TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO.: M-393-MSREE-2023-2025

Sustainability Assessment of Institutional Biogas Plant in Nepal-A Case Study of Sundarijal Arsenal Biogas Plant

by

Mahesh Kumar Ghimire

A THESIS
SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER OF SCIENCE IN RENEWABLE ENERGY ENGINEERING

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING
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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a project report entitled "**Sustainability Assessment of Institutional Biogas Plant in Nepal - Case Study of Sundarijal Arsenal Biogas Plant"** submitted by Mahesh Kumar Ghimire in partial fulfillment of the requirement for the degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

In developing nations, the sustainability of institutional biogas facilities is a major concern. This study aims to explore & develop a methodology to assess the institutional biogas plants. As such, the sustainability of a 40 m^3 institutional biogas plant at Sundarijal Arsenal Barrack, Kathmandu, Nepal has been studied. Despite its design to replace conventional fuels like LPG, the plant operates at only 22% of its capacity meeting only 3% of cooking demand but could reach 13.7%. Thus, the research evaluates technical, economic and environmental benefits using field data, interviews, and performance assessments. Limited feedstock and temperature variations significantly reduce biogas yield which averaged 1.63 m^3/day. The current LCOE is Rs. 3/MJ, exceeding that of LPG and electricity, but could be reduced to Rs. 0.66/MJ at full capacity which will make biogas feasible than other energy cooking alternative. Moreover, the system offsets 21.88 tons of CO_2-equivalent emissions annually, with potential for 99.3 tons at full operation. The findings highlight that with improved feedstock management and operational optimization, institutional biogas systems can offer a sustainable energy alternative in Nepal.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	
AEPC	Alternative Energy Promotion Centre
ARI	Acute Respiratory Infection
BAU	Business as Usual
BC	Black Carbon
BS	Bikram Sambat (Nepali Calendar)
°C	Degree Celsius
CES	Center for Energy Studies
CH_4	Methane
C/N	Carbon to Nitrogen ratio
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CRF	Capital Recovery Factor
ESC	Energy Security and Cleanliness
GGC	Gobar Gas Company (Nepal)
gm	Gram
GW	Global Warming
HGR	Human Gut Resource
IRR	Internal Rate of Return
IS	Indian Standard
kg	Kilogram
kWh	Kilowatt-hour
kW	Kilowatt
LCOE	Levelized Cost of Energy

LEAP	Long-range Energy Alternatives Planning
LHV	Lower Heating Value
LPG	Liquefied Petroleum Gas
MCB	Miniature Circuit Breaker
MGR	Methane Generation Rate
MJ	Megajoule
MPa	Megapascal
MW	Megawatt
NA	Not Available / Not Applicable
NMVOC	Non-Methane Volatile Organic Compounds
N_2O	Nitrous Oxide
NOC	Nepal Oil Corporation
NOx	Nitrogen Oxides
NPV	Net Present Value
OC	Organic Carbon
PBP	Payback Period
SDG	Sustainable Development Goals
SWAT Lab	Soil, Water, and Air Testing Laboratory
TS	Total Solids
VS	Volatile Solids

CHAPTER ONE: INTRODUCTION

1.1 Background

Biomass energy for cooking and heating remains a key to daily life in rural Nepal; an overwhelming majority of the population still depends on traditional biomass fuels, including firewood, animal dung, and crop residues. For instance, recent statistics have it that about 54% of the population of Nepal uses biomass, including firewood, agricultural residues, and animal dung, for cooking, mostly in rural areas [1]. While traditional cooking methods are deeply rooted in the cultural practices of Nepalese, they have quite a number of disadvantages. The use of firewood contributes to deforestation and air pollution, resulting in serious health risks from indoor air pollution, mostly in poorly ventilated kitchens where women spend considerable time cooking and heating[2].Women apparently face an unequal burden of suffering disproportionately. Women suffer from various respiratory diseases, including asthma, Chronic Obstructive Pulmonary Disease COPD, pneumonia, bronchitis, and lung cancer and so on, as the great bulk of these rural households still use conventional cook stoves rather than smokeless stoves, which increases health risks due to indoor air pollution [3], [4]. Reliance on biomass for cooking also leads to environmental degradation, particularly in terms of deforestation [5][6]. As the demand for firewood increases, local forests are being depleted at an alarming rate, putting pressure on the country's natural resources. This deforestation also exacerbates soil erosion, loss of biodiversity, and increased carbon emissions, further contributing to the negative effects of climate change [5][6]. Moreover, this has increased forest degradation and loss through the dependence of biomass fuel for cooking. The human induced pressure on the forest resources has been exacerbated due to the increased demand. These are the underlying causes causing soil erosion, landslides, loss of biodiversity, and an increase in carbon emissions among many others [5]. All these further increases global warming and the effects of climate change that are both challenges to the environment and public health. The use of unclean energy further exacerbates the existing disparity between rural and urban areas [7]. The cooking energy sector in Nepal, therefore, poses serious challenges to both public health and environmental sustainability.

In counterpart, urban areas of Nepal have seen a decline in the use of biomass, as liquefied petroleum gas—LPG—has taken the lead as the source for cooking and heating energy.

A study showed that 44.28% of the urban population depends on LPG [1]. The use of LPG, however, remains restricted due to its high cost, limited accessibility, and dependence on imported fuel, thus being quite unreliable as a source for many households. Inconsistent electricity supply in many regions further complicates energy access for cooking, underscoring the need for more reliable and sustainable alternatives. Therefore, clean and affordable cooking transition is one of the utmost priorities in Nepal[8]. As the country's population grows and urbanizes, there is an urgent need for sustainable cooking energy solutions that can address the environmental, health, and economic challenges associated with traditional biomass use [9]. Therefore, the adoption of renewable energy technologies such as biogas presents a viable alternative that can help reduce dependence on biomass, mitigate environmental degradation and just solutions to clean cooking.

Biogas is produced through the anaerobic digestion of organic materials, such as agricultural residues, animal manure, and kitchen waste; hence, it is a sustainable and environmentally friendly source of energy for cooking and heating [10][11]. Biogas has quite a number of benefits. It does not cause deforestation or contribute to carbon emissions as firewood does. The by-product from the production of biogas is a nutrient-rich organic fertilizer, known as digestate, which enhances agricultural productivity and reduces dependence on chemical fertilizers. This helps improve waste management practices since household and agricultural waste are converted to energy [10], [11], [12].

One of the key advantages of biogas is its environmental benefit. Unlike firewood and other traditional fuels, biogas does not contribute to deforestation or carbon emissions when used for cooking. Moreover, the by-product of biogas production, known as digestate, is a nutrient-rich slurry that can be used as a high-quality organic fertilizer, benefiting agricultural productivity and reducing the need for chemical fertilizers [11], [12], [13]. By converting waste into energy, biogas also contributes to improved waste management, making it an efficient and environmentally friendly solution [12].

Timeline summary of the history of biogas in Nepal [14]

1960: Reverend B.R. Saubolle constructed Nepal's first biogas plant at St. Xavier's School

1968: The Indian Aid Mission displayed a Gobar Gas plant in Kathmandu.

1973: Only 4-9 biogas plants were in operation, primarily serving wealthy households.

1974: The first official biogas program was launched, aimed at reducing deforestation and increasing manure use. The Agricultural Development Bank of Nepal supported this program with interest-free loans, resulting in the construction of 199 biogas plants.

2012-2017: The National Rural and Renewable Energy Program (NREP) set an ambitious target to install 130,000 household biogas plants and 1,200 community plants, showcasing a commitment to clean energy and reducing biomass dependence.

2017: Nepal established its first large-scale biogas plant, the Envipower Nepal Energy & Fertilizer Company, marking a shift towards advanced biogas infrastructure and commercial operations.

2019: Nepal reached 426,000 household biogas plants and 1,993 community and institutional plants [15]demonstrating significant progress in scaling up renewable energy adoption.

2020: The World Bank supported the Scaling up Renewable Energy Program (SREP) biogas project, addressing financial and technical barriers to energy transition.

2019-2023: The 15th Five-Year Plan set goals to install an additional 200,000 household biogas plants and 500 large-scale plants, underscoring the importance of biogas for energy security, emission reduction, and rural livelihood improvement.

