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

UTTAR PRADESH

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UTTAR PRADESH

Contents

List of Tables vi

List of Figures v

1. Executive Summary 01

2. Introduction 04

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) 19

3.5 Agricultural Overview 20

3.6 Forest Resources 23

3.7 Livestock Population 24

3.8 Industry and Processing Units 26

4. Data Collection 27

4.1 Primary Data Collection 27

4.2 Secondary Data Collection 28

5. Stakeholder Mapping 31

5.1 Identification of Relevant Stakeholders 31

6. GIS-based Satellite Mapping 33

6.1 Cropping Pattern and Analysis 33

6.2 Land Use and Biomass Distribution Mapping 35

7. Methodology 37

7.1 Agricultural Residue 37

7.2 Livestock Residue 41

8. Biomass Category, Sources and Availability 42

8.1 Agricultural Residues 43

8.2 Animal Waste 52

8.3 Energy Crops 54

8.4 Other Types of Biomass 54

9. Biomass Quantification Results 55

9.1 Total Biomass Availability by Category 61

9.2 High-Potential Zones for Biomass Supply and CBG Production 56

10. Recommendations 62

List of Tables

Table 1 : Tehsil-wise, feedstock-wise CBG potential in TPD 02

Table 2 : Potential availability of biomass in Uttar Pradesh 07

Table 3 : Different feedstock and their biomass residues 09

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

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

Table 6 : District agricultural and climate profile of Lucknow 17

Table 7 : Productivity of food grains in different agro-climatic zones of Uttar Pradesh 18

Table 8 : Agricultural land area and cropping intensity in Lucknow district 21

Table 9 : Tehsil-wise cropped area of *Rabi* crops (in ha) during 2023-24 22

Table 10 : Tehsil-wise production of *Kharif* crops (in ha) during 2023-24 22

Table 11 : Sowing pattern for major *Kharif* and *Rabi* crops which are both irrigated and rainfed 23

Table 12 : Total forest area (by classification) in Lucknow 23

Table 13 : Tehsil-wise livestock statistics and cattle in cowsheds 24

Table 14 : Animal categories and their dung/litter generation potential 25

Table 15 : Details of existing biomass-based industries in Lucknow 26

Table 16 : Residue-to-crop ratio and surplus fraction for various agricultural residue 28

Table 17 : Biogas yield for various feedstocks as per NIBE estimates 29

Table 18 : Conversion factor for surplus biomass residue calculation of animals 29

Table 19 : Calorific values for animal residue 29

Table 20 : Tentative CBG yield from various feedstocks 30

Table 21 : Stakeholders in bio-energy value chain 32

Table 22 : Tehsil-wise land-use analysis for Lucknow in hectares 35

Table 23 : Tehsil-wise surplus biomass and potential CBG generation for various agricultural residue 43

Table 24 : Tehsil-wise surplus biomass residue and potential CBG generation from various animal residues 52

Table 25 : Potential daily generation of CBG as per NIBE and SATAT estimates 60

List of Figures:

Figure 1 : Source-wise renewable power potential in India, 2023 05

Figure 2 : State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23 06

Figure 3 : Biomass power potential in India 06

Figure 4 : State-wise total biomass production, biomass utilisation, and surplus biomass potential 07

Figure 5 : Classification of biofuels 08

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 : Processflow diagram for a compressed biogas plant 13

Figure 9 : District map of Lucknow as per the 2011 census 16

Figure 10 : Agro-climatic zones in Uttar Pradesh 19

Figure 11 : Agricultural land holdings in Lucknow 20

Figure 12 : Crop yield during 2020-23 for major crops sown in Lucknow during *Kharif* and *Rabi* ... 21

Figure 13 : Traditional use of cow-dung as kitchen fuel and manure 25

Figure 14 : Geographical spread of *Kharif* crops in tehsils of Lucknow district during 2023-24 34

Figure 15 : Geographical spread of *Rabi* crops in tehsils of Lucknow district during 2023-24 34

Figure 16 : Land cover analysis for tehsils of Lucknow district during 2023-24 36

Figure 17 : Flow diagram of the methodology used 38

Figure 18 : Flow diagram for crop residue estimation 39

Figure 19 : Crop residue management practices 40

Figure 20 : Tehsil-wise annual availability of paddy straw, press mud and cattle dung 56

Figure 21 : Tehsil wise daily CBG generation potential for major feedstocks: 4 Paddy straw, cattle dung, and sugarcane press mud (as per NIBE estimates) 57

Figure 22 : Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per SATAT estimates) 58

Figure 23 : CBG Potential from major feedstocks (NIBE estimates) 59

Figure 24 : Tehsil-wise CBG potential from cattle sheds 59

Figure 25 : Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants 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 Lucknow district, has a moderate potential for biomass-based Compressed Biogas (CBG) production from its biomass resources.

Biomass Availability and CBG Potential in Lucknow

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

- **Major Biomass Feedstocks**: Paddy straw, and cattle dung emerge as the major biomass feedstock
- **High-Potential Zones**: Mohanganj and Bakshi ka Talab emerge as the top biomass source. The tehsils have high paddy straw availability.

- **CBG Generation Potential**: The district has the potential to generate approximately 11.884 tonnes per day (TPD) of CBG from major feedstocks, such as, paddy straw, and cattle dung, thereby contributing to the goal envisioned under the SATAT (Sustainable Alternative Towards Affordable Transportation) Scheme, which envisions installing 5,000 CBG plants by 2030.

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

Tehsil	Paddy Straw	Cattle Dung	Total
Mohanlal Ganj	2.36	2.28	4.64
Bakshi ka Talab	1.15	1.05	2.2
Sarojani Nagar	1	0.57	1.57
Malihabad	0.74	1.55	2.29
Lucknow (Sadar)	0.24	0.944	1.184
Lucknow District	5.49	6.394	**11.884**

- **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 11.884 TPD CBG plants can abate approximately 11,928.5 T CO_2 emissions annually[1].
  - In other words, 11.884 TPD of CBG can replace 11.884 TPD of CNG which will correspond to daily carbon emission savings of 32.681 T of CO_2.
- **Supply Chain Considerations**: Efficient logistics and storage solutions are essential for sustainable biomass utilisation.

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

Recommendations

1. **Hybrid Feedstock Utilisation**
   - Encourage blending of paddy straw, 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 (within 3-5 km radius) for setting up of CBG plants.
   - Locate plants close to cowsheds, poultry farms, and fuel stations to optimise feedstock procurement and CBG distribution.

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

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

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

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

02

Introduction

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

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

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

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

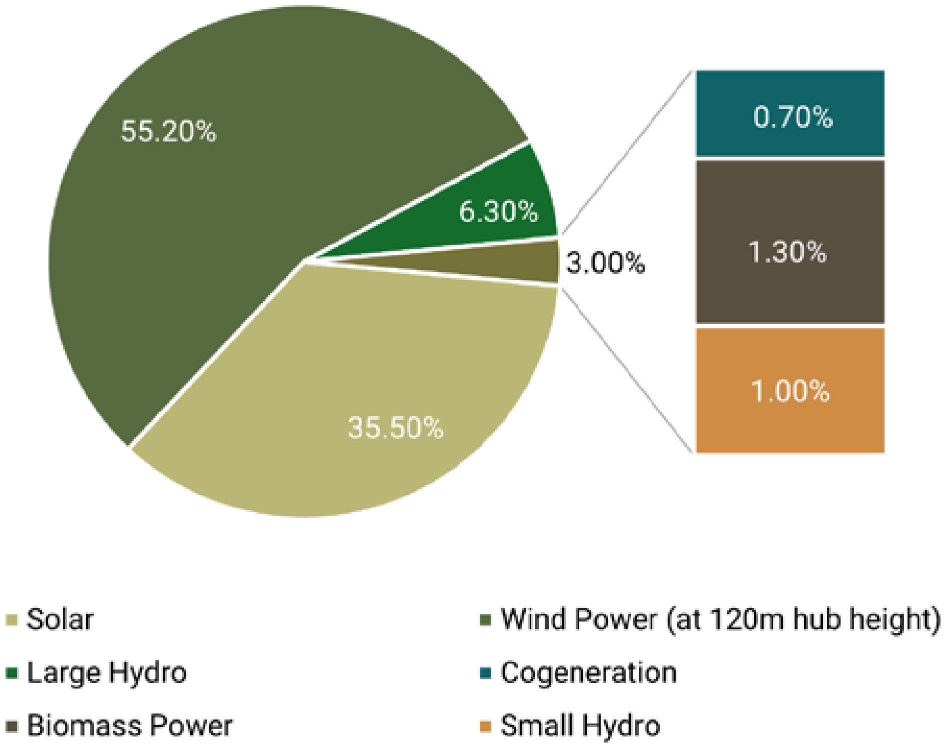


Figure 1: Source-wise renewable power potential in India, 2023[5,6]

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

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

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

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

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

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

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

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

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

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

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

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

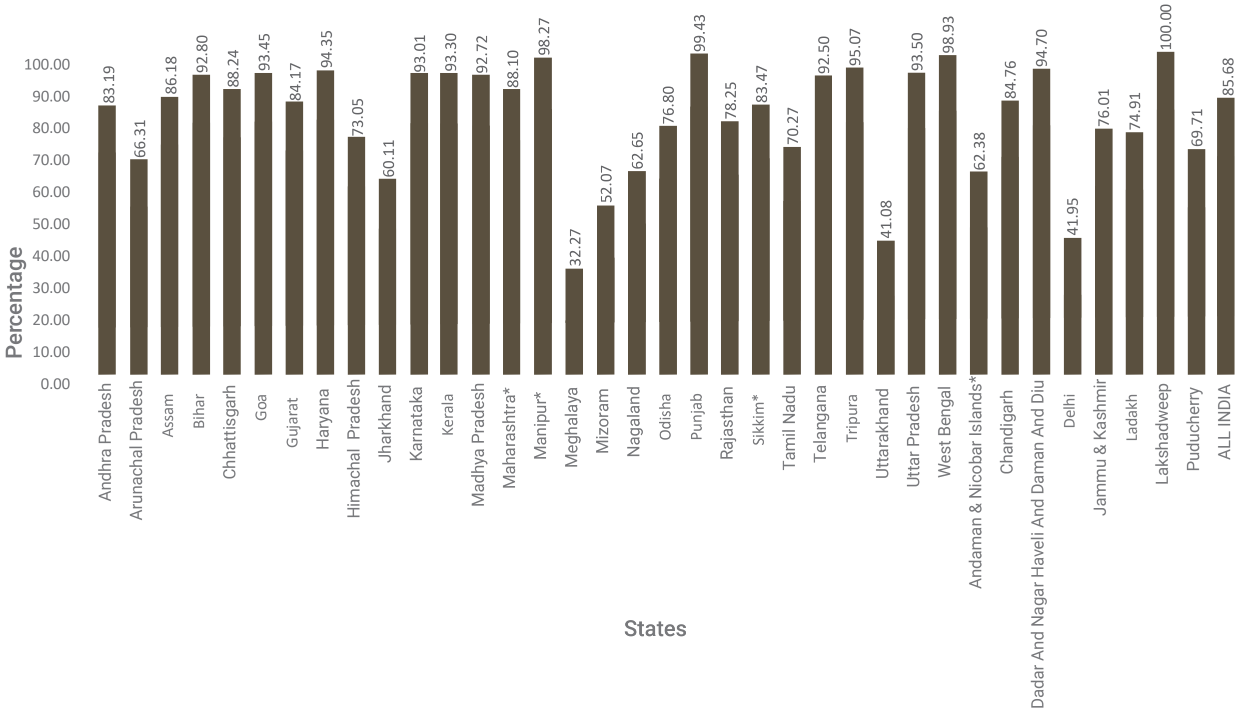


Figure 2: State-wise percent of cultivated land to the total agricultural/cultivable land during 2022-23[15]

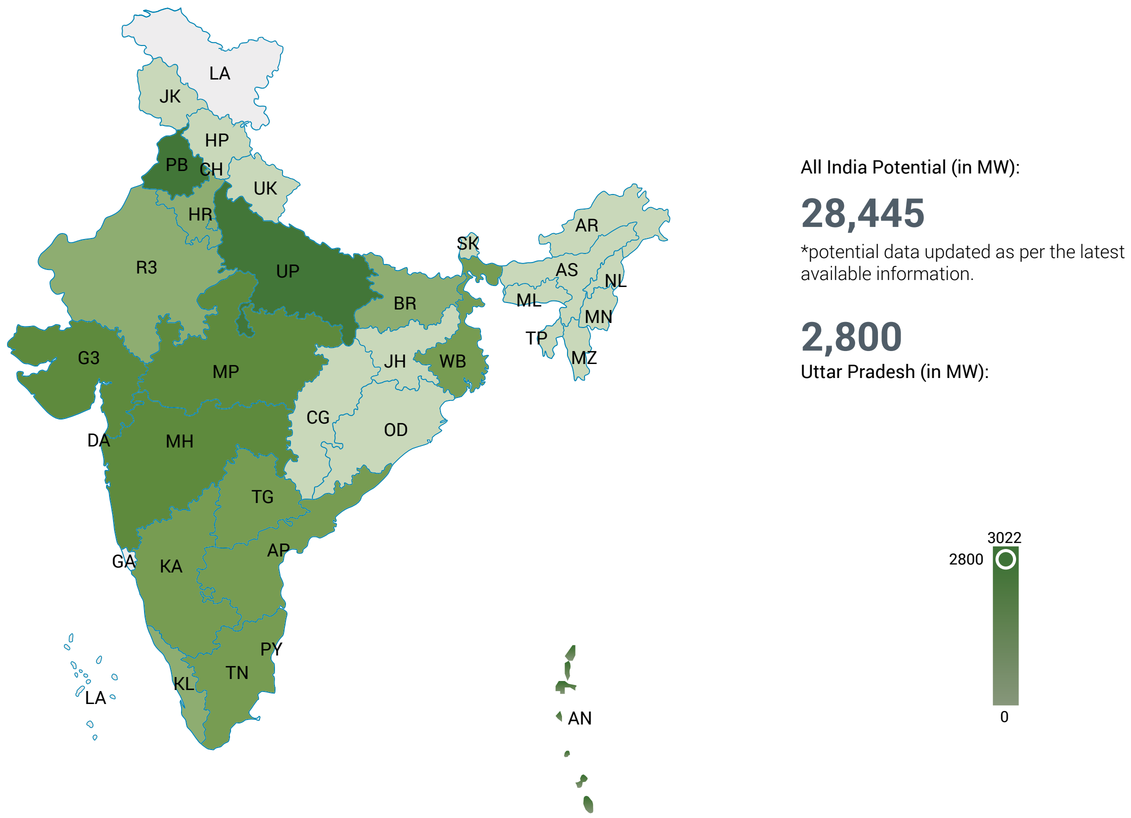


Figure 3: Biomass power potential in India[16]

