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THESIS NO: M-403-MSREE-2020-2025

Performance Analysis of Large Size Biogas Plants in Nepal

by

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A THESIS

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULLFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

APRIL, 2025

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ABSTRACT

The increasing demand for sustainable energy solutions has driven interest in large-scale biogas plants as a viable option for renewable energy generation and waste management in Nepal. This study analyzes the performance of large-scale biogas plants by evaluating key parameters such as feedstock composition, Total Solids (TS), Volatile Solids (VS), biogas yield, and operational efficiency. The research incorporates data from multiple biogas plants, assessing their efficiency based on feedstock characteristics, digestion conditions, and biogas production potential, production capacity and production.

The findings indicate that plants with higher VS content (above 80% of TS) and well-optimized TS levels (8-12%) achieve superior biogas yields. Additionally, factors such as hydraulic retention time, temperature control, and process stability significantly impact overall system performance. Economic and environmental assessments highlight the potential of large-scale biogas plants to contribute to energy security, waste reduction, and greenhouse gas mitigation in Nepal.

Despite their benefits, challenges such as feedstock variability, high initial investment, and process inefficiencies, reliability issue, limit widespread adoption and sustainability. To enhance sustainability, strategies such as co-digestion of multiple feedstocks, process automation, and financial incentives must be prioritized. This study provides valuable insights into optimizing large-scale biogas plants, offering recommendations to improve their efficiency, scalability, and long-term sustainability in Nepal’s energy landscape.

Keywords: Biogas, Large-Scale Biogas Plants, Total Solids, Volatile Solids, Renewable Energy, Nepal, Sustainability, Reliability, Co-digestion, Feed stocks, Waste management

ACKNOWLEDGEMENT

This current study is the outcome of extensive collaboration and support from various individuals within the institute and outside of the institute. I wish to express my sincere appreciation to Associate Prof. Dr. Ajay Kumar Jha, who acted as my thesis supervisor. He provided me with the opportunity, essential resources, and invaluable guidance, offering insightful suggestions throughout the entire thesis project.

I would like to take this opportunity to express a deep sense of gratitude and thankfulness to Dr. Hari Bahadur Darlami, Program Coordinator, Renewable Energy Engineering, Department of Mechanical and Aerospace Engineering, Pulchowk Campus for allowing me to carry out this study.

I am thankful to the entire MSREE personnel for creating an excellent interactive atmosphere for thesis work. I appreciate the suggestions, information, assistance, and productive criticism from colleagues and teachers Lastly, I am thankful to all those who have directly or indirectly assisted me with my thesis work

I am also very grateful towards my family and friends who helped directly or indirectly for the completion of my thesis and keep on motivating me by word of success and are always enthusiastic to know the relevant area of the project and provide me with lots of suggestions from time to time.

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LIST OF ABBREVIATION

MSW	Municipal Solid Waste
GPR	Gas Production Rate
m^3/day	Cubic Meters per Day
W2E	Waste to Energy
MGEAP	Municipal Green Energy Acceleration Program
TPD	Tons per Day
DFS	Detailed Feasibility Study
T&C	Testing and Commissioning
CH_4	Methane
CO_2	Carbon Dioxide
H_2S	Hydrogen Sulfide
O_2	Oxygen
NH_3	Ammonia
CSTR	Continuous Stirred Tank Reactor
AD	Anaerobic Digestion
TS	Total Solids
VS	Volatile Solids
HRT	Hydraulic Retention Time
SLR	Substrate Loading Rate
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand

CHAPTER ONE : INTRODUCTION

1.1 Background

Biogas technology has emerged as a significant renewable energy solution in Nepal, contributing to sustainable waste management, energy security, and environmental conservation. The adoption of biogas plants has been widely promoted by government and non-governmental organizations, mainly targeting rural households and commercial enterprises. The primary drivers behind biogas adoption include the need to reduce dependency on traditional biomass fuels, mitigate greenhouse gas (GHG) emissions, and promote sustainable agricultural practices (AEPC, 2018). Over the past few decades, Nepal has witnessed the installation of thousands of small and large-scale biogas plants, demonstrating the potential of anaerobic digestion for energy generation and waste treatment. However, the efficiency and overall performance of these plants vary significantly depending on technical, climatic, and financial factors (Gautam et al., 2009).

The efficiency of biogas production is largely influenced by feedstock type, digester design, temperature, and retention time. Studies have shown that cow dung and human excreta yield higher methane content compared to agricultural residues, primarily due to their balanced carbon-to-nitrogen ratio (Gautam et al., 2009). The climatic conditions in Nepal also play a crucial role, as microbial activity in biogas digesters is highly sensitive to temperature variations. In the Himalayan region, lower temperatures have been reported to reduce the efficiency of biogas generation due to slower microbial digestion processes. Meanwhile, studies on different digester designs, such as fixed-dome, floating-drum, and polyethylene tubular digesters, have found that fixed-dome digesters provide higher gas production and durability despite their higher installation costs.

The economic feasibility of biogas plants is another critical factor affecting their adoption and long-term sustainability. Small-scale household biogas plants have been shown to provide significant savings on firewood and liquefied petroleum gas (LPG) costs, with an estimated payback period of 5–7 years, depending on plant size and government subsidies (Pokharel, 2010). Large-scale commercial plants tend to have a shorter payback period due to their higher gas production and utilization in industrial applications (Bhattarai et al., 2016). Financial incentives, such as subsidies covering up to 40% of installation costs, have played a crucial role in promoting biogas technology (AEPC, 2018). However, the lack of access to financing and high upfront costs remain major barriers to widespread adoption (Shakya et al., 2019).

Despite the potential benefits, biogas plants in Nepal face several challenges. Poor maintenance, lack of technical expertise, and seasonal variations in feedstock supply have been identified as significant hurdles to long-term sustainability (Dhakal et al., 2020). Addressing these challenges requires improved feedstock management, capacity-building programs, and advancements in digester technology. Research on hybrid energy systems integrating biogas with solar and wind energy has gained attention as a potential solution to enhance energy reliability (Sharma et al., 2022). Future efforts should focus on optimizing digester efficiency, strengthening financial mechanisms, and expanding commercial biogas applications.

1.2 Problem Statement

Large-size biogas plants in Nepal hold significant potential for clean energy generation, yet many suffer from low gas output, poor maintenance, seasonal feedstock issues, and a lack of skilled operation. These challenges lead to underperformance and reduce their contribution to Nepal's energy and climate goals.

There is a lack of systematic performance evaluations, including financial analysis, making it difficult for stakeholders to understand operational inefficiencies or ensure cost-effective sustainable investments.

This thesis addresses these gaps by analyzing the technical and financial performance of large-size biogas plants in Nepal, identifying key factors affecting their efficiency, and providing recommendations to enhance their overall viability.

1.3 Objectives

1.3.1 Main objective

The main objective of this study is to analyze the performance of large size biogas plants in Nepal by evaluating their operational efficiency and key challenges to enhance their sustainability.

1.3.2 Specific objectives

- To evaluate the technical performance of selected large-size biogas plants in Nepal by analyzing key operational parameters such as biogas yield, feedstock input, and plant utilization rate.
- To assess the financial performance of these plants through cost-benefit analysis, operational and maintenance costs, and overall economic viability.
- To identify the major challenges and success factors influencing the performance of large-size biogas plants and provide practical recommendations for improving their efficiency and sustainability.

1.4 Scope of Work

The scope of this study covers the technical, and operational aspects of biogas plants in Nepal. It includes an evaluation of different biogas plant designs, feedstock types, and environmental factors affecting gas production efficiency. Additionally, challenges related to maintenance, scalability, and operational sustainability are identified, with recommendations for technical improvements and policy support. The findings aim to provide insights for improving biogas plant performance and promoting wider adoption in Nepal.

1.5 Limitations

- **Data Availability and Accuracy** – The study relies on available data from existing biogas plants, which may have inconsistencies or gaps, affecting the accuracy of performance analysis.
- **Scope of Coverage** – The research focuses on selected biogas plants in Nepal and may not fully represent the performance variations across all regions and plant sizes.

CHAPTER TWO : LITERATURE REVIEW

2.1 Biogas Energy

Biogas is a renewable energy source produced through the anaerobic digestion of organic matter such as agricultural waste, manure, and municipal waste. It primarily consists of methane (CH_4) and carbon dioxide (CO_2), making it a viable alternative to fossil fuels (Bond & Templeton, 2011). Biogas can be used for electricity generation, heating, and as a fuel for vehicles. Nepal has been promoting biogas technology for decades, significantly improving rural energy access and reducing dependency on traditional biomass fuels (BSP-Nepal, 2017).

2.2 Biogas Production Process

The biogas production process involves four key stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Each stage is critical for the effective breakdown of complex organic materials into biogas (Angelidaki et al., 2003). The efficiency of biogas production depends on factors such as temperature, pH level, feedstock type, and retention time. Figure 1 illustrates the basic biogas production process and its key components.

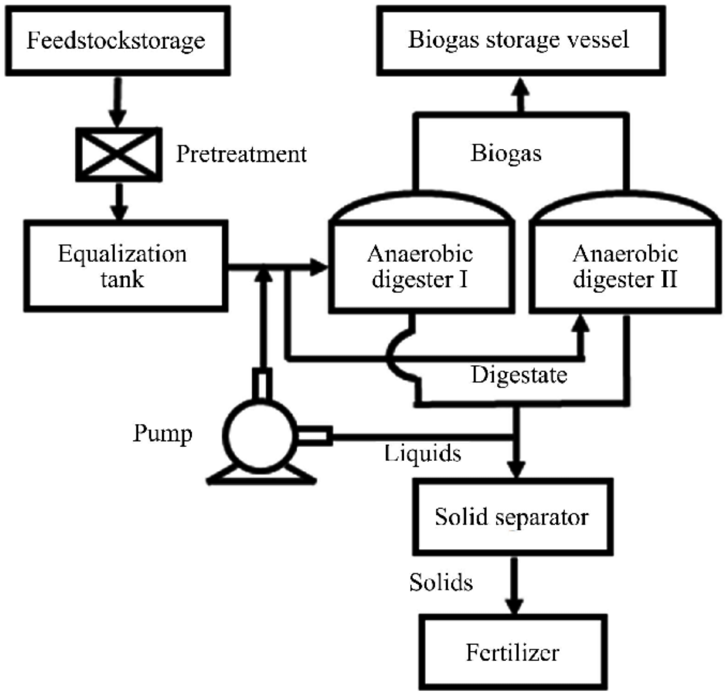


Figure 1 Biogas Production Process

Source: Flow diagram for digester and biogas production. (2019). Retrieved from https://www.researchgate.net/figure/Flow-diagram-for-digester-and-biogas production_fig2_330755486

2.3 Biogas Plant Design and Components

Biogas plants are designed based on feedstock availability, climatic conditions, and energy demand. The common types of biogas plants include fixed dome, floating drum, and balloon digester systems. Each type has its advantages and limitations. The key components of a biogas plant include:

- Digester: The main chamber where anaerobic digestion occurs.
- Inlet and Outlet Chambers: Facilitate the movement of organic feedstock and slurry.
- Gas Holder: Stores the produced biogas before utilization.
- Slurry Management System: Ensures proper disposal and utilization of digestate as bio-fertilizer (Rajendran et al., 2012).

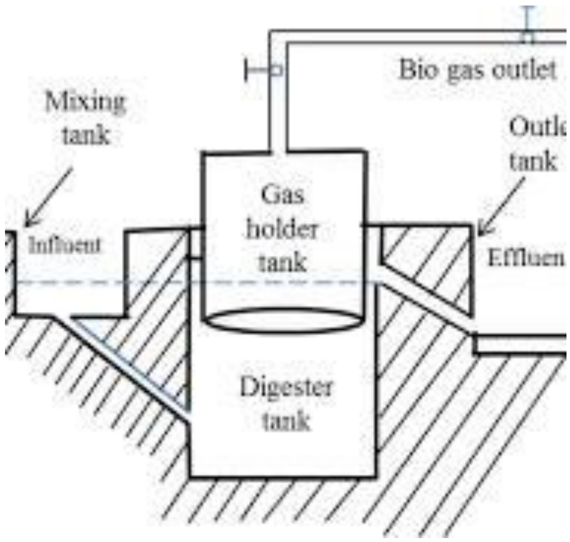


Figure 2 Components of a Biogas Plant

Source: Simple schematic of a biogas plant. (2017). Retrieved from https://www.researchgate.net/figure/Simple-schematic-of-a-biogas-plant_fig3_318503013

Classification of Biogas Plants Based on Size

Biogas plants can be classified into different categories based on their size, primarily determined by the volume of feedstock they process or the amount of biogas they produce per day. The three common categories are:

1. **Small-Scale (Household) Biogas Plants**
   - These are designed for individual households.
   - Typically handle **15–50 kg of organic waste** or **dung per day**.
   - Produce up to **2–6 cubic meters of biogas per day**.
   - Mainly used for cooking and lighting in rural areas.
2. **Medium-Scale Biogas Plants**
   - Suitable for small farms, schools, hostels, or community groups.

- Process approximately **50–250 kg of organic waste per day**.
- Generate about **6–25 cubic meters of biogas per day**.
- Can meet energy needs for cooking, heating, and small-scale electricity generation.

3. **Large-Scale Biogas Plants**

- Designed for institutions, commercial farms, industries, or municipalities.
- Handle **more than 250 kg of feedstock per day** or produce **over 25 cubic meters of biogas daily**.
- Often integrated with electricity generation (biogas gensets), thermal applications, or upgraded to biomethane for bottling or injection into gas grids.

2.4 Historical Development of Biogas in Nepal

The history of biogas in Nepal goes back to 1955, when a Late Father B. R. Saubolle, a Belgian School Teacher at St. Xavier's School, Godavari in Kathmandu, was fabricated out of a used 200-liter oil drum and it had a metallic gas holder on top. Only a few individuals were involved in biogas technology until the world energy crisis of 1973, which then triggered a global interest in this sector. The use of biogas has been expanding rapidly in Nepal since the biogas support program (BSP) was initiated in 1992 by the Netherlands Development Organization (SNV) with the financial support from the Netherlands Directorate-General for International Cooperation (DGIS). At the time there was only one company, the Gobar Gas Company (GGC), building and managing biogas plants and only one bank, the Agricultural Development Bank (formerly ADB/N), providing loans to biogas farmers. Today, biogas sector has emerged as aspirant sector with more than 500000 constructed plants of which 20 are large scale and over 103 registered private construction companies. The development of the number of biogas plants that were installed by AEPC from 2061 to 2074 B.S is shown in figure 3, showing that biogas has been viable and implementable technology in Nepal.