This timeline illustrates the steady progress of biogas adoption in Nepal, highlighting the growing recognition of its potential to improve energy sustainability and rural development. Biogas technology has since become an integral part of Nepal's sustainable development strategy. It also directly contributes to attaining a number of SDGs, namely: ensuring access to clean energy, SDG 7; taking urgent action to combat climate change by reducing greenhouse gas emissions, SDG 13; and ensuring good health and well-being by resolving indoor air pollution, SDG 3. Besides, biogas supports sustainable waste management, SDG 12, conservation of forests and biodiversity, SDG 15, and clean water and sanitation, SDG 6. Economically, it provides jobs and alleviates energy costs, therefore reducing poverty and contributing to sustainable economic growth (SDGs 1 and 8) [16], [17]. These multifaceted benefits make biogas technology crucial in resolving

Nepal's energy, environmental, and socio-economic challenges, offering a scalable solution toward achieving long-term sustainability. Likewise, these environmental and socioeconomic advantages and global commitment motivated policymakers in Nepal to promote domestic waste-based biogas production.

The pivotal role of biogas programs in SDG, for Nepal underlines the need for government support and integration of renewable energy sources among rural communities. Future research should focus on increasing the efficiency of biogas technologies, enhancing their environmental benefits, and ensuring long-term sustainability. Another area likely to have a significant impact on energy access and environmental preservation in rural settings is investigating ways of increasing biogas adoption in remote locations, possibly through mobile or decentralized systems [13]. Such local waste materials could be exploited by optimizing biogas technologies to continue lessening dependence on imported fuels and opening up the road to a sustainable, self-reliant energy future for Nepal. These environmental and socioeconomic advantages and global commitment motivated policymakers in Nepal to promote domestic waste-based biogas production [13].

Institutional biogas plants are biogas systems created to supply energy to establishments like security agencies, schools, hospitals, hostels, prisons and other institutional settings [18]. These facilities create biogas from organic waste, such as kitchen scraps, animal dung, and agricultural residues, which is a safe and affordable substitute for firewood, LPG, or electricity for heating and cooking. Institutional biogas plants are differentiated as small, medium, and large concerning their size, the capacity of waste, and energy output. Small plants can treat about 10 cubic meters of biogas daily. These plants are quite appropriate for schools, hospitals, and farms. Such small-sized plants convert the organic waste into cooking gas and energy meant for small heating or lighting purposes. Medium-scale biogas plants typically produce between 10 and 100 cubic meters of biogas daily, catering to larger entities such as community centers, hotels, or medium-sized agricultural operations. These facilities facilitate the transformation of substantial organic waste, comprising food scraps and agricultural by-products, into energy sources including cooking gas, thermal energy, and electricity. Biogas plant of more than 100 cubic meters per day, catering to large institutions or municipalities for cooking, heating, electricity generation, or other industrial processes by processing large volumes of commercial wastes. It is categorized according to the number of wastes processed, the energy requirements of an institution, and other by-products developed such as dig estates used as organic fertilizers. Nepal government along with other governmental and non-governmental organizations promotes and installed around half million and more than 500 institutional large-scale biogas plant [19]

Biodegradable resources including human waste, solid waste, agricultural residues, etc. t hat are found in public institutions like schools, hospitals, police and army barracks, hou ses of worship, senior citizen homes, and orphanages are used to create institutional biog as.The subsidy for institutional/community biogas plants will be given priority to produc tive end uses because of the significant economic growth potential and social inclusion t hat these plants offer.All commercial businesses that are privately owned, including sma ll/cottage industries, slaughterhouses, cattle farms, and poultry farms, are regarded as co mmercial entities.Businesses that produce a lot of organic waste have a great chance of p roducing biogas. [20].

In Nepal, the majority of security establishments in the Kathmandu Valley rely on LPG for cooking.However, because night soil and kitchen waste are readily available in large quantities, these institutions have an equal chance of implementing biogas technology. This would help to mitigate global warming by capturing methane released in the biogas digester from this available biomass and by substituting a substantial amount of fuel wo od for heating and cooking. [21].

Study conducted on security installation of Nepal suggested that installing biogas plants in army barracks is vital for efficiently managing organic waste while providing a sustainable energy source. These plants transform kitchen and human waste into biogas, reducing dependency on external fuels and cutting operational costs. They enhance energy security, particularly in remote areas where supply chains may be disrupted. Additionally, biogas plants improve sanitation within the barracks, decreasing health risks associated with waste accumulation. By reducing greenhouse gas emissions, they also contribute to environmental sustainability, aligning with broader efforts to promote eco-friendly practices within the military infrastructure [21]

Large public institutions, particularly the security agencies, have begun the switch to large scale biogas plants to save on imported cooking fuel. The Armed Police Force has taken the lead in this regard, floating tenders for 20 plants across the country, whereas Nepal

Police has planned to install another 20. So far, the government focal agency has collaborated with the Nepal Army and the Department of Prison Management for the installation of biogas units with the aim of achieving energy self-sufficiency together with organic waste management [22].

By providing medium-scale solutions to meet the energy and sanitation needs of institutions like schools, hospitals, prisons, and security agencies like army barracks, institutional biogas plants bridge the gap between residential and commercial biogas systems. Institutional plants handle larger volumes of organic waste, typically from communal facilities or centralized kitchens, and require trained personnel for operation and maintenance, in contrast to domestic plants, which serve individual households [18]. Despite being smaller and less commercially oriented, institutional systems place a strong emphasis on sustainability: economically addressing localized energy and waste management needs. Their dual function of supplying clean energy and improving sanitation, particularly in urban areas, makes them significant and scalable, making them a viable solution to Nepal's energy and environmental problems..

In the context of army barracks, which produce substantial amounts of organic waste, biogas plants could significantly reduce waste-related environmental pollution. The economic feasibility of biogas plants in Nepal’s army barracks is another crucial factor. Biogas technology is considered an economically viable solution, as it provides a renewable energy source and reduces the reliance on external energy inputs, such as electricity or LPG by producing biogas on-site, army barracks can cut down on fuel costs, which are often substantial in such institutional settings. However, upfront capital costs for biogas plants can be high, particularly for larger systems designed to meet the energy demands of institutional settings. Financial incentives and government subsidies can further support the economic viability of these projects.

Technical and the environmental sustainability of biogas plants is contingent upon their proper operation and maintenance. Inadequate management of digesters or improper waste handling can lead to inefficiencies or environmental hazards. Therefore, adopting best practices in system design, maintenance, and monitoring is crucial for maximizing the environmental benefits of biogas production.

Biogas technology holds substantial potential for the sustainable development of institutional energy systems in Nepal, particularly in army barracks. The integration of biogas plants into these settings could offer multiple benefits in terms of energy production, waste management, and environmental protection. However, for these projects to be successful, careful consideration of the technological, economic, and social aspects, along with overcoming existing barriers, is essential. research is needed which focuses on addressing the technical, financial, and operational challenges of scaling up biogas technology in institutional settings and developing strategies to ensure its long-term sustainability.

Nepal government agency, Alternative Energy Promotion Center (AEPC) initiated the initiation to install a medium to large-scale biogas plant in several security agencies like the Armed Police force, Nepal police, and Nepal Army by conducting a feasibility study at the beginning of 2016 [20]AD the exact number of plants installed is not confirm. Though the initiation was taken and the biogas plant was installed many of the installed plants are either not functioning or terminated the reason for the termination is yet to be evaluated.

1.2 Problem Statement

Institutional biogas plants are one of the best alternatives to satisfy the growing energy and environmental challenges in Nepal. The organic wastes generated by the respective institutions, such as army barracks, are transformed into renewable energy by the plants. This will lower the dependence on imported fossil fuels and contribute to lessening greenhouse gas emissions. Another set of important issues concerns the successful establishment and further operation of institutional biogas plants in Nepal.

In 2016, the Alternative Energy Promotion Centre signed a memorandum with the NA to construct big-sized biogas plants to utilize the energy acquired from the waste within two years. The plants of different sizes were installed in several army bases under the agreement. However, a majority of them have either not functioned according to the plans so far or remained unused. The causes of such failures are not known largely because of lack of research about the problem.

A big concern is that the usually insufficient quantity of biogas being produced raises critical questions about the long-term functionality of such systems for cooking fuel needs. While numerous sustainability analyses of institutional biogas plants have been conducted in developing countries, few studies relate to Nepal. The biogas plant will be sustainable based on the context in which the system operates by considering the prevailing economic conditions, climate, cultural practices, and appropriate institutional frameworks.

