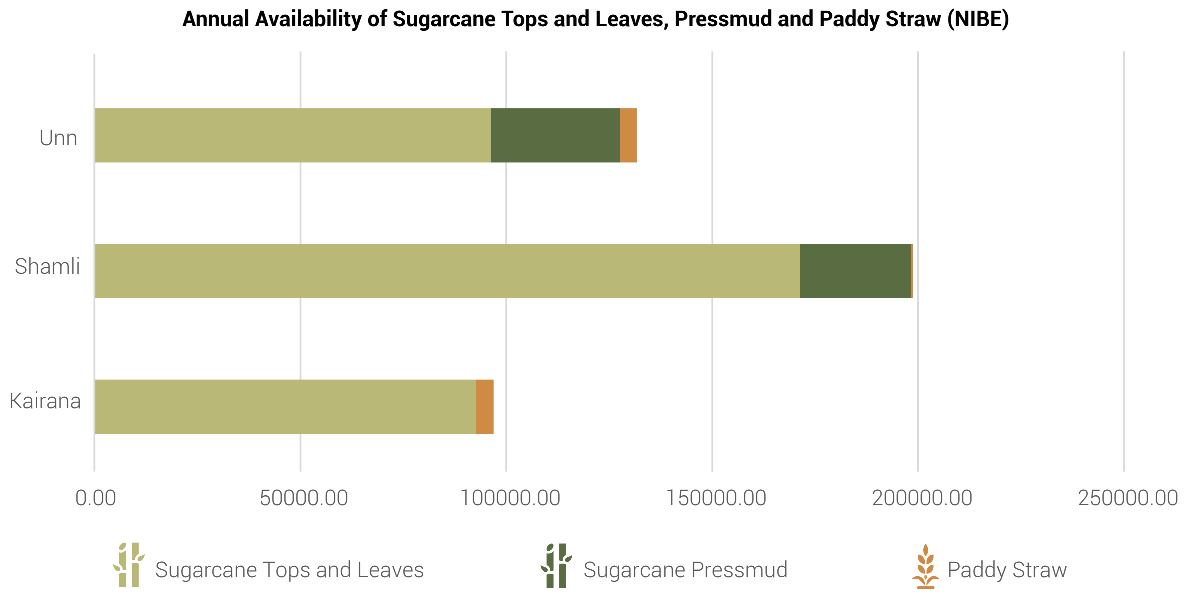
83 Pandey K.C. and Roy A.K., 2011. p.23, Forage Crops Varieties, Indian Grassland and Fodder Research Institute (IGFRI)