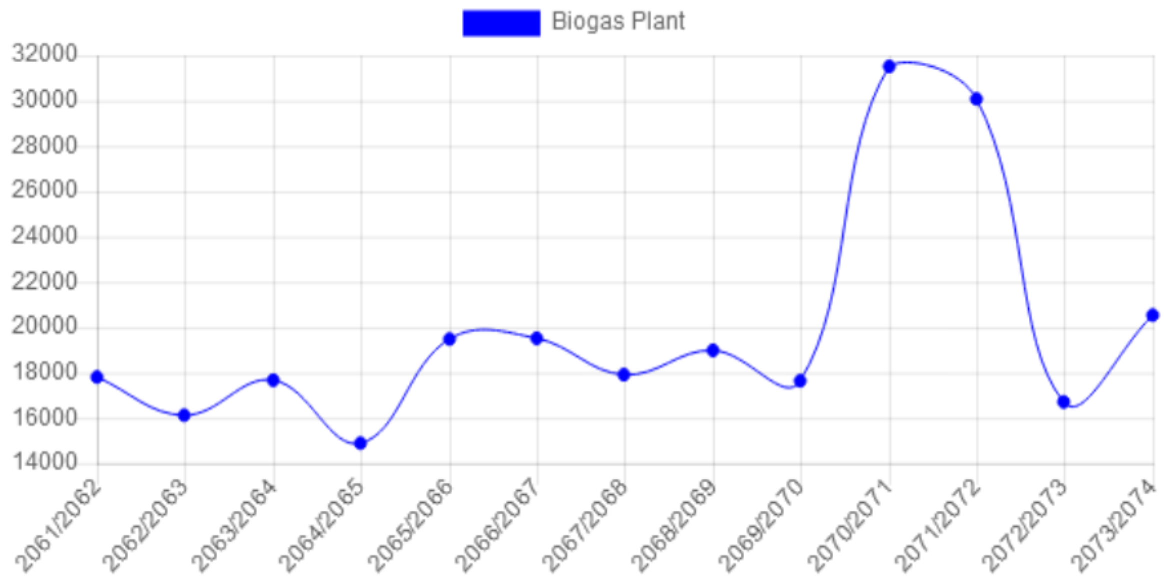


Figure 3 Number of biogas plants installed from 2061 to 2074 BS.

Source: Alternative Energy Promotion Center(AEPC)

2.5 Status of large-scale biogas and its technology in Nepal

Biogas is produced by anaerobic digestion or fermentation also called decomposition of organic wastes by the action of methanogenic bacteria which is major source of alternative energy in Nepal and currently it is promoted by AEPC through Scaling Up Renewable Energy Program (SREP)-Extended Biogas Project, National Rural & Renewable Energy Program (NRREP) and Renewable Energy for Rural Area (RERA) in cooperation with microfinance institutions including cooperatives and Biogas Credit Unit (BCU). Production of biogas in large scale in Nepal current in the developing phase. Not so much advanced and diverse technologies are installed. Commonly are either modified GGC 2047 model or double membrane CSTR technology is newly adopted and installed in all the projects built before. There are only few construction companies, consulting agencies, developers, experts, skilled manpower and masons are in this field. According to AEPC, there are only 11 Construction companies and 44 consulting agencies are shortlisted by AEPC in 2020 and are capable of doing consulting and construction jobs for promotion development of large-scale biogas plant in Nepal.

2.6 Global Scenario in Biogas

Globally, the share of renewable energy supply & consumption has been increasing over time and the same way as share of biogas in total of bio energy supply due to the advancement of its technology. It is estimated that there is a total of around 132,000 small, medium or large-scale digesters operating in the world. Around 61 billion m3 of biogas was produced globally in 2016. And Europe alone produces more than half of the biogas produced globally while Asia share is 30 %.

Table 1 Biogas production globally

Year	Biogas(Billion m^3)	Biogas(EJ)
2000	13.2	0.28
2005	23.1	0.50
2010	38.7	0.84
2015	60.0	1.30
2016	60.8	1.31

Global direct consumption of biogas was around 35 Mtoe in 2018. Currently, over 60% of biogas production capacity lies in Europe and North America. As the leading biogas-producing region, Europe has around 20000 biogas plants, with the majority situated in Germany. Most are built for on-site electricity generation and co-generation, with around 500 plants dedicated to the upgrading of biogas [10]. Year Biogas (Billion m^3) Biogas (EJ) 2000 13.2 0.28 2005 23.1 0.50 2010 38.7 0.84 2015 60.0 1.30 2016 60.8 1.31 4 The global biogas demand in the Sustainable Development Scenario is as shown in figure 4.

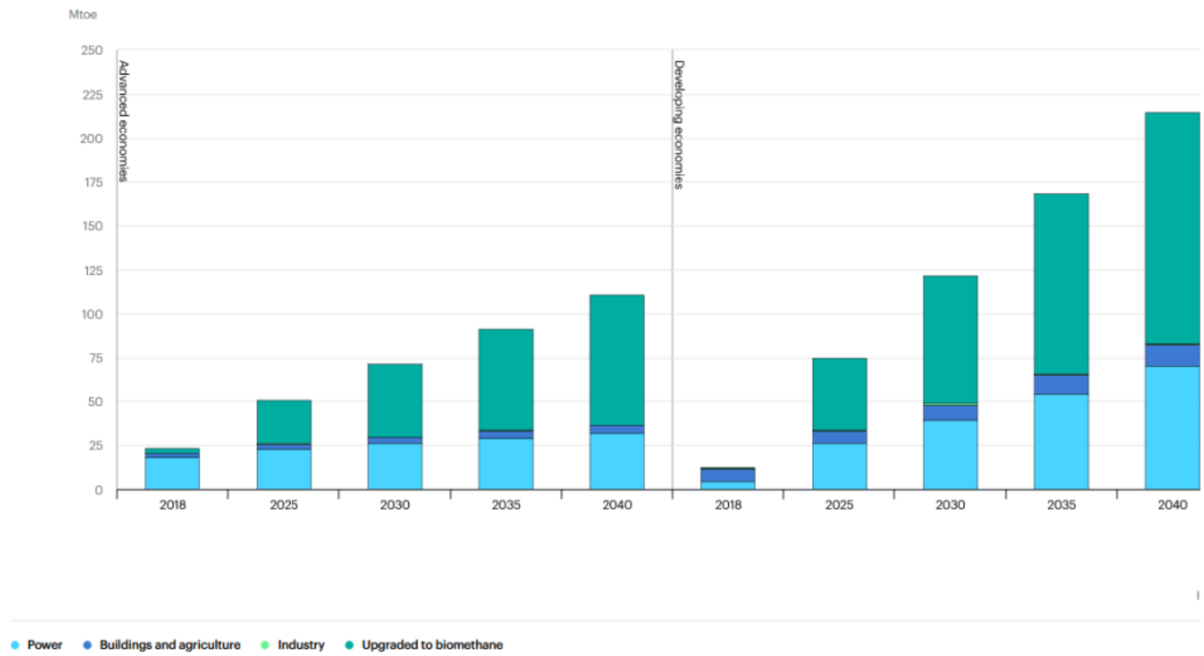


Figure 4 Global biogas demand in the Sustainable Development Scenario, 2018-2040

Source: IEA Key World Energy Statistics 201

2.7 Performance Parameters of Biogas Plants

The performance of biogas plants is assessed based on several key parameters:

- Biogas Yield: The volume of biogas produced per unit of feedstock.
- Methane Content: Determines the energy potential of the produced gas.
- Retention Time: The duration for which feedstock remains in the digester.
- Temperature and pH: Affect microbial activity and overall efficiency.
- Efficiency of Gas Utilization: Measures the effectiveness of biogas use in cooking, electricity generation, or heating (Weiland, 2010).

*

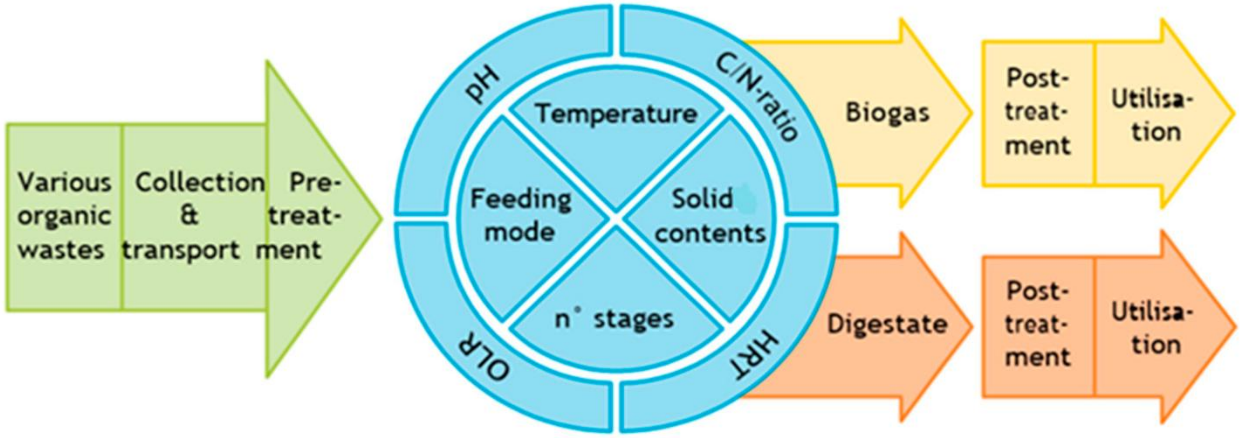


Figure 5 Performance Parameters of Biogas Plants

2.8 Challenges and Barriers in Biogas Implementation

Despite its potential, biogas technology faces several challenges, including:

- Technical Barriers: Inefficient design, poor maintenance, and gas leakage issues.
- Economic Constraints: High initial investment costs and lack of financial incentives.
- Social Acceptance: Limited awareness and cultural barriers to biogas adoption.
- Policy and Institutional Gaps: Lack of structured policies and technical support (Surendra et al., 2014).

2.9 Biogas Development in Nepal

Nepal has a long history of biogas development, with initiatives led by organizations like the Biogas Sector Partnership-Nepal (BSP-Nepal). The country has installed over 300,000 household biogas plants, significantly contributing to rural electrification and environmental conservation. The government provides subsidies and technical support to promote biogas adoption (AEPC, 2020). The expansion of large-scale biogas plants for commercial and industrial applications is a growing trend, addressing urban waste management and energy security challenges.

2.10 Future Prospects of Biogas in Nepal

With increasing energy demand and environmental concerns, the future of biogas in Nepal looks promising. Advancements in biogas purification and upgrading technologies can enhance its application as a clean fuel for transportation. Integration with other renewable energy sources, such as solar and wind, can improve overall energy reliability. Policy support, financial incentives, and technical innovation will be crucial in scaling up biogas technology in Nepal (Ghimire, 2013).

2.11 Large-Scale Biogas Plants: Global and Nepalese Perspective

Large-scale biogas plants, also known as industrial or community biogas plants, are designed to process organic waste from municipal solid waste (MSW), agro-industrial residues, slaughterhouse waste, and large-scale farms (Abbasi et al., 2012). Unlike household-scale digesters, large biogas plants require sophisticated feedstock management, optimized digestion conditions, and advanced biogas upgrading technologies (Gollakota et al., 2020).

In Nepal, large-scale biogas projects have gained momentum, particularly in commercial, industrial, and institutional sectors. For example, the Alternative Energy Promotion Centre (AEPC) and the Biogas Sector Partnership-Nepal (BSP-Nepal) have supported the installation of over 100 large biogas plants across the country, targeting industries such as dairy farms, poultry farms, slaughterhouses, and municipal waste treatment facilities (AEPC, 2021). The Nepalese government’s subsidy scheme and carbon financing mechanisms under the Clean Development Mechanism (CDM) have further boosted the adoption of large biogas plants (Shrestha et al., 2018).

2.12 Key Performance Indicators of Large-Scale Biogas Plants

The efficiency and performance of large biogas plants depend on multiple technical, operational, and economic parameters, including:

- Biogas Yield per Unit of Feedstock – The amount of biogas generated per kg of volatile solids (VS) or total solids (TS) (Weiland, 2010).
- Methane Content (%) – Typically, 55–65% methane concentration is desirable for high calorific value and efficient energy conversion (Ferguson et al., 2014).

- Organic Loading Rate (OLR) – The rate at which organic material is fed into the digester, measured in kg of chemical oxygen demand (COD) or VS per cubic meter of digester volume per day (Mata-Alvarez et al., 2014).
- Hydraulic Retention Time (HRT) – The average time feedstock remains in the digester, typically ranging from 20–50 days for mesophilic conditions (Khanal, 2019).
- Digester Temperature and pH Stability – Large plants operate in either mesophilic (35–40°C) or thermophilic (50–55°C) conditions, with optimal pH between 6.8–7.5 (Koch et al., 2016).
- Gas Utilization Efficiency – How effectively the produced biogas is used for power generation, cooking, heating, or vehicle fuel (Rajendran et al., 2012).

2.13 Case Studies of Large-Scale Biogas Plants in Nepal

Several successful case studies of large biogas plants in Nepal provide insights into their technical, economic, and environmental performance:

1. **GGC Biogas Plant at Sujal Dairy, Pokhara**

- Installed in 2019, this plant processes cow manure and dairy waste, producing 400–500 m^3 of biogas per day.
- The generated biogas replaces diesel fuel for milk processing, reducing carbon emissions by 50 tons per year (GGC, 2020).

2. **Nepalgunj Slaughterhouse Biogas Plant**

- Utilizes slaughterhouse waste, with a digester capacity of 300 m^3.
- Produces bio-CNG for vehicle fuel, demonstrating the potential of biogas as a transportation fuel alternative (Shakya et al., 2022).

3. **Godavari Municipal Waste Biogas Plant**

- Processes organic fraction of municipal solid waste (OFMSW) from households and markets.

- Generates electricity (50 kW) from biogas, reducing dependency on the national grid (BSP-Nepal, 2021).

2.14 Challenges in the Performance of Large-Scale Biogas Plants in Nepal

Despite their potential, large-scale biogas plants face several technical and operational challenges:

- **Feedstock Availability and Quality** – Seasonal fluctuations in livestock manure, food waste, and crop residues impact continuous biogas production (Surendra et al., 2014).
- **High Initial Investment Costs** – Large plants require expensive infrastructure such as high-capacity digesters, gas storage systems, and biogas purification units (Ghimire, 2013).
- **Digestate Management** – Effective use of bio-slurry as organic fertilizer is crucial but often underutilized (Thapa et al., 2020).
- **Gas Leakage and Losses** – Poor pipeline infrastructure and low-pressure gas storage systems can result in biogas losses of 5–10% (Karki et al., 2016).
- **Policy and Institutional Barriers** – Inadequate government incentives, financing options, and regulatory frameworks hinder large-scale biogas expansion (AEPC, 2021).