An institutional biogas plant with 40 m^3 capacities was constructed at a Nepal army camp (Sundarijal Arsenal) by conducting a feasibility study by the Nepal Government Agency AEPC, aiming to substitute conventional energy sources like firewood, LPG, and grid electricity as a cooking fuel purpose. There is a huge scope of availability of feedstock as 20-30 kg food waste and 80-100 kg human excreta are generated at the camp during the feasibility study. Still, its contribution to the cooking fuel portfolio is very low. Mainly reliable and sufficient biogas is not generated to cater the cooking fuel and this situation has questioned the sustainability of the biogas plant. Although several sustainability assessment studies have been carried out in the field of institutional biogas plants in developing countries [23], [24], [25]such studies are rare in the Nepalese context. The sustainability of biogas plants is context-specific and is heavily influenced by the socioeconomic, climatic, cultural, and institutional contexts under which it functions. Therefore, developing the sustainability framework and conducting a sustainability assessment of the institutional biogas plant at Sundarijal Barrack is the rationale of this study.

Sundarijal Arsenal Biogas Plant has been operated for the 2 years. Despite the significant potential of the Sundarijal Arsenal Biogas Plant, its operational efficiency remains significantly below expectations, functioning at only 22% of its design capacity. Besides, its techno-economic viability and environmental impact have not been comprehensively evaluated. A thorough assessment of these aspects is essential to justify its promotion as a sustainable energy solution and to inform strategic improvements for enhancing its long-term sustainability.

1.3 Rationale and Gap

This research is significant for energy policymakers, security agencies, and renewable energy planners. The findings will help guide future investments in institutional biogas plants, optimize existing systems, and contribute to Nepal's renewable energy targets under the Sustainable Development Goals (SDGs), specifically SDG 7 (Affordable and Clean Energy), SDG 13 (Climate Action), and SDG 3 (Good Health and Well-being). By enhancing the performance and sustainability of institutional biogas plants, Nepal can reduce its reliance on fossil fuels, improve waste management, and transition towards a more self-sufficient and environmentally friendly energy future.

Although several studies have evaluated the performance of domestic biogas systems, limited research has been conducted on the sustainability of institutional biogas plants in Nepal, particularly within security institutions. This study aims to address this research gap by assessing the technical, economic, and environmental performance of the Sundarijal Arsenal Biogas Plant. The findings will help determine key factors affecting the sustainability of institutional biogas plants and provide recommendations for enhancing operational efficiency.

1.4 Main Objective:

- To conduct a sustainability assessment of the Sundarijal Arsenal Biogas plant to identify technical, economic and environmental factors governing their sustainability.

Specific Objectives:

- To identify key technical, economic, and environmental factors influencing sustainability
- To evaluate the levelized cost of energy (LCOE) and its competitiveness with LPG and electricity
- To assess the actual performance of the Sundarijal Arsenal biogas plant compared to its design expectations
- To quantify the contribution of biogas to the barrack's energy mix

1.5 Limitations

- Unavailability of Accurate measuring equipment and methods may cause deviation of measured data.
- Potential challenges in quantifying non-monetary environmental benefits.
- Site-specific results may limit generalizability to other contexts.

CHAPTER TWO: LITERATURE REVIEW

2.1 Biogas Status of Nepal

2.1.1 Domestic Biogas

Biogas is generated through the anaerobic digestion of organic matter, primarily from domestic animal manure and human waste. The resulting slurry serves as an environmentally friendly alternative to chemical fertilizers. This contributes to cost savings and maintaining a clean and sustainable environment. In Nepal, with its significant agricultural sector involving 60.4% of the population, the abundant biomass from livestock and farming activities makes biogas an ideal technology for cooking, with approximately 1.9 million households (42% of the total) having the potential for household biogas system installation, as highlighted in the recent study [26]

Table 2.1: Annual Biogas Production and Fuel wood Saving Potential of Nepal

	Mountain	**Hill**	**Low Land**
Annual per capita fuel wood consumption (kg/year)	712	598	482
Annual per capita biogas requirement (m3/year)	155	130	106
Annual net weight of fresh dung (kg/household/year)	3,501	5,386	7,669
Average household size (number of people)	6	4	4
Annual potential biogas production (m3/household/year)	22	49	64
Weight of per capita saving of fuel wood (kg per capita)	101	224	292
Percentage share of saving of fuel wood (%)	14	37	60

Source (WECS 2024)

1 m^3 biogas = 4.57 kg fuel wood

1 kg fresh dung = 0.036 m^3 biogas

The Government of Nepal has been regularly promoting the implementation of biogas plants of various capacities, including 2 cubic meters, 4 cubic meters, 6 cubic meters, and 8 cubic meters, specifically for domestic use. These plants adhere to the GGC 2047 standard, and the modified design based on GGC 2047.Since FY 2075/76, there has been only a slight increase in biogas installations. As of 2078/79, there has been a cumulative

0f 439,547 installations.

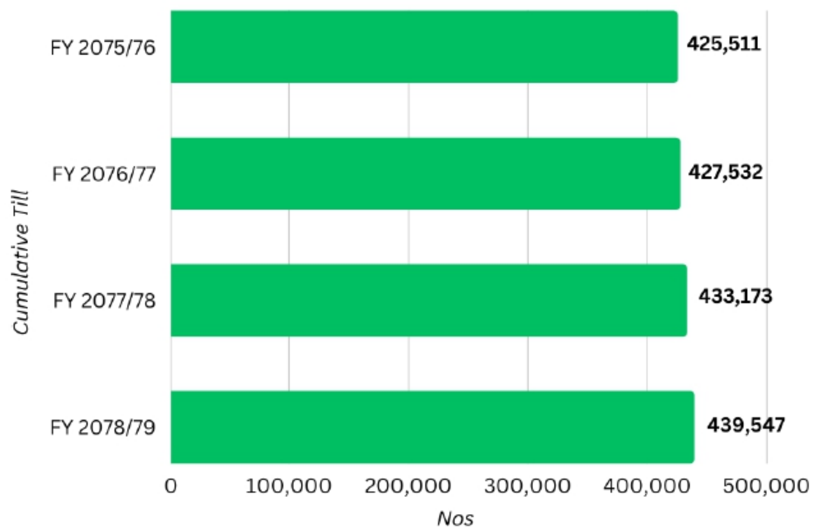

Figure 2.1: Cumulative Installation of Domestic Biogas

2.1.2 Institutional Biogas

Large plants that have a capacity of 12 cubic meters or more use biodegradable materials like solid waste, human waste, agricultural residues, etc. accessible in public settings like schools, hospitals, army and police barracks, places of worship, senior citizen residences, and orphanages. The subsidy for institutional/ community biogas plants will be given priority to productive end-uses because of the strong potential for enterprise development and social inclusion that these plants offer. [26]

Nepal has made significant progress in biogas technology with the construction of large biogas plants that can produce more than 12 cubic meters of gas. The modified GGC 2047 model and long-term practices, along with insightful knowledge gained from global technological experiences, are responsible for this advancement. Commercial installations as well as institutional, community-level systems are included in the broad category of large biogas plants. The number of large biogas installations as of 2078/79 was 355 [1], [26].

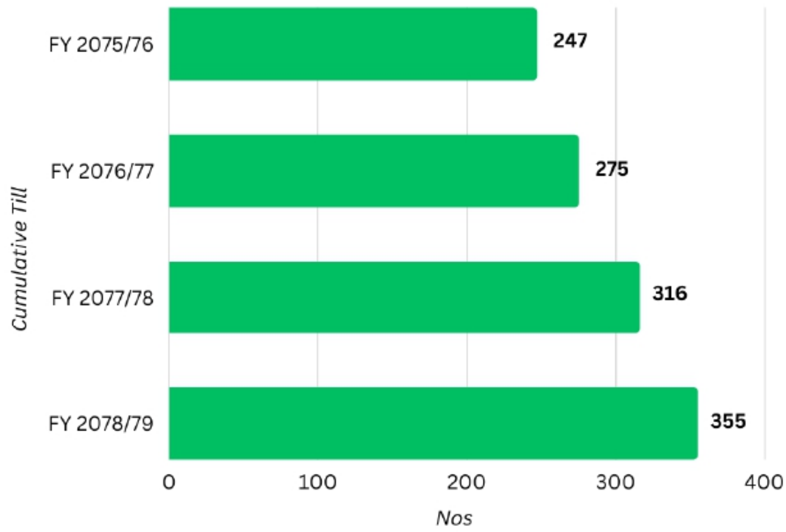

Figure 2.2: Cumulative Installation of Large Biogas Plants

While the majority of large biogas plants in Nepal are institutional, there are also notable examples of commercial-scale installations. These include 4,200 m^3 plants in Pokhara, 3,750 m^3 plants in Nawalparasi, and 3,500 m^3 plants in Syangja. [27]

2.1.3 Province's Wise Biogas Distribution in Nepal

Figure 2.3 shows distribution of biogas production in Nepal's provinces. At 28.1%, Bagmati holds the largest percentage, followed by Gandaki (24.2%) and Koshi (19.6%).The contributions from Lumbini and Madhesh are 9.8% and 11.2%, respectively.Karnali and Sudurpashchim hold smaller shares, at 3.1% and 4.1%, respectively.In contrast to the comparatively lesser contributions from Sudurpashchim and Karnali, this distribution shows that Bagmati, Gandaki, and Koshi are the main producers of biogas, indicating better developed development and usage of biogas resources in these regions.[1].