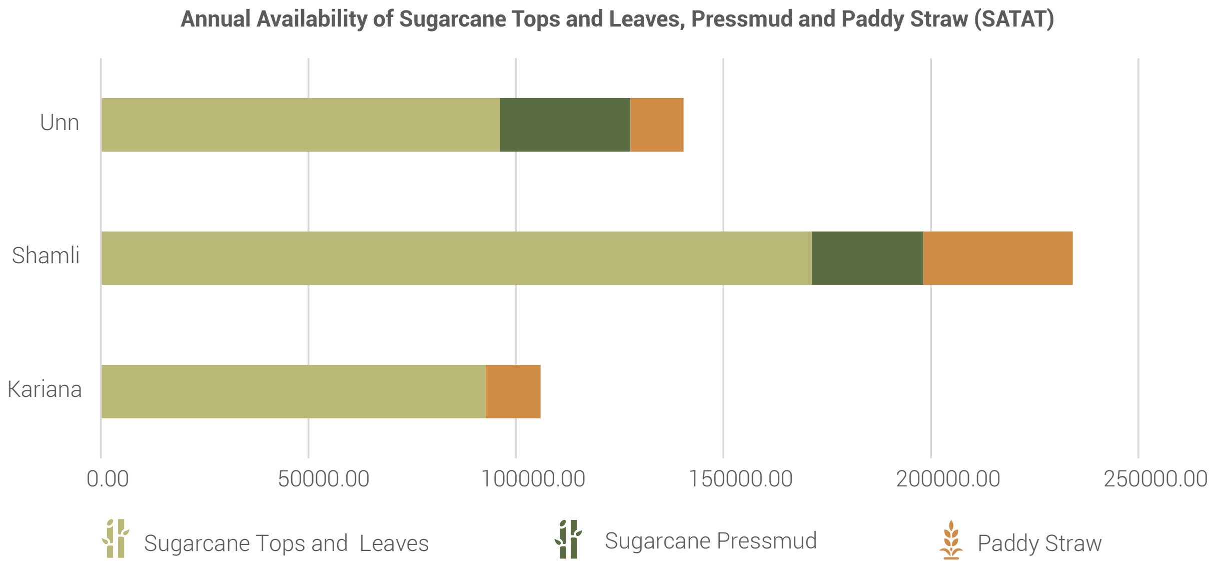
09

Biomass Quantification Results

9.1 Total Biomass Availability by Category

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





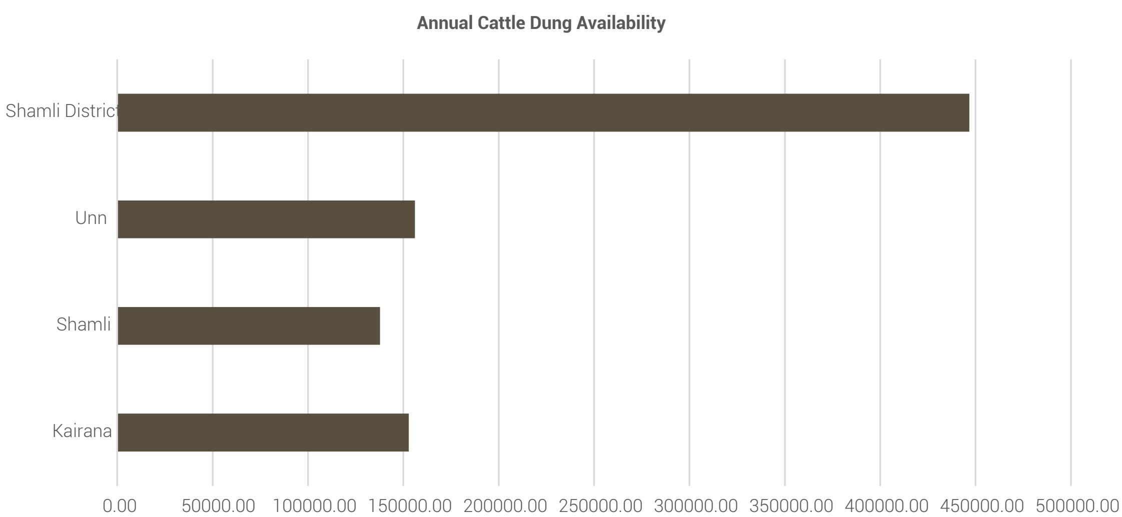


Figure 24: Tehsil-wise annual availability of sugarcane leaves, paddy straw, press mud and cattle dung

9.2 Variations in Biomass Availability and Pricing

The availability and generation of sugarcane press mud have varied over the years. From the figures *Fig.25 & Fig. 26*, the variation in availability of press mud in all the sugar mills can be attributed to the varying quantities of sugarcane crushed annually in these mills. *Fig.27* depicts the year-on-year change in press mud that is generated. The reasons that can be attributed to varying production could be due to adverse weather conditions (drought and excessive rainfall), crop diseases, etc. This condition is prevalent across the State. This can affect the pricing of the press mud. Based on the data that was shared by the Cane Commissioner, the cost of press mud for all sugar mills hovered between INR 25 to 45 per quintal during 2022-25.

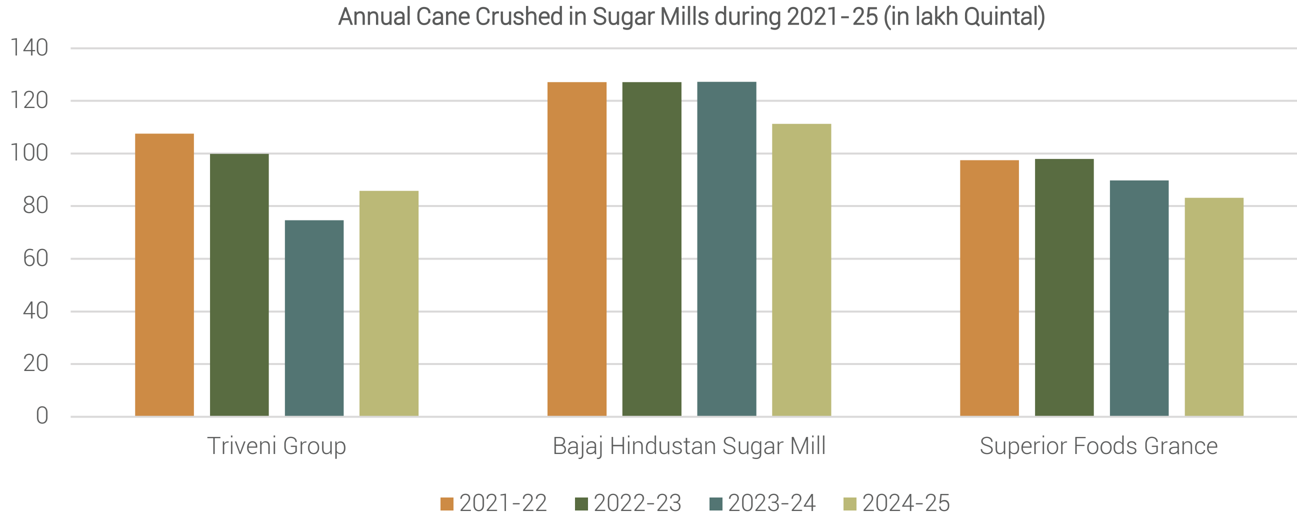


Figure 25: Annual cane crushed in sugar mills during 2021-25[84]