2.15 Future Strategies for Improving Large-Scale Biogas Performance in Nepal

To enhance the efficiency and sustainability of large-scale biogas plants, the following strategies can be implemented:

- **Biogas Upgrading for Bio-CNG Production** – Investing in biogas purification technologies (PSA, water scrubbing, membrane separation) can improve methane purity to >90%, making it viable as a vehicle fuel (Aryal et al., 2021).
- **Co-Digestion of Mixed Feedstocks** – Blending livestock manure with food waste, sewage sludge, or agricultural residues can enhance biogas yield and improve digestion stability (Angelidaki et al., 2003).

- **Hybrid Energy Systems** – Integrating biogas with solar PV and battery storage can provide continuous power supply for rural and industrial applications (Katuwal & Bohara, 2009).

- **Carbon Trading and CDM Funding** – Expanding participation in carbon financing programs can improve financial viability and attract investments in Nepal's large biogas sector (Shrestha et al., 2018).

2.15 Large Biogas Plants in Nepal

The tables list large biogas sub-projects implemented under two programs in Nepal: SREP-Extended Biogas and MGEAP. Under SREP, six projects were established in districts like Parasi, Kaski, Syangja, Sunsari, and Rupandehi, with plant sizes ranging from 0.2 to 45 TPD. Under MGEAP, 18 larger-scale biogas plants were developed across various municipalities, including MSW-based and agro-based projects. These plants, located in Morang, Sarlahi, Surkhet, Kapilvastu, Nawalparasi, and others, have plant sizes ranging from 30 to 67.61 TPD, showcasing Nepal's growing emphasis on renewable energy and waste-to-energy solutions.

Table 2 Large Biogas Sub-Projects Constructed under SREP-Extended Biogas

S.N.	**Name of Project**	**Location**	**Plant Size (TPD)**
1	Envipower Energy and Fertilizer P. Ltd. (Phase 1)	Shukrauli, Parasi	40
2	Envipower Energy and Fertilizer P. Ltd. (Phase 2)	Shukrauli, Parasi	17
3	Gandaki Urja P. Ltd.	Pokhara, Kaski	45
4	Khilung Kalika Agro Farm P. Ltd.	Putalibazar, Syangja	40
5	KK Livestock and Research Centre	Bishnupaduka, Sunsari	0.2
6	Lumbini Agro Products & Research Centre	Tikuligadi, Rupandehi	24

Table 3 Large Biogas Sub-Projects under MGEAP

S.N.	**Name of Project**	**Location**	**Plant Size (TPD)**
1	Jeewan Bikash Samaj	Katahari-2, Morang	47.13
2	Kalash Cattle Farming	Dhore-5, Parsa	36
3	Kamdhenu Gas tatha Mal Udhyog	Netragunj-4, Sarlahi	48.8
4	Eastern Star Krishi Sahakari Sanstha Ltd.	Rangeli, Morang	52
5	Dhaulagiri Natural Foods and Herbs P. Ltd.	JitpurSimara, Bara	52
6	Nextera Energy & Rohan Traders JV (Damak MSW)	Damak, Jhapa	30
7	Dev Training and Management Service (Dhangadhi MSW)	Dhangadhi, Kailali	30
8	Nepal Energy Development Company (Ghorahi MSW)	Ghorahi, Dang	40
9	Kankai Birta Arjun Nabikaraneya Urja (MSW)	Kankai, Jhapa	40
10	Waste and Enviro Management P. Ltd. (Itahari MSW)	Itahari, Sunsari	30
11	KP Byawasayik Sewa P. Ltd. (Birendranagar MSW)	Birendranagar, Surkhet	40
12	Annapurna Poultry Breeders Farm	Chainpur-1, Chitwan	40
13	Venture Waste to Energy (Dharan MSW)	Dharan, Sunsari	52
14	Dumbikas Poultry Farm P. Ltd.	Binayi Tribeni, Nawalpur	67.61
15	Emerald Energy Pvt. Ltd	Pratapur, Nawalparasi	60
16	Fossil Solutions Pvt Ltd	Suddhodhan, Kapilvastu	60
17	Jankapur Agro Pvt. Ltd	Dharapani, Dhanusha	60
18	Shivam Jaibik Gas Tatha Khad Pvt. Ltd	Jagarnathpur, Parsa	60

2.16 International Large-Size Biogas Plants

Large-size biogas plants are crucial for sustainable energy production, effective organic waste management, and greenhouse gas reduction worldwide. They are designed to handle high feedstock volumes and are often integrated with power generation, thermal applications, or biomethane upgrading. The table below presents notable examples of such plants across the globe:

Name of Plant	**Country**	**Capacity**	**Feedstock**	**Application**	**Year of Commissioning**	**Technology Type**
Ludlow Anaerobic Digestion Plant	United Kingdom	~5 MW electricity	Food & agricultural waste	Electricity generation	2013	CSTR (Continuously Stirred Tank Reactor)
GWE Agro-Waste Biogas Plant	Thailand	~7 MW (thermal)	Cassava pulp	Thermal energy for industry	2011	UASB (Upflow Anaerobic Sludge Blanket)
BioEnergie Park Güstrow	Germany	~46 million m^3/year	Energy crops, manure, organic waste	Biomethane injection to gas grid	2009	CSTR + Upgrading to Biomethane

Blue Sphere Corporation	USA	5.2 MW electricity	Organic food waste	Electricity to grid	2016	CSTR + CHP
Sichuan Rural Biogas Project	China	Institutional & household	Animal waste, crop residues	Household & community energy	2005–present (phased)	Fixed Dome (household), CSTR (large)
Amager Bakke (CopenHill)	Denmark	Integrated WTE plant	Biodegradable municipal waste	District heating, electricity	2017	Dry fermentation & incineration hybrid
Maple Leaf Foods Biogas Plant	Canada	~2.85 MW	Food processing waste	Electricity generation	2020	CSTR + CHP

2.17 Feedstocks Used in Large-Size Biogas Plants and Co-Digestion

Biogas plants, particularly large-scale ones, require an appropriate selection of feedstocks to optimize methane production. The feedstocks used in these plants must be biodegradable organic materials that, when broken down by microbial activity, can produce biogas (mainly methane and carbon dioxide).

Common Feedstocks for Large-Size Biogas Plants

1. **Agricultural Waste**: A major feedstock for biogas production is agricultural residue such as crop leftovers (corn stover, wheat straw), manure from livestock, and silage. These materials are high in organic content and are readily available in rural areas, making them ideal for large biogas plants.
2. **Animal Manure**: Manure from dairy cattle, pigs, and poultry is another commonly used feedstock. It contains high levels of organic matter and is easily digestible for the anaerobic bacteria involved in biogas production.
3. **Food Waste**: Large-scale biogas plants often utilize food scraps and leftovers, which are rich in carbohydrates and fats. These materials decompose quickly and generate a high methane yield.
4. **Industrial Organic Waste**: Biogas plants can also process organic waste from food processing industries, such as spent grains, fruit and vegetable waste, and by-products from dairy or meat production.
5. **Energy Crops**: In some cases, dedicated energy crops like maize, sorghum, and switchgrass are grown specifically for biogas production. These crops are chosen for their high yield and fast growth rate, providing a consistent supply of feedstock.

Co-Digestion in Large-Scale Biogas Plants

Co-digestion refers to the process of mixing two or more different types of organic waste in a single biogas digester to enhance biogas production. This approach has several benefits:

1. **Improved Methane Yield**: Co-digestion often leads to higher methane production than single-substrate digestion. For example, when manure is co-digested with food waste, the food waste's higher energy content can help optimize the methane output from the mixture.
2. **Nutrient Balancing**: Different organic materials have varying nutrient profiles. Co-digestion allows for the mixing of feedstocks that complement each other in terms of carbon-to-nitrogen (C:N) ratio, which is critical for the efficiency of the

anaerobic digestion process. The right balance of nutrients can enhance microbial activity and digestion rates.

3. **Waste Diversion and Management**: Co-digestion provides an opportunity for the management of various waste streams that would otherwise require separate treatment or disposal. By mixing agricultural, industrial, and food waste, biogas plants can reduce the overall environmental impact of waste disposal.
4. **Operational Flexibility**: By allowing the use of various feedstocks, co-digestion provides more flexibility in plant operations. If one feedstock is in short supply, the plant can rely on alternative or additional feedstocks to maintain consistent biogas production.

Challenges of Co-Digestion

While co-digestion offers several advantages, it also presents challenges:

- **Inconsistent Feedstock Supply**: Variability in the quality and quantity of feedstocks can lead to operational issues. For instance, seasonal variations in agricultural waste may affect the overall feedstock availability.
- **Technical Complexity**: The mixing of different organic materials requires careful monitoring of the digestion process to avoid issues such as scum formation, which can reduce biogas production.
- **Costs of Waste Collection and Transport**: Gathering various types of feedstocks from different sources can increase logistical costs, especially if the materials need to be transported over long distances.

In conclusion, the selection of appropriate feedstocks and the use of co-digestion are crucial factors for the success of large-scale biogas plants. By optimizing feedstock selection and leveraging the benefits of co-digestion, these plants can maximize their efficiency, reduce operational costs, and contribute significantly to sustainable energy production.

2.18 Applications of Large-Size Biogas Plants in Nepal

Large-size biogas plants in Nepal are becoming an essential solution for addressing energy, waste management, and environmental challenges. Below are the key applications of these plants in Nepal:

1. Renewable Energy Production

- **Electricity Generation**: Biogas plants provide electricity to off-grid rural areas, supporting local communities and small industries.
- **Biomethane for Transport**: Upgraded biogas (biomethane) can be used as a clean fuel for vehicles, reducing reliance on imported fossil fuels.

2. Waste Management

- **Agricultural Waste**: Large biogas plants help manage crop residues and livestock manure, preventing pollution and reducing open-field burning.
- **Food Waste**: These plants also process organic waste from food industries, reducing landfill use and waste disposal costs.

3. Fertilizer Production

- **Organic Fertilizer**: The digestate from biogas production serves as an organic fertilizer, improving soil health and reducing dependence on chemical fertilizers, benefiting Nepal’s farming sector.

4. Supporting Clean Cooking Solutions

- **Biogas for Cooking**: Large biogas plants supply clean cooking energy to rural households, replacing traditional biomass stoves and reducing indoor air pollution.

5. Industrial Applications

- **Powering Agro-Based Industries**: Biogas can power small agro-industries like dairy and food processing, reducing energy costs and environmental impact.
- **Industrial Heat**: Heat from biogas can be used in various industries, such as tea and brick making, reducing reliance on fossil fuels.

6. Carbon Credit Generation and Climate Mitigation

- **Methane Capture**: Biogas plants capture methane from waste, reducing greenhouse gas emissions and contributing to climate change mitigation.
- **Carbon Credits**: Nepal's biogas plants can participate in carbon credit programs, generating additional revenue.

7. Rural Development and Job Creation

- **Energy Access**: Biogas plants provide renewable energy to off-grid communities, improving living standards and supporting small businesses.
- **Job Creation**: These plants create local jobs in construction, maintenance, and operation, boosting the rural economy.

8. Sustainable Agriculture

- **Livestock Waste Management**: Biogas plants help manage livestock waste while providing energy for farm operations, promoting sustainable farming practices.
- **Nutrient Recycling**: The use of digestate as fertilizer helps reduce soil degradation and improves agricultural productivity.

9. Research and Education

- **Technology Demonstration**: Large biogas plants serve as educational and research platforms for biogas technology, promoting awareness and capacity building in local communities.

In summary, large biogas plants in Nepal offer a range of benefits, including renewable energy production, waste management, sustainable agriculture, and climate change mitigation, contributing to rural development and environmental sustainability.

CHAPTER THREE : METHODOLOGY

Methodology is an approach towards proper affair with project exquisite for the completion of a well-balanced project. The conceptual framework of the project is given below:

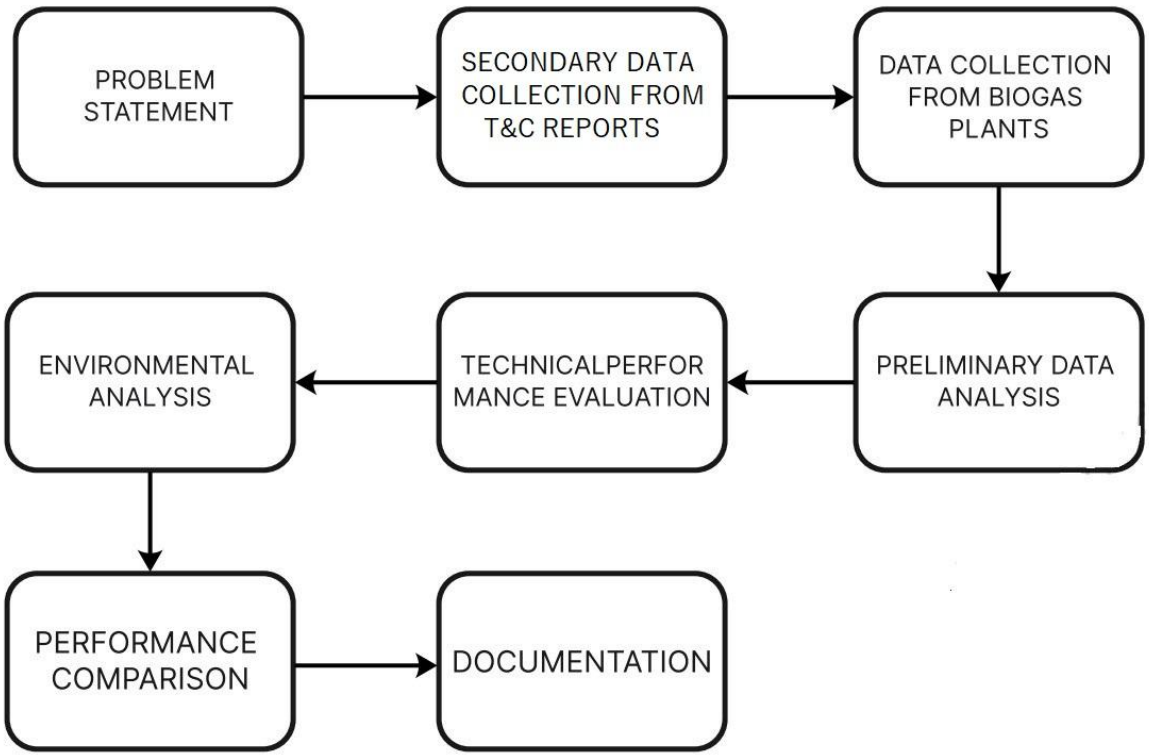


Figure 6 Methodology

3.1 Research Approach

The study focuses on understanding the existing technologies, operational challenges, and performance indicators of large-scale biogas plants in Nepal. Research papers, technical reports, policy documents, and case studies will be reviewed to gather relevant insights. This step was conducted throughout the research process to refine the analytical framework.

