Distributed Solid Waste Treatment By Biogas System Enhancing Public Health And Environment Safety

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I. INTRODUCTION

1.1SOLIDWASTE MANAGEMENT

Solid waste refers to the byproducts of household or commercial activities that have lost their value to the original owner but may hold significance for others. The waste generated is a direct consequence of the modern way of human civilisation, presenting both challenges and opportunities. On one hand, the growing quantity of waste poses a serious issue for communities, especially in rapidly developing Indian cities striving to compete with global economies. On the other hand, it opens up possibilities for proper waste management that can not only address environmental concerns but also create economic opportunities. Despite the ambitions of Indian cities in their pursuit of rapid economic development, effective waste management has remained a significant challenge. The magnitude of waste generated has yet to be adequately addressed, highlighting a gap in the overall development strategies. The need for a more robust waste management system is evident, one that not only disposes of waste responsibly but also explores avenues for reusing materials, reducing environmental impact, and potentially generating income through proper waste management practices. In the current scenario, the dichotomy between the fast-paced economic development and the struggle to manage the escalating waste crisis poses a critical question. How can cities, aiming for global competitiveness, restore their economic aspirations with the imperative need for efficient waste management? This challenge highlights the importance of adopting sustainable waste management practices, emphasising waste disposal, reduction, reuse, and resource recovery. In doing so, communities can move beyond viewing waste as a problem and instead recognise it as a valuable resource that, if managed thoughtfully, can contribute to both environmental sustainability and economic well-being.

The responsibility of solid waste removal is mandated as an obligatory function of local governments; however, solid waste management (SWM) emerges as a major challenge for numerous urban local bodies(ULBs) in India, especially in cities characterised by high population density. India generates about 0.1kg, 0.3-0.4, and 0.5 kg per capita per

day in small, medium and large cities and town and with rising per capitain come, it is estimated that the waste generation per capita will increase in comparison to other south-east Asian countries like Indonesia (0.7), Thailand (1.05), Singapore (3.763), etc (Jain, 2017). The country faces unique challenges marked by various geographical and socio-economic which further complicates the implementation of uniform waste management strategies. Each region in the country may have distinct waste generation patterns and disposal preferences, necessitating distinct solutions for better solid waste management. The challenge, therefore, extends beyond the technical aspects of waste management; it requires a nuanced understanding of the regions to design and implement strategies that resonate with the local population. Public awareness and participation also become integral in encouraging sustainable waste management practices. Establishing a systematic and regular waste removal mechanism is essential to uphold a clean environment and enhance public health in urban settings.

CURRENT STATE OF SOLID WASTE MANAGEMENT IN INDIA

As cities grow and expand due to rapid urbanization and economic development, the sheer volume of waste generated places aburden on the existing waste management infrastructure and resources. As a result, handling and disposing of this mounting waste in an efficient manner becomes a crucial task to prevent environmental degradation and associated health hazards. According to the CPCB (Central Pollution Control Board) report 2020-21, the overall quantity of solid waste generated stand sat 160,038.9 tons per day (TPD) in the country. Out of which 152,749.5 TPD of waste is collected in an efficient manner. Out of the total collected waste ,79,956.3TPD ,constituting 50 per cent ,undergoes some form of treatment, while 29,427.2TPD, i.e.,18.4 percent, is directed to landfills and 50,655.4 TPD, representing 31.7 per cent of the total waste generated remains unaccounted 3.The consistent and in discriminate disposal of Municipal Solid Waste(MSW) is in tri cately connected to unscientific practices, urbanisation, population growth, life style ethics, and a lack of ecological awareness. For example, open dumping of MSW has detrimental effects on both the environment and human health. Solid waste management includes a spectrum of activities spanning the generation, storage, collection ,transfer, transport, processing, and disposal of solid wastes. The mismanagement of these stages not only leads to environmental degradation but also poses a serious threat to the well-being of the residents in these densely populated urban areas. India has traditionally adopted a centralized waste management approach, focusing on composting due to the substantial biodegradable component in its waste stream. In this centralised system, waste generated within a city is transported to external treatment and disposal sites. Although land filling is a common destination for most waste, this process results in the accumulation of waste at disposal sites, depleting the Earth's assimilative capacity

TYPES OF SOLID WASTE

Municipal Solid Waste (MSW): Includes household waste, commercial waste, and wastefrom institutions. Common components are foodwaste, plastics, paper, metals, and glass.

Industrial Waste: Generated from manufacturing and industrial processes. It can include hazardous and non-hazardous materials.

Construction and Demolition Waste: Includes debris from construction, renovation, and demolition activities.

Electronic Waste (E-waste): Discarded electronic appliances and devices, which can contain hazardous materials.

Biomedical Waste: Waste generated from healthcare facilities, including syringes, medical devices, and contaminated materials.

CHALLENGES IN SOLID WASTE MANAGEMENT

- Growing Waste Generation: Rapid urbanization and population growth lead to increased waste generation, often outpacing the capacity of existing waste management systems.
- Environmental Impact: Improper waste disposal contributes to air and water pollution, soil contamination, and loss of biodiversity.
- Public Health Risks: Accumulated waste can attract vectors like rats and mosquitoes, leading to disease outbreaks.
- Resource Recovery: Many valuable materials in waste, such as metals and plastics, are not recovered, resulting in resource depletion.
- Climate Change: Landfills produce methane, a potent greenhouse gas, contributing to climate change.