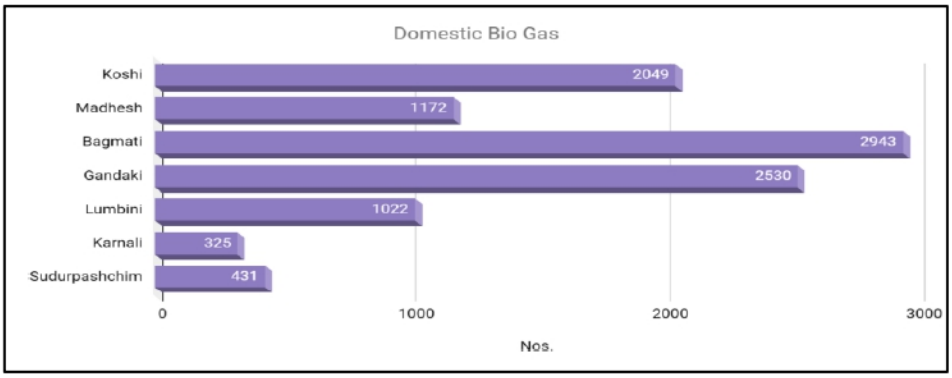

Figure 2.3: Domestic Biogas in Various Locations

2.2 Past Study

2.2.1 Feasibility Study Carried Out By AEPC

In the year 2017 Clean and Green Nepal Thapathali, Kathmandu, Nepal in coordination with Alternative Energy Promotion Center (AEPC) conducted a feasibility study on institutional biogas in Sundarijal Arsenal, sundarijal, Kathmandu, and provided construction and operational parameter as a design consideration tabulated in Table .2.2.

Table 2.2: Design Parameters of Feasibility Study

S.N	Parameters	NRs	Remarks
1	Total size of the biogas	40 m^3	
2	Gas Production	7.4 m^3/day	
3	Total investment cost	11,57,458	
4	Government subsidy	694,474	
5	Barrack Contribution as Unskilled labour at free of cost	231,491	
6	Investment from Nepal Army	231,493	
7	Persons Residing inside Barrack	300	
8	Project Type	Institutional	
9	Quantity of kitchen waste for input	28kg/day	
10	Quantity of human Waste	90kg/day	
11	Volume of Fuel consumption (Kerosene)	50 Liters/day	

Source (AEPC 2017)

2.2.2 A Glimpse into Community and Institutional Biogas Plants in Nepal

In 2011 conducted a case study on the institutional and community biogas plant of Kathmandu Valley, Nepal. Six community and institutional biogas plants were studied and concluded that institutional biogas plants in Nepal demonstrate higher success rates compared to community plants due to better ownership and clearly defined responsibilities. Key factors for sustainability include proper training, technical knowledge, and robust after-sales service. Common technical challenges such as low gas production and leakages necessitate regular maintenance and precise technical solutions tailored to the specific waste types of the institution.

Promoting biogas plants as both energy and sanitation solutions enhances their sustainability impact, particularly in urban areas where sanitation is a major concern. The selection of appropriate technology models, such as TED for kitchen waste and CCG for animal manure, is crucial. That study recommended further research to optimize the functionality and sustainability of these systems, addressing both energy deficits and environmental concerns. This study couldn't specify precise challenges governing the sustainability of the plant.[18]

2.2.3 Evaluation of Biogas Sanitation System in Nepalese Prison

Analysis of biogas plants that have been installed in Nepalese prisons. The assessment comes to the conclusion that biogas plants are a suitable way to treat kitchen waste and backwater together in prisons and other similar institutional settings in developing nations. But in the case of biogas and prisons, the well-known adage "a technology is only as good as its operation and maintenance" also holds true. The best way to promote a technology is to show that it works properly and that its users accept it. Issues of strong ownership and responsibilities for maintenance work are important aspects that require particular attention for biogas digesters at institutions. Inadequate operation and maintenance can have more negative effects than positive ones, such as greenhouse gas emissions from methane or health hazards from gas leaks in the kitchen. In order to improve hygienic conditions and supply clean, renewable cooking energy, ICRC will support the development of biogas plants for institutions (prisons, schools, and hospitals) in other nations. This is in line with the successful experience in Nepal.[28]

2.2.4 Sustainability Assessment of Large Biogas Plant in Nepal

A study on sustainability assessment of a large-scale biogas plant in Nepal the study explored the operational status of an existing biogas plant. The study revealed that the plant's technical, financial, and environmental performance is well below its design capacity. [29]

This study recommended that to ensure the sustainability of technical, financial, and environmental performance of other biogas plants, meticulous planning, a strong local technical team, close collaboration with relevant experts, and independent (both national and international experts) third-party evaluation and monitoring organizations are crucial. [29]

2.2.5 Global Warming Mitigation Potential of Biogas Technology in Security Institutions of Kathmandu Valley, Central Nepal

In contrast, another study was carried out to assess the potential for biogas technology to mitigate global warming in security institutions in the Kathmandu Valley. The study's design was to estimate the potential size of biogas plants from the total amount of organic waste (kitchen waste and night soil), as well as the GHG emissions from night soil, the global warming mitigation potential (GMP), and the carbon credits of potential biogas plants in the security institutions (Army and Police barracks) in the Kathmandu Valley. That's what the study finds. In a security facility, 37 m3 biogas plants can typically be installed. 0.22 tons of CH4, 4.55 tons of CO2, and 0.33 tons of N2O were found to be emitted annually by one institution. Furthermore, the average annual cumulative greenhouse gas emissions from a single institution were 111.09 tons of CO2-equivalent emissions. Last but not least, the average GMP of one such institution is 7.69-ton CO2-eq/year. At a rate of $10 per ton CO2-equivalent, each barrack in the Kathmandu Valley could make $76.19 annually through CDM. [21]

2.2.6 Effective Use of Bio waste in Institution

A study was conducted in Tamilnadu, India on the effective use of bio waste available in institutions on the year 2014. Studies conclude that the production of biogas from human waste, and kitchen waste has shown that biogas can be produced from institutional wastes by anaerobic digestion. These wastes are readily available in the institution and it can be a source of fuel if used properly. Through this carbon dioxide emissions can be reduced effectively. The use of biogas for cooking and laboratory use for heating helps to reduce the energy cost.[30]

2.2.7 Evaluation of the Performance of Institutional Biogas Plants in Uganda

In year 2008 a study was conducted to evaluate the performance of institutional biogas plants installed in Uganda the study found that a total of 28 institutional biogas systems were installed in the county. 13 are in secondary schools, 11 in prisons, 7 in community households, 2 in military camps and 2 in training centres. Much needs to be improved on the operation aspects as only 11 of 28 institutional biogas systems operate very well, 5 operate with major defects and 6 have never operated (either abandoned or wrongly designed) The size of the digesters varies from 16 to over 1000 mtr^3. Digesters of $16m^3$ to 40 m^3 were installed and operate very well in community households of 15 people (Religious Missions, etc) and are fed by 5 to 10 cows' dung. Secondary schools opted for digesters with the capacity of 60, 76, and 100 m^3 but 3 biogas systems of 100 m3 have never operated because they were wrong-designed (not built in series) and too big compared to the number of students living full-time in the school. Other biogas systems installed in secondary schools do not perform well due to the lack of sufficient gas to operate a stove of at least 200 Litres. The lack of follow-up and technical support is also a hindrance to the success of secondary school biogas systems. Prison biogas systems are by far the biggest in use in the country and vary in size from 200 to 1250 m^3. These have experienced success in the reduction of fuel wood used for cooking (estimated at an average of 19% but with a much higher potential) and the improvement of the environment around prisons both in smell and health aspects. Nevertheless, lack of follow-up and technical support affects significantly the efficiency of the prison biogas system; 4 of 8 prison systems are operating with major defects. Two biogas plants installed in the army barrack are never operated.[25]