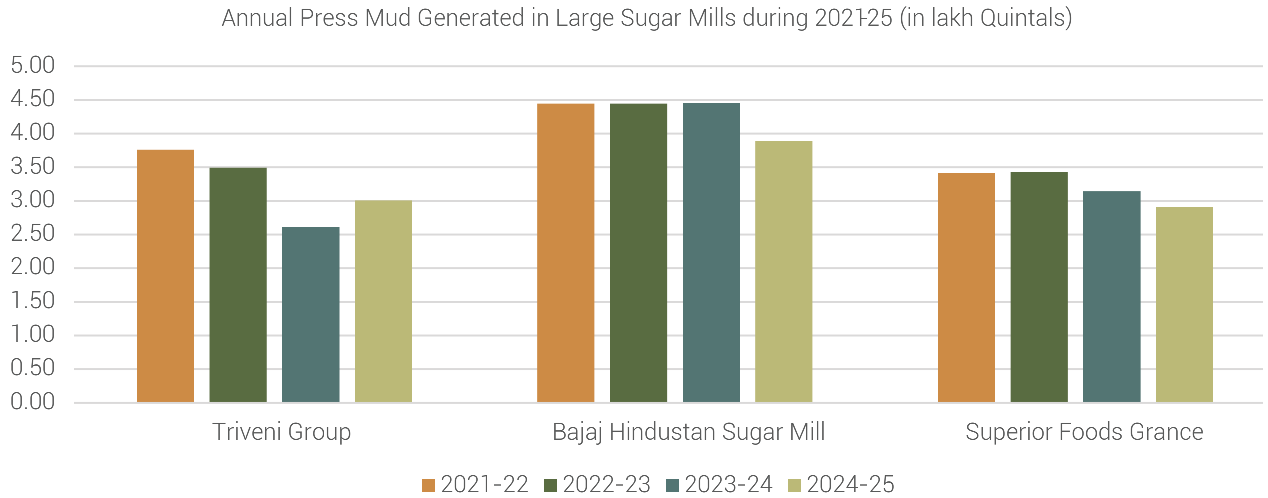


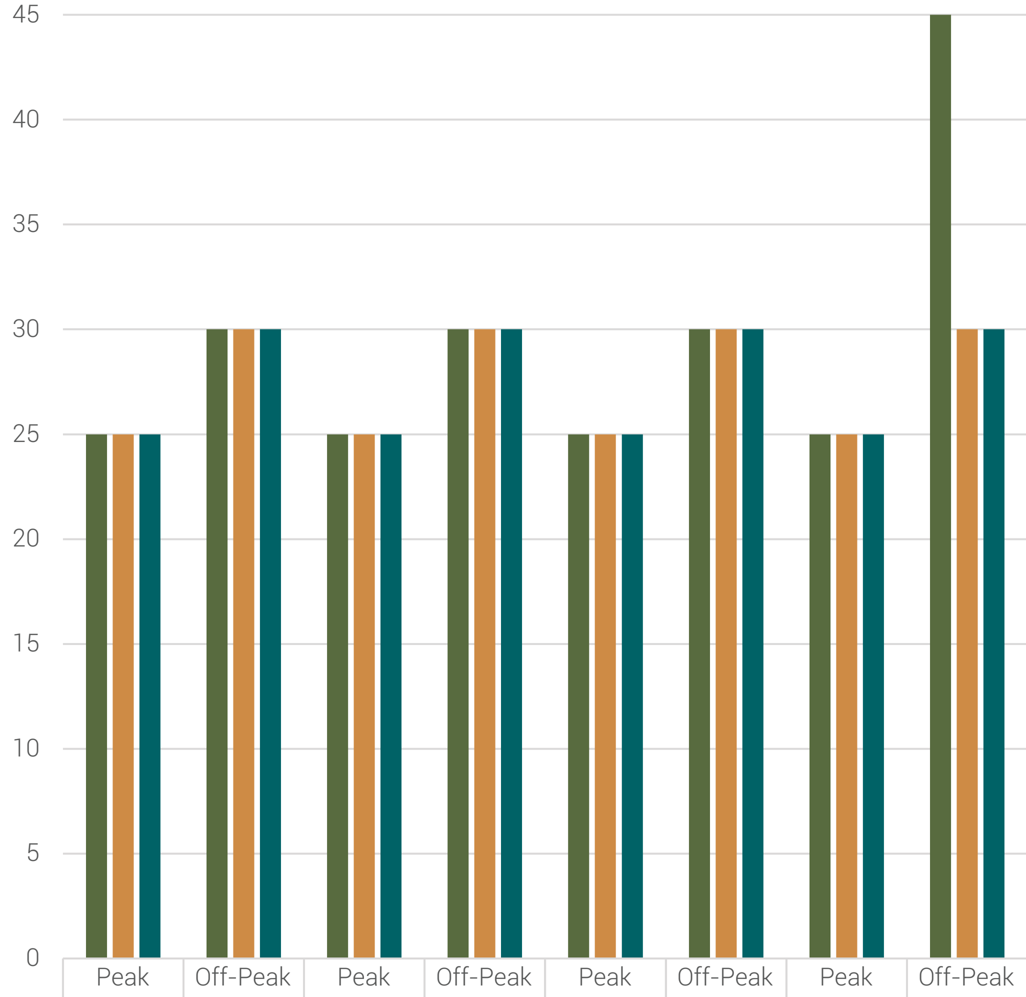
Figure 26: Annual press mud generated in sugar mills