3.2 Field Visits and Case Studies

To obtain real-time data and practical insights, field visits was conducted to selected biogas plants in Nepal. Site selection was based on factors such as plant capacity, operational duration, and geographical distribution. Key parameters like feedstock type, gas production, system efficiency, and maintenance challenges were documented. Case studies were developed for representative plants to highlight best practices and challenges.

3.3 Data Collection

Performance data was collected through primary and secondary sources. Primary data was gathered through surveys, interviews with plant operators, and on-site measurements of gas yield, temperature variations, and digestate quality. Secondary data was obtained from government records, feasibility studies, and operational reports of biogas plants mainly from AEPC.

The data was gathered through field surveys, real-time monitoring, and operational records to ensure accuracy and reliability. The plant capacity and feedstock input were determined through on-site weighing systems and operational records. Tools such as weighing scales, load sensors, and moisture analyzers were used to measure the waste and feedstock before entering the digester. Gas production measurement was conducted using flow meters, SCADA systems, and operator logs. Biogas flow meters, gas chromatography analyzers, and pressure gauges recorded production data, while periodic gas sampling verified methane content.

The testing and commissioning (T&C) date and timeline were collected from project reports and commissioning documents. Official plant logs, project timelines, and Gantt charts were reviewed to validate historical records, supported by interviews with plant operators. Total gas production was recorded through SCADA logs, operator reports, and cumulative data analysis. Fertilizer output measurement involved on-site weighing and laboratory testing using weighing machines and soil and nutrient analyzers. Daily solid digestate output was measured and tested for quality in laboratories.

Surveys and validation methods included site visits, interviews with plant staff, and real-time observation. Sampling and testing were performed to analyze gas and fertilizer quality, while historical data from feasibility studies and operational logs were reviewed to compare projected and actual values. Data storage and analysis were managed using manual records, digital spreadsheets (Excel, Google Sheets), and cloud-based SCADA databases. Analysis tools such as Excel for trend analysis, Python for data modeling, and Power BI for visualization were used.

A structured approach to data collection using a combination of field measurements, automated monitoring, and historical record analysis ensures comprehensive evaluation of WTE projects.

3.4 Performance Evaluation Metrics

The performance of biogas plants was assessed based on the following key metrics:

- Gas Yield: Volume of biogas produced per unit of feedstock.
- Methane Content: Percentage of methane in the biogas.
- Feedstock Utilization Efficiency: Conversion rate of organic matter to biogas.
- Thermal Efficiency: Energy output per cubic meter of biogas.
- Digestate Quality: Nutrient composition of the bio-slurry for agricultural use.
- Operational Stability: Frequency of system failures, downtime, and required maintenance.

3.5 Technical Analysis

A detailed technical analysis was performed to assess the energy output, efficiency, in biogas plants. The mass balance and energy balance approach were used to quantify input and output parameters. The efficiency of biogas production was estimated using the following equation:

$$\eta = \frac{E_{output}}{E_{input}} \times 100\%$$

where,

E_{output} = Energy generated from biogas,

E_{input} = Energy content of feedstock.

Biogas Yield (Specific Biogas Production - SBP)

$$\mathrm{SBP} = \frac{\mathrm{V_{biogas}}}{\mathrm{M_{feedstock}}} \times 100\%$$

Where:

- V_{biogas} = Volume of biogas produced (m³)
- $M_{feedstock}$= Mass of feedstock input (kg or ton)

Methane Content in Biogas

$$\mathrm{CH4}(\%) = \frac{\mathrm{V_{CH4}}}{\mathrm{V_{biogas}}} \times 100$$

Where:

- V_{CH4} = Volume of methane in biogas (m³)
- V_{biogas} = Total volume of biogas (m³)

Energy Content of Biogas

$$\mathrm{Ebiogas} = \mathrm{V_{biogas}} \times \mathrm{LHV_{biogas}}$$

Where:

- V_{biogas} = Volume of biogas (m³)
- LHV_{biogas} = Lower heating value of biogas (MJ/m³, typically 20-25 MJ/m³)

Retention Time (Hydraulic Retention Time - HRT)

$$\mathrm{HRT} = \mathrm{Q_{inflow}}/\mathrm{V_{digester}}$$

Where:

- $V_{digester}$ = Volume of digester (m³)
- Q_{inflow} = Daily feedstock input (m³/day)

Organic Loading Rate (OLR)

$$\boldsymbol{OLR = V_{feedstock}/M_{digester}}$$

Where:

- $\boldsymbol{M_{feedstock}}$= Mass of organic material fed per day (kg/day)
- $V_{digester}$ = Volume of digester (m³)

Digester Temperature Impact on Biogas Production

$$Q_{biogas} = k \times e^{-Ea/RT}$$

Where:

- Q_{biogas}= Biogas production rate
- k = Pre-exponential factor
- Ea = Activation energy (J/mol)
- R= Universal gas constant (8.314 J/mol·K)
- T = Digester temperature (K)

CO_2 and H_2S Removal Efficiency in Biogas Purification

$$\eta_{purification} = \frac{C_{inlet} - C_{outlet}}{C_{inlet}} \times 100$$

Where:

- C_{inlet}= Initial concentration of CO_2 or H_2S (ppm or %)
- C_{outlet} = Final concentration after purification

To enhance the sustainability and scalability of large-size biogas plants in Nepal, the methodology involved selecting a representative sample of biogas plants based on factors like operational capacity, feedstock type, and geographical location. Data was collected on various aspects such as energy production, feedstock utilization, operational downtime, financial performance, and environmental impact. Performance evaluation was conducted using key indicators such as energy efficiency, feedstock usage, and financial sustainability. The study also identified key challenges, including technical, financial, social, and regulatory barriers, and propose solutions to address these issues. Recommendations focus on technological improvements, financial models, policy reforms, capacity-building initiatives, and community engagement to enhance the efficiency and scalability of biogas plants.

3.6 Comparative Analysis:

A comparative analysis was conducted to evaluate the efficiency, economic feasibility, and sustainability of different large-scale biogas plants. This involves:

- **Technology Comparison:** Evaluating the performance of different digester types (e.g., fixed dome vs. CSTR).
- **Feedstock Comparison:** Assessing variations in gas yield and methane content for different organic waste sources.
- **Regional Comparison:** Identifying performance differences based on geographical and climatic factors.
- **Economic Comparison:** Comparing capital investment, operational costs, and revenue generation potential among different plants.
- **Environmental Benefits Comparison:** Analyzing CO_2 reduction and waste management effectiveness across different biogas systems.

By integrating these comparative metrics, the study aims to identify best-performing biogas systems and provide recommendations for optimizing Nepal's large-scale biogas sector.

3.6 Documentation and Report Preparation

Finally, all findings were systematically documented in a research report. The results were interpreted, conclusions drawn, and recommendations provided for improving the performance and sustainability of biogas plants in Nepal.

CHAPTER FOUR : RESULTS AND DISCUSSION

A technical comparison of biogas plants is conducted to evaluate their efficiency, performance, and sustainability. The study considers key indicators such as gas production, feedstock type, fertilizer output, and overall plant efficiency. The findings are based on data collected from three waste-to-energy biogas plants in Nepal.

4.1 Overview of Selected Biogas Plants

Secondary Data Collection from 14 Plants

The first phase of the study involved collecting secondary data from 14 different Waste-to-Energy (W2E) projects operating with various feedstocks such as municipal solid waste (MSW), poultry waste, and cow dung. The goal was to assess the gas production rate (GPR) and actual gas yield of each plant.

Table 4: Secondary Data from T & C Reports - Gas Production from 14 W2E Projects

S.N.	Name of Project	Gas Production Rate (GPR) (m^3/day)	Actual Gas Produced (m^3/day)
1	Annapurna Poultry Breeders Farm	197.8	199.92
2	Dumkibas Poultry Farm P. Ltd.	4000	4677.9
3	Jeewan Bikash Samaj	2501.59	2756
4	Kalash Cattle Farming	1440	1528
5	Kamdhenu Gas tatha Mal Udhyog	4000	4102.62
6	Eastern Star Krishi Sahakari Sanstha Ltd.	2080	2100
7	Dhaulagiri Natural Foods and Herbs P. Ltd.	2080	2125

8	Dharan MSW	1800	1917
9	Itahari MSW	1860	1860
10	Kankai/Birtamod/Arjundhara MSW	4000	4079.7
11	Damak MSW	1484	2520
12	Ghorahi MSW	2000	2664.487
13	Birendranagar MSW	986.3	1745
14	Dhangadhi MSW	1892	2067.554

The study initially gathered primary data from 14 biogas plants utilizing various feedstocks, including municipal solid waste (MSW), poultry waste, and cow dung. The analysis revealed that some plants, such as Birendranagar MSW (177%), Damak MSW (169.8%), and Ghorahi MSW (133.2%), produced significantly higher gas volumes than initially projected, suggesting potential underestimations in feasibility studies or process optimizations. In contrast, Itahari MSW achieved exactly 100% of its projected gas output, indicating stable performance.

4.1.1 Sampling Methodology

Objective:

The goal of this sampling process was to select representative large-size biogas plants from a population of 14 plants in Nepal, ensuring a confidence level above 90%.

Population of Plants (N = 14):

The 14 plants considered for selection are:

1. Annapurna Poultry Breeders Farm
2. Dumkibas Poultry Farm P. Ltd.
3. New Era
4. Kalash Cattle Farming
5. Kamdhenu Gas tatha Mal Udhyog
6. Eastern Star Krishi Sahakari Sanstha Ltd.

7. Dhaulagiri Natural Foods and Herbs P. Ltd.
8. Dharan MSW
9. Itahari MSW
10. Kankai/Birtamod/Arjundhara MSW
11. Damak MSW
12. Ghorahi MSW
13. Birendranagar MSW
14. Dhangadhi MSW

Sampling Method:

The Simple Random Sampling (SRS) technique was employed to select plants from the population. This technique ensures that each plant had an equal chance of being selected, reducing potential biases in the selection process. Given that the plants are relatively similar in size and type, Simple Random Sampling was deemed the most suitable method.

Justification of Confidence Level:

The selection process aimed to ensure a representative sample of plants. With a population of 14 and a random sampling process, the resulting sample provides a **confidence level above 90%**. This is appropriate for an exploratory study where the goal is to assess general performance trends across a diverse group of plants.

Random Sampling Process:

To carry out the random selection, a **Python-based random sampling** method was used. The code ensures reproducibility and fairness by allowing for an unbiased selection. The process involved:

python

```
plants = [
    "Annapurna Poultry Breeders Farm",
    "Dumkibas Poultry Farm P. Ltd.",
    "New Era",
```

```
    "Kalash Cattle Farming",
    "Kamdhenu Gas tatha Mal Udhyog",
    "Eastern Star Krishi Sahakari Sanstha Ltd.",
    "Dhaulagiri Natural Foods and Herbs P. Ltd.",
    "Dharan MSW",
    "Itahari MSW",
    "Kankai/Birtamod/Arjundhara MSW",
    "Damak MSW",
    "Ghorahi MSW",
    "Birendranagar MSW",
    "Dhangadhi MSW"
]

random.seed(42)
sample = random.sample(plants, 3)
print("Selected Plants:", sample)
```

Selected Plants:

The following 3 plants were chosen through the random sampling process:

1. **New Era**
2. **Kamdhenu Gas tatha Mal Udhyog**
3. **Kankai/Birtamod/Arjundhara MSW**

Conclusion:

The Simple Random Sampling (SRS) method was used to select a sample from the population of 14 biogas plants. Through this process, 3 plants were randomly chosen for further analysis. The sampling technique ensures that the sample is unbiased and representative of the broader population, and the confidence level for this sampling is above 90%, making it statistically reliable for performance analysis.

4.1.2 Primary Data for Detailed Study

From the 14 projects, three plants were selected for detailed technical analysis.

Table 5: Detailed Study of 3 W2E Plants

S. N.	Name of Project	Location	Type of Feedstock	Capacity (TPD)	Projected Gas (m³/day)	Actual Gas (m³/day)	Efficiency (%)	Total Gas Till Date (m³)	Fertilizer Output (kg/day)
1	Nextera Energy Damak MSW	Damak, Jhapa	MSW & Poultry	30	1484	2520	169.8	2,240,280	12,600
2	Kamdhenu Gas tatha Mal Udhyog	Netragunj-4, Sarlahi	Cow Dung &Press Mud	40	4000	4102.62	102.6	3,934,413	20,513.1
3	Kankai/Birtamod/Arjundhara MSW	Kankai, Jhapa	MSW & Cow Dung	40	4000	4079.7	102.0	2,129,603	20,398.5

For a more detailed study, secondary data was collected from three selected plants: Damak MSW, Kamdhenu Gas tatha Mal Udhyog, and Kankai/Birtamod/Arjundhara MSW. Damak MSW demonstrated the highest efficiency among them, producing 2520 m³/day at 169.8% of the projected value. Kamdhenu Gas tatha Mal Udhyog, which operates on cow dung, showed a stable and predictable efficiency of 102.6%, producing 4102.62 m³/day.

Similarly, Kankai/Birtamod/Arjundhara MSW operated at 102% efficiency with a daily gas production of 4079.7 m³/day.

The findings indicate that MSW-based plants exhibit significant variations in efficiency due to fluctuations in waste composition and digestion conditions, whereas cow dung-based plants demonstrate more predictable performance, and higher biogas yields per unit of feedstock. Further improvements in waste segregation, retention time optimization, and pre-treatment methods could enhance the efficiency of MSW-based plants, ensuring more consistent biogas production.

The following table presents the basic technical details of the three selected biogas plants:

4.2 Technical Performance Analysis

4.2.1 Projected vs. Actual Gas Output

Each plant was designed with a projected gas output, but actual production often varies due to operational efficiency, feedstock quality, and process optimization.

Table 6 Projected vs. Actual Gas Output

Project Name	**Projected Gas Output (m3/day)**	**Actual Gas Output (m3/day)**
Damak MSW	1484	2520
Kamdhenu Gas	4000	4102.62
Kankai MSW	4000	4079.7
Annapurna Poultry	197.8	199.92
Dumkibas Poultry	4000	4677.9
Jeewan Bikash	2501.59	2756
Kalash Cattle	1440	1528
Dhaulagiri	2080	2125

Dharan MSW	1800	1917
Itahari MSW	1860	1860
Ghorahi MSW	2000	2664.487
Birendranagar MSW	986.3	1745
Dhangadhi MSW	1892	2067.554

A bar chart (displayed below) compares projected vs. actual gas production. Notably:

- Most plants exceeded their projected output.
- Birendranagar MSW (176.92%) and Damak MSW (169.81%) had the highest efficiency.
- Itahari MSW performed exactly as projected (100%).