2.2.8 Evaluation of Institutional Biogas Plant in Prison of Nepal

An evaluation study of five biogas plants within Nepalese prisons was carried out from April to June 2009. Findings indicated that all five fixed-dome digesters (modified GGC2047 design, with capacities of 10m3, 20m3, and 35m3) exhibited airtight domes and maintained high process stability (pH levels of 7.1 - 7.4, temperatures between 26-30°C, and Redox readings of -380mV) without any build-up of inhibitory substances [31](VFA, NH4-N). During the final monitoring phase, daily gas production for four out of the five digesters was observed to exceed the anticipated biogas output determined during the pre-construction period. The average gas production from human waste alone was recorded at 27NL/person/day, with additional contributions from entire kitchen waste amounting to 62NL/person/day. The methane content ranged from 57 to 78 Vol-%, depending on the type of feedstock used; however, all systems had hydrogen sulphide concentrations in their biogas that surpassed 1000ppm. None of the monitored facilities utilized the nutrient-rich effluent (Total N: 760mg/L, with 63% as NH4-N, Total P: 61mg/L) as fertilizer. The technology has been positively received by the majority of inmates, who reported a general enhancement in living conditions following the installation of the biogas systems. Approximately 59% of the interviewed prisoners noted a decrease in smoke in the kitchens (leading to fewer respiratory health issues), while 49% indicated improvements in sanitary and hygiene conditions. [31]

2.2.9 Sustainability Issues of Household Bio digesters in Nepal

A study about the sustainability issue of household Bio digester in Nepal was conducted in the year 2023 study concluded that the successful operation of a biogas plant requires continuous monitoring of operational parameters such as temperature, feed materials loading, close observation of functionality of their components, inspection of the plant for leakages in regular interval. Failure to do so results in poor efficiency of the bio digester and its overall performance in terms of biogas yield.[32]

2.3 Literature Gap

From the above studies, we can see that there are many studies about domestic, institutional, and commercial large biogas plants. In the case of Nepal, the study of institutional biogas plants is done mainly in prisons and the study was about performance analysis. Past studies have not focused on the sustainability assessment of installed biogas plants and there are very few studies about the sustainability assessment of institutional biogas plants in army barracks and other security agencies of Nepal.

CHAPTER THREE: METHODOLOGY

This study follows a structured methodology to assess the sustainability of the Sundarijal Arsenal Biogas Plant. The research process is divided into sequential stages, starting with a technical analysis, followed by an economic and environmental assessment, and concluding with a comprehensive sustainability evaluation. Based on the findings, policy recommendations will be formulated to optimize the system and support future decision-making Methodological Process is shown in Figure 3.1

The research begins with problem identification and scope definition, the key research objectives and define the boundaries of the study established. A literature review was conducted to understand the current state of biogas technology, sustainability indicators, and relevant evaluation methods. This helped to identify key parameters for assessment.

Data collection and system characterization conducted, which involves gathering both primary and secondary data. Primary data is obtained through on-site data collection and monitoring, measurement of biogas yield, energy input and output, and system efficiency. Secondary data is collected from existing literature, technical reports, and policy documents. At this stage, system boundaries are defined to outline the plant's inputs, outputs, and operational constraints.

The technical analysis focuses on evaluating the performance of the biogas plant by assessing feedstock characteristics, biogas production rates, energy conversion efficiency, and system reliability. This step helps in identifying potential operational improvements and efficiency enhancements.

Following this, I carried out an economic analysis, which included evaluating the capital investment, operational and maintenance costs, revenue generation, and overall financial viability of the system. Key financial metrics such as the levelized cost of energy (LCOE) is analysed to determine the plant's economic feasibility.

In next step, an environmental impact assessment was conducted, which examines greenhouse gas (GHG) emission reductions, waste management benefits, and efficiency on resource utilization. The assessment provides insights into the environmental advantages of the biogas plant compared to conventional energy and waste disposal methods.

The final step was a comprehensive sustainability evaluation, where I integrate the findings from the technical, economic, and environmental assessments to provide a holistic understanding of the plant's sustainability by comparing the obtained result with plants design consideration. The evaluation will focus on identifying strengths, weaknesses, and key improvement areas based on individual sustainability indicators.

Lastly, based on the study's findings, I develop recommendations and optimization strategies to enhance the biogas plant's efficiency, economic viability, and environmental benefits. These recommendations aim at providing guidance for policymakers, stakeholders, and future research initiatives, ensuring the long-term sustainability of the system.

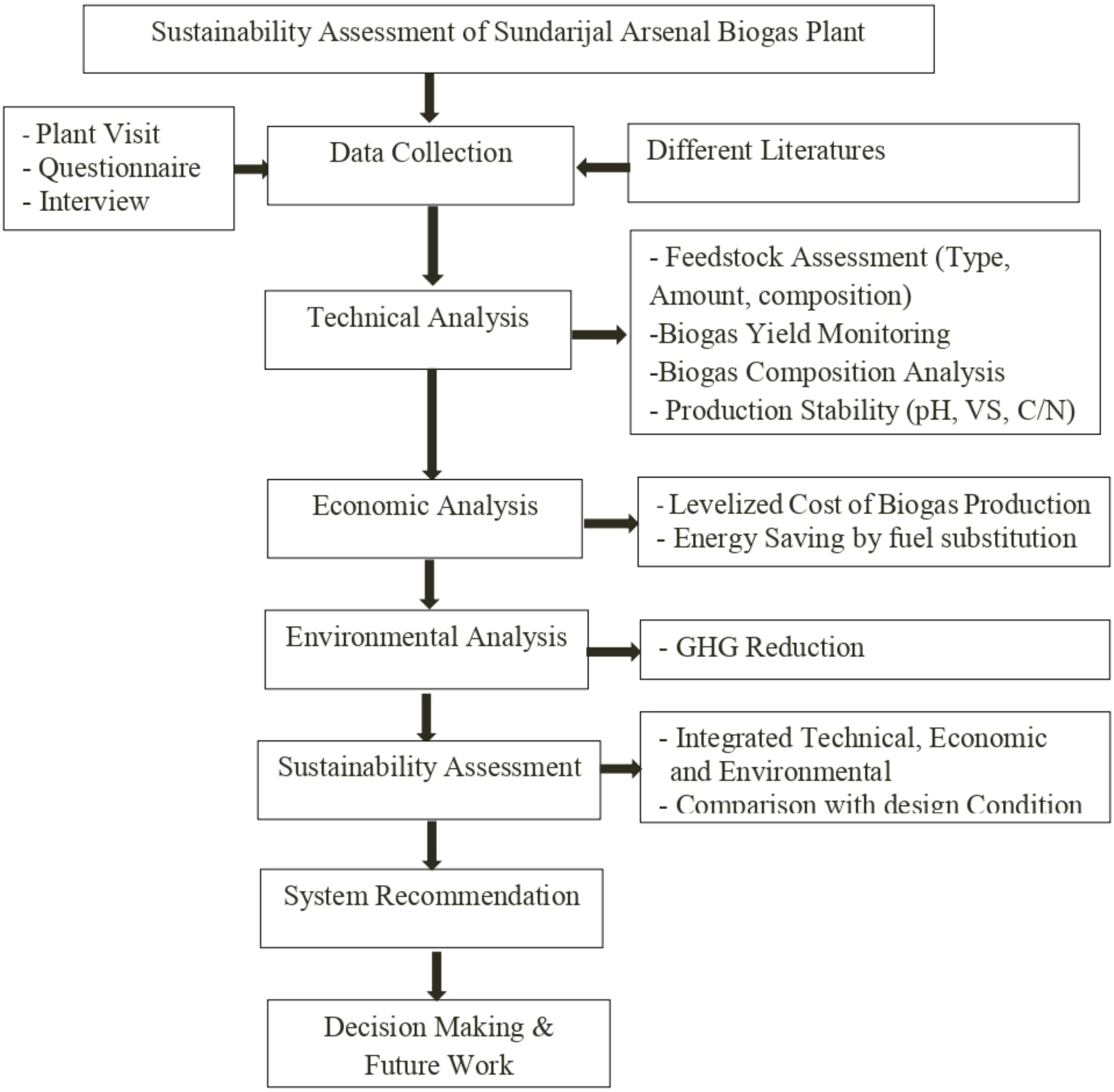

Figure 3.1 Flowchart of Methods of Study

3.1 Technical Analysis

The technical analysis encompasses a design assessment, feedstock characterization, process efficiency evaluation, energy output analysis, and feedstock conversion efficiency assessment to compare actual operating conditions with design expectations.