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

Figure 27: YoY change in annual cane crushed and press mud generated during 2021-25

It can be observed from *Figure 28* that the press mud price varies significantly in a year. A typical sugar mill runs only for 180 days in a year during the kharif season (mid-November to April). This season is characterised as a peak season. During this period, the price of sugarcane press mud is usually lowest in the year. As we move to non-sugar or off-peak season, price for press mud spikes. The reasons for the spike in price include: high demand for supply of press mud, shortage in availability of coal, high temperature, etc. As temperature increases, quality of press mud increases due to low moisture content. In speaking with the sugar mill operators following reasons were identified for fluctuations in press mud prices during the year 2020-25:

- Price varies from plant to plant based on the operating efficiency, cane crushing capacity, quality of press mud that is generated (usually press mud with low sulphur content is preferred and is priced higher)
- Sugar Mills use coal as a supplementary fuel to run their co-generation unit and in seasons where the coal availability or its price is not favourable, press mud is captively used for cogeneration which reduces the surplus pressmud
- Price also varies between sugar and non-sugar season in a particular year. Usually, it remains low in winter and increases as the temperature increases



	2021-22 Peak	2021-22 Off-Peak	2022-23 Peak	2022-23 Off-Peak	2023-24 Peak	2023-24 Off-Peak	2024-25 Peak	2024-25 Off-Peak
Triveni Group	25	30	25	30	25	30	25	45
Bajaj Hindustan Sugar Mill	25	30	25	30	25	30	25	30
Superior Foods Grance	25	30	25	30	25	30	25	30

Figure 28: Press mud price variations[85]

9.3 High-Potential Zones for Biomass Supply and CBG Production

It can be observed that Shamli has the highest sugarcane cultivation and hence, sugarcane leaves. However, Unn tehsil has the highest pressmud availability and corresponding CBG potential. Significant paddy straw available in Behat and Shamli are consumed by the existing CBG plants.

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:

85 Entries 'zero' or 0 indicate that there was no sale of pressmud or the data was unavailable with the sugar mill

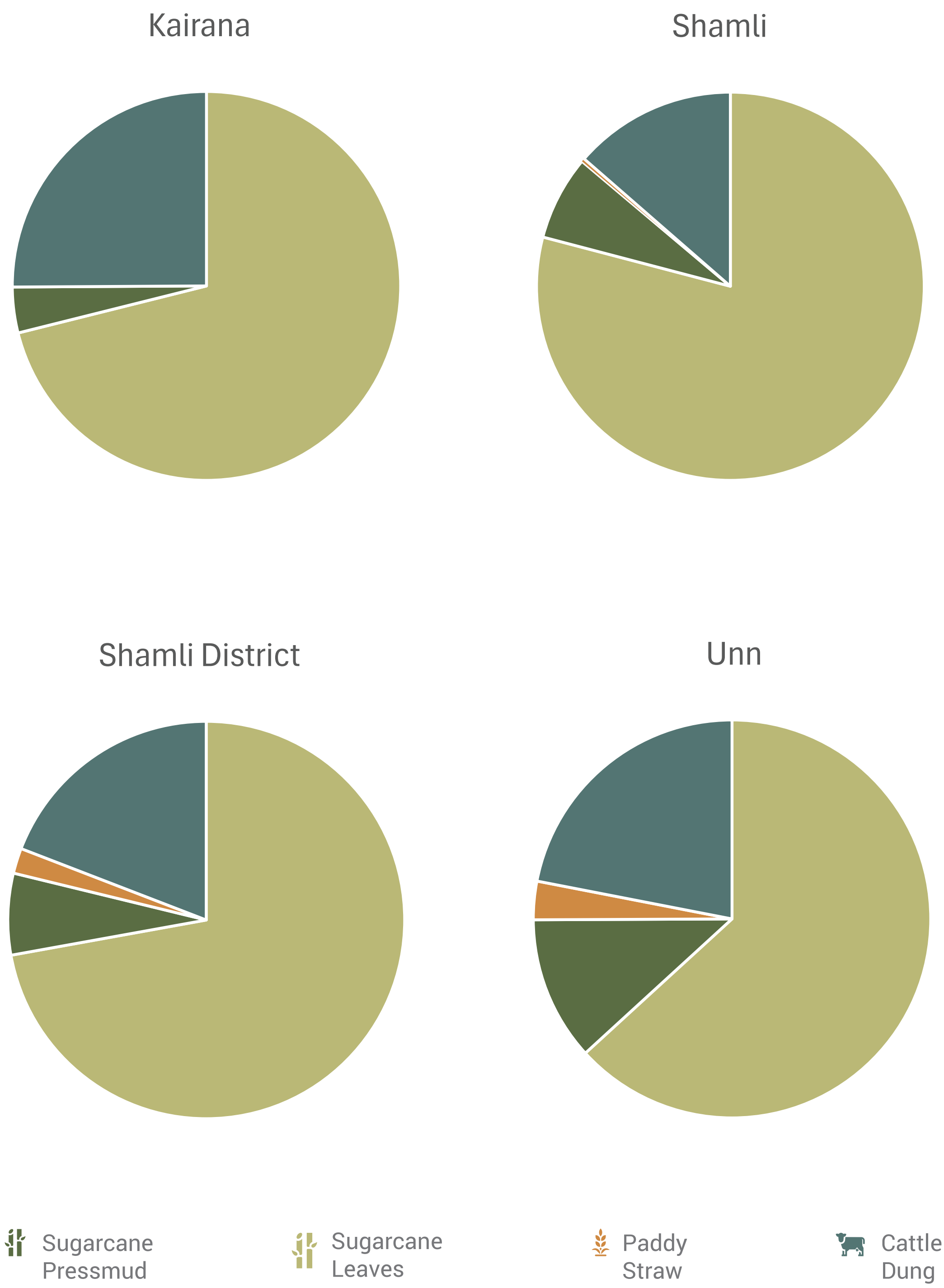


Figure 29: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, sugarcane leaves, cattle dung, and sugarcane press mud (as per NIBE estimates)