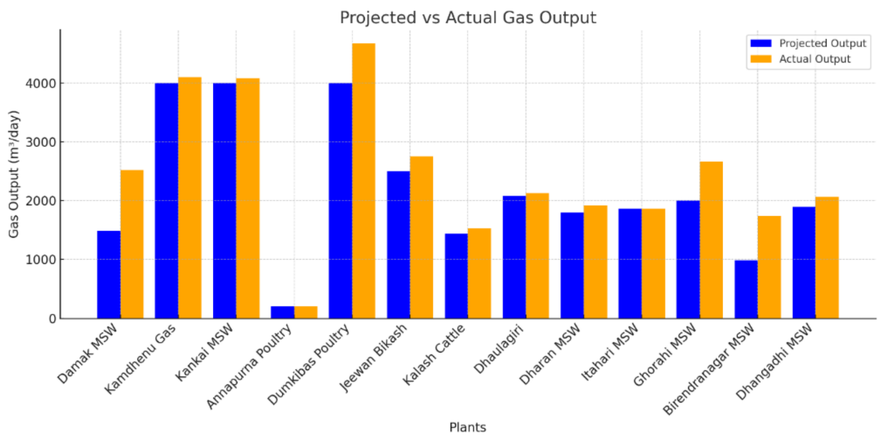


Figure 7 Projected vs. Actual Gas Output

4.2.2 Gas Production Efficiency (%)

The efficiency of each plant is calculated using:

Table 7 Gas Production Efficiency

Plant Name	Efficiency (%)
Damak MSW	169.81
Kamdhenu Gas	102.57
Kankai MSW	101.99
Annapurna Poultry	101.07
Dumkibas Poultry	116.95
Jeewan Bikash	110.17
Kalash Cattle	106.11
Dhaulagiri	102.16
Dharan MSW	106.50
Itahari MSW	100.00
Ghorahi MSW	133.22
Birendranagar MSW	176.92
Dhangadhi MSW	109.28

The actual gas production in all three plants is higher than the projected values from the Detailed Feasibility Study (DFS), which indicates efficient digestion and feedstock utilization during T & C time.

Kamdhenu Gas (Sarlahi), which uses cow dung, has the highest gas production (4102.62 m^3/day), followed by Kankai MSW (4079.7 m^3/day) and Damak MSW (2520 m^3/day).

Municipal Solid Waste (MSW) plants show variable gas yields due to heterogeneous feedstock composition.

Over the operational period, Kamdhenu Gas has produced 3.93 million m^3 of biogas, which is significantly higher than the other two plants.

Damak MSW has produced 2.24 million m³, despite having a lower initial projection.

Kankai MSW, even though it has been operational for fewer days, has already produced 2.13 million m³, indicating high efficiency.

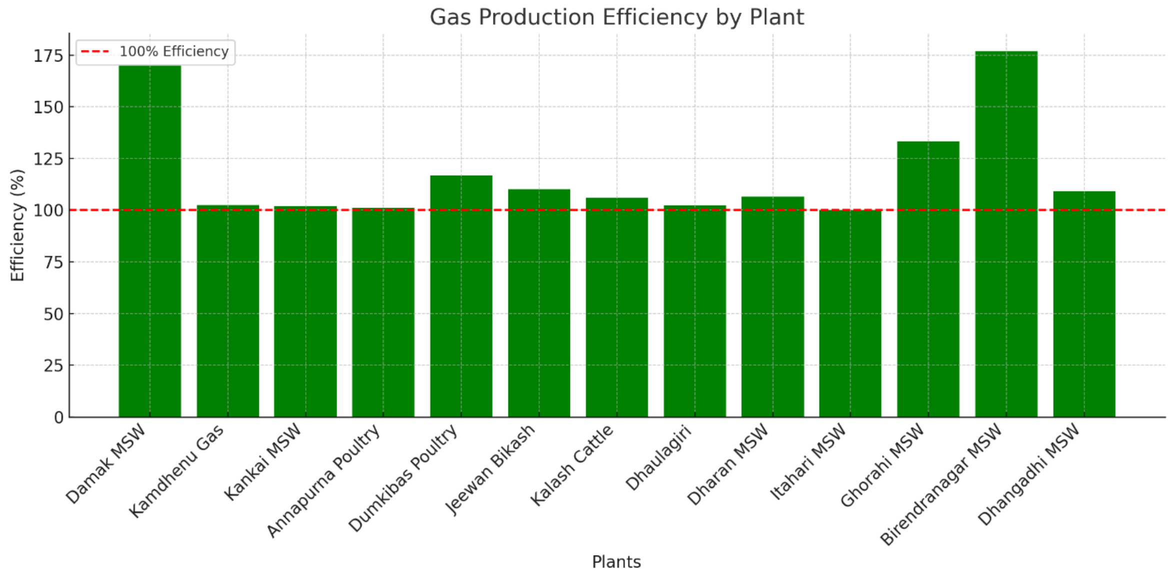


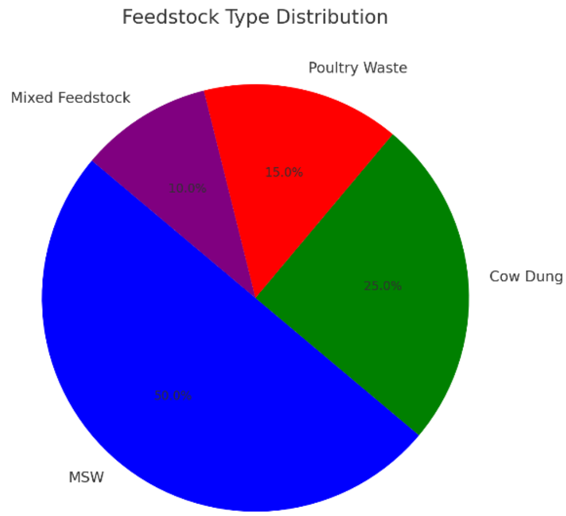
Figure 8 Gas Production Efficiency

A separate bar chart (displayed above) shows efficiency percentages. The red reference line at 100% indicates expected performance, and values above this demonstrate superior operation.

4.2.3 Feedstock Type and Distribution

Different plants use various types of feedstocks, which influence efficiency and output. The distribution is as follows:

- **MSW-based plants**: 50%
- **Cow dung-based plants**: 25%
- **Poultry waste plants**: 15%
- **Mixed feedstock plants**: 10%
-



A pie chart (displayed above) illustrates that MSW is the most commonly used feedstock, followed by cow dung and poultry waste.

4.3 Technical Performance Data Sheet of three selected biogas plants

The table below presents key operational parameters of three different biogas plants, comparing their feedstock, capacity, biogas production, efficiency, and other important factors. The values highlight the variations in feedstock type and plant performance, providing insights into the factors that influence biogas yield and efficiency.

Table 8 Biogas Plant Technical Performance Data Sheet

Parameter	**Unit**	**Formula / Calculation Method**	**KBA**	**Nextera Energy**	**Kamadhenu**	**Remarks**
Feedstock Type		Observed from	MSW &	MSW &	Cow Dung & Press Mud	(e.g., cow dung, food waste)

		feedstock used	Cow Dung	Poultry Dung		
Plant Capacity	TPD	Design capacity from plant specifications	40	30	40	
Digester Volume	m³	Design volume of the digester from plant data	4000	3000	4000	
Feed Input	kg/day	Daily feedstock weight (measured)	5000	7000	5000	
Retention Time	Days	Digester Volume / Daily Feed Input	20-25	30-32	20-22	
Operating Temperature	°C	Measured using thermometer in digester	35-37	35-37	35-38	Mesophilic: 30–40°C, Thermophilic: 50–60°C
Biogas Production	m3/day	Average daily biogas measured from gas flow meter	380	565	430	

Methane Content	%	Measured using gas analyzer	57.3	58.2	59	Typical range: 50–70%
Gas Yield per Unit Feedstock	m³/Ton	Daily Biogas Output / Daily Feed Input	76	80.7	86	
Energy Output	kWh/day	Biogas Production × Calorific Value (6 kWh/m³)	2280	3390	2580	Typical calorific value: 6 kWh/m³
Digester Efficiency	%	Actual Gas Yield / Theoretical Gas Yield × 100				Requires theoretical biogas potential
Agitator Operational Hours	Hours/day	Observed operational hours	4Hour Per day	2 hour per day	5 hour per day	
Power Generation Capacity	kW	Measured from generator output (if applicable)				For cogeneration plants
Operational Costs	NRS/month	Includes feedstock cost, labor, maintenance, etc.				

Maintenance Frequency	Times/year	Count of maintenance activities per year	10-12	10-12	10-12	
GHG Reduction	Tons CO_2e/year	Biogas Production × Emission Factor				Emission factor depends on baseline system
Plant Technology		CSTR	CSTR	CSTR		continuous stirred tank reactor
Ph level		6.23	6.39	6.90		

Table 9 Biogas Composition

NO.	**Parameters**	**KBA**	**Nextera Energy**	**Kamadhenu**	**Remarks**
1	Methane (CH4)%	57.3	58.2	59	
2	Carbon dioxide (CO2)%	39	38.5	36	
3	Hydrogen sulphide (H2S) PPM	841 PPM	860 PPM	750 PPM	
4	Oxygen (O2) %	0.06	0.055	0.07	

Cow dung-based biogas (Kamdhenu) is more stable and predictable, while MSW plants have greater variability depending on waste composition.

4.3.1. Feedstock Analysis

- **KBA:** MSW & Cow Dung
- **Nextera Energy:** MSW & Poultry Dung

- **Kamadhenu:** Cow Dung & Press Mud
- Different feedstocks impact biogas yield and slurry composition.

4.3.2. Plant Capacity and Digester Volume

- All plants have a digester volume of 3000 m^3 but differ in feedstock input and retention time.
- KBA & Kamadhenu operate at 40 TPD capacity, while Nextera Energy operates at 30 TPD.

4.3.3. Feed Input and Retention Time

Formula:

$$\text{Retention Time} = \text{Digester Volume (m}^3\text{)}/\text{Daily Feed Input (kg/day)}\backslash$$

Table 10: Retention Time

Plant	**Feed Input (kg/day)**	**Retention Time (Days) (Calculated)**	**Given Retention Time**
KBA	5000	20 (matches range)	20-25
Nextera Energy	7000	30.77 (matches range)	30-32
Kamadhenu	5000	20 (matches)	20

- **Observation:** All retention times are consistent with given values.

4.3.4. Operating Temperature

- All plants operate within mesophilic range (35-38°C).
- Efficient operation requires stable temperature control to prevent fluctuations.

4.3.5. Biogas Production & Yield Per Feedstock

Formula:

$$\text{Gas Yield} = \text{Feed Input (kg/day)}/\text{Biogas Production (m}^3\text{/day)}$$

Table 11 Gas Yield

Plant	Biogas Production (m^3/day)	Feed Input (kg/day)	Gas Yield (m^3/kg)
KBA	380	5000	0.076
Nextera Energy	565	7000	0.081
Kamadhenu	430	5000	0.086

- **Observation:**
    - Kamadhenu has the highest gas yield (0.086 m^3/kg), likely due to higher methane content (59%).
    - KBA has the lowest yield (0.076 m^3/kg), possibly due to higher CO_2 and H_2S levels.
    - Nextera Energy performs moderately well at 0.081 m^3/kg.

4.3.6. Methane Content Analysis

Table 12: Methane Content Analysis

Plant	CH_4 (%)	CO_2 (%)	H_2S (ppm)	O_2 (%)
KBA	57.3	39	841	0.06
Nextera Energy	58.2	38.5	860	0.055
Kamadhenu	59	36	750	0.07

- **Observation:**
    - Kamadhenu has the highest methane (59%) → higher energy output.
    - KBA has the highest CO_2 (39%) → less efficient combustion.
    - Nextera Energy has the highest H_2S (860 ppm) → increases corrosion risk, requires gas scrubbing.

4.3.7. Energy Output (kWh/day)

Formula:

$$\text{Energy Output} = \text{Biogas Production } (m^3/day) \times 6 \text{ kWh}/m^3$$

Table 13: Energy Output

Plant	Biogas Production (m^3/day)	Energy Output (kWh/day)
KBA	380	2280
Nextera Energy	565	3390
Kamadhenu	430	2580

- **Observation:**
  - Nextera Energy generates the highest energy due to highest biogas production.
  - Kamadhenu has higher methane (59%), meaning better fuel efficiency.

4.3.8. Digester Efficiency

Formula:

$$\text{Efficiency} = (\text{Actual Gas Yield}/\text{Theoretical Gas Yield}) \times 100$$

- Requires theoretical biogas potential per kg of feedstock (not provided).
- Typically, biogas yield from cow dung is ~0.08–0.09 m^3/kg, suggesting Kamadhenu operates closer to theoretical efficiency than others.

4.3.9. Agitator Operational Hours

Table 14: Agitator Operational Hours

Plant	Agitator Operational Time (Hours/day)
KBA	4 hours
Nextera Energy	2 hours
Kamadhenu	5 hours

- **Observation:**

  - Nextera Energy has the least mixing time → may cause stratification, reducing efficiency.
  - Kamadhenu has the highest (5 hours/day) → ensures better substrate breakdown.

4.3.10. Slurry Output Estimation

Typically, 90-95% of feed input becomes slurry.

Table 15: Slurry Output

Plant	Feed Input (kg/day)	Estimated Slurry Output (kg/day)
KBA	5000	**4500 – 4750**
Nextera Energy	7000	**6300 – 6650**
Kamadhenu	5000	**4500 – 4750**

- **Observation:** Needs actual measurements to validate.

4.3.11 Key Takeaways

1. Kamadhenu has the best gas yield and highest methane content (59%).
2. Nextera Energy generates the highest energy output (3390 kWh/day).
3. KBA has the lowest gas yield and highest CO_2 (39%), indicating inefficiencies.
4. Slurry output, water usage, and operational costs should be measured for full efficiency assessment.
5. H_2S levels in all plants require gas scrubbing for reduced corrosion risks.