3.1.1 Design Assessment

A structured questionnaire was developed to evaluate the design aspects of the biogas plant, including plant type, model, location, construction materials, present condition, water availability, and maintenance requirements. Interviews with the operators of the plants and maintenance staff were administered to learn the operational functionality of the system. Additionally, design specifications such as anticipated daily feedstock input, biogas yield, and slurry output were compared with the actual operational data.

3.1.2 Feedstock Assessment

Feedstock assessment involved determining the type, quantity, and composition of the feedstock, including pH value and carbon-to-nitrogen (C/N) ratio. The plant primarily utilizes kitchen waste from the barrack's kitchen and human waste from army personnel residing in the barrack. Daily organic waste generation was recorded over 90 days in summer (13 April –16 July 2024) and 90 days in winter (17 November, 2023 –16 February, 2024). Kitchen waste included vegetable scraps and food leftovers. Human waste input was estimated based on barrack occupancy, with an assumed per capita generation of 0.3 kg per day. Laboratory analysis was conducted to determine volatile solids (VS) content, C/N ratio, and pH, using reports from SWAT Lab Pvt. Ltd., Kathmandu, and established literature.

3.1.3 Process Efficiency

Process efficiency was assessed by monitoring daily biogas yield, operating temperature, and biogas composition (CH_4/CO_2 ratio).

- Biogas yield was recorded using a Zhejiang Chint biogas flow meter installed at the kitchen inlet (see the Photo on appendix).
- Gas utilization patterns were documented, including biogas consumption for cooking beans, pulses, and eggs at different times of the day.

- Ambient temperature was monitored using an analogue thermometer placed in the kitchen. Seasonal variations in temperature were analysed to determine their effect on biogas production.
- Biogas composition was analysed at different intervals using a Portable Infrared Syngas Analyser (Gasboard-3100P and Gasboard-3200plus).
- Comparison of actual vs. design values was conducted to assess deviations in plant performance.

3.1.4 Energy Output

Energy output was calculated based on daily biogas yield and methane calorific value using the formula:

$$E = V * C \quad (1)$$

Where:

E = Energy output (MJ/day),

V= Biogas volume (m^3/day),

CV = Calorific value of methane (MJ/m^3).

Likewise, the biogas calorific value was determined based on the measured methane content, which was done through the gas analyser.

$$\text{Energy output} = \text{Biogas volume } (m3) \text{ x Calorific value } (MJ/m3) \quad (2)$$

3.1.5 Feedstock Conversion Efficiency

Feedstock conversion efficiency insights into how effectively biogas plants are converting feedstock into biogas. This evaluates how effectively the plant is working. This is calculated by using the formula

$$\text{Feedstock Conversion Efficiency} = \frac{Average\ Daily\ Biogas\ produced}{Average\ Daily\ feedstock\ input} \quad (3)$$

The obtained values were compared with standard conversion rates to assess plant efficiency.

3.2 Economic Analysis

Economic analysis assesses the economic viability of the biogas plant, focusing on the Levelized Cost of Energy (LCOE) and energy savings from LPG substitution.

3.2.1 Levelized Cost of Energy (LCOE)

LCOE represents the cost per unit of energy generated over the plant's lifetime. It is calculated using the formula:

$$\text{LCOE}= \frac{Total\ Biogas\ Production\ over\ Plant\ Life\ Time}{Total\ Life\ cycle\ cost} \quad (4)$$

Total life cycle cost = Initial investment cost+ Annual Maintenance cost+ fuel cost

$$\text{Capital Recovery Factor (CRF)} = \frac{r(1+r)n}{(1+r)n-1} \quad (5)$$

r = discount factor

n = No of year

Annualized Investment Cost =Net Investment cost ×CRF (6)

The initial investment cost and the maintenance costs are obtained from the plant owner. Since it is an institutional biogas plant, there is a government subsidy that will be deducted from the investment cost. Likewise, since feedstock is available freely for this biogas plant as it utilizes kitchen waste and human waste, the cost associated with feedstock is also obtained from the plant owner if there is any.

3.2.2 Energy Saving

The main use for the biogas generated is for cooking, the energy/cost saved is associated and compared with the LPG usages. Thus, the LPG saved after using biogas is calculated by measuring the weight of LPG used to cook the same type and amount of food items. To obtain an accurate weight of the LPG cylinder before the food item is cooked, the weight of the LPG cylinder is taken before and after the food item is cooked using a digital weighing machine.

3.3 Environmental Analysis

The environmental analysis evaluates the emission reduction potential and sustainability benefits of the biogas plant. The primary focus is on CO_2-equivalent emission reductions from fossil fuel substitution (LPG replacement) and methane or CH_4 emissions avoided.

$$CO_2 \text{saved} = \text{LPG saved} \times 2.98 \text{ kg of } CO_2. \quad (7)$$

The CO_2 emissions avoided are calculated by the formula [33]

Similarly, the CH_4 emissions avoided are calculated with the formula [34]

$$\text{Methane Emissions Avoided } (m^3) = \text{Volume of } CH_4 \text{ Produced } (m^3) \times 0.175 * 0.717\text{kg} \quad (8)$$

3.4 Comparison of Actual Performance with Design Consideration

An integrated analysis is carried out based on computed data from this study with actual design consideration, by comparing results obtained. Which will provide actual performance of the plant in comparison to its design consideration.

CHAPTER FOUR: RESULT AND DISCUSSION

This chapter presents all the recorded data and findings from the study periods, and it evaluates them using a conceptual framework that was created. All necessary computations are performed using the formula specified in the approach. The sustainability of the plant is assessed by comparing the obtained results with design considerations and standards.

4.1 Technical Analysis

In this chapter, different calculations & technical analysis were carried out.

4.1.1 General Information Design of the Plant

Clean and Green Nepal Thapathali, Kathmandu, Nepal conducted a GCC2047 model biogas plant feasibility assessment in 2017 through the Nepali government's Alternative Energy Promotion Centre (AEPC). The funding, subsidy, construction company selection, and construction modality of the plant were all completed in 2019. However, it was discovered through stakeholder and plant owner interviews that the COVID-19 situation caused the plant construction to be delayed and finished in 2022.Table 4.1 displays the general and technical evaluation conducted during the study period.

Table 4.1: Technical Condition of the Biogas Plant

S.N.	Name of Institution		Sundarijal Arsenal Office
1	Type of institution		Army Barrack
2	Location	Province	Baghmati
		District	Kathmandu
		Municipality	Gokarneshwor
		Ward no	1

S.N	Plant Details	
1	Model	Modified GCC 2047
2	Size	40m3
3	Application	Cooking
4	Construction materials	Brick
5	Gas pipe	PVC

6	Location of plant	Sunny	
7	Distance of water source from plant (m)	30m	
8	Distance of plant from kitchen	60m	
9	Water to feedstock Ratio	Not consistence	It is recommended to maintain 2:1
10	Feedstock storage condition	Exposed to weather	It is recommended to cover feedstock
11	Present condition and cleanliness of the biogas system components	Satisfactory	
12	problems faced with operating the system	Lack of knowledge about feedstock mixing and water to feedstock ratio	Proper training is necessary
13	Maintenance work	Change of Pressure gauge	

During frequent observation of the plant, it is observed that the physical condition of the biogas plant is well maintained. There was no leakage problem. The plant location is sunny and the cleanliness of the system components was well maintained. The distance of the plant from gas output is found to be long. Since the plant was operated only for 2 years there was not much maintenance work done besides the replacement of gas pressure. It was found that there was a lack of training in operation, feedstock mixing ratio, and maintenance of the plant.

4.1.2 Operational Performance of Plant

The operational performance of the biogas plant is evaluated by analyzing feedstock, biogas yield, and other parameters that influence the performance of biogas yield. Different parameters and data related to the operation of the plant are elaborated below. Table 4.2 shows the feedstock test results from the laboratory.