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

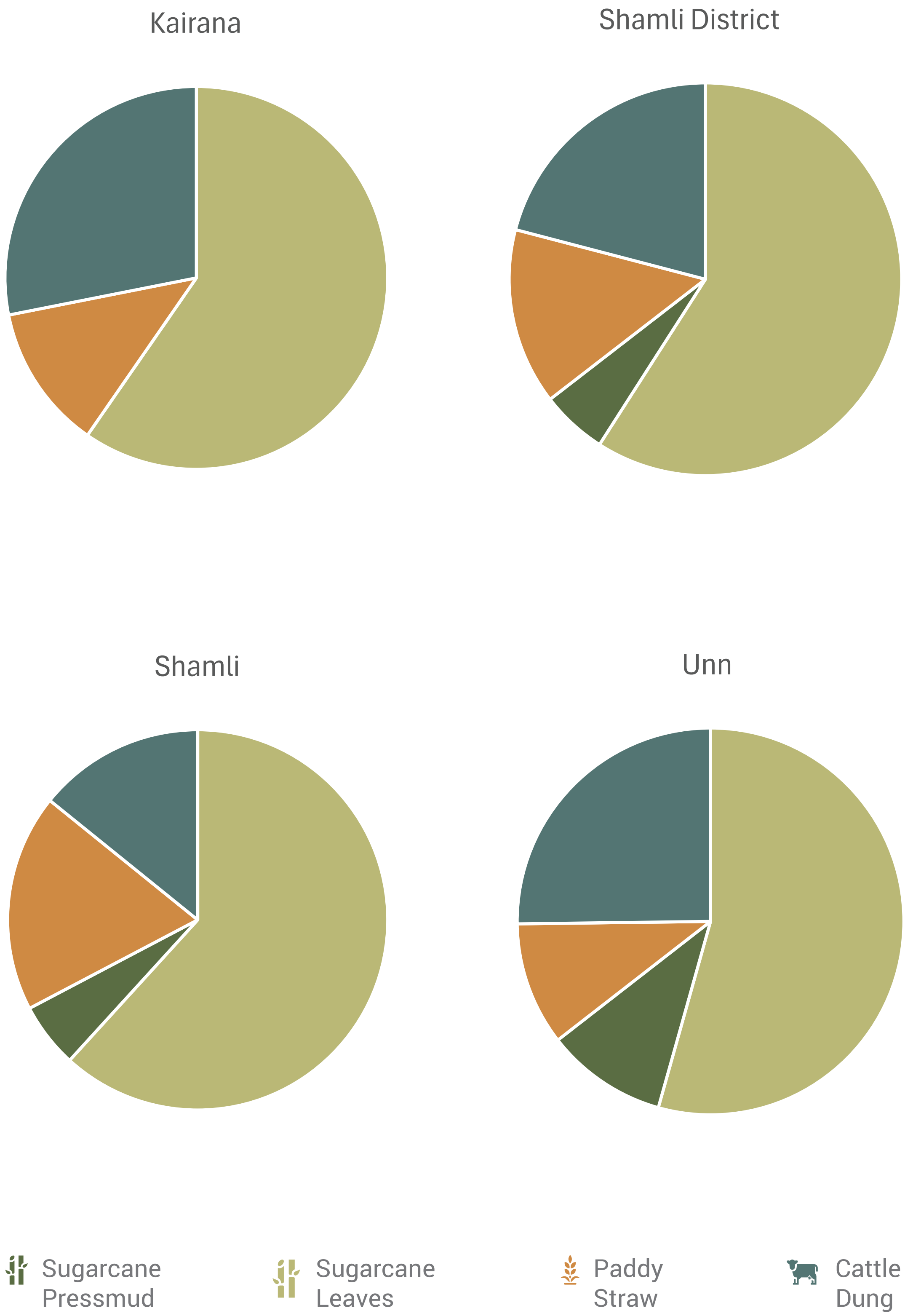


Figure 30: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, Sugarcane leaves, cattle dung, and sugarcane press mud (as per SATAT estimates)

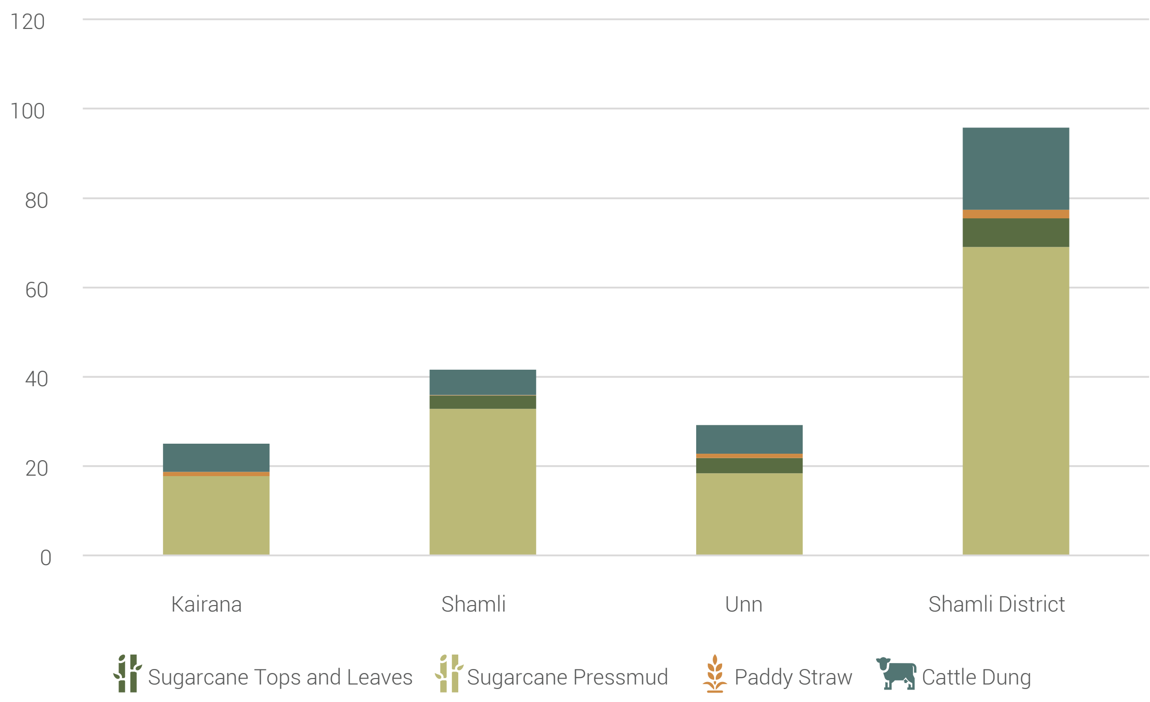


Figure 31: CBG potential from major feedstocks (NIBE estimates)