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

16 India Climate and Energy Dashboard (ICED) 2025

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

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

Table 2: Potential availability of biomass in Uttar Pradesh

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

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

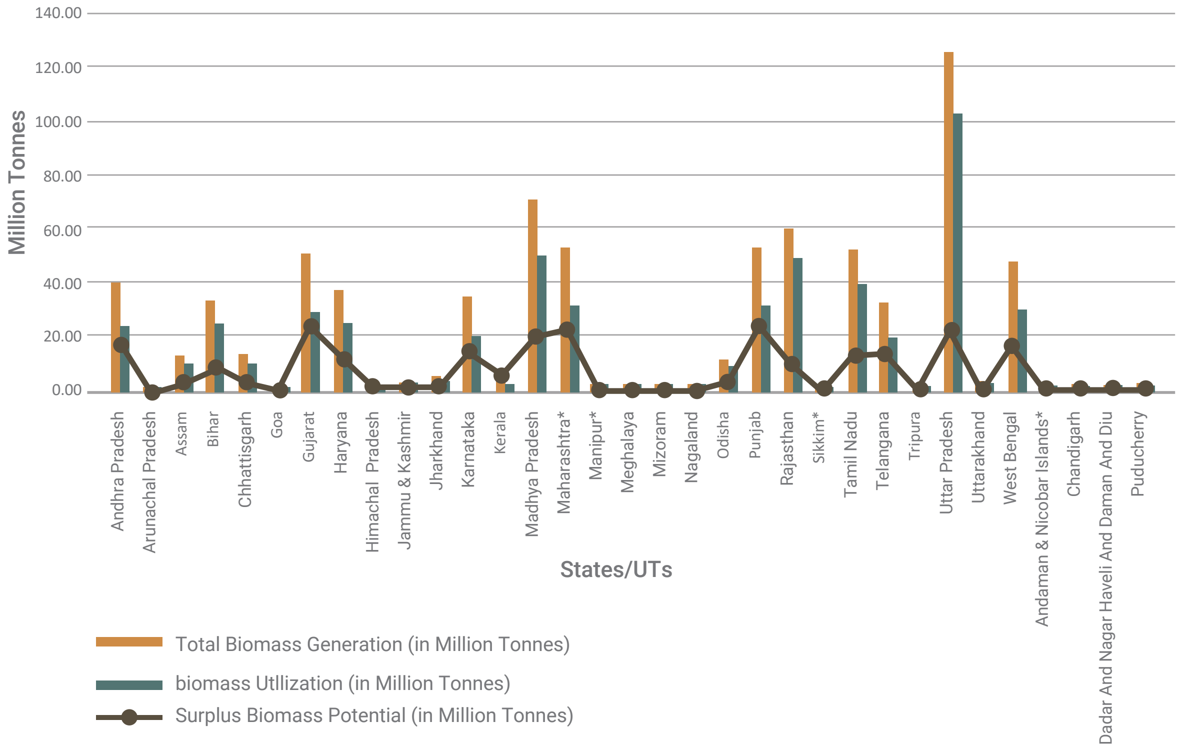


Figure 4: State-wise total biomass production, biomass utilisation, and surplus biomass potential[19]

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

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

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

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

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

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

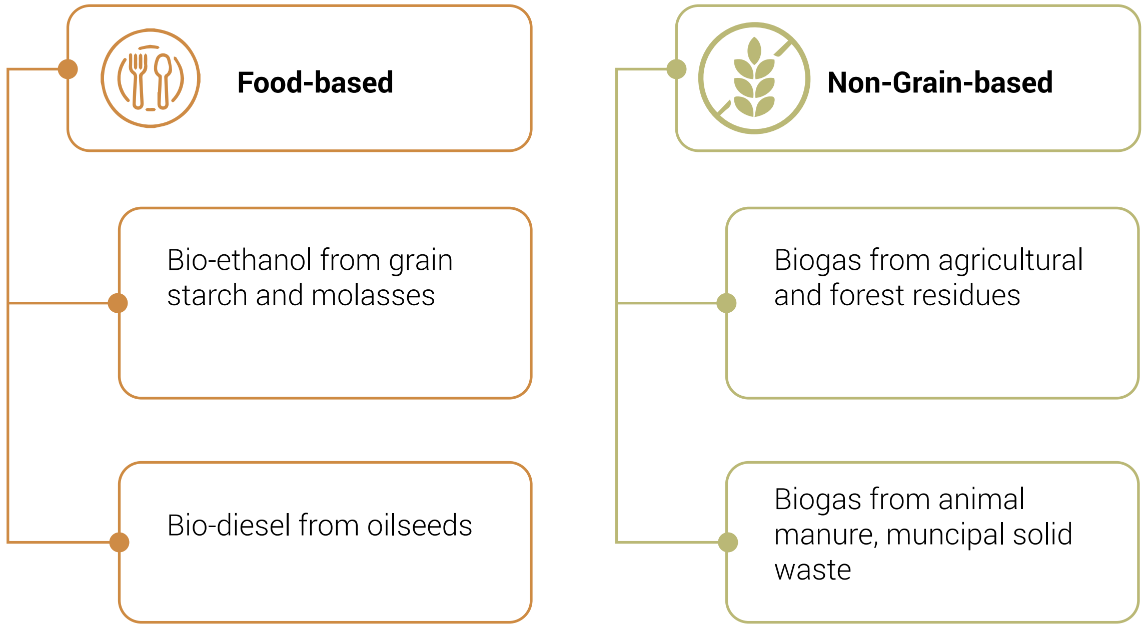


Figure 5: Classification of biofuels

2.1 Scope of the Study

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

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

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

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

Table 3: Different feedstock and their biomass residues

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

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

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

2.2 Importance of Biomass Quantification

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

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

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

2.3 Overview of Compressed Biogas (CBG) Industry

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

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

Figure 6: Bio-chemical process flow for biogas production

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

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

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

Table 4: Chemical composition of raw biogas vs. CBG

Composition	Raw Biogas	Bio-CNG/CBG
Methane	55-65 percent	>90 percent
Carbon dioxide	30-40 percent	<4 percent
Hydrogen sulphide	0.1-4 percent	<16 ppm
Nitrogen	3 percent	<0.5 percent
Oxygen	0.1-2 percent	<0.5 percent
Moisture	1-2 percent	0 percent
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 percent
Carbon dioxide (max)	4 percent
Oxygen (max)	0.5 percent
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 its thermal efficiency and storage stability.[26] After the substrate is homogenised and dewatered, it is preheated in a preparation tank before it is actually fed into a digester.[27]

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

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

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

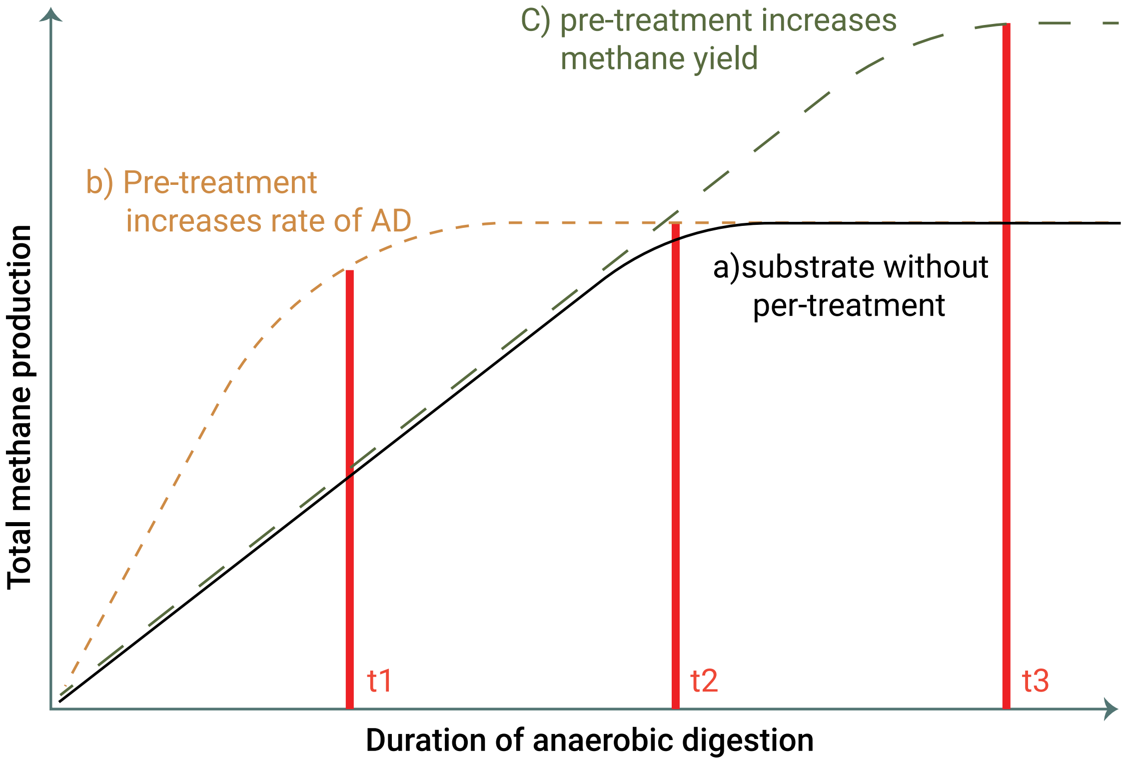


Figure 7: Pretreatment method can increase the rate of anaerobic digestion or can increase the methane yield[28]

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

28 IEA Bioenergy 2014

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

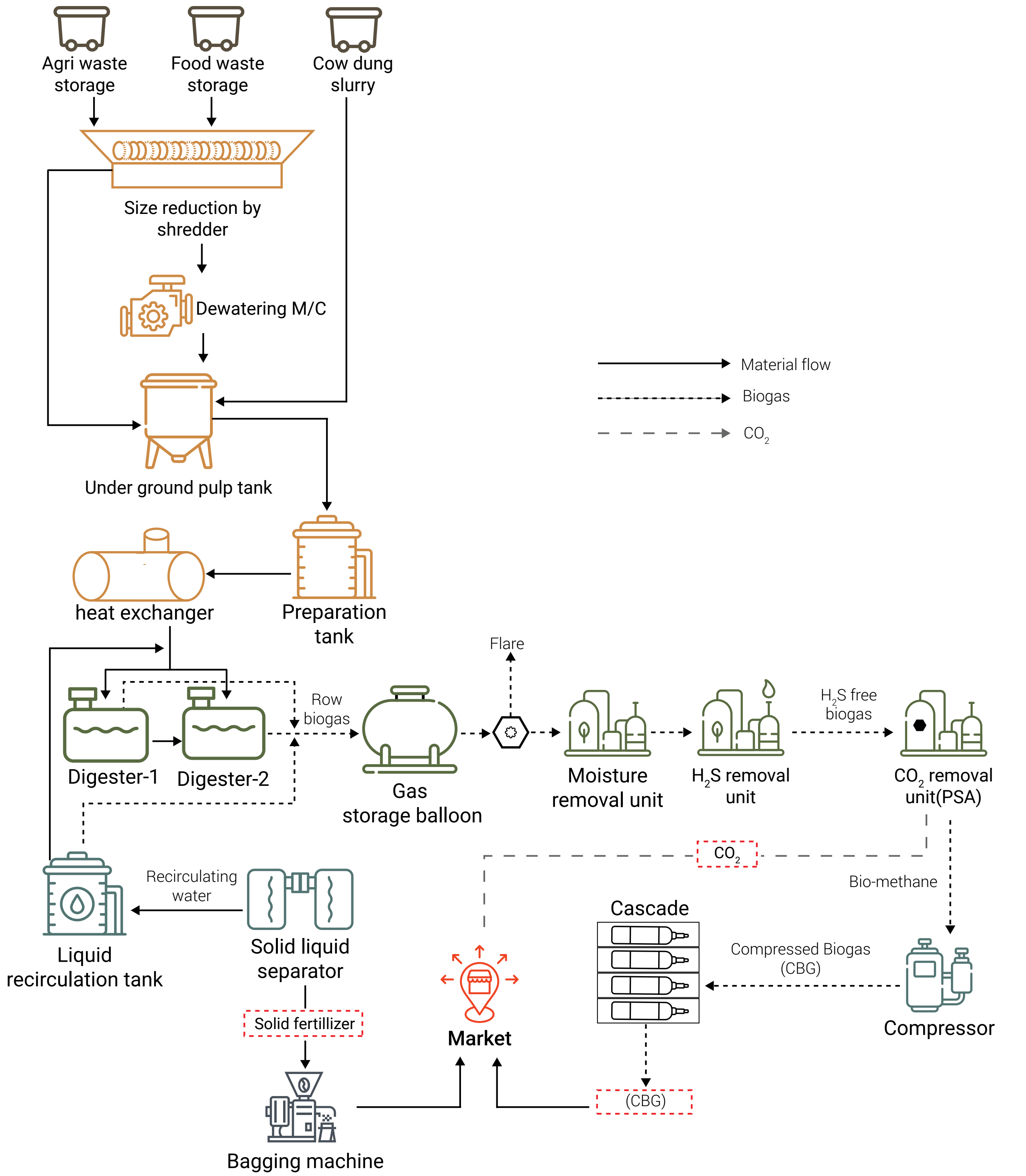


Figure 8: Process flow diagram for a Compressed Biogas Plant[30]

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

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

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

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

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

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

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

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

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

03 District Profile

3.1 Geographic Overview[36]

Lucknow is the capital and the largest city of Uttar Pradesh. The city stands at an elevation of approximately 125 m above sea level and spans over an area of 2,528 sq. kms. The city is located between 26°30′ and 27°10′ north latitude and 80°34′ and 81°12′ east longitude, bounded on the east by Barabanki, on the went by Unnao, on the south by Raebareli and in the north by Sitapur and Hardoi, the district sits on the north-western shore of the Gomti River. According to the census 2011 data, the district has a total population of around 45,89,838 with a population density of 1,816 inhabitants per sq. km.[37]

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

37 District Census Handbook, Lucknow, Census of India 2011 Part XII-A

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

3.2 Administrative Units (Tehsils/Blocks)

For administrative convenience, the district is divided into 4 sub-districts which are: Malihabad, Lucknow, Bakshi Ka Talab and Mohanlalganj. There are 807 villages in the district and 498 Gram Panchayats in the district[38].