STRATEGIES FOR EFFECTIVE SOLID WASTE MANAGEMENT

- Waste Reduction: Encouraging practices that minimize waste generation at the source through education and legislation.
- Recycling and Composting: Promoting recycling programs and composting organic waste to divert materials from landfills.
- Waste-to-Energy Technologies: Utilizing waste as a resource for energy generation, thereby reducing landfill volume and generating renewable energy.
- Public Awareness Campaigns: Educating communities about the importance of proper waste management and sustainable practices.
- Integrated Waste Management: Implementing a combination of strategies tailored to the specific needs and resources of a community or region.

BACKGROUND INFORMATION ON BIODEGRADABLE WASTE MANAGEMENT DEFINITION AND COMPOSITION

- Biodegradable waste consists of organic materials that can decompose naturally through the action of microorganisms. Common sources include:
- Food Waste: Leftover food from households, restaurants, and food processing.
- YardWaste: Grassclippings, leaves, branches, and other garden debris.
- Agricultural Residues: Crop leftovers, such as straw and husks.
- Paper Products: Non-toxic paper and cardboard, which can break down naturally.

IMPORTANCE OF BIODEGRADABLE WASTE MANAGEMENT

- Waste Reduction: Effective management of biodegradable waste helps reduce the overall volume of waste sent to landfills, mitigating environmental impacts.
- Resource Recovery: Biodegradable waste can be converted into valuable products, such as:

- Biogas: A renewable energy source produced through anaerobic digestion, which can be used for heating, electricity generation, or as vehicle fuel.
- Compost: Nutrient-rich material that improves soil health and promotes sustainable agriculture.
- Climate Change Mitigation: By reducing the amount of organic waste in landfills, communities can lower methane emissions, contributing to climate change mitigation efforts.

METHODS OF BIODEGRADABLE WASTE MANAGEMENT

- Composting Process: Involves the aerobic decomposition of organic matter by microorganisms, resulting in compost that can enrich soil.
- Benefits: Reduces landfill waste, improves soil quality, and promotes plant growth.
- Anaerobic Digestion Process: Organic waste is broken down in the absence of oxygen,producing biogas and digestate. The biogas can be captured and used as energy, while digestate can be used as fertilizer.
- Benefits: Generates renewable energy, reduces waste volume, and recycles nutrients back into the soil.
- Education and Public Participation: Encouraging community involvement in waste separation, composting, and understanding the benefits of managing biodegradable waste effectively.

CHALLENGES IN BIODEGRADABLE WASTE MANAGEMENT

- Contamination : Non-biodegradable materials mixed with organic waste can hinder composting and digestion processes.
- Infrastructure Needs: Implementing composting and anaerobic digestion systems requires investment in infrastructure and technology.
- Public Awareness: Many communities lack awareness of the importance of managing biodegradable waste, leading to inadequate participation in waste separation and composting efforts

BIOGAS PLANT IN SOLID WASTE MANAGEMENT

- Biogas plants play a significant role in solid waste management by providing an effective method for managing organic waste. Here’s how they contribute to solid waste management:
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Waste Diversion

- Biogas plants divert organic waste from landfills, reducing the overall volume of solid waste and minimizing landfill-related issues, such as space limitations and methane emissions from decomposing waste.

Resource Recovery

- By converting organic waste into biogas, biogas plants recover energy and nutrients, contributing to a circular economy.
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By converting organic waste into biogas, biogas plants recover energy and nutrients, contributing to a circular economy.
The production of biogas provides renewable energy, while the digestate can be used as a high-quality fertilizer.

Reduction of Green house Gas Emissions

Landfills are significant sources of methane emissions. By processing organic waste in biogas plants, methane production is managed more effectively, thereby reducing overall greenhouse gas emissions and contributing to climate change mitigation.

Local Energy Production

Biogas plants can provide localized energy solutions, allowing communities to generate their own electricity and heat from waste materials, enhancing energy security and sustainability.

Community Involvement

Implementing biogas plants often involves community engagement and participation, raising awareness about waste management and sustainable practices. This fosters a culture of responsibility and environmental stewardship.

Economic Benefits

Biogas plants can create jobs in waste collection, plant operation, maintenance, and energy production, contributing to local economic development.

PROJECT OBJECTIVES

- To Explore distributed biogas system: Establish decentralized biogas treatment facilities within communities to effectively process organic solid waste, reducing the volume of waste sent to landfills & reducing reliance on centralized waste management facilities.
- To Improve Public Health Outcomes: Analyze the impact of distributed biogas systems on public health by reducing the risks associated with improper waste disposal, such as disease transmission and pest infestations.
- To Enhance Environmental Safety: To Evaluate the environmental benefits of using biogas systems, including reductions in greenhouse gas emissions, improved soil quality through the use of digestate, and decreased pollution from landfills.
- To promote renewable energy usage and reduce environmental impacts.

II. LITERATURE REVIEW

Geoffrey Hamer (2003) The safety and acceptability of many widely used solid waste management practices are of serious concern from the public health point of view. Such concern stems from both distrust of policies and solutions proposed by all tiers of government for the management of solid waste and a perception that many solid waste management facilities use poor operating procedures. Waste management practice that currently encompasses disposal, treatment, reduction, recycling, segregation and modification has developed over the past 150 years. Before that and in numerous more recent situations, all wastes produced were handled by their producers using simple disposal methods, including terrestrial dumping, dumping into both fresh and marine waters and uncontrolled burning. In spite of ever-increasing industrialisation and urbanisation, the dumping of solid waste, particularly in landfills, remains a prominent means of disposal and implied treatment.