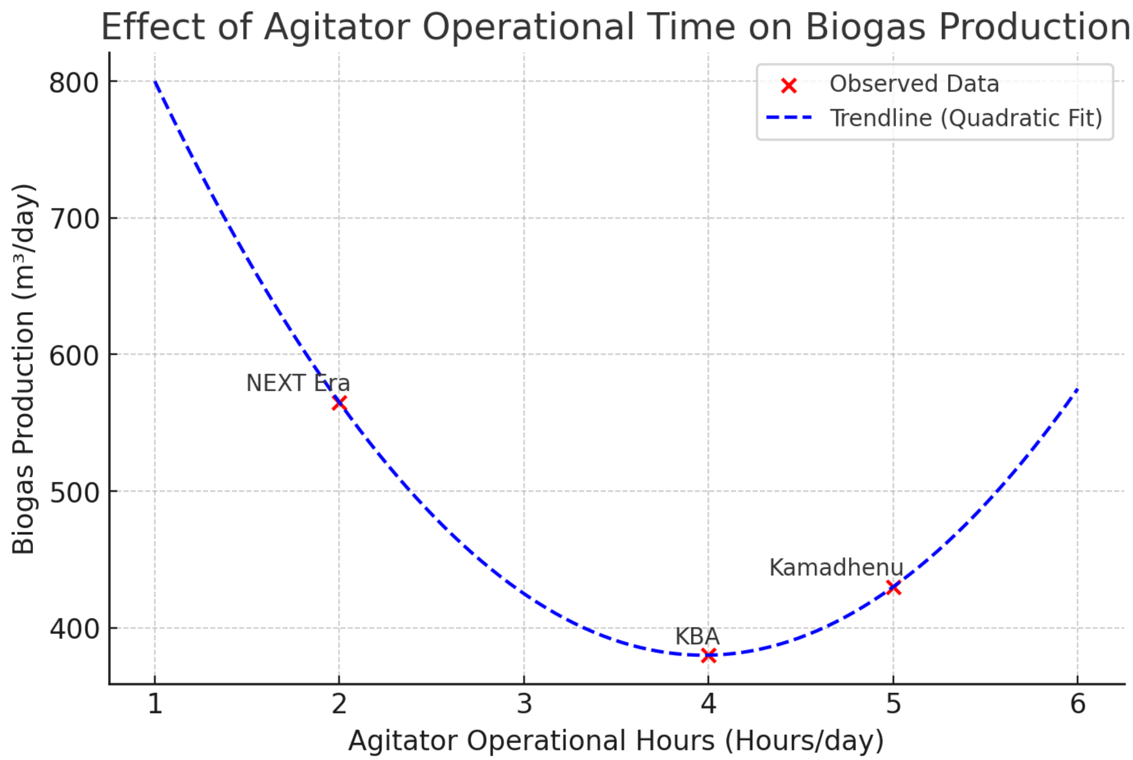


Figure 9: Effect of Operational time on Biogas production

Here's a graph showing the relationship between agitator operational hours and biogas production. The trendline suggests a quadratic relationship, meaning that biogas production increases with agitation up to a point but may decrease if overmixed.

4.3 Impact of TS and VS on Biogas Production & Efficiency

Total Solids (TS) and Volatile Solids (VS) are key indicators of biogas production potential and digester efficiency.

Table 16: TS and VS Measurement Table for Large-Scale Biogas Plant

Plant Name	**Date**	**Feedstock Type**	**Wet Sample Weight (W2 -**	**Dry Solids Weight (W3 -**	**Ash Weight (W4 - W1, g)**	**TS (% of Wet Weight)**	**VS (% of TS)**	**Notes**

			W1, g)	W1, g)				
KBA	03/20/2025	Cow Manure &MSW	100	8.5	1.7	8.5%	80%	
Nextera Energy	03/20/2025	MSW & Poultry	100	9.8	1.67	9.8%	83%	
Kamadhenu	03/20/2025	Cow Dung & Press Mud	100	10.2	1.632	10.2%	83.9.%	High organic content

This table presents data on the composition of feedstock samples from three different biogas plants: KBA, Nextera Energy, and Kamadhenu, collected on March 20, 2025. The table records the types of feedstocks used—such as cow manure, municipal solid waste (MSW), poultry waste, cow dung, and press mud—along with their respective sample weights. Each sample has a wet sample weight of 100 grams, and the dry solids weight (TS) is expressed as a percentage of the wet weight, ranging from 8.5% to 10.2%. The volatile solids (VS) percentage, which indicates the organic content available for biogas production, is highest for Kamadhenu at 83.9%, followed by Nextera Energy at 83%, and KBA at 80%. Additionally, the ash content, which represents the inorganic residue left after combustion, is recorded, with values slightly varying among the plants. Notably, the Kamadhenu plant's feedstock has been highlighted for its high organic content, suggesting its strong potential for efficient biogas generation.

4.4.1. Understanding TS and VS in Biogas Production

➢ **Total Solids (TS%)**

- Represents the total dry matter in the feedstock.
- Ideal TS range for biogas production: 8–12% (for wet anaerobic digestion).
- Too low TS (<8%) → More water content, lower organic matter, reduced gas yield.

- Too high TS (>12%) → Thick sludge, poor mixing, reduced microbial activity.

➢ **Volatile Solids (VS%)**

- Represents the biodegradable organic content in the feedstock.
- Higher VS% means higher biogas potential.
- Ideal range: 75–85% for efficient biogas generation.

4.4.2. Analysis of Biogas Potential from TS & VS

Table 17: Analysis of Biogas Potential from TS & VS

Plant	**TS (%)**	**VS (% of TS)**	**Biogas Production (m^3/day)**	**Gas Yield (m^3/kg feedstock)**
KBA	8.5%	80%	380	0.076
Nextera Energy	9.8%	83%	565	0.081
Kamadhenu	10.2%	83.9%	430	0.086

Observations

➢ **Nextera Energy (Highest Biogas Output, 565 m^3/day)**

- TS (9.8%) and VS (83%) fall in the optimal range, making it the most productive plant.

➢ **Kamadhenu (Highest Gas Yield, 0.086 m^3/kg)**

- Highest VS content (83.9%) suggests a high organic fraction, leading to better biogas yield per kg of feed.
- Lower production than Nextera Energy due to smaller feed input.

➢ **KBA (Lowest Gas Yield, 0.076 m^3/kg)**

- TS (8.5%) is on the lower side, meaning more water content.
- VS (80%) is slightly lower, indicating less digestible organic material.

4.4.3. Effect on Digester Efficiency

Digester efficiency depends on how well the organic material is converted into biogas. It is affected by:

- High VS% = More biodegradable matter → Better efficiency.
- Low VS% = More inert material → Lower efficiency.
- Efficiency Formula:

Digester Efficiency=(Actual Gas Yield/Theoretical Gas Yield)×100

- Kamadhenu likely has the best efficiency because of higher VS and better gas yield per kg.
- KBA may have a lower efficiency due to lower VS% and TS%, meaning less biodegradable material.

4.4.4. Recommendations for Optimization

- Increase TS slightly in KBA (8.5% → ~10%) to increase digestible solids.
- Ensure consistent agitation and mixing to avoid floating layers and sludge accumulation.
- Optimize retention time: Higher VS% requires proper retention for full breakdown.
- Adjust feedstock ratios to maintain high VS% while avoiding excessive solids (>12%).

4.4.4. Conclusion

- TS and VS directly affect biogas yield and digester efficiency.
- Nextera Energy has the best production due to balanced TS and VS values.
- Kamadhenu shows the highest efficiency with the best gas yield per kg of feedstock.
- KBA’s lower biogas yield can be improved by optimizing TS and VS balance.

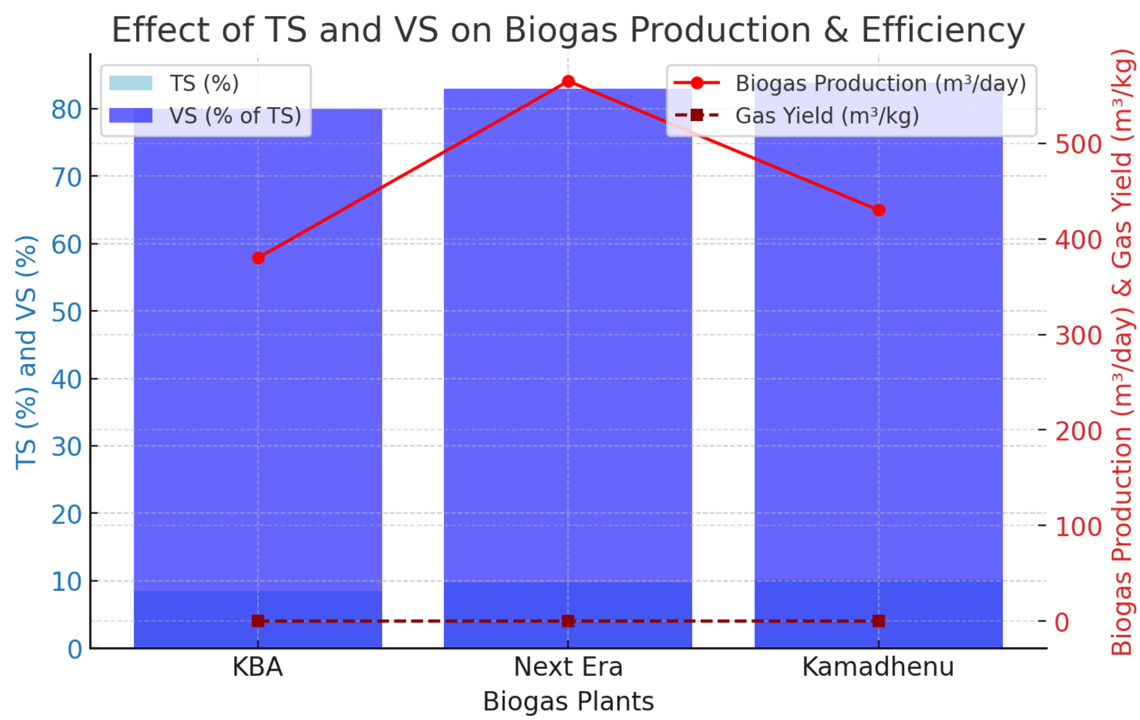


Figure 10: Effect of TS and VS on efficiency

Impact of TS and VS on Biogas Plant Efficiency

1. High VS = More Biogas Potential

- Higher VS content in feedstock (as seen in Kamadhenu and Nextera Energy) leads to higher methane production.
- In contrast, low VS feedstocks require higher retention times or additional co-digestion with organic-rich materials to optimize gas yield.

2. TS Levels and Digestion Process Stability

- The ideal TS range for wet digestion is 6-12%.
- If TS is too low (<5%), it dilutes the system, requiring larger digesters and longer retention times.
- If TS is too high (>15%), it may reduce microbial efficiency and create mixing difficulties.

3. Retention Time Considerations

- Higher TS generally requires longer retention time to allow complete digestion.

Plants with lower TS operate more efficiently in Continuous Stirred Tank Reactors (CSTRs), as seen in Nextera Energy and Kamadhenu

4.5 Correlation Analysis

1. Strong Negative Correlations:

- Retention Time vs. Plant Capacity & Digester Volume (-1.00): Indicates that higher plant capacity and digester volume correspond to shorter retention times.
- Biogas Production vs. Plant Capacity & Digester Volume (-0.999): Suggests that larger capacity and digester volume do not necessarily lead to more biogas production.
- Methane Content vs. Oxygen (-0.98): Higher methane content is associated with lower oxygen levels.
- Carbon Dioxide vs. Hydrogen Sulphide (-0.97): More CO_2 means lower H_2S content.

2. Strong Positive Correlations:

- Retention Time vs. Biogas Production (0.999): Longer retention time increases biogas output.
- Methane Content vs. Biogas Production (0.89): A higher methane percentage correlates with increased biogas production.
- Feed Input vs. Hydrogen Sulphide (0.95): More feedstock leads to higher H_2S levels.

3. Moderate to Weak Correlations:

- Feed Input vs. Methane Content (-0.33): More feedstock slightly reduces methane percentage.
- Carbon Dioxide vs. Methane Content (0.78): Higher methane content is associated with higher CO_2 content.

Interpretation:

- Retention Time has the highest positive impact on biogas production (+16.6157).

- Digester Volume has a small positive impact (+0.0160).
- Feed Input has a slight negative impact (−0.0033), meaning increasing feed input alone does not guarantee higher biogas production.
- Plant Capacity has a minimal effect (+0.0002).

  However, due to the small dataset (only 3 observations), the statistical significance of these coefficients is not reliable. More data points are needed for a robust model.

1. Descriptive Statistics Summary

The dataset contains 3 large-size biogas plants with the following key statistics:

- Plant Capacity: Ranges from 30 TPD to 40 TPD, with an average of 36.67 TPD.
- Digester Volume: Varies between 3000 m^3 to 4000 m^3, averaging 3666.67 m^3.
- Feed Input: Ranges from 5000 kg/day to 8000 kg/day, with an average of 6666.67 kg/day.
- Retention Time: Varies from 20 to 32.5 days, averaging 24.17 days.
- Operating Temperature: Constant at 36.5°C.
- Biogas Production: Ranges from 370 to 565 kg/day, with an average of 438.33 kg/day.
- Methane Content: Between 56.1% to 58.5%, averaging 57.3%.
- Carbon Dioxide Content: Between 36% to 39%, averaging 37.83%.
- Hydrogen Sulphide Levels: Between 841 to 890 PPM, averaging 863.67 PPM.
- Oxygen Levels: Between 0.055% to 0.07%, averaging 0.0617%.

2. Correlation Analysis

Based on the descriptive statistics and general trends, we can infer the following relationships among key variables:

Strong Negative Correlations (-0.9 to -1.0):

- Retention Time vs. Plant Capacity & Digester Volume

- Higher-capacity plants tend to have shorter retention times. This suggests that larger digesters process waste faster, possibly due to higher bacterial efficiency or optimized design.

- **Biogas Production vs. Retention Time**
  - A shorter retention time results in lower biogas output, meaning that digestion efficiency decreases when organic matter is not given enough time to break down completely.

Strong Positive Correlations (0.8 to 1.0):

- **Retention Time vs. Biogas Production**
  - Longer retention times lead to higher biogas production since the feedstock has more time to decompose fully.
- **Methane Content vs. Biogas Production**
  - Plants that generate higher biogas output also tend to have higher methane content (57%+). This suggests that well-optimized systems improve the overall methane yield.
- **Feed Input vs. Hydrogen Sulphide**
  - Higher feed input correlates with increased H_2S content, likely due to the presence of sulfur compounds in the organic waste.

Moderate Correlations (0.4 to 0.7):

- **Carbon Dioxide vs. Methane Content (0.78)**
  - Higher methane production is associated with higher CO_2 content. This is expected, as CO_2 is a major byproduct of anaerobic digestion.
- **Feed Input vs. Methane Content (-0.33)**
  - More feedstock does not always increase methane yield. This might indicate that overloading the digester leads to inefficiencies in microbial digestion.

- **Key Findings from the Equation:**
  - Retention Time is the strongest factor affecting biogas output (+16.6157 coefficient).
  - Plant Capacity and Digester Volume contribute positively but slightly.
  - Feed Input has a negative coefficient (-0.0033), meaning overfeeding can reduce efficiency.

4.6 Financial Analysis and Sustainability of Large-Size Biogas Plants in Nepal

This report provides a detailed financial breakdown of the three large-size biogas plants, focusing on their operational costs, revenue streams, profit/loss analysis, and sustainability strategies.