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

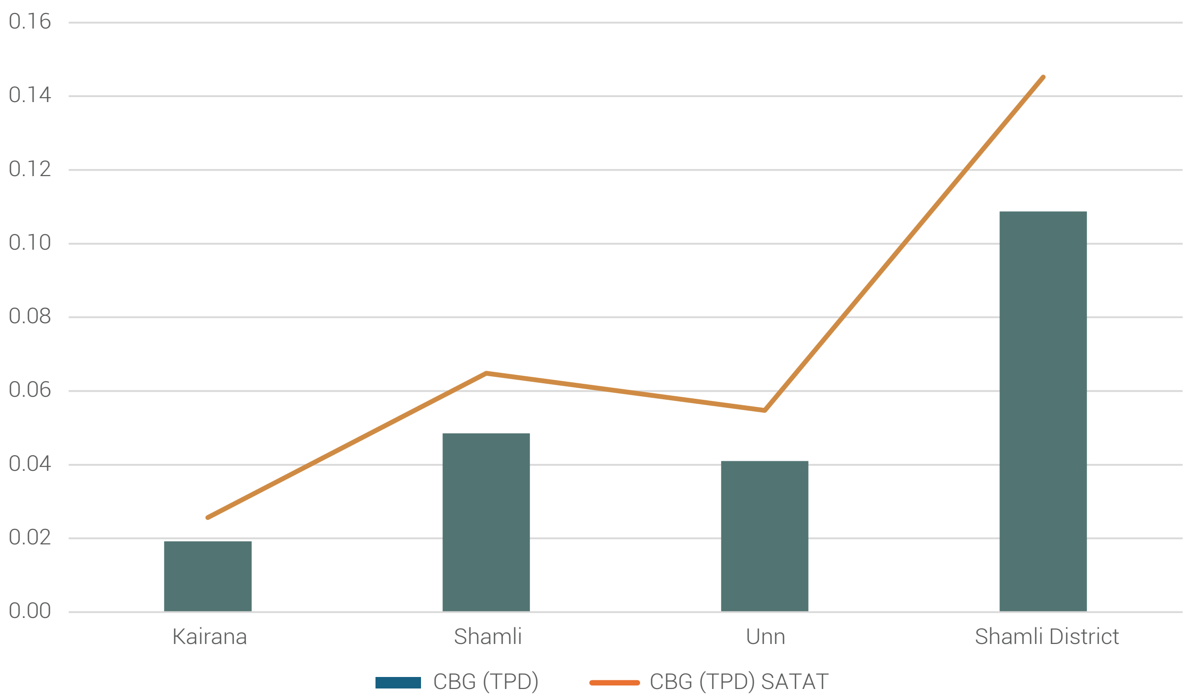


Figure 32: Tehsil-wise CBG potential from cattle sheds

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 Fig 35), including the quantity and variety of organic waste to be processed, the primary objective of waste treatment, demand for CBG, consumption patterns, local environmental conditions such as soil type and groundwater levels, regional climate factors like temperature and seasonal wind patterns, and the expertise level of the operational staff. This multifaceted approach ensures that CBG plants are optimised for efficiency, sustainability, and adaptability to local conditions.

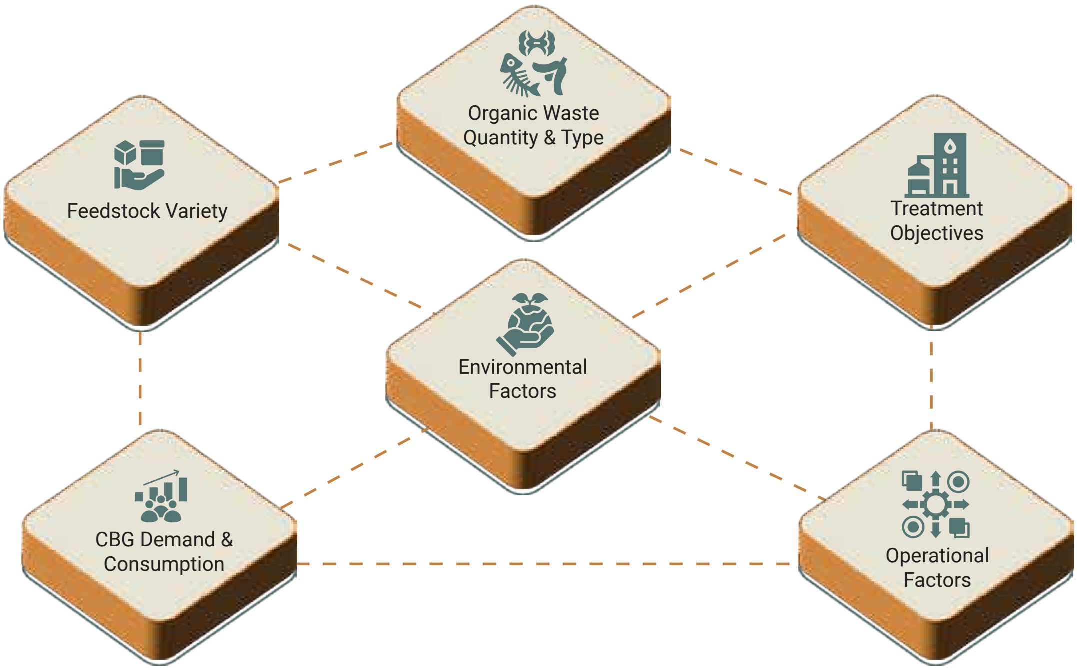


Figure 33: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

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

Table 28: Potential daily generation of CBG as per NIBE and SATAT estimates

Tehsil	Sugarcane Leaves	Sugarcane Pressmud	Paddy Straw	Cattle Dung	Total
Kairana	17.77	0	0.95	6.27	24.99
Shamli	32.86	2.93	0.11	5.653	41.553
Unn	18.45	3.42	0.91	6.407	29.187
Shamli District	69.08	6.35	1.97	18.33	95.73