Amit Kapoor1 & Natalia Chakma (2024) This paper presents an in-depth study and analysis of solid waste management, highlighting the dual nature of solid waste as a challenge and an opportunity for Indian cities. It further emphasises that immediate sustainable waste management solutions are needed to solve environmental issues and achieve economic potential. Constructive approaches that involve public engagement and take geographical differences into account are essential. Through the implementation of sustainable practices such as waste disposal, reduction, reuse, and waste recovery, communities can turn waste from an issue into an asset that benefits the environment, the economy, and public health in urban areas. Although various regulations and laws have been introduced to improve waste management, such as the shift from centralised (2000) to decentralised (2016) approaches, challenges persist during the implementation process of these regulations. A shift towards responsible practices, along with investment in infrastructure, finance, technology, and awareness, are necessary to alleviate the challenges and achieve effective waste management.

Chukwunonso Chinedu Anyaoku, Saeid Baroutian (2018)This study recommends on how best an SS-AD system can be incorporated into the 'least GHG emitting' ISWM to lower the operational costs of the ISWM system. The final ISWM superstructure recommended by this study included a centralized section for commercial MSW waste, and a decentralized section primarily for residential MSW waste, and the superstructure was recommended for densely poulated urban areas. Furthermore, the decentralized section of the ISWM superstructure included the collection of source-sorted waste from households, decentralized storage for collected recyclables and digestate, and the sale of biogas exclusively as domestic cooking gas. Innovative design and operational modifications proposed for the decentralized SS-AD system were: modular and detachable digester cells for managing digester bed failure, and a vertical stacking design for achieving compactness and scalability for the digester.

Giacomo D'Alisa ,Federico Demaria (2024) This article propose an analytical and conceptual tool to illuminate connections between capital development and environmental injustices. The research examines how capital- driven industrial policies foster changes in social metabolisms and cause new socio-environmental impacts, leading to ecological distribution conflicts It also explores why diverse actors mobilize and resist these changes. Building on Kapp's ecological economics theory of social costs and David Harvey's concept of accumulation by dispossession, we highlight the role of capital accumulation in environmental injustices through cost-shifting strategies, terming it "Accumulation by Contamination" (AbC). In this context, AbC refers to the process wherein capital socialises the costs of contamination, degrading the means of existence and bodies of human beings who oppose these processes of capital valorisation and engage in environmental conflicts. We make a compelling case for AbC by exploring waste-related conflicts at various industrial developmental stages. Waste, viewed as a 'common bad,' emerges as a strategic realm for capitalists seeking to expand the scale and scope of accumulation. The intricacies of waste management, its market potential, and guaranteed profitability through subsidies and processes of financialisation attract significant investments globally.

Daniel Gonz´alez (2024),In this paper, Composting has demonstrated to bean effective and sustainable technology to valorise organic waste in the framework of circular economy, especially for biowaste. Composting can be performed in various technological options, from full-scale plants to community or even individual composters. However, there is scarce scientific information about the potential impact of community composting referred to gaseous emissions. This work examines the emissions of methane and nitrous oxide as main GHG, ammonia, VOC and odours from different active community composting sites placed in Spain, treating kitchen, leftovers and household bio waste. Expectedly, the gaseous emissions have an evident relation with the composting progress, represented mainly by its decrease as temperature or biological activity decreases. GHG and odour emission rates ranged from 5.3 to 815.2 mg CO2eq d-1 kg-1VS and from 69.8 to 1088.5 ou d- 1 kg-1VS, respectively, generally being lower than those find in open-air full- scale composting. VOC characterization from the community composting gaseous emissions showed a higher VOC families' distribution in the emissions from initial composting phases, even though terpenes such as limonene, α-pinene and β-pinene were the most abundant VOC along the composting process occurring in the different sites studied. The results presented in this study can be the basis to evaluate systematically and scientifically the numerous current projects for a worldwide community composting implementation in decentralised bio waste management schemes.

Deval Singh (2024) This paper discuss some major issues, facts, and suggestions related to the sustainable management of DBPs in urban and rural areas. The review methodology adopted is based on an extensive literature review, consolidating insights from various scholarly articles, websites, and reported documents. The review examined the significance of different feedstock characteristics, such as moisture content, carbon/biomass ratio, carbon/nitrogen ratio, total solids, total volatile solid and particle size to enhance biogas production yield. It was found that the co-digestion process for two or more categories of feedstock had higher efficacy compared to the single-use feedstock. The study also dissected potential sites for DBPs, which can serve benefits related to resources and logistics to multiple stockholders (suppliers, producers, and buyers). The study aims overcome challenges for potential end-users, such as households, farms, or industries, which can ensure direct benefits to communities via clean and renewable energy sources. It also gives an opportunity to technocrats, policy makers, practitioners, and researchers to come-up with indigenous technology and management strategies to promote DBPs.

HamsaIyer (2016)This paper explores the scale at which different institutions/communities have taken efforts to successfully manage their waste. Most people are unable to achieve 100% decentralized management due to ack of appropriate channels for managing rejects and sanitary waste. More importantly, it is imperative to understand the failure and limitations of the municipal corporation since they are financially dependent on the centre and state for their functioning. But despite all those constraints, it makes sense to gauge energy and material recovery potentials and correlate to municipal waste management. By means of different examples and a technology provider for bio-medical waste, we are able to make an impact towards creating greener, sustainable communities.