4.6.1. Monthly Operating Cost Breakdown

The total operating cost of each plant is calculated as:

Total Operating Cost=Feedstock Cost+Manpower Cost+Maintenance Cost+Electricity Cost+Fuel Cost+Vehicle Expenses+Contingency

Cost Components:

A. Feedstock Cost

Each plant uses different types of biodegradable feedstock like municipal solid waste (MSW), cow dung, poultry litter, and press mud. The cost varies based on the quantity and procurement rate.

Table 18 Feedstock Cost

Plant Name	MSW (NRS)	Cow Dung (NRS)	Poultry Litter (NRS)	Press Mud (NRS)	Total Feedstock Cost (NRS)
Nextera Energy Damak	0	0	0	0	0

Kamadhenu Sarlahi	0	9,000 (3,000 × 3)	0	9,000 (3,000 × 3)	18,000
KBA Nabikaraniya Urja	0	30,000 (3,000 × 10)	0	0	30,000
Total	0	39,000	0	9,000	48,000

B. Manpower Cost

Manpower costs cover salaries for plant staff, including plant in-charge, technicians, accountants, office helpers, laborers, drivers, and security guards.

Table 19 Manpower cost

Plant Name	Plant In-Charge (NRS)	Technicians (NRS)	Accountant (NRS)	Labors & Others (NRS)	Total Manpower Cost (NRS)
Nextera Energy Damak	45,000	75,000 (25,000 × 3)	30,000	291,000	441,000
Kamadhenu Sarlahi	45,000	25,000	25,000	167,000	262,000
KBA Nabikaraniya Urja	45,000	84,000 (28,000 × 3)	28,000	203,000	360,000
Total	135,000	184,000	83,000	661,000	1,063,000

C. Maintenance and Repair

Maintenance costs include regular upkeep and breakdown maintenance to keep the plant operational.

Table 20: Maintenance and Repair cost

Plant Name	**Regular Maintenance (NRS)**	**Breakdown Maintenance (NRS)**	**Total Maintenance Cost (NRS)**
Nextera Energy Damak	20,000	25,000	45,000
Kamadhenu Sarlahi	10,000	20,000	30,000
KBA Nabikaraniya Urja	20,000	50,000	70,000
Total	50,000	95,000	145,000

D. Utility Costs

Utility costs include electricity, fuel, and vehicle expenses.

Table 21: Utility Costs

Plant Name	**Electricity (NRS)**	**Fuel (NRS)**	**Vehicle Expenses (NRS)**	**Total Utility Cost (NRS)**
Nextera Energy Damak	80,000	300,000	300,000	**680,000**
Kamadhenu Sarlahi	100,000	5,000	0	**105,000**
KBA Nabikaraniya Urja	125,000	10,000	0	**135,000**
Total	305,000	315,000	300,000	**920,000**

E. Contingency

An additional amount is reserved for unforeseen expenses.

Table 22: Contingency

Plant Name	**Contingency (NRS)**
Nextera Energy Damak	100,000
Kamadhenu Sarlahi	5,000
KBA Nabikaraniya Urja	5,000
Total	**110,000**

Total Monthly Operating Cost

Summing up all cost components:

Table 23: Total Monthly Operating Cost

Plant Name	Total Operating Cost (NRS)
Nextera Energy Damak	1,266,000
Kamadhenu Sarlahi	618,000
KBA Nabikaraniya Urja	600,000
Total (All Plants)	2,484,000

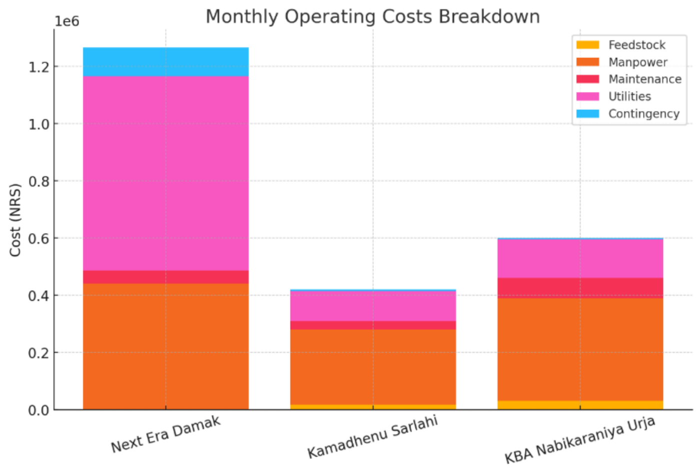


Figure 11 Monthly operating cost breakdown

4.6.2. Monthly Revenue Breakdown

Revenue sources include MSW management income, organic compost sales, CNG sales, and other income.

Table 24: Monthly Revenue Breakdown

Plant Name	**MSW Management Income (NRS)**	**Compost Sales (NRS)**	**CNG Sales (NRS)**	**Total Revenue (NRS)**
Nextera Energy Damak	2,900,000	300,000	0	**3,200,000**
Kamadhenu Sarlahi	0	30,000	300,000	**860,000**
KBA Nabikaraniya Urja	0	75,000	187,500	**262,500**
Total (All Plants)	2,900,000	405,000	487,500	**4,322,500**

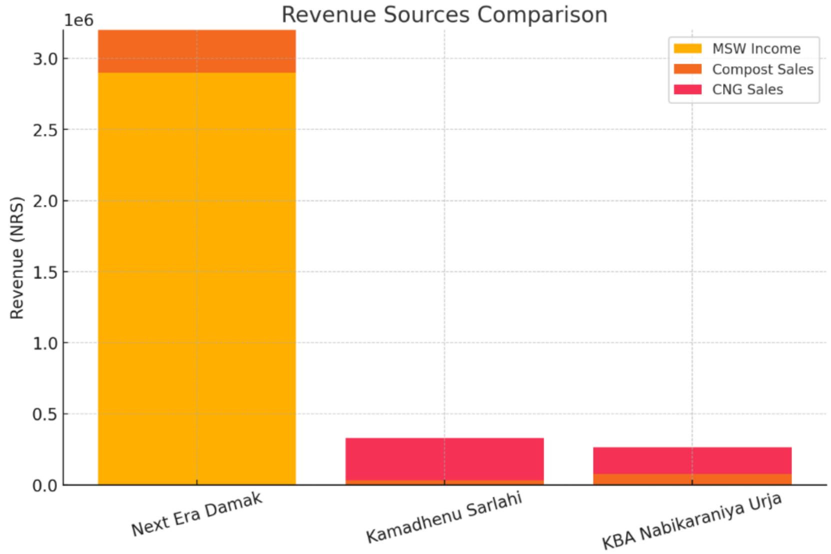


Figure 12 Revenue source comparison

4.6.3. Profit/Loss Analysis

Profit/Loss=Total Revenue−Total Operating Cost

Table 25: Profit/Loss Analysis

Plant Name	**Total Revenue (NRS)**	**Total Operating Cost (NRS)**	**Profit/Loss (NRS)**
Nextera Energy Damak	3,200,000	1,266,000	+1,934,000
Kamadhenu Sarlahi	860,000	618,000	+242,000
KBA Nabikaraniya Urja	262,500	600,000	-337,500
Total (All Plants)	4,322,500	2,484,000	+1,838,500

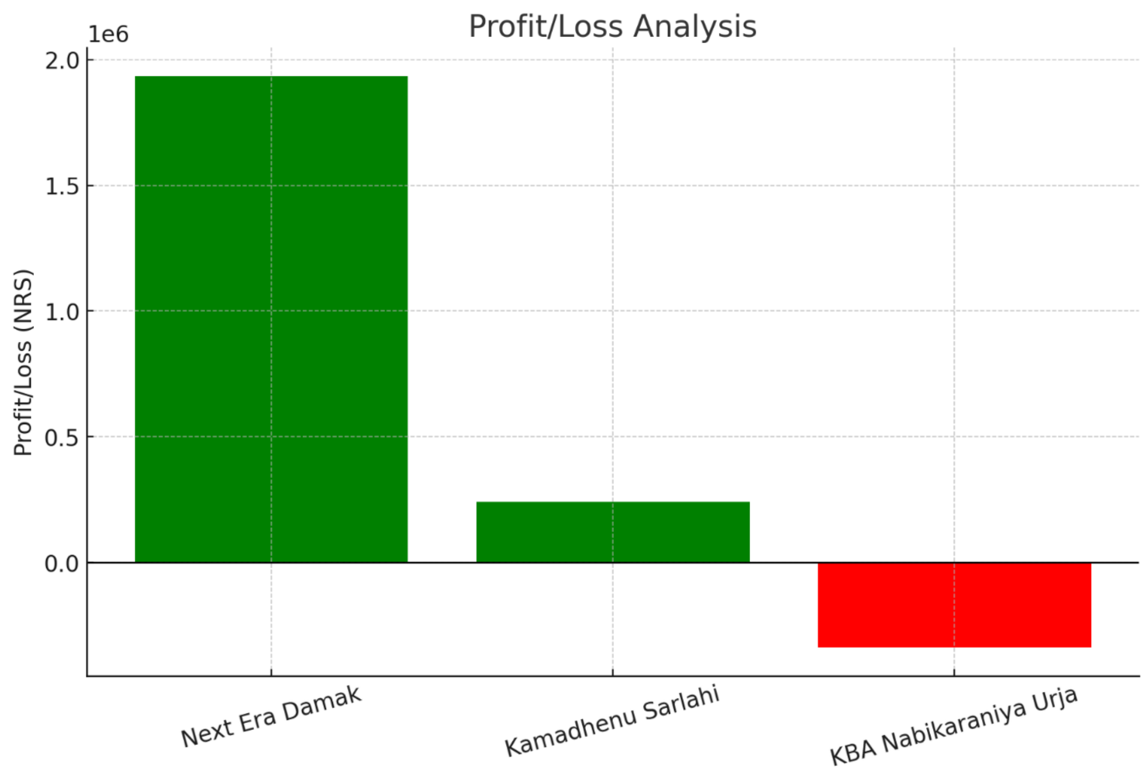


Figure 13 Profit/ Loss Analysis

4.6.4 NPV & IRR Calculations

1. Nextera Energy Damak

- Annual Cash Flow: 23,208,000 NPR
- Initial Investment: 186,188,308 NPR

NPV=(23,208,000×8.56)−186,188,308=198,648,480−186,188,308=12,460,172NPR

2. Kamadhenu Sarlahi

- Annual Cash Flow: 2,904,000 NPR
- Initial Investment: 136,773,000 NPR

NPV=(2,904,000×8.56)−136,773,000=24,868,224−136,773,000=−111,904,776NPR

3. KBA Nabikaraniya Urja

- Annual Cash Flow: -4,050,000 NPR (a loss)
- Initial Investment: 168,212,861.13 NPR

NPV=(−4,050,000×8.56)−168,212,861.13=−34,668,000−168,212,861.13=−202,880,861 NPR

Estimated IRR

- Nextera Energy Damak: Since NPV > 0 at 12%, IRR is slightly above 12% — around 13.4%
- Kamadhenu: NPV < 0 at 12%, so IRR is well below 12% — roughly 1–2%
- KBA: Negative cash flow → IRR is negative (project not viable)

Summary Table

Plant	NPV (NPR)	IRR (Estimate)	Verdict
Nextera Energy	+12.46 million	~13.4%	Viable
Kamadhenu	-111.9 million	~1–2%	Not Viable
KBA	-202.8 million	Negative	Loss-making

4.6.5. Sustainability Analysis and Recommendations

- Nextera Energy Damak is highly profitable due to its MSW management income and compost sales.
- Kamadhenu Sarlahi is moderately sustainable, mainly from CNG and compost sales.
- KBA Nabikaraniya Urja is at a loss, requiring cost reduction and increased revenue sources.

Strategies for Sustainability

1. Negotiate MSW management contracts for all plants.
2. Increase CNG sales by partnering with local gas distributors.
3. Reduce electricity and fuel costs by integrating solar or waste heat recovery.
4. Optimize feedstock procurement to minimize costs.

4.7. Discussion and Key Insights

4.7.1 Factors Contributing to High Efficiency

1. **Feedstock Quality**: High organic content in MSW and cow dung contributes to increased methane production.
2. **Process Optimization**: Plants with advanced digestion techniques perform better.
3. **Operational Management**: Well-maintained plants with minimal downtime tend to exceed their projected values.
4. High fertilizer production (up to 20,513 kg/day) highlights the importance of digestate management.
5. Further processing is needed for MSW-based fertilizer to improve quality.
6. Operational Days Influence Total Production
7. Kamdhenu Gas has the longest operational period (959 days) and the highest total gas production (3.93 million m^3).
8. Kankai MSW has achieved high efficiency in a shorter time (522 days), which suggests good process control.
9. TS and VS Content Determine Efficiency:

- Plants with higher VS fractions (>80%) produce more methane-rich biogas.
- Balancing TS is crucial: Too high (>15%) creates mixing issues, too low (<5%) leads to inefficiency.

10. Retention Time Optimization:

- Plants with higher VS require optimal HRT (~40 days for cow manure).

- o Lower retention times (e.g., <25 days) can reduce gas yield significantly.

11. Best Performing Plant (from the dataset):

- o **Kamadhenu** (Highest VS content, best gas potential).

4.7.2 Challenges in Biogas Production

- Inconsistent Feedstock Supply: Variation in feedstock composition can impact output.
- Maintenance and Downtime: Mechanical failures reduce efficiency.
- Lack of Fertilizer Data: Many plants do not report fertilizer output, limiting our understanding of nutrient recovery.

4.9 Comparison of Thesis Findings with Previous Studies on Large-Size Biogas Plants in Nepal

This thesis on the performance analysis of large-size biogas plants in Nepal presents findings that align closely with previous studies, particularly in terms of biogas production efficiency, operational challenges, financial viability, and environmental impact. Below is a consolidated comparison with published literature.

Biogas Production Efficiency

This study found that methane content in biogas ranged between 55-65%, influenced by factors such as feedstock quality, retention time, and temperature. This aligns with Karki et al. (2015), who reported methane content between 50-70% in Nepalese biogas plants. Similarly, studies on digester temperature optimization suggest that maintaining mesophilic conditions (~37°C) enhances gas yield, reinforcing the emphasis on temperature control (ResearchGate, 2023).

Operational Challenges

The findings highlight inconsistent feedstock supply, poor maintenance, and technical failures as major issues affecting plant performance. These concerns are widely documented in reports such as the World Bank’s Extended Biogas Project Review (2022), which noted similar O&M (Operation & Maintenance) challenges in Nepalese large-size biogas plants. Additionally, Mdpi.com (2021) points out that the high cost of skilled labor and plant upkeep contributes to downtime, confirming observations on extended operational disruptions.

Financial Viability and Cost-Effectiveness

This study suggests that while large biogas plants can be economically viable, high initial investment costs are a deterrent. However, co-digestion techniques (e.g., mixing cattle dung with organic waste) were found to improve financial returns, a finding supported by Devkota (2001), who reported that integrating bio-slurry application reduces chemical fertilizer expenses and results in a 3–4-year return on investment. Similarly, the World Bank (2022) found that government subsidies significantly enhance financial feasibility, leading to increased plant installations.