38 District Census Handbook, Lucknow, Census of India 2011 Part XII-A

3.3 Climatic Conditions

The district is a situated in sub-tropical region. Accordingly, its climate is sub-tropical monsoon type. There are three main season-summer, rainy and winter. The summer season starts from March and continues up to June whereas Rainy season starts from July and continue till October and winter season from November to February. The maximum temperature recorded was 45.0°C and minimum was 3.6°C. The average rainfall recorded for was around 953 mm.[39]

Table 6: District agricultural and climate profile of Lucknow

District Agricultural and Climate Profile				
Agro-Ecological Sub Region[40] (ICAR[41])	Central Plain Zone[42]			
Rainfall[43]				
Season	**Average Annual Rainfall (mm)**	**Normal Rainy Days (no.)**	**Normal Onset**	**Normal Cessation**
Southwest Monsoon (June-September)	848.4	-	3rd week of June	3rd week of September
Post-monsoon (October-December)	46.1	-	-	-
Winter (January-March)	43.1	-	-	-
Pre-monsoon (April-May)	21.6	-	-	-
Annual	959.2	-	-	-
Temperature (in degree celsius)[44]	**Maximum**		**Minimum**	
	41.9		0.5	
Soil	Deep, fine soils moderately saline and sodic associated			
Major Climate Contingency and Frequency	**Regular**	**Occasional**		**None**
Drought				√
Flood				√
Cyclone				√

39 https://lucknow.nic.in/more-about-lucknow/

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

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

42 https://www.icar-crida.res.in/CP/Uttar_Pradesh/UP49-Lucknow-26.07.14.pdf

43 Agriculture Contingency Plan for district: Lucknow, 2014, Department of Agriculture and Farmers' Welfare (https://www.icar-crida.res.in/CP/Uttar_Pradesh/UP49-Lucknow-26.07.14.pdf)

44 https://updes.up.nic.in/esd/reports/diary percent20eng percent202022_full.pdf

District Agricultural and Climate Profile		
Hailstorm	√	x
Heat wave	√	x
Cold wave		√
Frost		√
Sea water intrusion		√
Sheath Blight, Stemborrer, Pyrilla loos smut, Heliothis, Rust etc white grub.		√

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

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

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

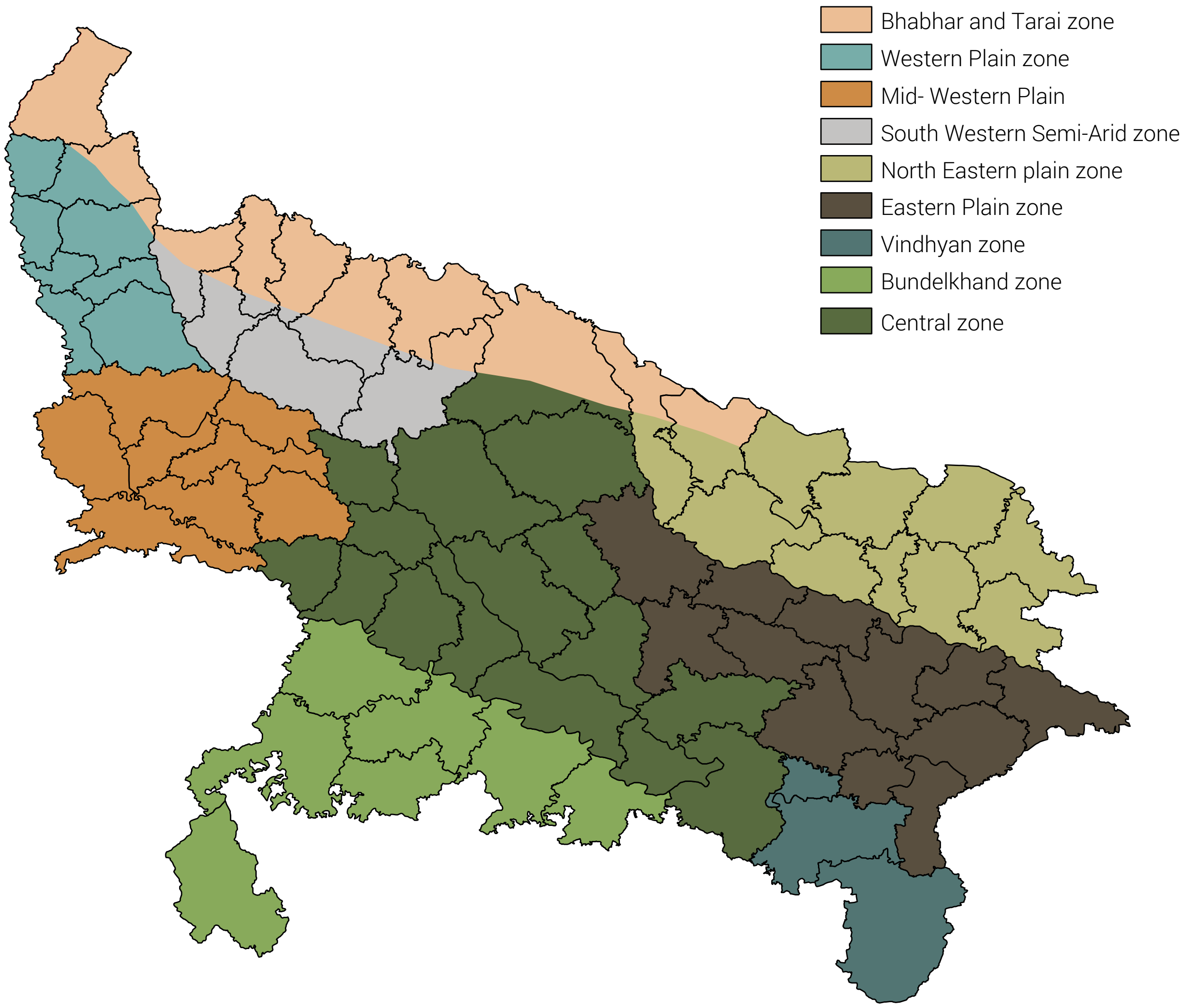


Figure 10: Agro-climatic zones in Uttar Pradesh[45]

3.4 Demographics (Urban/Rural)

The total population of Lucknow stands at 45,89,838, with approximately 33.8 percent residing in rural areas and 66.2 percent living in urban centres. Agriculture does not serve as the primary occupation in the district, with only 24.5 percent of the working population engaged as cultivators or agricultural labourers[44].

In terms of agricultural landholdings, 95.92 percent of the land holdings in the district were less than 2 hectares (ha) while only 3.76 percent of the holdings were between 2-4 ha, while less than 0.73 percent of holdings were 4 ha and above.[46] In terms of agricultural income, during 2022-23, the gross value of agricultural produce per ha of net area sown was INR 379813.30[47].

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

46 Statistical Diary, Uttar Pradesh 2022

47 District-wise development indicators, Uttar Pradesh, 2024

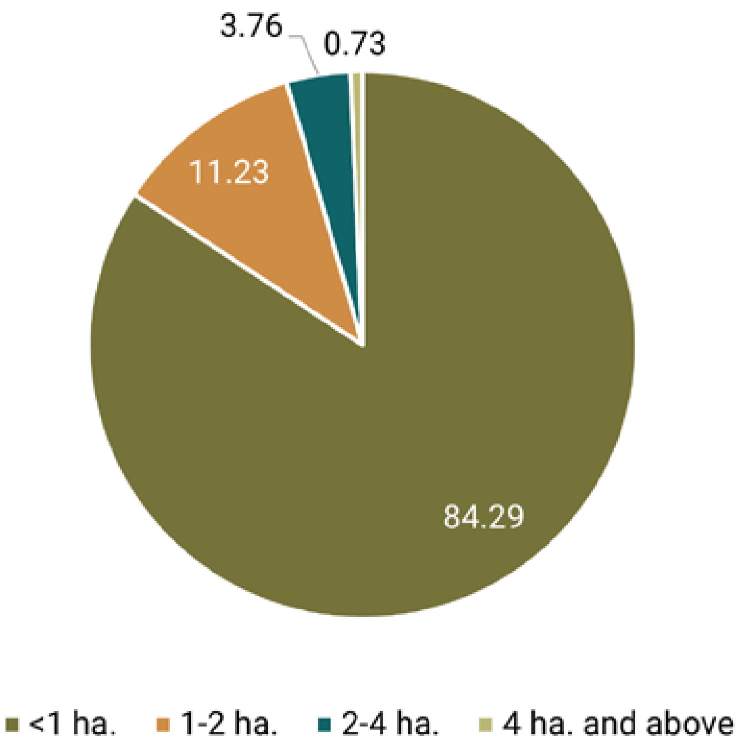


Figure 11: Agricultural land holdings in Lucknow

3.5 Agricultural Overview

Lucknow being the capital of Uttar Pradesh has more urban population residing in the district, rather than rural population. Agriculture does not serve as the primary occupation of the district. There are 807 inhabited villages in the district, covering a total reported area of 2,057.3 sq. Km. At the district level, approximately 1,35,459 ha was the net sown area, as per the Statistical Diary 2010, and the area is well irrigated by canal, government tubewells, private tubewells and other sources.[48]

3.5.1 Total Agricultural Area[49]

Lucknow is predominantly not an agricultural district in Uttar Pradesh. At the district-level, around 1,35,459 ha, out of which majority of the total cultivable area has got irrigation facility.[50]

48 District Census Handbook for Lucknow, 2011

49 District Profile, Krishi Vigyan Kendra, Lucknow

50 District Census Handbook for Lucknow, 2011

Table 8: Agricultural land area and cropping intensity in Lucknow district

Agricultural Land Use	Area ('000 ha)	Cropping Intensity (percent)
Net sown area	135.7	120 percent
Areas own more than once	73.9	
Gross cropped area	209.7	

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

The region of Lucknow district sees three major harvests- *Rabi, Kharif* and Zaid. Wheat and Barley are the main *Rabi* crops that are grown in the area, along with Gram, Peas, *Arhar*, Oilseeds etc. The main Kharif crops grown in the region are- Paddy, Maize, Juwar, Bajra, Urad, Moong and Soyabean. Development of fruit belt, especially of Mango has attained the main attraction of the cultivators and the area of Kakori and Malihabad has seen majority of distinguishable Mango plantations. Under the crop pattern onions and potatoes and followed by Maize and Wheat followed by vegetables, and mixed crop cultures still continues in the district.

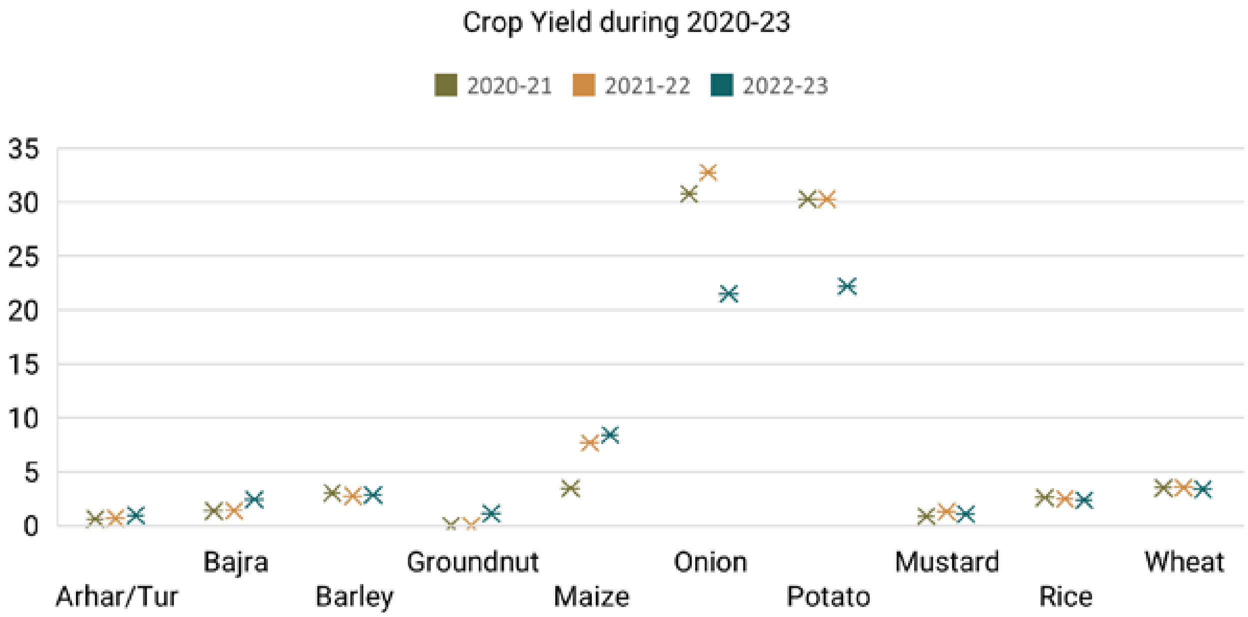


Figure 12: Crop yield during 2020-23 for major crops sown in Lucknow during *Kharif and Rabi*[51]

Rabi crops are sown around mid-November and harvested during spring (April to June) while Kharif crops are sown during the first week of June to mid-July and are harvested during September to October. During 2023-24, the prominent *Rabi* crops were wheat and potato where wheat alone occupied 51 percent of the total cropped area. Other *Rabi* crops include Barley, Masoor, vegetables, etc. that were sown and cultivated during the same period.