Paolo Battistoni (2007) This paper explores the use of food waste disposers (FWDs) can be an interesting option to integrate the management of municipal wastewaters and household organic waste in small towns and decentralized areas. This strategy can be even more environmentally friendly if a suitable treatment process of the resulting sewage is performed in order to control nutrients emission. However, still nowadays, part of the scientific and technical community considers the application of this technology a possible source of problems. In this study, the FWDs were applied, with a market penetration factor of 67%, in a mountain village of 250 inhabitants. Further, the existing wastewater treatment plant (WWTP) was upgraded by applying an automatically controlled alternate cycles process for the management of nutrients removal. With specific reference to the observed results, the impact of the ground food waste on the sewerage system did not show particular solids sedimentation or significant hydraulic overflows. Further, the WWTP was able to face the overloads of 11, 55 and 2g per capita per day of TSS,COD and TN, respectively. Then, the increase of the readily biodegradable COD (rbCOD/COD from 0.20 to 0.25) and the favourable COD/TN ratio (from 9.9to 12)led to a specific denitrification rate of some 0.06 kg NO3-N/(kg MLVSS day). Therefore, not only COD removal, but also the total nitrogen removal increased: the denitrification efficiency reached 85%. That led to a better exploitation of the nitrogen bound oxygen and a consequent reduction of energy requirements of 39%. The final economic evaluation showed the benefits of the application of this technology with a payback time of 4–5 years.

May A Massoud (2019) This study determines the recommended level of administrative and financial decentralisation for each solid waste management operation and explore the susceptibilities and prospects of each level of govern ancein Lebanon. Primar y data was gathered from environmental experts and concerned organisations using a semi-structured in-depth interview. Results reveals that the optimal model for solid waste management in the case of Lebanon incurs devolving collection, which would assimilate local populations into the decision making process and reduce opposition towards devised solid waste management plans. Delegation and the construction of centralised treatment facilities is recommended as it incentivises municipal cooperation and permits the installation of methodologies and technologies that reflect the limitations, public attitudes, and waste dynamics of each distinct geographical territory. Deconcentrating disposal would limit the number of landfills constructed and facilitate monitoring. Administrative and constitutional reformations that clearly define the roles and responsibilities of public agencies would reduce the influence of the central authority on peripheral states.

Vladimir Prebiliˇc (2024) This study investigates waste-to-energy (WtE) technologies for municipal waste management in Koˇcevje, Slovenia. An analysis of available waste streams reveals substantial energy potential from mixed municipal waste, biodegradable waste, and livestock manure. Various WtE technologies, including incineration, pyrolysis, gasification, and anaerobic digestion, are compared. The results show that processing mixed municipal waste using thermo chemical processes could annually yield upto 0.98 GWh of electricity, and, separately, 3.22 GWh of useable waste heat for district heating or industrial applications. Furthermore, by treating 90% of the biodegradable waste, up to 1.31 GWh of electricity and 1.76 GWh of usable waste heat could be generated annually from biodegradable municipal waste and livestock manure using anaerobic digestion and biogas combustion in a combined heat and power facility. Gasification coupled with a gas-turbine-based combined heat and power cycle is suggested as optimal. Integration of WtE technologies could yield 2.29 GWh of electricity and 3.55 GWh of useable waste heat annually, representing an annual exergy yield of 2.98 GWh. Within the Koˇcevje municipality, this amount of energy could cover 23.6% of the annual household electricity needs and cover the annual space and water heating requirements of 10.0% of households with district heating. Additionally, CO_2- eq. emissions could be reduced by up to 20%, while further off setting emissions associated with electricity and district heat generation by 1907 tons annually.These findings highlight the potential of WtE technologies to enhance municipal self-sustainability and reduce landfill waste.

DISTRIBUTED COMMON BIOGAS PLANTS (DCB) FORMS MANAGEMENT

DCB PLANTS: INTEGRATED WASTE SEGREGATION AND PROCESSING

In a DCB plant system, waste is collected and first divided into two primary categories: biodegradable and non-biodegradable. This segregation process is crucial for efficient biogas production and effective recycling.

BIODEGRADABLE WASTE UTILIZATION

The biodegradable waste—such as food scraps, agricultural residue, and green waste—is directed to the biogas plant for anaerobic digestion. This organic waste undergoes a decomposition process to produce biogas, a renewable energy source. The biogas can then be used for cooking, heating, or electricity generation, helping to reduce dependence on conventional fossil fuels.

The by-product of this process, known as digestate, is a nutrient-rich material that can be used as organic fertilizer, promoting sustainable agricultural practices and enhancing soil health.

NON BIODEGRADABLE WASTE PROCESSING

Non-biodegradable waste is separated and transported to dedicated waste processing and recycling units. Here, it is further sorted into recyclable materials like plastics, metals, and glass, which are sent for recycling, thus reducing the waste that would otherwise end up in landfills.

Non-recyclable components are appropriately disposed of or directed towards specialized treatment facilities, depending on local waste management policies.

ADVANTAGES OF SEGREGATION

- Enhanced Biogas Plant Efficiency: Proper segregation ensures that only organic waste enters the biogas plant, reducing contamination and increasing biogas yield.
- Resource Recovery: Non-biodegradable waste is effectively recycled, turning materials like plastics and metals back into usable resources and promoting a circular economy.
- Reduced Environmental Impact: Diverting both organic and non-organic waste from landfills minimizes methane emissions, reduces pollution, and conserves land space.
- By implementing a systematic approach to waste segregation and treatment, distributed common biogas plants create a sustainable waste management model. This system not only generates renewable energy and organic fertilizer but also enables resource recovery from non-biodegradable waste, leading to cleaner communities and more sustainable cities.