Table 4.2: Feedstock and Slurry Composition

S. N	Source	Parameter	Value	Unit	Method
1.	Human waste	pH	6.4	-	
		CN Ratio	22.25	-	
		Total solid	3480	mg/l	
		Volatile solid	58.1	mg/l	
2	Kitchen Waste	pH	5.7	-	
		CN Ratio	32.35	-	
		Total solid	10,190	mg/l	
		Volatile solid	72.37		
3	Slurry	pH	7.3	-	
		CN Ratio	19.99	mg/l	
		Total solid	4396	mg/l	
		Volatile solid	66.38	mg/l	

Similarly, the biogas composition analysis using Gasboard-3100P and 3200plus revealed 52% methane, 15.99% CO_2, and an LHV of 4,144 kcal/m^3, indicating moderate methane production and efficient organic degradation. While the plant operates continuously, optimizing feedstock and digestion conditions or reducing CO_2 could further enhance methane content and energy efficiency.[35]

4.1.3 pH and C/N Analysis and Variation

During this research, kitchen waste was acidic, pH ranged from (3.4–5.5) from food waste and required some adjustment. pH analysis highlights the significance in anaerobic digestion, where an optimal range of 6.5–7.5 supports methanogenic activity. As such, adjustment of water-to-feedstock ratio to 2:1 increased pH to 5.5 but remained suboptimal. Likewise, human waste (pH 6.2–6.4) was close within acceptable limits, sustaining microbial activity. The pH of the slurry (7.17 – 7.3) indicated effective buffering, maintaining stable levels of digestion. Thus, despite the acidity of kitchen waste, the higher proportion of human waste provided for a balanced pH. The increase in pH compared to the initial feedstock suggests that the digestion process effectively neutralized acidic components.

Likewise, a balanced C/N ratio (20:1–30:1) is essential for maintaining nutrient equilibrium and optimizing methane yield in the biogas plant [35]

The kitchen waste (C/N 32.35) had an excess of carbon, which can disrupt microbial efficiency and slow down degradation. On the contrary, human waste (C/N 11.25) reduced the C/N within the optimal range, ensuring consistent microbial activity and digestion stability. The slurry C/N ratio (19.99), though slightly below optimal, indicates that nitrogen is effectively utilized during digestion, supporting microbial balance. These results highlight the necessity of adjusting feedstock composition through co-digestion strategies, such as blending kitchen waste with nitrogen-rich feedstock (example human waste) to sustain microbial health and enhance methane production. Addressing C/N imbalances is crucial for maintaining long-term digester stability and maximizing the plant's biogas yield, ensuring both environmental and operational sustainability.

4.1.4 Total Solids (TS) and Volatile Solids (VS) Analysis for Biogas Production

Human waste exhibited a TS concentration of 3,480 mg/L with a VS fraction of 58.1 mg/L, suggesting a significant proportion of biodegradable material, contributing to stable biogas production. Kitchen waste, with a higher TS concentration (10,190 mg/L) and VS fraction (72.37 mg/L), has greater biogas potential due to its high organic content. However, its acidic nature requires careful management to prevent microbial inhibition. Slurry TS (4,396 mg/L) and VS (66.38 mg/L) indicate that a substantial portion of organic matter was successfully degraded, confirming the digester's efficiency in breaking down feedstock and sustaining methane production.

4.1.5 Feedstock Characteristics and Variation

The biogas plant primarily utilizes kitchen waste and human waste as feedstock, with daily feeding schedules. The average daily kitchen waste input was found to be 4 kg, while the human waste contribution was approximately 23.33 kg, leading to a total average daily feedstock input of 27.26 kg. The study observed that kitchen waste generation fluctuates based on the number of individuals residing in the facility, as it is directly related to food preparation and consumption patterns. Variations ranged from 1 kg to 4 kg per day, with higher waste generation recorded when more individuals were present.

Similarly, human waste exhibited significant variation, ranging from 10 kg to 35 kg per day. As for the kitchen waste, the number of residents in the facility was a key determinant in waste production, with a peak value of 35.8 kg recorded when the barrack housed approximately 115 individuals. This correlation highlights the necessity of considering population dynamics when assessing feedstock availability for biogas production. Figure 4.1, Figure 4.2, 4.3 below represent the various feedstock variations throughout the research period about 180 days.