51 Area Production Statistics, Ministry of Agriculture and Farmers Welfare

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

Tehsil	Agri Plantation	Maize	Paddy	Pulses	Total
Bakshi ka Talab	4391.62	1888.39	8117.16	921.50	15318.67
Sadar	8472.14	1023.20	1709.20	445.98	11650.53
Malihabad	24759.88	1725.98	5213.08	216.15	31915.10
Mohanlal Ganj	7774.42	1986.63	16660.52	2685.15	29106.72
Sarojani Nagar	8002.55	859.66	7039.44	1306.24	17207.88
Total	**53400.62**	**7483.85**	**38739.41**	**5575.02**	**105198.90**

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

Tehsil	Mustard	Other Crop	Peas	Potato	Vegetable	Wheat	Total
Bakshi ka Talab	809.59	486.78	481.13	2343.24	439.68	10853.53	15413.95
Sadar	158.66	227.80	216.05	478.31	134.42	3251.69	4466.93
Malihabad	202.92	170.26	425.78	932.66	194.88	7682.54	9609.04
Mohanlal Ganj	1130.02	2042.81	-	617.91	132.04	22611.89	26534.66
Sarojani Nagar	40.59	785.19	20.64	67.54	17.61	9881.70	10813.26
Total	**2341.78**	**3712.83**	**1143.60**	**4439.65**	**918.63**	**54281.36**	**66837.85**

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

In Lucknow, majority of land is irrigated by canal, government tubewells, private tubewells and other sources. The land level is plain and fertile.

52 Analysis by Vasudha Foundation, 2025

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

Sowing window for major field crops	Rice	Maize/ Jowar/ Bajra	Black gram	Wheat	Lentil	Mustard	Pea
Kharif – Rainfed	June-July	June-July	July-August	-	-	-	-
Kharif – Irrigated	June-July	June-July	-	-	-	-	-
Rabi – Rainfed	-	-	-	-	October	October	September-October
Rabi – Irrigated	-	-	-	November-December	-	October-November	September-October

3.6 Forest Resources

3.6.1 Total Forest Area[53]

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

District	Calculated Area (km^2)	Very Dense Forest (km^2)	Moderate Dense Forest (km^2)	Open Forest[54] (km^2)	Total (km^2)	Scrub[55] (km^2)
Lucknow	2,528	0	161.18	240.08	401.26	8.09

Forest area consists of Babul, Dhak, Neem, Sheesham, and Bamboo trees which are grown in scattered and barren land. In sandy areas, palm trees and thorny bushes grow. In Ganga area, there are moderately dense forests comprising of huge trees and different kinds of vegetation. The district abounds in orchards. Mango trees are grown in groves and on the roadsides. The other varieties of trees include Banyan, Gular, Pakar, Fig, Vaska, etc.

3.6.2 Types of Forests and Residue Generated

Forestry residue consists of small trees, branches, leaves, bark, tops, and un-merchantable wood left in the forest after cleaning, thinning, or final felling. Woody biomass requires thermal gasification at high temperature in a low-oxygen environment to convert it into a mixture of gases, mainly carbon monoxide, hydrogen and methane (syngas)[56]. To produce a stream of biomethane of high purity, this syngas is cleaned to remove any acidic and corrosive components. Therefore, woody biomass which consists of residues from forest management and wood processing has to follow the gasification route, unlike other feedstocks like agricultural residue or Municipal Solid Wastes (MSW). Biomass such as paper, wood, dried leaves, wooden shavings, etc are generally high in lignin and cellulose. These

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

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

55 Scrub denotes lands having bushes and/or poor tree with canopy density less than 10 percent. Such lands are delineated largely within or around continuous forest areas (Source: Forest Survey of India)

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

substances are not suitable for the commercial biogas generation.[57]

3.7 Livestock Population

Uttar Pradesh is one of the top five milk producing states, contributing approximately 14.93 percent of the total milk production in the country during 2021-22.[58] The continuous rise in population of animals has also led to significant increase in livestock residues. Uttar Pradesh also has one of the highest number of livestock among all states.

3.7.1 Cattle, Poultry, and Other Livestock Statistics

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

Tehsil	Animal	Population	Total Cattle
Mohanlal Ganj	Cattle	58,169	8689
	Goat/Sheep	30,785	
	Swine	3,928	
	Poultry (Chicken)	29,960	
Bakshi ka Talab	Cattle	28,122	4407
	Goat/Sheep	23,361	
	Swine	1,095	
	Poultry (Chicken)	1,43,803	
Sarojani Nagar	Cattle	22,856	1806
	Goat/Sheep	22,267	
	Swine	464	
	Poultry (Chicken)	2,58,766	
Malihabaad	Cattle	39,454	4930
	Goat/Sheep	40,478	
	Swine	658	
	Poultry (Chicken)	7,06,458	
Sadar	Cattle	24,002	1640
	Goat/Sheep	13,119	
	Swine	239	
	Poultry (Chicken)	7,987	

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.

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

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

59 Animal Husbandry Department, Government of Uttar Pradesh

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

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

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

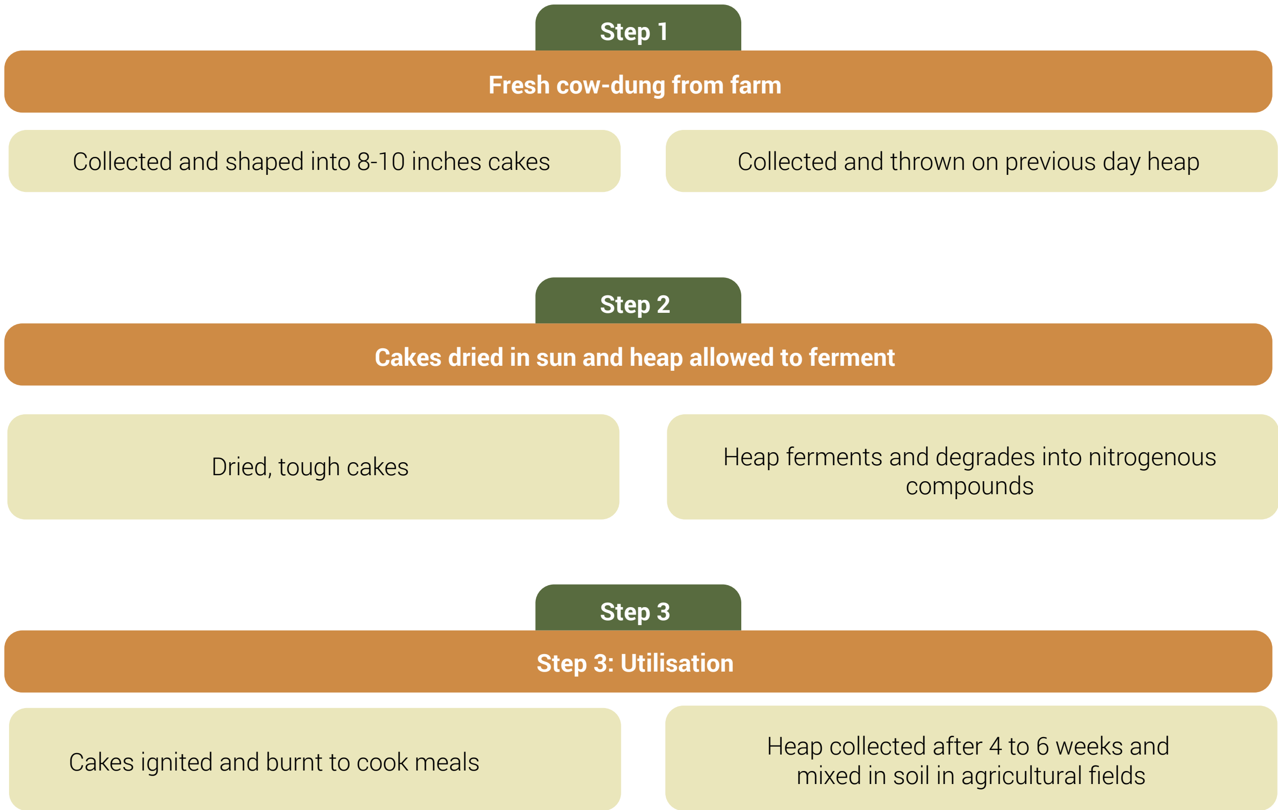


Figure 13: Traditional use of cow-dung as kitchen fuel and manure[64]

60 Avcioglu, A.O., Turker. et. al., Status and potential of biogas energy from animal wastes in Turkey, Renew, Sustain,, Energy Rev. 2012, Vol. 16, pp. 1557-1561

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

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

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

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

3.8 Industry and Processing Units

3.8.1 Existing Biomass-based Industries

There are two under-construction Compressed Biogas Plant in Lucknow, one in Bakshi ka Talab and one in Sarojini Nagar Tehsil. The plant specifications are as follows:

Table 15: Details of existing biomass-based industries in Lucknow

Plant Capacity	Feedstock/ Raw Material	By-Products	Off taker	Procurement Plan
6 Tonnes Per Day (TPD)	Maize Straw, Cattle Dung, Napier Grass, Poultry Litter	FOM, LFOM	CBG is proposed to be sold to an Oil Marketing Company at market rate	Plant is under construction and will be operational in one month. Primary feedstocks would be maize straw and Napier grass blended with cow dung and chicken litter. With a daily feedstock requirement of 150 TPD, 45 percent of the feedstock will be Napier grass, 2.5 percent of cow dung, and 8 percent of poultry litter and the rest, maize straw
10 TPD	Sugarcane Press Mud, Cattle Dung	FOM, LFOM	CBG is proposed to be sold to an Oil Marketing Company at the market rate	Plant is proposed to procure sugarcane press mud from a sugar mill in the neighbouring district as there are no sugar mills and sugarcane cultivation in the district.
45 cubic metres per day (MPD)	Cattle Dung	Bio-slurry	Biogas used for heating purposes in cowshed	Commercial-scale biogas plant installed and functional inside a cowshed facility in Pilibhit Tehsil (under GOBARdhan)

04 Data Collection

4.1 Primary Data Collection

Primary data sets of land cover, usage, and cropping patterns 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 crops. 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.

4.2 Secondary Data Collection

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

Table 16: 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]

65 National Biomass Atlas of India, 2023

66 As per the NIBE's approximations

Table 17: Biogas yield for various feedstocks as per NIBE estimates

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

For animal waste, we derived the collectable dung, total solids, estimated theoretical biomass, availability coefficients for different animal groups (Large/Small/Swine/Poultry) summarised in Table 21.

Table 18: Conversion factor for surplus biomass residue calculation of animals

Category	Animal	Collectable Dung (Kg/day)	Total Solids	Availability Coefficient	Biogas in m^3	Multiplication Factor[67]
Large	Cows, Buffalo	22.5	25 percent	70 percent	0.6	4.76086
Small	Sheep, Goat	1.6	29 percent	20 percent	0.4	4
Swine	Pigs	2.7	29 percent	60 percent	0.4	4
Poultry	Broiler, Layer, and Other	0.045	29 percent	60 percent	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 19: Calorific values[68,69] for animal residue

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

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 20: 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	7 T[71]
Bagasse	1	10 KL
Municipal Solid Waste	1	10 T
Cow Dung	1	20 T
Chicken Litter	1	50 T
Forest Residue	1	25 T
Napier Grass	1	15 T
Sewage Waste	1	10 T

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

71 Biogas yield would be approximately 7 percent for Sugarcane Leaves as per the CBG industry

05

Stakeholder Mapping

5.1 Identification of Relevant Stakeholders

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

Table 21: 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
Private	Under-construction CBG Plants	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 bajra was grown prominently in tehsils of Malihabad and Lucknow (Sadar), while paddy was grown largely in almost all tehsils. Tehsils of Sarojani Nagar and Mohanlalganj, among other tehsils also grew pulses during this period.