Tehsil	Sugarcane Leaves	Sugarcane Pressmud	Paddy Straw	Cattle Dung	Total
Kairana	17.77	0	3.65	8.375	29.795
Shamli	32.86	2.94	9.85	7.547	53.197

Kairana	17.77	0	3.65	8.375	29.795
Shamli	32.86	2.94	9.85	7.547	53.197

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, Shamli district has a CBG potential of approximately 95 TPD based on the biomass available during the year 2023-24 and also on the net biomass available after considering the existing biomass-based industries. Out of all the Tehsils, Shamli tehsil has the highest potential for CBG production with sugarcane leaves and sugarcane pressmud contributing more than 80% of its total feedstock. Unn leads after Shamli with approximately 29 TPD of CBG production. At the end, it is crucial to note that the CBG quantification was conducted under ideal conditions. In reality, actual CBG production is influenced by several key operational parameters, including optimal temperature, pH levels, moisture content, toxicity levels, carbon-to-nitrogen (C/N) ratio, organic loading rate, and retention time. This underscores the importance for developers/investors to consider these multiple factors to maximise CBG yield.

10 Recommendations

1. Shamli has a high theoretical potential for CBG with sugarcane leaves and paddy straw as its major feedstock. It is important to ensure that CBG plants are designed to handle combination feedstocks with paddy straw, Napier grass and cattle dung that can support year-round plant operation and maximises biogas yield. Among the feedstocks that were considered for the study, for a given quantity of biomass residue, press mud has the highest CBG yield.
2. Availability of appropriate biomass and reliable supply chain are indispensable for sustainability and financial feasibility of a CBG plant. Harvestable crop residues per unit of land also depend on region-specific crop production practises. Farmer's willingness to collect crop residues depend critically on the yields and on the biomass, prices provided in the market.[86]
3. A beneficial, reliable, and transparent pricing and payment mechanism can incentivise collection and availability of biomass. This would establish a biofuel-led economy that can offer unique opportunities for farmers, enhance their regular incomes by turning waste into wealth. This additional stream of income can be particularly beneficial during times of market volatility or poor harvests of traditional crops and continue to drive economic growth at grassroot level.
4. Encourage farmers to use bio-slurry from CBG plants as an organic fertiliser to improve soil health and crop productivity. Implement comprehensive training programs to educate farmers on its benefits and proper application methods. Additionally, provide hands-on demonstrations and success stories to encourage adoption. Establish support networks and incentives to facilitate widespread usage and long-term sustainability.

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

5. CBG/Bio-fuel plant has to be designed, and tailor-made based on the crop residues for which the long-term availability is guaranteed based on forecasting and observing past trends.[87] Sugarcane and paddy have been dominant kharif crops for a long period of time and will continue to do so. From Agriculture Production Statistics, we can infer that sugarcane production has been on a steady rise with an average YoY growth rate of approximately 65 percent.
6. Explore the installation of Agricultural Photovoltaics (AgriPV) systems on fallow land to establish a conducive microclimate, promoting land reclamation for cultivation. These systems can support the growth of crops like Napier grass by improving soil moisture retention, minimising evapotranspiration, and offering partial shade. By harnessing AgriPV technology, farmers can optimise land use, enhance agricultural resilience, and increase overall productivity.
7. Examine ways to assist farmers in integrating AgriPV systems within horticultural zones to improve crop yields and biomass production. Research has shown that certain crops, including leafy greens and shade-tolerant vegetables, thrive under AgriPV systems, leading to enhanced growth and increased biomass availability for CBG generation. Supporting this initiative can optimise land use while promoting sustainable energy and agriculture.
8. For viable operations of CBG plant, logistics is key which can include residue harvest, collection, storage, transportation, etc. These are spatially interlinked and need meticulous planning. Barren lands or Fallow lands around the sugar mills (in 3-5km radius) can be identified for development of CBG projects. Proximity to cowsheds, poultry farms, and off-takers can also be mapped. For example, Petrol or Gas stations are potential off takers for CBG. Cultivation of energy crops like Napier grass should be prioritised only after considering the local biodiversity concerns.

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

9. Dedicated biomass banks can be established either through a third-party agency or through existing institutions like FPOs that can ensure collection and storage of residues after harvest. Considering the seasonal availability of crop residues, efficient contingency planning should be in place in the event of supply shortage linked to any extreme event such as pandemic or climate-linked disaster. This can potentially cut off the supply chain and can leave the plant operations

87 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)

stranded. To ensure continuous operations, storage of excess crop residues can be planned either in-house or through an agency where the storage time could be decided based on the useful life of the residue. For example, press mud can last no longer than 60 days, so they can be organised in a live storage while paddy straw which can sustain longer can go into a dead storage. Feedstocks like paddy straw involves careful handling to preserve its energy value and prevent degradation due to microbial activity, moisture, or fire hazards.

NOTES

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