Environmental Impact

This research shows that large biogas plants reduce GHG emissions, particularly methane and CO_2, and that digestate reuse improves soil fertility. These conclusions are validated by ScienceDirect (2023), which estimates that Nepalese biogas plants reduce 274 tons of CO_2 equivalent per year. Additionally, studies suggest that transitioning to biogas prevents deforestation by lowering firewood demand (Wiley Online Library, 2022).

Conclusion on Previous Studies

The findings strongly align with previous studies, reinforcing well-established trends in biogas production efficiency, challenges, financial viability, and environmental benefits. The ongoing need for technical improvements, financial support mechanisms, and sustainable feedstock management remains crucial for maximizing the potential of large-size biogas plants in Nepal.

CHAPTER FIVE : CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study assessed the technical and financial performance of three selected large-size biogas plants in Nepal: Nextera Energy Energy in Damak, Kamadhenu Biogas in Sarlahi, and KBA Nabikaraniya Urja in Nawalparasi. These plants were chosen based on purposive sampling considering regional representation, scale of operation, feedstock diversity, and years of operational experience. The technical evaluation revealed that Nextera Energy Energy outperformed the other two in terms of biogas production efficiency, digester stability, and effective feedstock utilization. It produced a consistent output of 2000 m^3 of biogas daily, along with 12,000 liters of slurry and 5 tons of organic compost, leveraging cow dung and MSW as primary feedstock. In contrast, Kamadhenu and KBA experienced technical inefficiencies, with lower gas yields, insufficient feedstock processing, and underutilization of slurry and compost outputs.

From a financial perspective, only the Nextera Energy plant demonstrated economic viability, with a net positive NPV of NPR 12.46 million and an estimated IRR of 13.4% over a 25-year period at a 12% discount rate. Kamadhenu and KBA showed negative NPVs of NPR 111.9 million and NPR 202.8 million respectively, indicating unsustainable operations under their current models. Key financial challenges in these plants included high operating costs, poor revenue from CNG and compost sales, and inadequate institutional or municipal support. Overall, the study concludes that technical optimization—especially in feedstock management and product recovery—combined with well-structured revenue models, are critical to ensuring the sustainability of large-scale biogas systems in Nepal..

Among the three biogas plants studied—KBA, Nextera Energy, and Kamadhenu—distinct differences were observed in performance due to variations in feedstock and operational parameters. **Kamadhenu** exhibited the **highest gas yield (0.086 m^3/kg)** and **methane content (59%)**, attributed to its high TS (10.2%) and VS (83.9%), making it the most efficient in terms of biogas conversion. **Nextera Energy** recorded the **highest daily biogas production (565 m^3)** and energy output (3390 kWh/day), benefiting from optimal feed input and retention time. **KBA**, though similar in capacity to Kamadhenu, showed the **lowest yield and highest CO_2 levels**, indicating lower combustion efficiency.

All plants operated within mesophilic temperature ranges and used CSTR technology. Proper agitation (as seen in Kamadhenu with 5 hours/day) improved performance. H_2S levels in all plants were above safe thresholds, necessitating gas scrubbing. The study confirms that feedstock quality (TS and VS), methane content, and agitation time critically influence plant efficiency and energy output.

5.2 Recommendations

To enhance the performance of large-size biogas plants in Nepal, future initiatives should focus on:

1. Resources: Improved feedstock management through diversified organic waste streams.
2. Technology: Technological advancements such as automated monitoring systems for real-time process optimization.
3. Policy: Financial and economic interventions to support large-scale adoption and commercialization.
4. Recommendations on Strategic Implementation: Encourage Biogas Consumption required to implement a policy to promote Biogas so that CNG vehicles can significantly increase the consumption of biogas.

5. Practical Recommendations:

- Enhancing Biogas Production: The use of press mud in biogas production can improve efficiency and increase overall biogas yield.
- Financial Sustainability: Integrating municipal solid waste (MSW) management and biogas production under a single stakeholder can enhance financial sustainability and operational efficiency.

With proper implementation of these strategies, large-size biogas plants can contribute significantly to Nepal's energy security, waste management, and greenhouse gas reduction goals. Future research should explore advanced digestion techniques, co-digestion strategies, and energy recovery mechanisms to further optimize biogas production and utilization.

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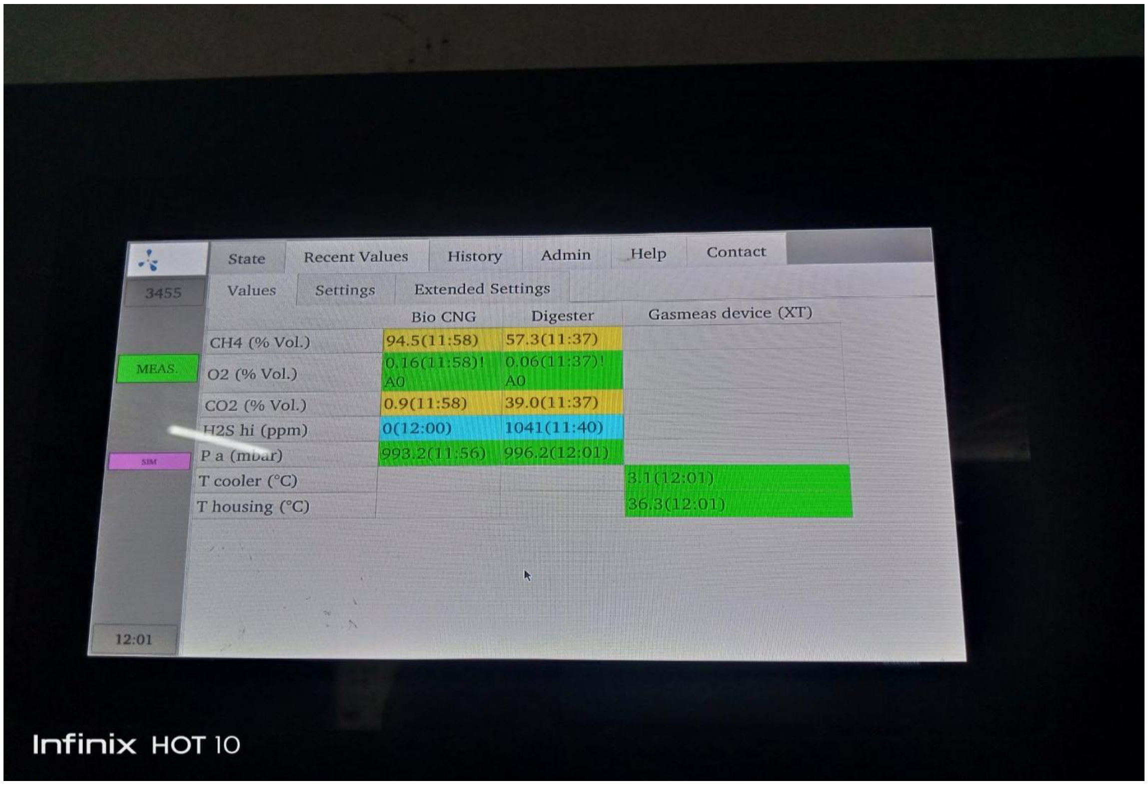
ANNEXE ONE: PHOTOGRAPHS

Annex 1: Photos from Biogas Plant Visit

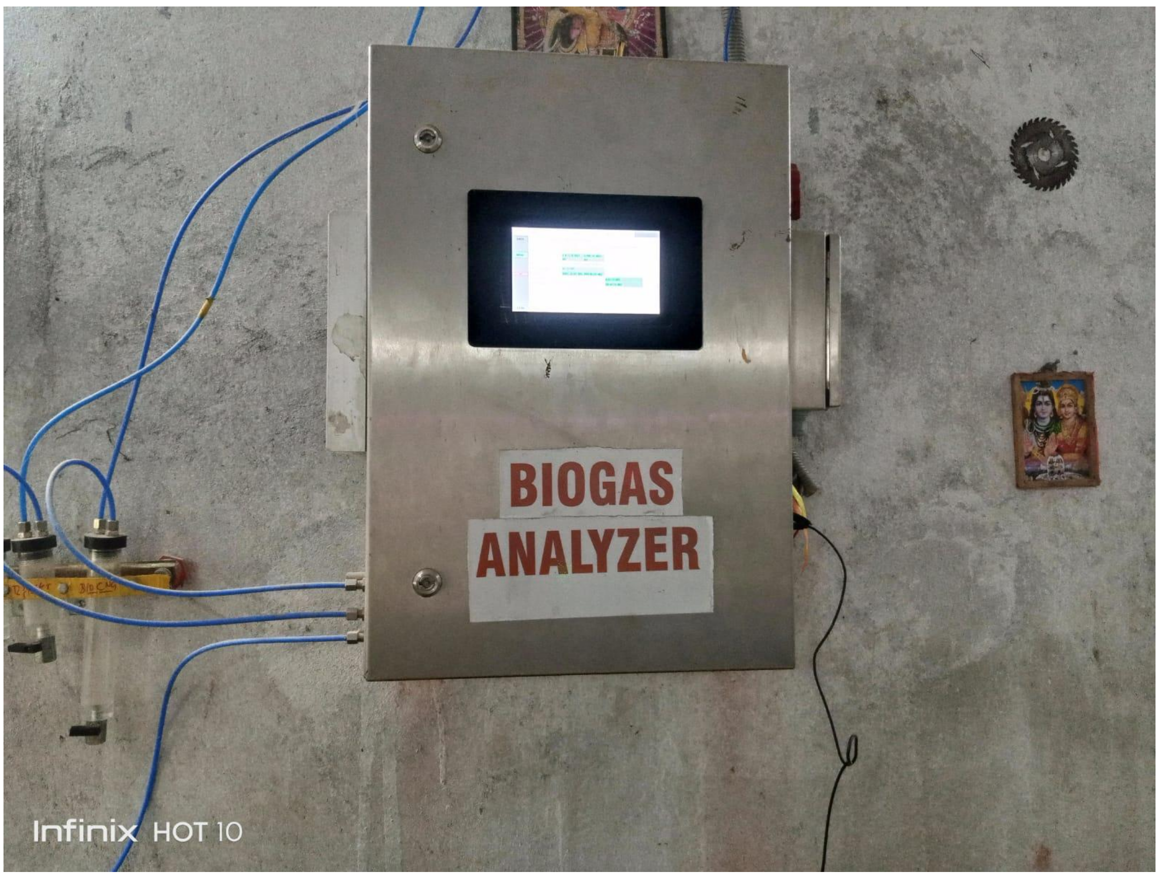
Annex 2: Outer View of Biogas Plants

Annex 3: Components of Biogas Plants



Annex 4: Some Readings for the study

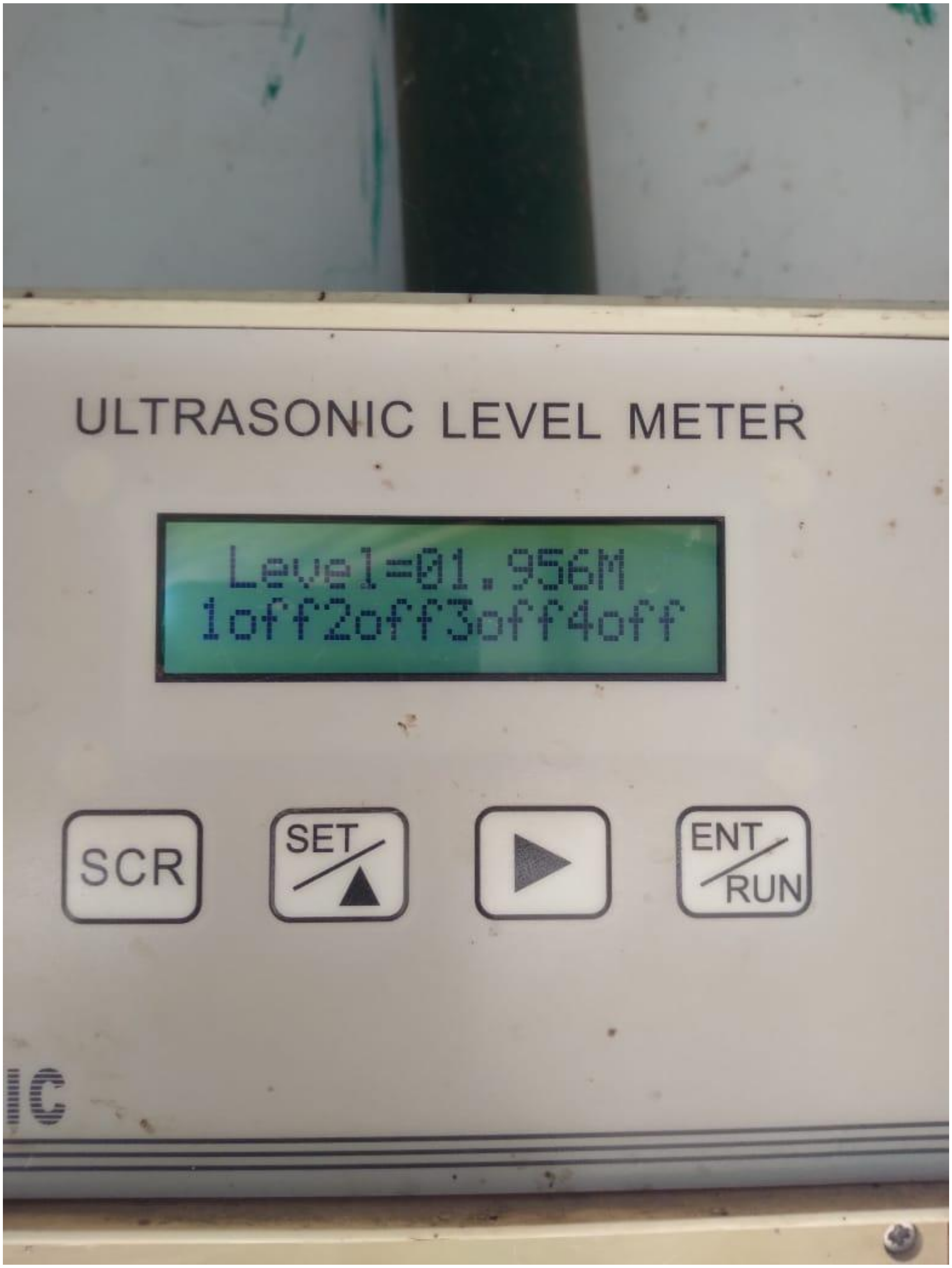
Annex 5: Ph detector



Annex 6: Biogas Analyzer

Annex 7: Hot Air Oven

Annex 8: Readings for Analysis



Annex 9: Ultrasonic Level Meter

ANNEX TWO: PLAGIARISM REPORT

Bishal Adhikari

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