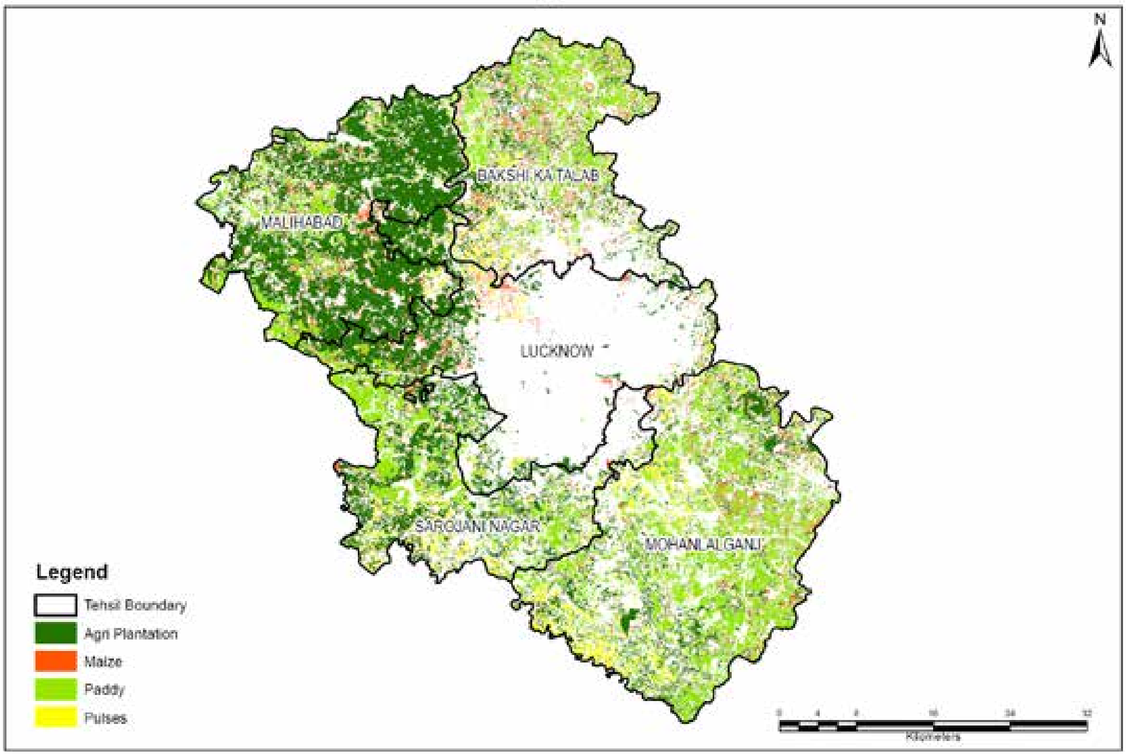


Figure 14: Geographical spread of *Kharif* crops in tehsils of Lucknow district during 2023-24[72]

During the Rabi season of 2023-24, wheat was grown in almost all tehsils and largely in Bakshi ka Talab, Mohanlalganj and Sarojani Nagar.

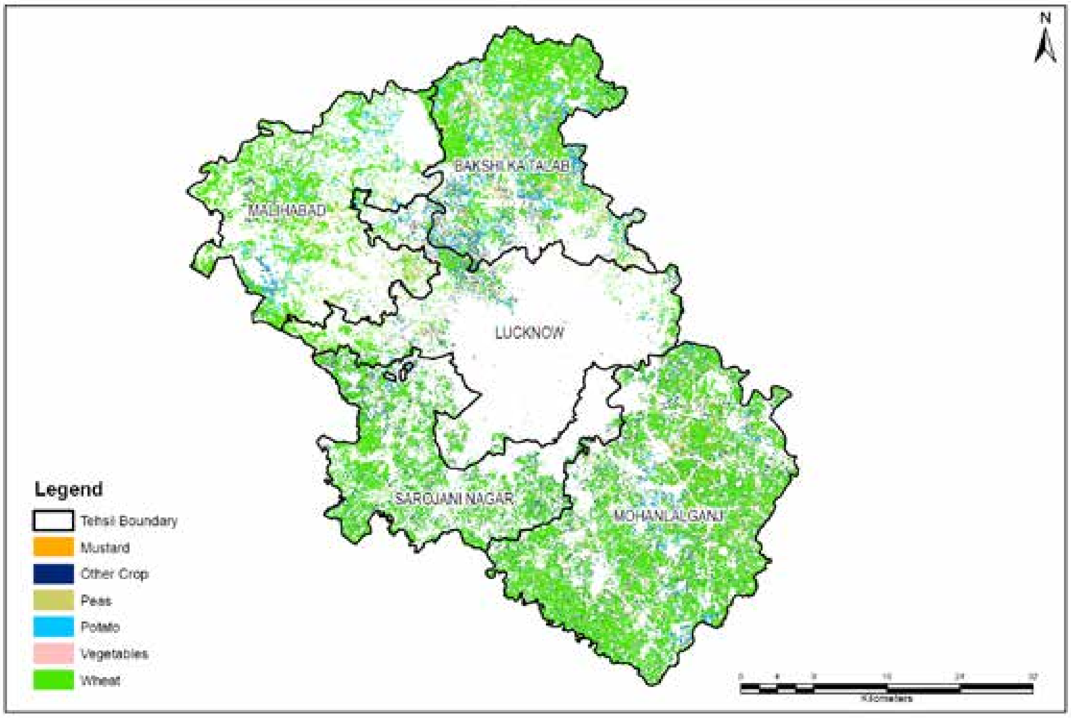


Figure 15: Geographical spread of *Rabi* crops in tehsils of Lucknow district during 2023-24[73]

72 Analysis by Vasudha Foundation, 2025

73 Analysis by Vasudha Foundation, 2025

6.2 Land Use and Biomass Distribution Mapping

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

Table 22: Tehsil-wise land-use analysis for Lucknow[74]

Tehsil	Barren/ Waste land	Built-Up	Crop land	Forest	Scrub	Waterbodies	Grand Total
Mohanlal Ganj	1810.06	11288.35	55417.8	237.84	432.93	665.31	69852.29
Malihabad	106.42	5758.11	41453.35	-	80.51	172.61	47571.01
Sadar	569.72	35435.92	15476.92	532.74	1792.95	664.18	54463.43
Sarojani Nagar	173.95	1196.04	26486.39	-	508.21	128.85	39266.45
Bakshi ka Talab	43.82	8437.87	70227.97	9745.04	4422.84	2696.82	89909.12
Total (ha)	**2703.98**	**72889.29**	**170013.62**	**2135.08**	**3356.16**	**1869.94**	**252968.07**

It can be observed from the Land Use analysis that tehsils Mohanlal Ganj and Sadar hold few tracts of barren/waste land. The district has forest cover in Tehsils of Bakshi ka Talab, Mohanlal Ganj and Sadar.

74 Analysis by Vasudha Foundation, 2025

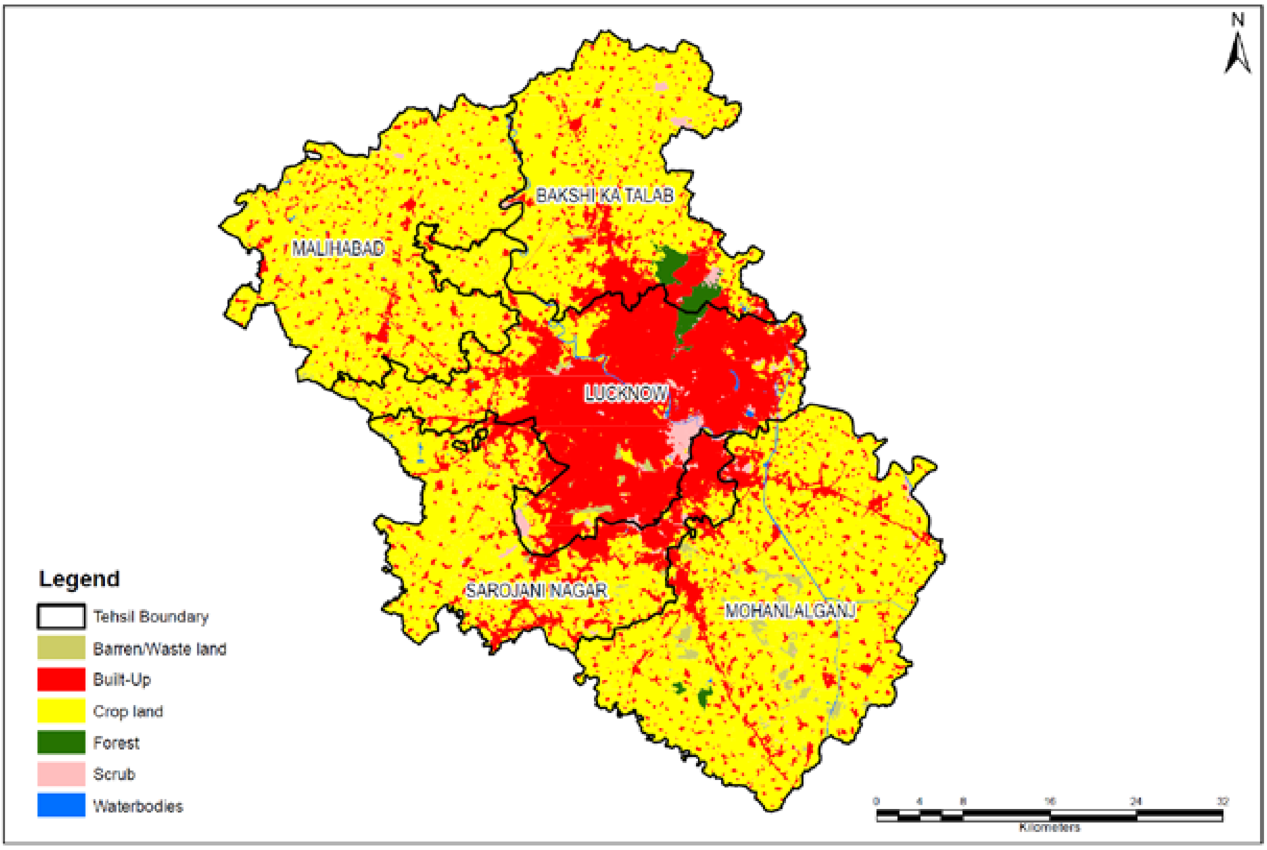


Figure 16: Land cover analysis for tehsils of Lucknow district during 2023-24[75]

75 Analysis by Vasudha Foundation, 2025

07 Methodology

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

7.1 Agricultural Residue

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

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

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

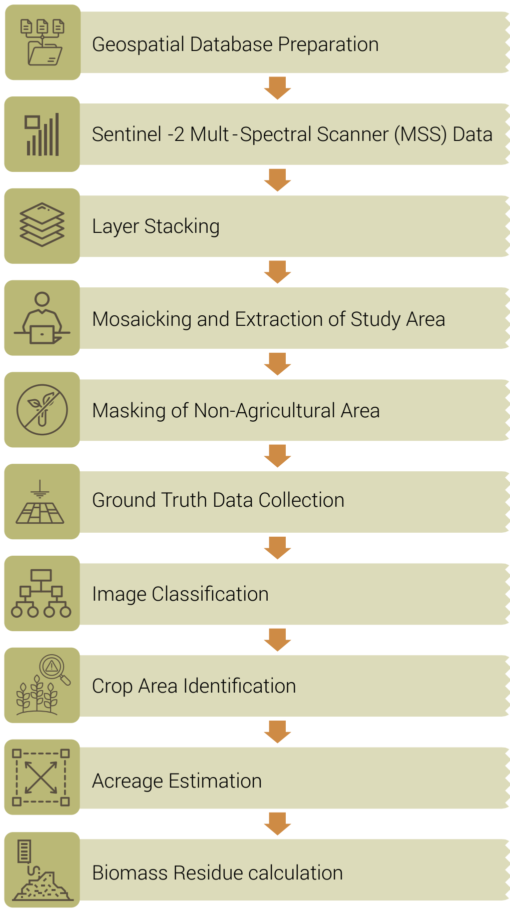


Figure 17: Flow diagram of the methodology used

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

Gross crop residue[77] can be defined as the sum total of crop residues produced for a particular crop. In general, there is a 1:1 grain-to-residue relationship between the dry matter of crop grain and the dry matter of crop residues.[78 79] It is determined based on three important parameters, area occupied by the particular crop, crop yield, and Residue Production Ratio value for that crop.

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

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

77 S,K, Lohan. et.al., 2018, Burning issues of paddy residue management in north-west states of India, Renewable and Sustainable energy reviews, 81, pp.693-706.