BIOGAS PLANT PROCESS

The basic concept of the design is based on a process known as Anaerobic Digestion (AD), containing high percentage of suspended solids. The segregated organic food waste will be brought to the plant site. It will further be crushed through crusher along with suitable quantity of waste to form slurry. This slurry will be fed in to the Inlet chamber. The slurry will be mixed properly and put into Anaerobic digester. In the digester, the organic waste is converted into Biogas and Bio-slurry. This slurry can be recycled using S-L separator in which the solid and liquid will be separated and the solid conditioner. The liquid manure will be partly recycled and the rest will be discharged suitably. The Biogas generated from the anaerobic digester will be collected in membrane balloon and suitably pressurized.

ANAEROBICDIGESTION

- The crushed organic waste is fed into an anaerobic digester, a sealed and insulated tank. Inside the digester, microorganisms (bacteria) break down the organic matter in a multi-stage process:
- Hydrolysis: Complex organic materials are broken down into simpler compounds (sugars, amino acids).
- Acidogenesis: These simpler compounds are converted into volatile fattyacids, hydrogen, and carbon dioxide by fermentative bacteria.
- Acetogenesis: The volatile fattyacids are further converted into aceticacid, along with additional hydrogen and carbon dioxide.
- Methanogenesis: Methanogenic bacteria convert the acetic acid and hydrogen into methane (CH_4) and carbon dioxide (CO_2), producing biogas.

BIOGAS COLLECTION

The produced biogas, primarily composed of methane and carbon dioxide, is collected from the digester. It can contain trace amounts of other gases, such as hydrogen sulfide.

BIOGAS UTILIZATION

The biogas can be used in various ways:

- Electricity Generation: It can fuel gas engines or turbines to generate electricity.
- Heating: Biogas can be used directly for heating applications or processed to produce biomethane, a purified form of biogas.
- Vehicle Fuel: Biogas can be upgraded and compressed to be used as a renewable vehicle fuel (CNG).

DIGESTATE MANAGEMENT

The remaining material after digestion, known as digestate, is nutrient- rich and can be used as organic fertilizer for agriculture, enhancing soil health and reducing the need for chemical fertilizers.

ADVANTAGES OF DCB

- Community Engagement: In DCB, community members can actively involve in the management and operation, fostering a sense of ownership and responsibility towards waste management.
- Optimized Waste Collection: DCB can efficiently gather organic waste from multiple households, reducing the logistical challenges associated with individual plants and minimizing transport costs.
- Resource Sharing: Communities can share resources, such as expertise and maintenance, leading to lower operational costs compared to individual plants, where each household bears the full burden of setup and maintenance.
- Flexibility and Adaptability: DCB can be tailored to the specific needs and conditions of the community, allowing for flexibility in design and operation that individual plants may lack.
- Reduced Environmental Impact: By processing waste locally, DCB can minimize transportation emissions, leading to a smaller carbon footprint compared to centralized plants.
- Enhanced Resilience: Communities with DCB are less vulnerable to disruptions. If one plant has issues, others can continue functioning, ensuring ongoing waste management and energy production.

COMPARISION WITHIN DIVIDUAL BIOGAS PLANTS

- Scale and Efficiency: DCB can process larger quantities of waste more efficiently than individual plants, which may struggle with lower volumes.
- Cost Distribution: The financial burden of installation and maintenance is shared among community members in common systems, while individual plants require full investment from one household.
- Technical Support: DCB often have access to professional management and technical support, whereas individual plants may rely on the homeowner's knowledge and resources.

COMPARISON WITH CENTRALIZED BIOGAS PLANTS

- Community Involvement: DCB encourage local participation, while centralized plants may feel disconnected from the community, leading to less public support.
- Logistical Efficiency: DCB reduce the need for transporting organic waste over long distances, minimizing costs and emissions compared to centralized plants that rely on external waste collection.
- Tailored Solutions: DCB can be more adaptable to local conditions and needs, whereas centralized plants may require uniform solutions that may not suit all areas.

SAMPLING AND ANALYSIS

SAMPLE COLLECTION

Mixed organic solid waste of 11 Kgs were collected from Canteen, Restaurant and House respectively. 1 kg of Sample. Where, remaining 10 kg of each sample have been used in the pilot scale biogas plant.

SAMPLE ANALYSIS

The Physico chemical analysis is carried out to determine the characteristics of Organic waste. The parameters analysed were Moisture content, Density, Calorific Value.

MOISTURE CONTENT

The sample is heated in an electric hot oven at 108°C± 2°C for 1 to 1.5 hours. After heating it is taken out from oven and cooled in a desiccator and weighed.
%of moisture content = (Lossinweight)/(weightofsample)x100

DENSITY

Measure the weight of Organic waste then calculate the density.
The density will be in kg/m³ if the weight is in kilograms and the volume is in cubic meters.

CALORIFICVALUE

The sample is burned in a calorimeter of known heat capacity. A known amount of fuel is kept in crucible supported over a ring, a fire Wire touching the sample of the fuel is then stretched across the electrode. The bomb is placed carefully in a Cu- Calorimeter containing water. After stirring the water temperature (t1) is noted. The electrodes are then connected with battery and circuit. Thus combustion of fuel takes place and heat is liberated. Now stirring of water continued and the final of water temperature (t_2) is noted.