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

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

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

The surplus crop residue of particular crop represents the amount of crop residues that are available for energy production after all the other competing uses such as cooking fuel, cattle feed, roof thatching, composting, animal bedding, and others are taken into consideration (as described in Figure 26).[80]

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

Equation 2: ***Surplus Crop Residue Calculation***

CRs denotes the surplus crop residue for n number of crops, in tonnes which is estimated based on the surplus factor developed depending on different uses of the crop residue. Surplus factor varies widely among the crops and also shows variations in the cropping seasons.[81,82]

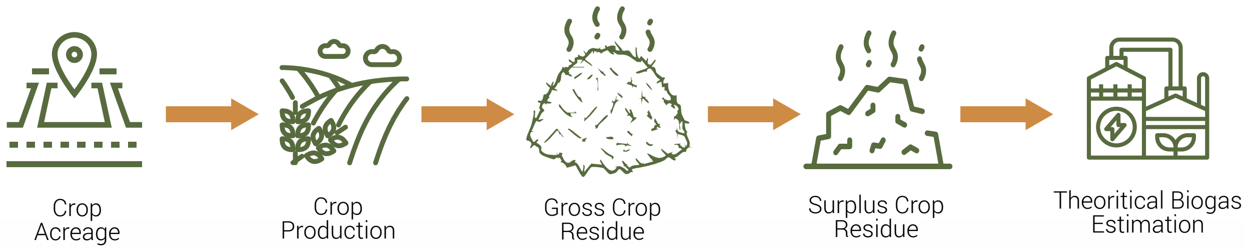


Figure 18: Flow diagram for crop residue estimation

80 V, Venkatraman., et. al., 2021 Assessment of Bioenergy Generation Potential of Agricultural Crop Residues in India, Circular Economy and Sustainability, 1(4) pp. 1335-1348

81 M, Hiloidhari and D.C., Baruah., 2011, Crop residue biomass for decentralized electrical power generation in rural areas (part I): Investigation of spatial availability, Renewable and Sustainable Energy Review, 15, pp. 1885-92

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

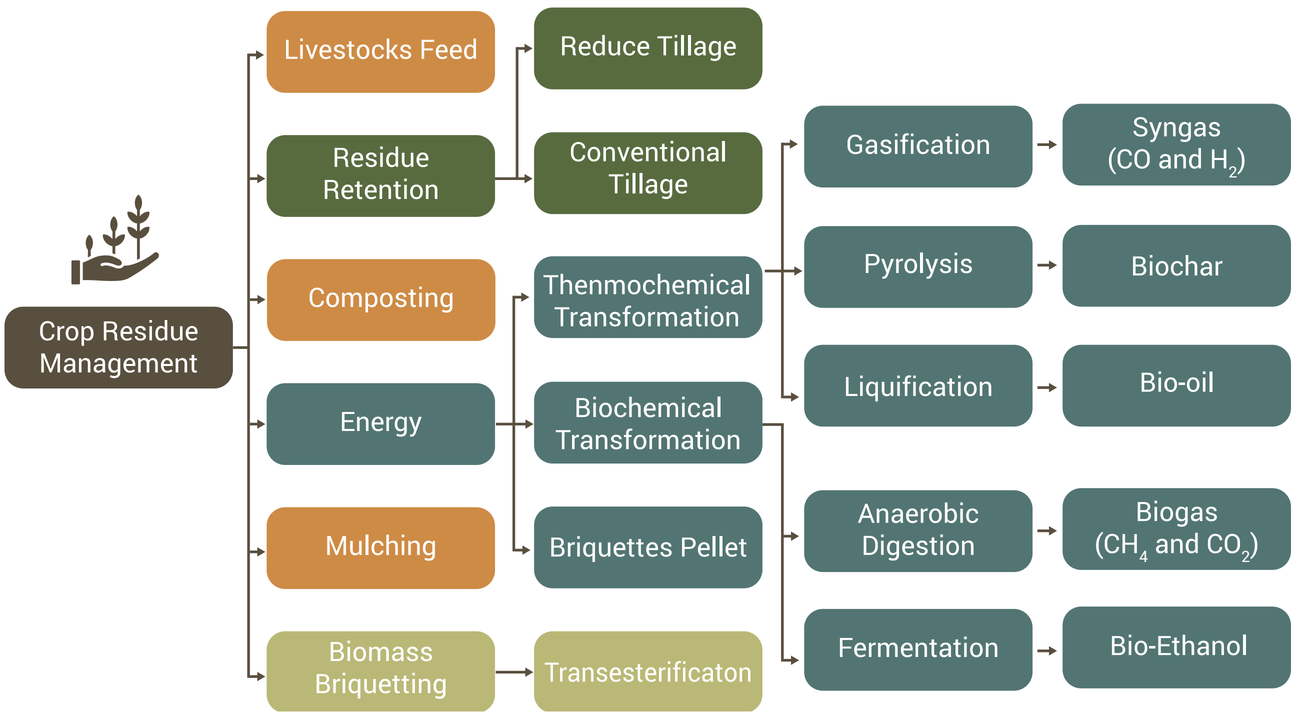


Figure 19: Crop residue management practices[83]

After taking into consideration of the competing uses for the specific crop residue, the net crop residue, CRn(j), is estimated for n number of crops at jth state, in tonnes.

$$CRn(j) = \sum_{i=1}^{n} CRs\ (i,j) - CRc(i,j)$$

Equation 3: ***Net Crop Residue Calculation***

Here, CRc denotes the competing usage of ith crop residue at jth state and CRn is the net crop residue available for energy generation at jth state.

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

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

Here, TBEn denotes the Theoretical Biogas Estimation (CBG) in TPD for nth crop at jth state, 0.55 indicates the percent composition of methane, BY denotes the Biogas Yield for the ith crop at jth state, 0.657 is the density of methane in kg/m^3.

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

7.2 Livestock Residue

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

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

Equation 5: Theoretical CBG Estimation from Livestock Residues

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

08

Biomass Category, Sources and Availability

The results for the Biomass Assessment are tabulated in Table 27. It describes for each Tehsil, the feedstock-wise annual biomass production during 2023-24 and corresponding gross residue and surplus residue that is available for CBG production. For agricultural crops, residue-to-crop ratios and corresponding surplus fractions for various are listed in Table 28. Similarly, the surplus animal dung/litter and biogas yield for various biomass residues are described in Table 21 and Table 23, respectively. Equations 1-6 were applied to arrive at the biogas yield results. We have two distinct results for CBG potential for the majority of the feedstocks because of the difference in residue-to-crop ratio as is the case for paddy straw, and different biogas yield ratios prescribed by NIBE and SATAT Scheme.

8.1 Agricultural Residues

Table 23: **Tehsil-wise surplus biomass and potential CBG generation for various agricultural residue**

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
Mohanlal Ganj	Wheat	22611.89	3.48	78689.38	Straw	118034.07	23606.81	23606.81	4.67	6.47
					Husk	23606.81	4721.36	4721.36	0.93	1.29
	Paddy	16660.52	2.49	41484.69	Straw	62227.04	10578.60	10578.60	2.36	9.09
					Husk	8296.94	1410.48	1410.48	0.31	
	Sugarcane	0	80.42	0.00	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Large)		0		0.00	0.00
					Press Mud (Medium)		0		0.00	0.00
					Tops and Leaves	0.00	0.00	0.00	0.00	0.00
	Jowar	0	1.34	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
					Husk/Leaves	0.00	0.00	0.00	0.00	0.00
					Cobs	0.00	0.00	0.00	0.00	0.00

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Maize	1986.63	1.74	3456.74	Stalks	6913.47	69.13	69.13	0.02	0.02
					Cobs	1037.02	10.37	10.37	0.003	0.003
					Leaves	414.81	4.15	4.15	0.001	0.001
	Mustard	1130.02	1.12	1265.62	Stalks	2278.12	2278.12	2278.12	0.624	0.624
	Rapeseed	0	1.12	0.00	Stalks	0.00	0.00	0.00	0.000	0.000
	Pulses (Tur/Arhar)	2685.15	0.74	1987.01	Stalks	4967.53	4967.53	4967.53	1.361	0.000
	Potato	617.91	27.83	17196.44	Stalks	1719.64	1719.64	1719.64	0.471	0.471
	Vegetables	132.04	15.37	2029.45	Stalks	202.95	202.95	202.95	0.056	0.000
	Other Crops (Barley)	2042.81	2.88	5883.29	Straw	7648.28	7648.28	7648.28	2.095	0.135
	Agri-Plantation (Bajra)	7774.42	1.73	13449.75	Stalks	26899.49	26899.49	26899.49	7.370	1.936
					Husk	4034.92	4034.92	4034.92	1.105	0.290
					Cobs	4438.42	4438.42	4438.42	1.216	0.320
Bakshi ka Talab	Wheat	10853.53	3.48	0.00	Straw	0.00	0.00	0.00	0.00	3.10
					Husk	0.00	0.00	0.00	0.00	0.62

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Paddy	8117.16	2.49	20211.73	Straw	30317.59	5153.99	5153.99	1.15	4.43
					Husk	4042.35	687.20	687.20	0.15	
	Sugarcane	0	80.42	0.00	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
					Tops and Leaves	0.00	0.00	0.00	0.00	0.00
	Jowar	0	1.34	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
					Husk/Leaves	0.00	0.00	0.00	0.00	0.00
					Cobs	0.00	0.00	0.00	0.00	0.00
	Maize	1888.39	1.74	3285.80	Stalks	6571.60	65.72	65.72	0.02	0.02
					Cobs	985.74	9.86	9.86	0.0027	0.0027
					Leaves	394.30	3.94	3.94	0.00108	0.00108
	Mustard	809.59	1.12	906.74	Stalks	1632.13	1632.13	1632.13	0.45	0.45
	Rapeseed	0	1.12	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
	Pulses	921.5	0.74	681.91	Stalks	1704.78	1704.78	1704.78	0.47	0.47

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Potato	2343.24	27.83	65212.37	Stalks	6521.24	6521.24	6521.24	1.79	1.79
	Vegetables	439.68	15.37	6757.88	Stalks	675.79	675.79	675.79	0.19	0.19
	Other Crops (Barley)	486.78	2.88	1401.93	Straw	1822.50	1822.50	1822.50	0.50	0.50
	Agri-Plantation (Bajra)	4391.62	1.73	7597.50	Stalks	15195.01	15195.01	15195.01	4.16	4.16
					Husk	2279.25	2279.25	2279.25	0.62	0.62
					Cobs	2507.18	2507.18	2507.18	0.69	0.69
Sarojani Nagar	Wheat	9881.7	3.48	34388.32	Straw	51582.47	10316.49	10316.49	2.04	2.83
					Husk	10316.49	2063.30	2063.30	0.41	0.57
	Paddy	7039.44	2.49	17528.21	Straw	26292.31	4469.69	4469.69	1.00	3.84
					Husk	3505.64	595.96	595.96	0.13	

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Sugarcane	0	80.42	0.00	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
					Tops and Leaves	0.00	0.00	0.00	0.00	0.00
	Jowar	0	1.34	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
					Husk/Leaves	0.00	0.00	0.00	0.00	0.00
					Cobs	0.00	0.00	0.00	0.00	0.00
	Maize	859.66	1.74	1495.81	Stalks	2991.62	29.92	29.92	0.01	0.00
					Cobs	194.46	1.94	1.94	0.00	0.01
					Leaves	179.50	1.79	1.79	0.00	0.00
	Mustard	40.59	1.12	45.46	Stalks	5.46	5.46	5.46	0.00	0.00
	Rapeseed	0	1.12	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
	Pulses	1306.24	0.74	966.62	Stalks	2416.54	2416.54	2416.54	0.66	0.00
	Potato	67.54	27.83	1879.64	Stalks	187.96	187.96	187.96	0.05	0.66
	Vegetables	17.61	15.37	270.67	Stalks	27.07	27.07	27.07	0.01	0.05

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Other Crops (Barley)	785.19	2.88	2261.35	Straw	2939.75	2939.75	2939.75	0.81	0.01
	Agri-Plantation (Bajra)	8002.55	1.73	13844.41	Stalks	27688.82	27688.82	27688.82	7.59	0.81
					Husk	4153.32	4153.32	4153.32	1.14	7.59
					Cobs	4568.66	4568.66	4568.66	1.25	1.14
Malihabad	Wheat	7682.54	3.48	26735.24	Straw	40102.86	8020.57	8020.57	1.59	2.20
					Husk	8020.57	1604.11	1604.11	0.32	0.44
	Paddy	5213.08	2.49	12980.57	Straw	19470.85	3310.05	3310.05	0.74	2.85
					Husk	2596.11	441.34	441.34	0.10	
	Sugarcane	0	80.42	0.00	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00
					Tops and Leaves	0.00	0.00	0.00	0.00	0.00

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Jowar	0	1.34	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
					Husk/Leaves	0.00	0.00	0.00	0.00	0.00
					Cobs	0.00	0.00	0.00	0.00	0.00
	Maize	1725.98	1.74	3003.21	Stalks	6006.41	60.06	60.06	0.02	0.02
					Cobs	900.96	9.01	9.01	0.00	0.00
					Leaves	360.38	3.60	3.60	0.00	0.00
	Mustard	202.92	1.12	227.27	Stalks	409.09	409.09	409.09	0.11	0.11
	Rapeseed	0	1.12	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
	Pulses	246.15	0.74	182.15	Stalks	455.38	455.38	455.38	0.12	0.12
	Potato	932.66	27.83	25955.93	Stalks	2595.59	2595.59	2595.59	0.71	0.71
	Vegetables	194.88	15.37	2995.31	Stalks	299.53	299.53	299.53	0.08	0.08
	Other Crops (Barley)	170.26	2.88	490.35	Straw	637.45	637.45	637.45	0.17	0.17
	Agri-Plantation (Bajra)	24759.88	1.73	42834.59	Stalks	85669.18	85669.18	85669.18	23.47	23.47
					Husk	12850.38	12850.38	12850.38	3.52	3.52
					Cobs	14135.42	14135.42	14135.42	3.87	3.87

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
Lucknow (Sadar)	Wheat	3251.69	3.48	11315.88	Straw	16973.82	3394.76	3394.76	0.67	0.93
					Husk	3394.76	678.95	678.95	0.13	0.19
	Paddy	1709.2	2.49	4255.91	Straw	6383.86	1085.26	1085.26	0.24	0.93
					Husk	851.18	144.70	144.70	0.03	
	Sugarcane	0	80.42	0.00	Bagasse (Small)		0.00		0.00	0.00
					Press Mud (Medium)		0.00		0.00	0.00
					Press Mud (Large)		0.00		0.00	0.00
					Tops and Leaves	0.00	0.00	0.00	0.00	0.00
	Jowar	0	1.34	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
					Husk/Leaves	0.00	0.00	0.00	0.00	0.00
					Cobs	0.00	0.00	0.00	0.00	0.00
	Maize	1023.2	1.74	1780.37	Stalks	3560.74	35.61	35.61	0.01	0.01
					Cobs	534.11	5.34	5.34	0.00	0.00
					Leaves	534.11	5.34	5.34	0.00	0.00

Tehsil	Crop	Production (T)			Crop Residue	Gross Residue (T)	Surplus Residue (T)	Net Residue (T)	CBG (NIBE) (TPD)	CBG (SATAT) (TPD)
		Area	Yield	Total						
	Mustard	158.66	1.12	177.70	Stalks	319.86	319.86	319.86	0.09	0.09
	Rapeseed	0	1.12	0.00	Stalks	0.00	0.00	0.00	0.00	0.00
	Pulses	445.98	0.74	330.03	Stalks	825.06	825.06	825.06	0.23	0.23
	Potato	478.31	27.83	13311.37	Stalks	1331.14	1331.14	1331.14	0.36	0.36
	Vegetables	134.42	15.37	2066.04	Stalks	206.60	206.60	206.60	0.06	0.06
	Other Crops (Barley)	227.8	2.88	656.06	Straw	852.88	852.88	852.88	0.23	0.23
	Agri-Plantation (Bajra)	8472.14	1.73	14656.80	Stalks	29313.60	29313.60	29313.60	8.03	8.03
					Husk	4397.04	4397.04	4397.04	1.20	1.20
					Cobs	4836.74	4836.74	4836.74	1.33	1.33

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 standardised method for collecting dung is essential. Only through such standardised collection techniques can a reliable cumulative biogas volume be determined, which is necessary for calculating the availability coefficient factor. This factor is crucial for predicting the expected and likely biogas yield from livestock waste.

Table 24: Tehsil-wise surplus biomass residue and potential CBG generation from various animal residues

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG Potential (NIBE)	CBG Potential (SATAT)
Mohanlal Ganj	Cattle	58076	317966100	79491525	55644067.5	55644.07	907977635.84	0.48	2.28	3.049
	Goat/ Sheep	30785	17978440	5213747.6	1042749.52	1042.75	13088591.98	0.01	0.06	0.08
	Swine	3928	3871044	1122602.76	673561.66	673.56	12056753.64	0.01	0.03	0.05
	Poultry (Chicken)	29,960	492093	142706.97	85624.18	85.62	1369986.91	0.00	0.01	0.01
Bakshi ka Talab	Cattle	28122	153967950	38491987.5	26944391.25	25575.64	439667798.66	0.22	1.05	1.463
	Goat/ Sheep	23361	13642824	3956418.96	791283.79	791.28	9932194.16	0.01	0.04	0.06
	Swine	1095	1079122.5	312945.52	187767.32	187.77	3361034.94	0.00	0.01	0.01
	Poultry (Chicken)	1,43,803	2361964.275	684969.64	410981.78	0	0	0	0	0

Tehsil	Animal	Population	Collectable Dung/Litter (Kg)	Total Solids (Kg)	Availability Coefficient (Kg)	Surplus Residue (T)	Bio Energy Potential (MJ)	Bio Energy Potential (MW)	CBG Potential (NIBE)	CBG Potential (SATAT)
Sarojani Nagar	Cattle	22856	125136600	31284150	21898905.00	21898.91	357337572.23	0.19	0.57	0.762
	Goat/ Sheep	22267	13003928	3771139.12	754227.82	754.23	9467067.65	0.01	0.04	0.06
	Swine	464	457272	132608.88	79565.33	79.57	1424219.37	0.00	0.00	0.01
	Poultry (Chicken)	258766	4250231.6	1232567.15	739540.29	739.54	11832644.64	0.01	0.05	0.08
Mali-habad	Cattle	39454	216010650	54002662.5	37801863.75	37801.86	616835691.93	0.33	1.55	2.07
	Goat/ Sheep	40478	23639152	6855354.08	1371070.82	1371.07	17209680.88	0.02	0.07	0.11
	Swine	658	648459	188053.11	112831.87	112.83	2019690.40	0.00	0.01	0.01
	Poultry (Chicken)	706458	11603573	3365036.068	2019021.64	2019.02	32304346.26	0.03	0.14	0.22
Lucknow (Sadar)	Cattle	24002	131410950	32852737.5	22996916.25	22996.92	375254480.60	0.20	0.94	1.26
	Goat/ Sheep	13119	7661496	2221833.84	444366.77	444.37	5577691.67	0.01	0.02	0.03
	Swine	239	235534.5	68305	40983.00	40.98	733595.75	0.00	0.00	0.00
	Poultry (Chicken)	7987	131186.48	38044.07	22826.45	22.83	365223.15	0.00	0.00	0.00

8.3 Energy Crops

Poplar Trees, Willow, Jatropha

These crops were not identified in our GIS crop maps. As per the State Agriculture Department, there are no such crops grown and cultivated for energy purposes in Lucknow district. However, existing CBG developers are planning to cultivate napier grass.

8.4 Other Types of Biomasses

8.4.1 Napier Grass

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

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

8.4.2 Groundnut Shell

Groundnut is sown and harvested during the *Kharif* season and yields groundnut shells as residue. During 2022-23, as per the Crop Production Statistics, groundnut was not cultivated in the district.

8.4.3 Sugarcane Bagasse

There are no small sugar mills in the district.

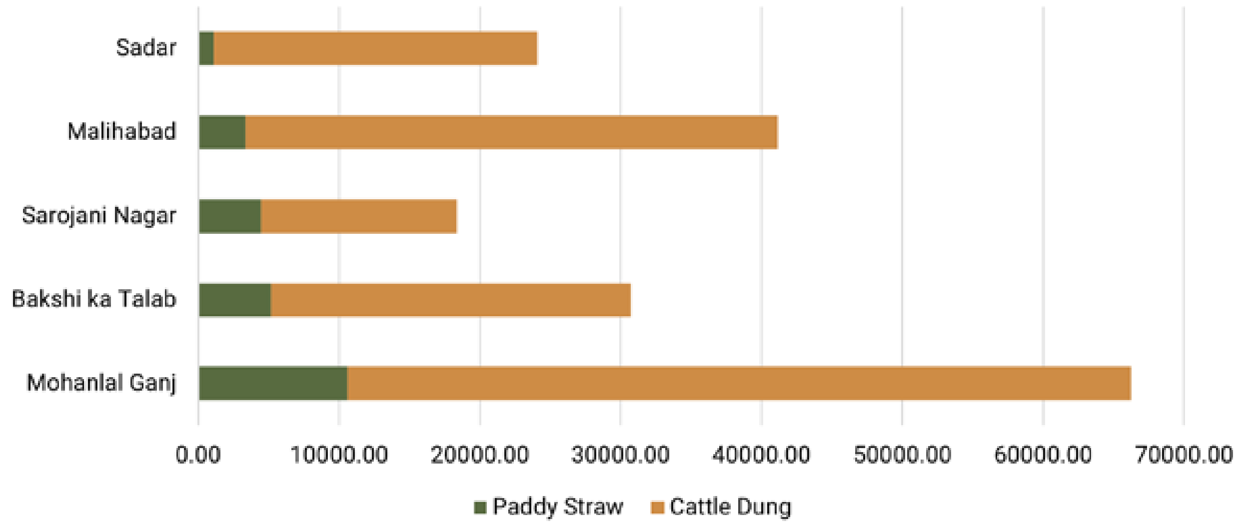
84 Pandey K.C. and Roy A.K., 2011. p.23, Forage Crops Varieties, Indian Grassland and Fodder Research Institute (IGFRI)

09

Biomass Quantification Results

9.1 Total Biomass Availability by Category

Major feedstocks that are taken into account for this categorisation are: paddy straw and cattle dung. Accordingly, the following results are observed for each Tehsil in Lucknow district.



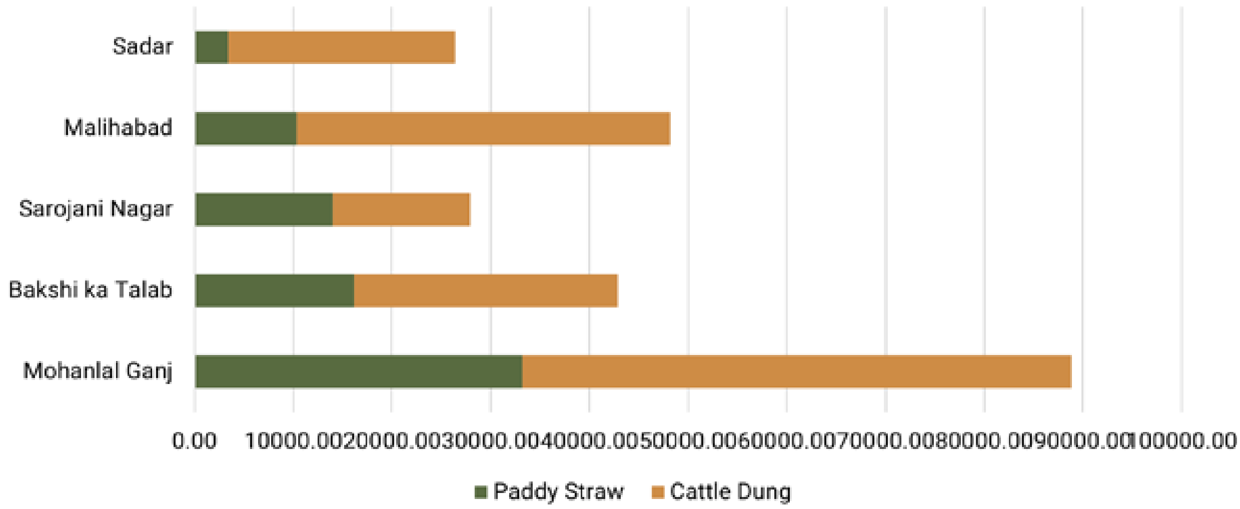


Figure 20: Tehsil-wise annual availability of paddy straw, press mud and cattle dung

9.2 High-Potential Zones for Biomass Supply and CBG Production

Among all tehsils, Mohanlal Ganj has the highest paddy straw availability, while the rest of them have comparable stock as agricultural residue. All tehsils of Lucknow have rich cattle dung availability which can be used as a combination feedstock with agricultural residue for CBG production. We can also see the variation in the availability of paddy straw in particular based on the different residue to crop ratios that were used.

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

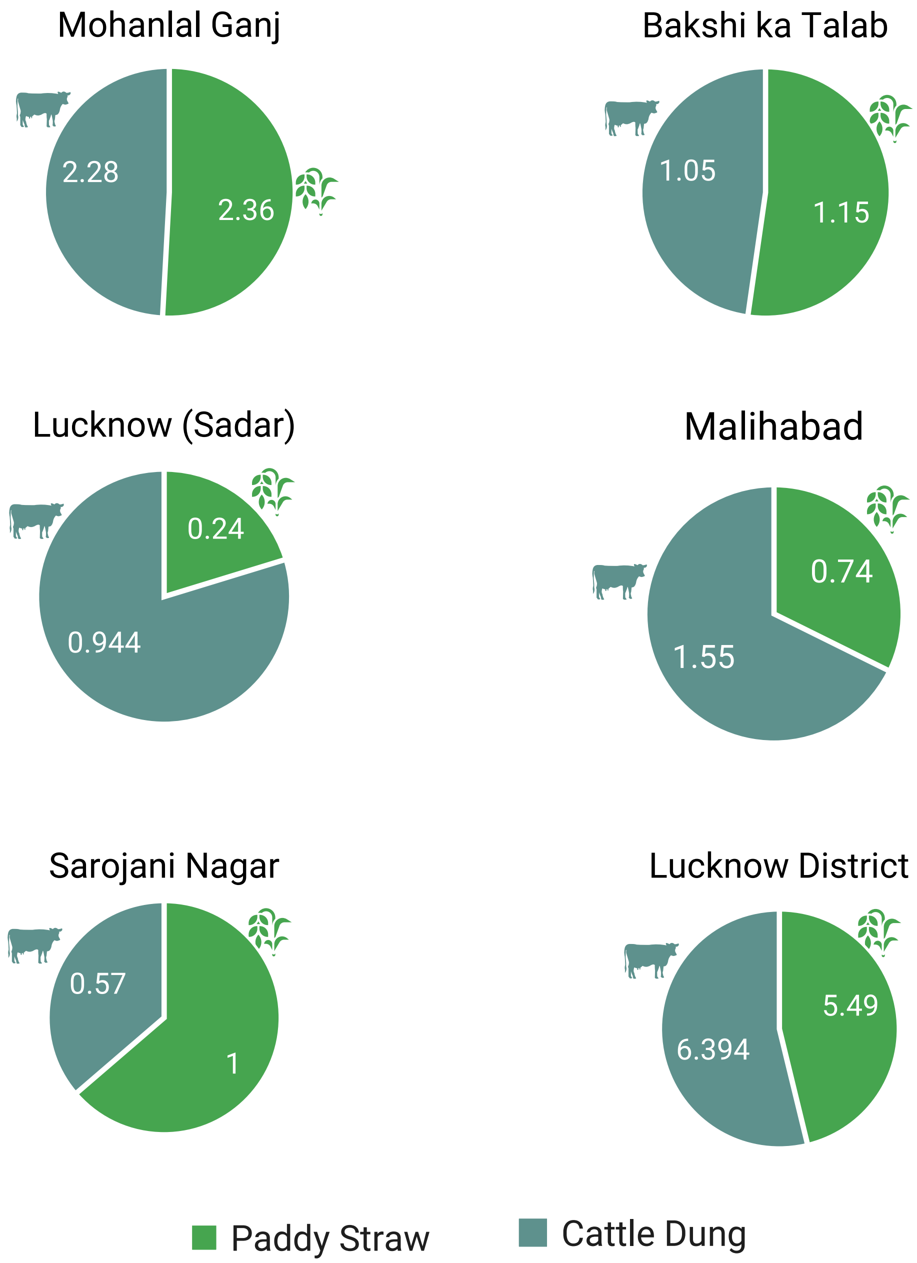


Figure 21: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per NIBE estimates)