HS,kcal/kg=[(T)(E)–e1-e2-e3-e4]/g

H_s=Gross calorific value, kcal/kg
T=Corrected temperature,°Cor°F E= Energy equivalent
g=Weight of the sample, g

The purpose of this analysis is to evaluate the characteristics of biodegradable waste for its suitability and efficiency in biogas production. The study focuses on determining moisture content, density, and calorific value, which are essential factors in assessing the biogas production potential.

MOISTURECONTENT

The moisture content of 60% is within the optimal range for anaerobic digestion, which requires a moist environment for microbial activity. High moisture levels enhance the breakdown of organic matter, promoting microbial growth necessary for biogas production. Sufficient moisture supports effective digestion, leading to potentially higher biogas yields. Excessive moisture, however, can dilute organic matter, so this value is suitable for stable biogas production.

DENSITY

The measured density of 453 kg/m³ indicates a compact biomass suitable for the anaerobic digestion process. Higher density values facilitate efficient loading and management within the digester, allowing more material to be processed in a confined space. Adequate density ensures that the feedstock can be uniformly distributed in the digester, promoting consistent biogas production and reducing the risk of uneven digestion or gas yield fluctuations.

CALORIFIC VALUE

The calorific value of 1100 Kcal/kg reflects the energy potential of the biodegradable waste. This value signifies the amount of energy stored in the waste, which can be converted into biogas. A calorific value above 1000 Kcal/kg is generally considered favorable for biogas production. With a sufficient calorific value, the waste has the potential to produce an optimal amount of methane, the primary energy component in biogas. This energy density suggests efficient energy conversion from waste to biogas.

EFFICIENCY IN BIOGAS PRODUCTION

Based on the analyzed parameters, the biodegradable waste sample exhibits favorable characteristics for biogas production. With a balanced moisture content, sufficient density, and appropriate calorific value, the waste is likely to support efficient biogas production with a steady methane output. The expected results are:

- Higher Biogas Yield: The moisture content and calorific value together suggest that the organic waste will undergo efficient anaerobic digestion, maximizing biogas yield.
- Methane Content: The calorific value indicates a good potential for methane production, enhancing the energy efficiency of the biogas.
- Quality Digestate: Post-digestion, the leftover digestate is expected to be nutrient-rich and useful as organic fertilizer, contributing to resource recovery and promoting a circular economy.

DESIGN AND ITS PROCESS

The collected biodegradable waste was processed as mentioned below to obtain biogas and bio slurry.

PROCESS FLOW DESIGN

PREPARATION STAGE:

Initial Seeding:

Use cow dung slurry to feed the anaerobic digester. This step enhances microbial activity and establishes a strong microbial culture in the digester.

Input Material Preparation:

Biodegradable waste is shredded using a crusher.

Combine shredded waste with water to form a slurry of optimal consistency.

ANAEROBIC DIGESTION:

Inlet Chamber Feeding:

Transfer the prepared slurry into the anaerobic digester via an inlet chamber.

Mixing:

Ensure uniform mixing of the slurry within the digester to enhance microbial contact and maximize biogas production.

Biogas Generation:

Organic matter in the slurry undergoes anaerobic decomposition, producing biogas (a mixture of methane and carbon dioxide) and bio-slurry.

The obtained biogas will be collected in membrane balloon and analysed in the laboratory.

OUTPUT PROCESSING:

Slurry Recycling:

- Recycle part of the liquid manure back into the system to maintain slurry consistency or can be used as fertilizer directly by diluting with water
- Use the solid component as a soil conditioner or organic fertilizer.
- Separate the slurry into solid and liquid components using a Solid-
- Liquid Separator(S-L Separator).

EQUIPMENT AND MATERIAL SPECIFICATION

SHREDDER

The shredder is designed to break down biodegradable waste into smaller, manageable pieces for efficient digestion in the anaerobic digester. It has a processing capacity of 25 kg per hour, powered by a 1 HP single-phase motor. The blades are made from rust-resistant stainless steel, ensuring durability and effective cutting. Safety features include overload protection and safety guards to prevent accidents during operation.

ANAEROBIC DIGESTER

The anaerobic digester facilitates the breakdown of organic waste under anaerobic conditions to produce biogas and bio-slurry. This pilot-scale digester has a capacity of 20liters and is made from high-density polyethylene(HDPE), which is durable and resist ant to chemical reactions. It operates with are tention time of 25–30 days to ensure complete digestion. The digester is cylindrical, with a height of 0.5meters and a diameter of 0.2meters. It includes a gas outlet made of PVC, equipped with a pressure-release valve for safety.

INLET CHAMBER

The inlet chamber allows for the controlled feeding of slurry into the anaerobic digester. It has a capacity of 1.5 liters and is constructed from high-density polyethylene (HDPE), which ensures durability and chemical resistance. The chamber is designed with a 10 mm diameter inlet pipe to facilitate the smooth flow of slurry into the digester, preventing blockages and ensuring operational efficiency.

MEMBRANE BALLOON

The membrane balloon is used to store biogas safely before it is pressurized or utilized. It has a storage capacity of 1 cubic meter and is constructed from multi-layered reinforced rubber, making it UV-resistant and gas-tight to prevent leaks. The balloon includes features such as a pressure monitoring gauge and a safety vent, ensuring safe and reliable storage of the biogas

ENERGY POTENTIAL OF BIOGAS

The energy potential of biogas from food waste depends on several factors, including the composition of the food waste, the efficiency of the anaerobic digestion process, and the methane yield. The obtained biogas is analysed by gas Chromatography (GC).

METHANE YIELD FROM FOOD WASTE

Food waste typically produces biogas with a methane (CH_4) content of around 60%. The amount of methane generated is influenced by the organic matter in the food waste, such as carbohydrates, fats, and proteins.

Methane(CH_4):60% Carbondioxide(CO_2):36%Other gases(traceamounts) :Nitrogen, hydrogen, hydrogen sulfide
Biogas production from food waste is around 0.5 m^3 of biogas per kg of food waste (depending on the waste composition).

ENERGY CONTENT OF BIOGAS

The energy content of biogas is primarily determined by its methane content. The energy value of biogas can be estimated using the lower heating value (LHV) of methane, which is 35.8 MJ/m^3.

The biogas produced contains 60% methane, the energy potential of the biogas can be calculated as:

Energy potential(MJ)=Biogas volume(m^3)×Methane content (as a fraction)×LH V of methane(MJ/m^3)

Using a rough estimate of 0.5 m^3 of biogas perk go ffood waste andassuming
60% methane content:

Energy potential(MJ)= 0.5m^3×0.6×35.8MJ/m=10.74MJ perkg of food waste

CONVERSION TOO THER ENERGY UNIT

1kWh= 3.6MJ.

QSo, the energy potential of food waste can be converted to kilowatt-hours (kWh) by dividing the energy in MJ by 3.6:

Energy potential (kWh)= 10.74MJ/3.6
≈2.98kWh perkg of foodwaste

FACTORS AFFECTING BIOGAS YIELD

- Waste composition: Higher organic content (carbohydrates, fats, and proteins) generally leads to more biogas production.
- Anaerobic digestion efficiency: The efficiency of the digestion process and operational factors (temperature, retention time, and microbial activity) can affect methane yield.
- On average, We can expect around 3 kWh of energy per kg of food waste from biogas production. This is a useful source of renewable energy, especially when considering large-scale food waste disposal or energy generation systems.

METHODS FOR ANALYZING DIGESTATE PARAMETERS

The composition of digestate is analyzed using a variety of physical and chemical methods to determine its key parameters. Organic matter, which constitutes 50% of the digestate, is measured using the Loss on Ignition (LOI) method. In this process, a known weight of the digestate is dried at 105°C to remove moisture, followed by ignition in a muffle furnace at 550°C to burn off the organic content. The weight loss during ignition represents the organic matter. The moisture content, which is 85% (wet weight), is determined using gravimetric analysis. A sample is dried at 105°C until a constant weight is achieved, and the difference between the initial and final weight provides the moisture percentage.

The nitrogen (N) content, approximately 2.5%, is analyzed using the Kjeldahl method.Thesampleisdigestedwithconcentratedsulfuricacidanda catalystto convert organic nitrogen into ammonium sulfate, which is then distilled and titrated. Phosphorus (P), making up 1.5%, is quantified through colorimetric analysiso rICP-OES(Inductively Coupled Plasma Optical Emission Spectroscopy). In colorimetric analysis, phosphorus reacts with molybdate to formablue colored complex measured spectrophotometrically,while ICP-OES provides direct quantification.

Potassium(K), present at1%, is analyzed using flame photometry or ICP-OES. The digestate is digested with an acid solution, and the potassium content is measured either by the intensity of emitted light in flame photometry or directly via ICP-OES. Calcium (Ca) and magnesium (Mg), accounting for 1% and 0.5%, respectively, are determined using Atomic Absorption Spectroscopy (AAS) or ICP-OES, both of which offer high sensitivity and precision after acid digestion of the sample.

Finally, the ash content, which makes up 10% of the digestate, is measured using gravimetric analysis. A known weight of the digestate is ignited in a muffle furnace at 550°C to burn off all organic material, leaving only the inorganic residue. The residue's weight represents the ash content. These comprehensive analyses provide valuable insights into the composition of digestate for its utilization as a fertilizer or soil conditioner.

ANALYSIS REPORT ON COMPOSITION OF DIGESTATE
APPLICATIONS OF DIGESTATE

Digestate can be used in several ways:

- As a Fertilizer: Due to its high nutrient content, digestate is often used as an organic fertilizer in agriculture, helping to improve soil fertility and structure.
- Composting: The solid fraction of digestate can be further composted to create high-quality compost for agricultural or horticultural use.
- Soil Amendment: It can also be used to improve soil organic matter content, especially in degraded soils.
- Proper management of digestate is important to avoid potential environmental issues such as nutrient runoff or contamination of groundwater. In many regions, regulations are in place to ensure the safe use of digestate as a fertilizer.

ENHANCING PUBLIC HEALTH AND ENVIRONMENTAL SAFETY THROUGH DECENTRALIZED BIOGAS PLANTS

A decentralized biogas plant, which processes organic waste on a smaller, localized scale, offers several advantages in terms of enhancing public health and environmental safety. Let's break down how the information you provided supports these advantages:

REDUCTION OF GREENHOUSE GAS EMISSIONS

- Biogas as a Renewable Energy Source: By converting food waste into biogas, decentralized biogas plants can help reduce reliance on fossil fuels, thus decreasing carbon dioxide (CO_2) emissions. Methane (CH_4),a potent greenhouse gas, is captured in the process and used as a clean energy source instead of being released into the atmosphere from landfills.
- Methane Capture: The methane content in biogas (50-70%) is highly useful, and capturing it for energy generation prevents its uncontrolled release into the atmosphere. This contributes to climate change mitigation, reducing the global warming potential of methane.
- Local Energy Production: The energy produced can be used locally for cooking, heating, or electricity generation, reducing the need for long- distance energy transmission, which typically results in energy losses and additional emissions.