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

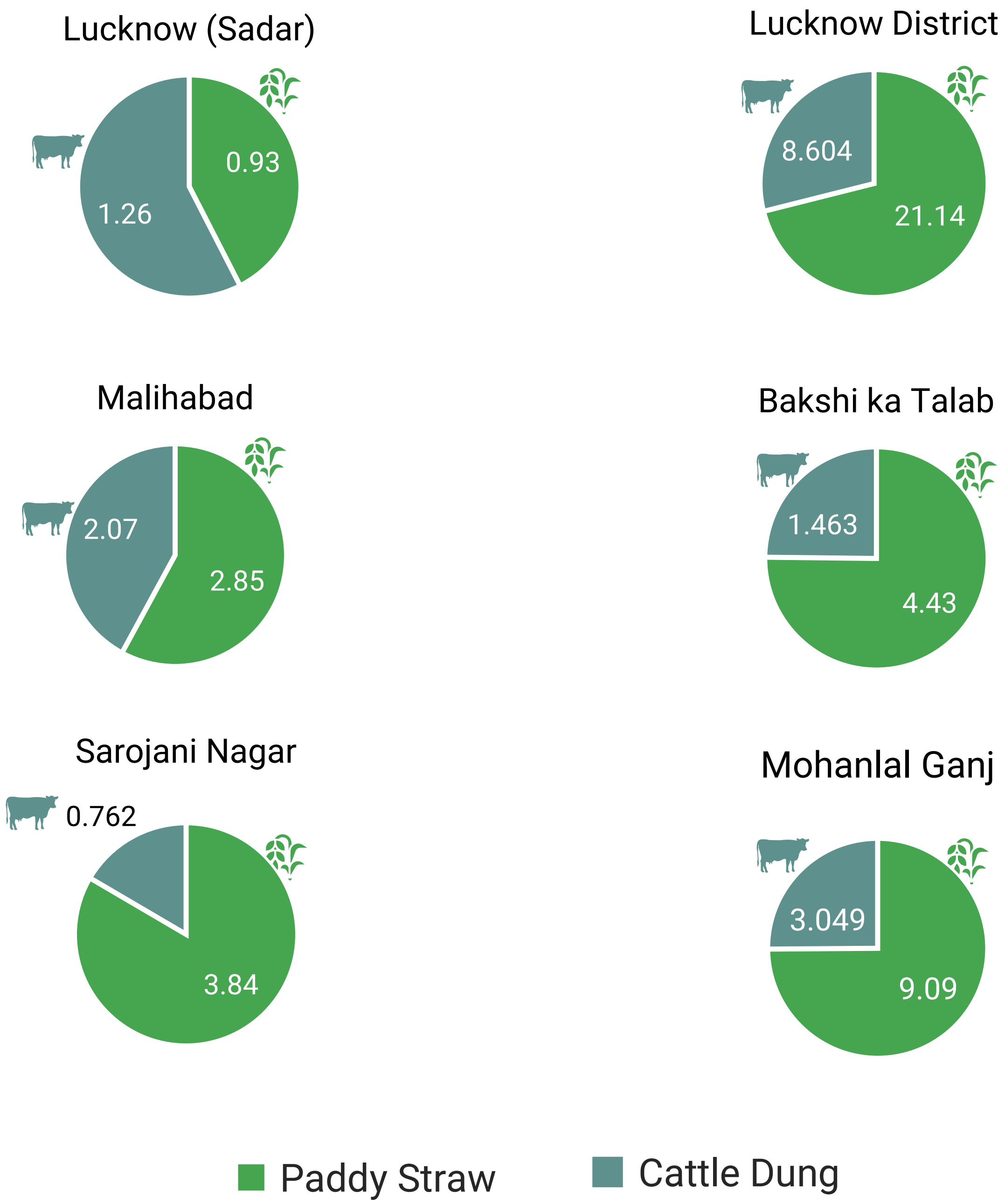


Figure 22: Tehsil-wise daily CBG generation potential for major feedstocks: Paddy straw, cattle dung, and sugarcane press mud (as per SATAT estimates)

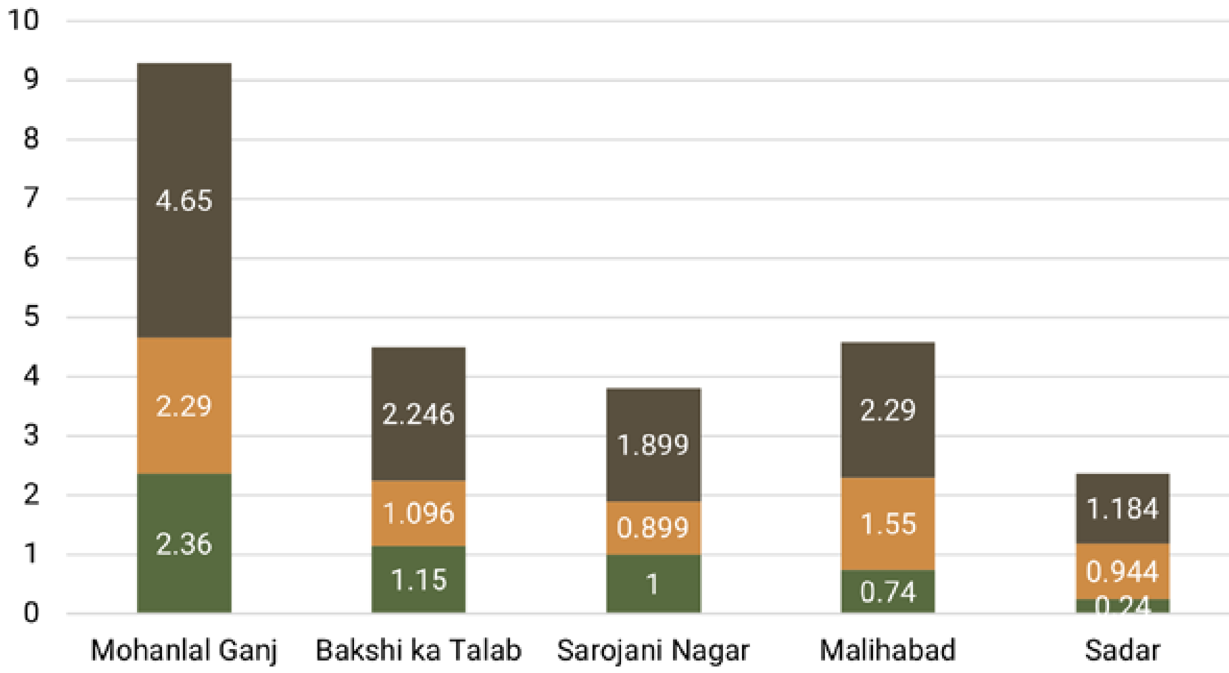


Figure 23: CBG potential from major feedstocks (NIBE estimates)

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.

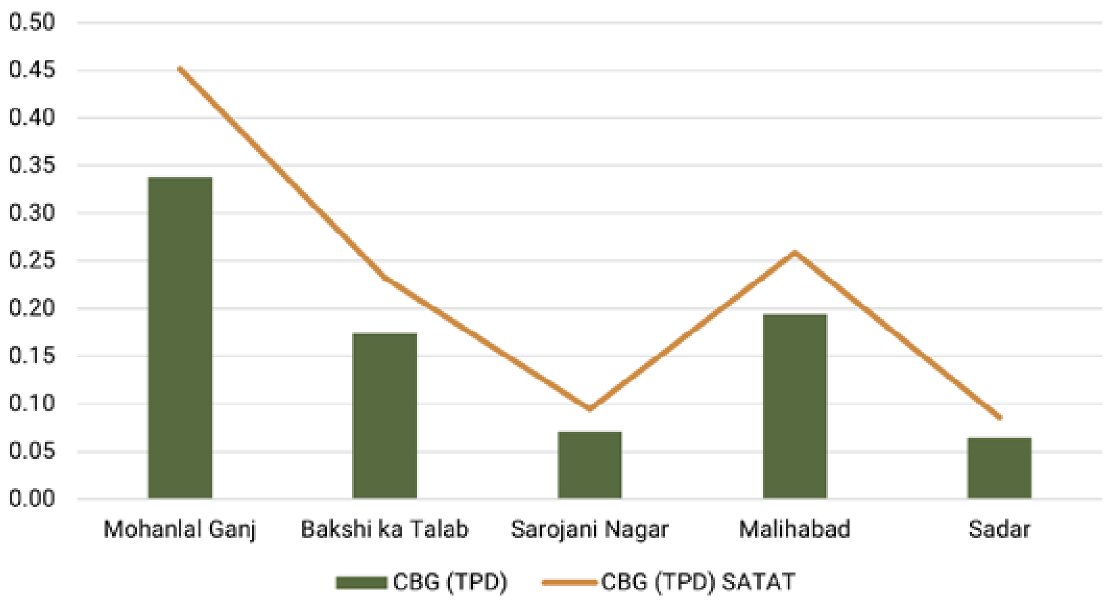


Figure 24: Tehsil-wise CBG potential from cattle sheds

While the CBG capacity from various feedstocks has been outlined, it's essential to recognise that CBG plants often operate on a mix of feedstocks rather than a single type. The sizing and design of these plants depend on a comprehensive set of factors (as captured in the Figure 39), 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.

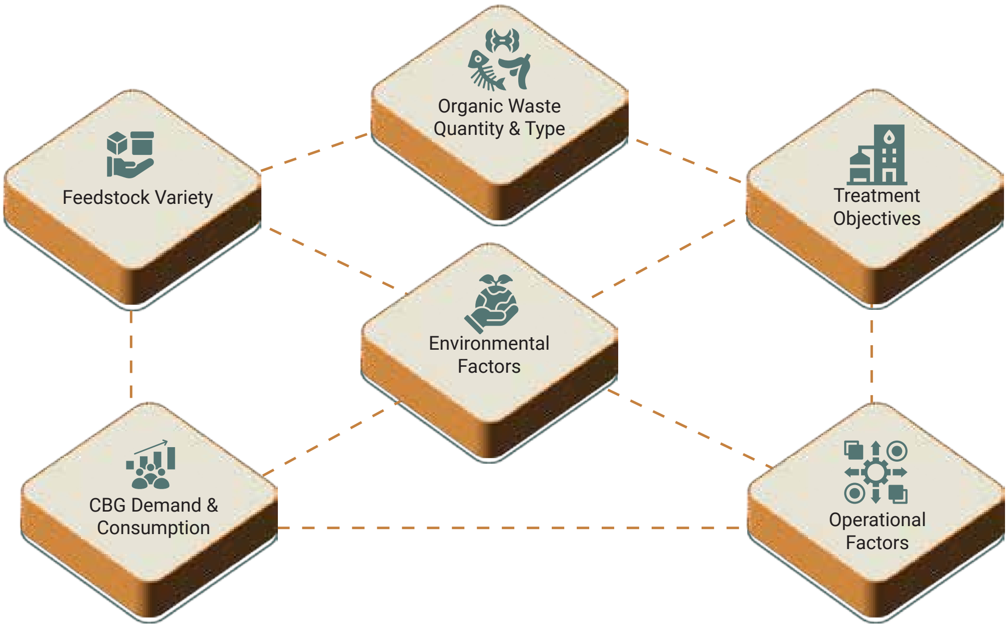


Figure 25: Multi-faceted approach for planning location, size, feedstock category, etc. for CBG plants

The total CBG potential (in TPD) has been summarised in Table 32.

Table 25: Potential daily generation of CBG as per NIBE and SATAT estimates

NIBE – CBG potential (in TPD) feedstock-wise in each tehsil			
Tehsil	**Paddy Straw**	**Cattle Dung**	**Total**
Mohanlal Ganj	2.36	2.28	4.64
Bakshi ka Talab	1.15	1.05	2.2
Sarojani Nagar	1	0.57	1.57
Malihabad	0.74	1.55	2.29
Sadar	0.24	0.944	1.184
Lucknow District	5.49	6.394	11.884

SATAT – CBG potential (in TPD) feedstock-wise in each tehsil			
Tehsil	**Paddy Straw**	**Cattle Dung**	**Total**
Mohanlal Ganj	9.09	3.049	12.139
Bakshi ka Talab	4.43	1.463	5.839
Sarojani Nagar	3.84	0.762	4.604
Malihabad	2.85	2.07	4.92
Sadar	0.93	1.26	2.19
Lucknow District	21.14	8.604	29.744

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, Lucknow district has a CBG potential of approximately 11.88 TPD based on the biomass available during the year 2023-24. Out of all the Tehsils, Mohanlal Ganj has the highest potential for CBG production with paddy straw contributing to 50.7 percent of the total feedstock. Bakshi ka Talab leads after Mohanlal Ganj on the potential CBG capacity with paddy straw contributing as the major feedstock. At the end, it is crucial to note that the CBG quantification was conducted under ideal conditions. In reality, actual CBG production is influenced by several key operational parameters, including optimal temperature, pH levels, moisture content, toxicity levels, carbon-to-nitrogen (C/N) ratio, organic loading rate, and retention time. This underscores the importance for developers/investors to consider these multiple factors to maximise CBG yield.

10 Recommendations

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

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

5. CBG/Bio-fuel plant 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.[86] 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 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.
9. Dedicated biomass banks can be established either through a third-party agency or through existing institutions like FPOs that can ensure collection and storage of residues after harvest. Considering the seasonal availability of crop residues, efficient contingency planning should be in place in the event of supply shortage linked to any extreme event such as pandemic or climate-linked disaster. This can potentially cut off the supply chain and can leave the plant operations stranded. To ensure continuous operations, storage of excess crop residues can be planned either in-house or through an agency where the storage time could be decided based on the useful life of the residue. For example, press mud can last no longer than 60 days, so they can be organised in a live storage while paddy straw which can sustain longer can go into a dead storage.

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

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