WASTE MANAGEMENT AND PUBLIC HEALTH

- Dealing with Food Waste: Decentralized biogas plants can help address the growing issue of food waste in urban and rural areas. Food waste often ends up in landfills, where itgenerates harmful methane emissions. By diverting food waste to biogas plants ,you reduce the burden on landfills, where waste often rots and releases toxins or methane into the air.
- Pathogen Reduction: The anaerobic digestion process helps to break down pathogens present in food waste, reducing the risk of diseases that could potentially spread from improperly managed waste. Though some pathogens remain, the digestion process significantly reduces microbial load, improving sanitation and public health.
- Reduced Waste Handling: Proper management of organic waste locally reduces the chances of contamination from waste handling, transport, and disposal. This prevents outbreaks of diseases related to waste mismanagement, such as cholera or dengue, and limits exposure to harmful bacteria.

SOIL FERTILITY AND AGRICULTURE

- Nutrient-Rich Digestate: The digestate produced by the biogas plant is rich in nutrients (such as nitrogen, phosphorus, potassium, calcium, and magnesium).These nutrients are essential for soil health and can be used as an organic fertilizer, promoting sustainable farming practices. This reduces the need for synthetic fertilizers, which can contaminate groundwater and lead to environmental hazards like eutrophication.
- Soil Amendment: Digestate can improve soil structure, increase its organic matter content, and enhance its water-holding capacity. This is particularly beneficial for degraded soils or areas with poor soil health, making local agricultural practices more resilient to climate extremes like droughts or floods.
- Reduced Chemical Inputs: By using biogas digestate as fertilizer, the need for chemical fertilizers is reduced, which also helps prevent soil contamination, groundwater pollution, and health issues related to the use of harmful agricultural chemicals.

IMPROVED LOCAL AIR AND WATER QUALITY

- Air Quality Improvement: Biogas plants that use organic waste reduce the need for open burning of waste, which is a common practice in many regions and contributes to air pollution. Burning waste, especially plastic, releases toxic pollutants such as dioxins and furans. In contrast, biogas plants convert waste to energy in a controlled environment, improving local air quality.
- Water Pollution Prevention: By reducing the volume of waste sent to landfills or open dumping grounds, biogas plants help prevent leachate from contaminating local water supplies. Leachate, the liquid that seeps through waste, can contain harmful chemicals, heavy metals, and pathogens, which are often found in landfills.

DECENTRALIZED ENERGY RESILIENCE

- Energy Security and Access: In remote areas or developing regions where access to electricity is limited, decentralized biogas plants offer a reliable source of renewable energy. This enhances energy security, supports local economies, and reduces dependence on external energy sources, which can be disrupted by political instability or supply chain issues.
- Waste-to-Energy Solutions: Decentralized biogas plants provide communities with a local solution to energy production, waste disposal, and even job creation in the form of plant management and waste collection

ECONOMIC AND SOCIAL BENEFITS

- Local Employment: The establishment of biogas plants can generate jobs in areas such as waste collection, plant operation, and maintenance, which can benefit local communities economically.
- Energy Savings: By using biogas locally, communities can reduce their reliance on costly external sources of energy, leading to energy savings and making energy more affordable and accessible, especially for low-income households.
- Circular Economy: A decentralized biogas plant supports the circular economy, where waste materials are converted into valuable resources (biogas for energy and digestate for fertilizer). This approach fosters sustainability and creates a more resilient, resource-efficient society.

PUBLICHEALTH AND ENVIRONMENTAL SAFETY REGULATIONS

- Regulated Waste Management: Decentralized biogas plants often operate in accordance with local waste management and environmental safety standards, ensuring that the processes adhere to best practices for minimizing environmental risks and protecting public health.
- Sustainable Practices: These plants help mitigate the environmental impacts associated with traditional waste disposal methods, such as landfill usage, burning, and the contamination of air, water, and soil.

In summary, decentralized biogas plants enhance public health and Environmental safety by:

- Reducing greenhouse gas emissions and contributing to climate change mitigation.
- Offering effective waste management solutions and improving sanitation.
- Producing nutrient-rich digestate for sustainable agricultural practices.
- Improving air and water quality by reducing waste burning and landfill usage.
- Providing local, renewable energy solutions and contributing to economic development.
- Supporting a circular economy, where waste isused as a resource.
- These advantages demonstrate that decentralized biogas plants can play a vital role in improving community resilience, promoting environmental sustainability, and ensuring long-term health benefits.

III. CONCLUSION

The analysis confirms that biodegradable waste possesses significant potential for biogas production, with optimal moisture content, density, and calorific value contributing to enhanced methane yield. The designed anaerobic digestion system efficiently converts organic waste into biogas, offering a renewable energy source while reducing environmental pollution. The by- product, digestate, is rich in nutrients and can be utilized as an organic fertilizer, further contributing to sustainable waste management practices. Implementing decentralized biogas plants can improve public health by reducing landfill waste and mitigating greenhouse gas emissions. This study underscores the importance of integrating biogas technology into waste management strategies to promote energy security, environmental sustainability, and circular.