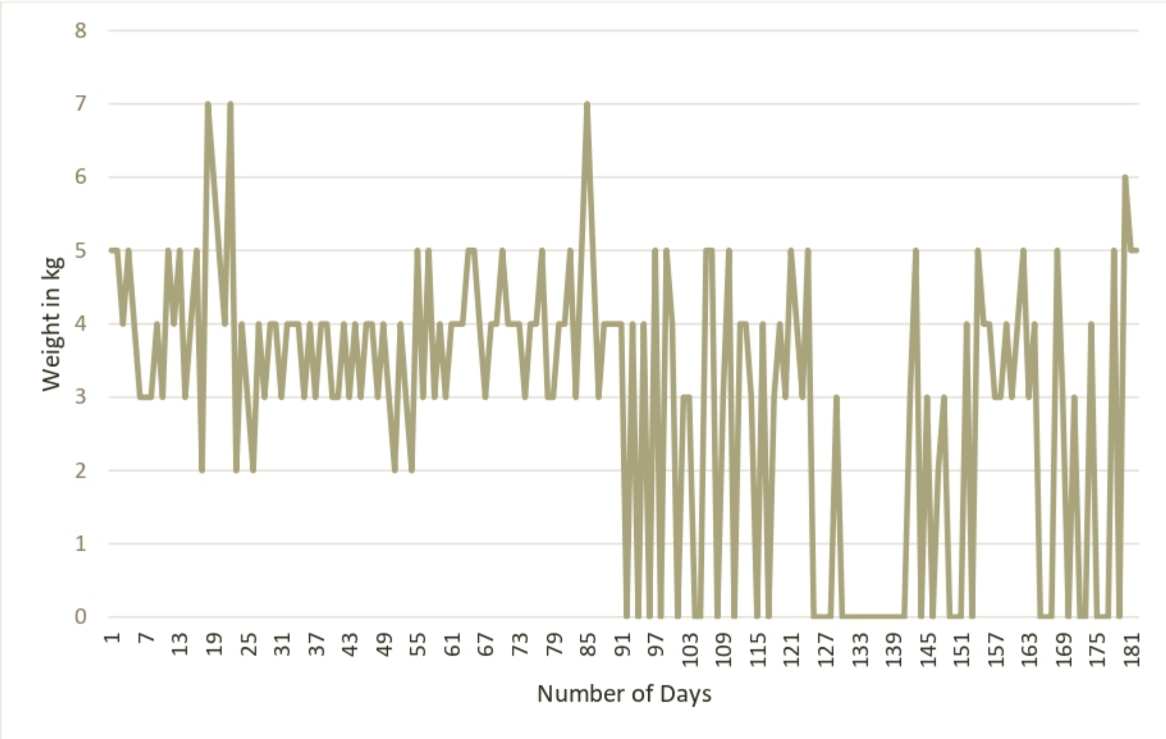

Figure 4.1: Kitchen Waste as Feedstock Variation

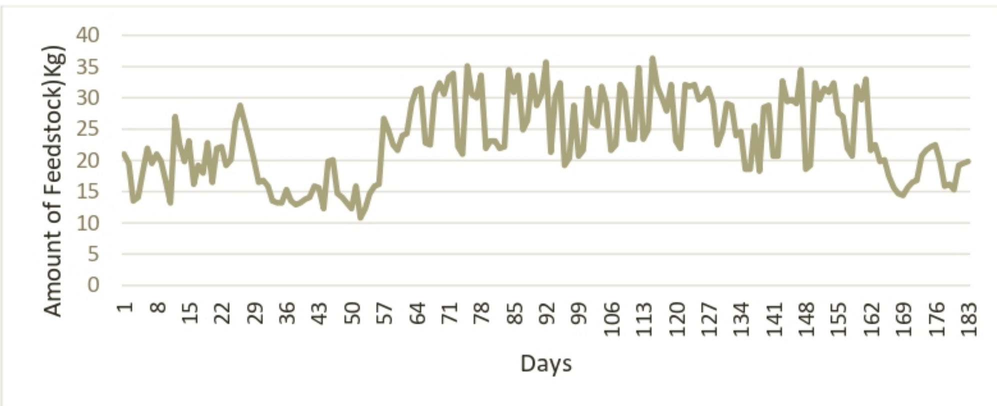

Figure 4.2: Human Waste as Feedstock Variation

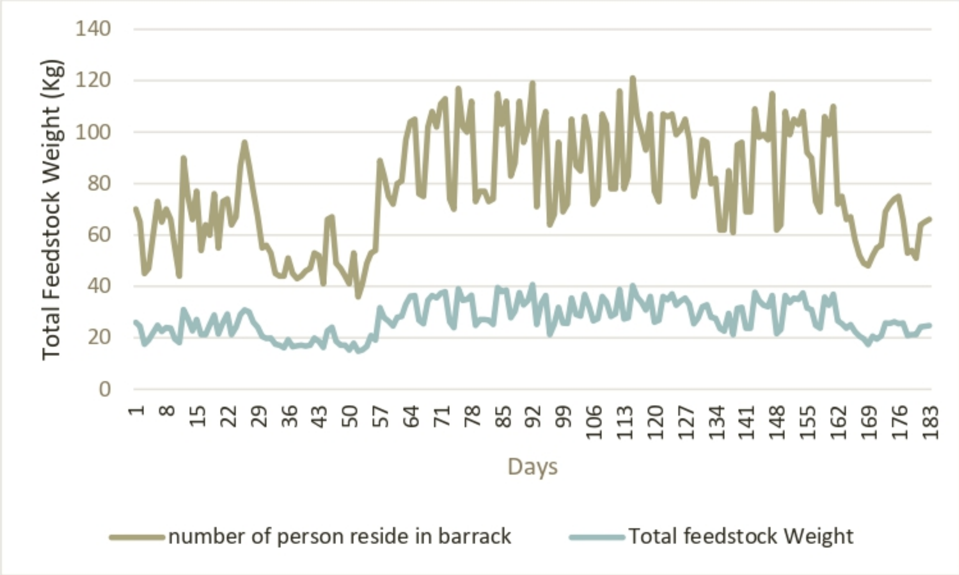

Figure 4.3: Number of Persons and Feedstock

4.1.6 Feedstock Conversion Efficiency

Comparison of the actual production with the design estimates indicates serious underperformance. From figure 4.8, the actual biogas production of the plant (1.63 m^3/day) is only 22% of the designed 7.4 m^3/day, indicating inefficiencies during operation. The primary reasons are reduced availability of feedstock, as kitchen waste and human waste feed are only 14% and 26% of design values, respectively. In addition, pH fluctuation and microbial digestion efficiency could further impact the biogas yield.

Conversion efficiency is calculated to be 0.060 m^3/kg. Though feedstock conversion efficiency remains within normal limits [36], the plant has fallen significantly short of its projected capacity since it is not being given proper input. Better feedstock supply, optimizing digestion conditions, and keeping pH levels at their optimal levels are necessary to enhance overall plant efficiency and achieve maximum biogas production.

4.1.7 Biogas Production

The daily feedstock input varied between 15 kg and 41 kg throughout the study period, which is illustrated in Figure 4.4. The data indicate that biogas production did not increase proportionally with minor feedstock increments beyond 30 kg. However, a noticeable rise in gas production was observed over time with sustained higher feedstock input.

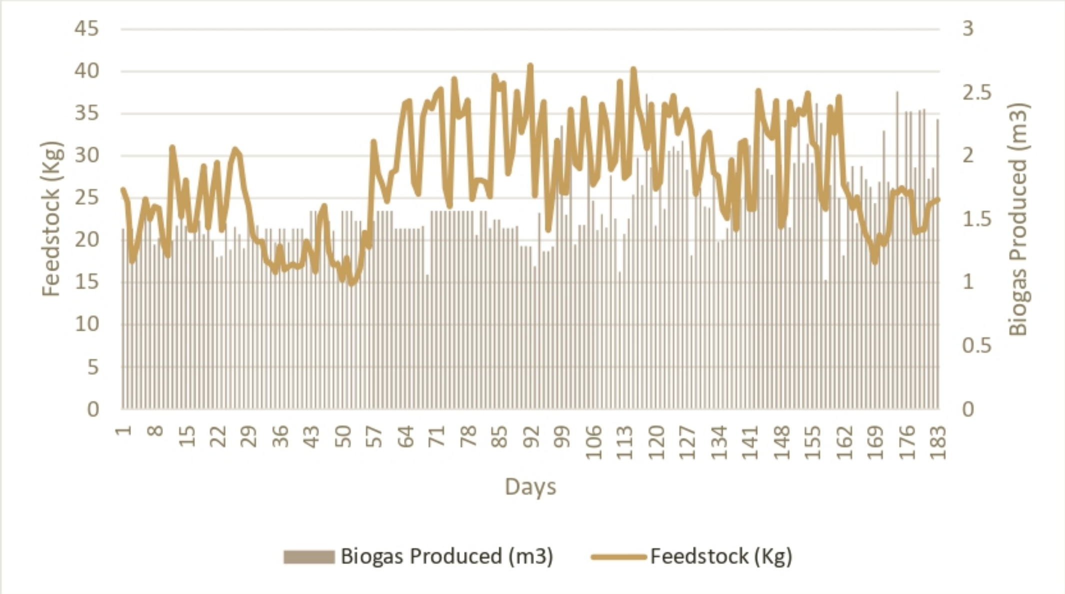

Figure 4.4: Daily Gas Produced and Feedstock Variation

The study recorded a daily average yield of biogas as 1.62 m^3 with seasonal variations between summer and winter periods. Biogas yield on daily basis ranged from 1.4 m^3 to 3.5 m^3 in summer, with an average yield of 1.81 m^3, which was 0.36 m^3/day higher than in winter. On the other hand, production in winter ranged from 0.9 m^3 to 1.5 m^3, averaging 1.44 m^3/day. These findings indicate the strong influence of seasonal temperature variation on biogas production.

Biogas yield was higher in summer likely due to optimal mesophilic temperatures (30–40°C), enhancing microbial activity and digestion efficiency, while winter led to reduced production due to lower temperatures and high-water content in human waste, hindering methane formation. Despite stable kitchen waste input (14.67%), temperature remained the key factor influencing seasonal variations. Effective thermal regulation, such as insulation or controlled heating, is essential to sustain consistent biogas production year-round.

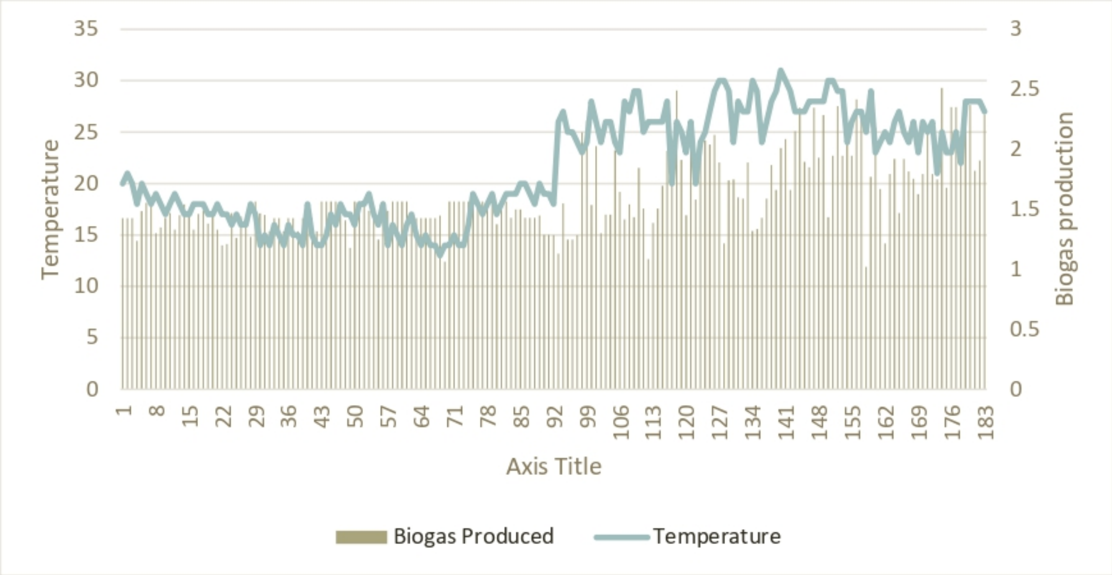

Figure 4.5: Biogas Production Vs Temperature

4.2 Energy Output

Energy output from the produced biogas is crucial for the army barrack since it can be used for cooking food in the army barrack. The following formula is used

Daily Energy Output = Biogas produced ×Calorific Value of methane

Average Methane Content =52%

Calorific Value of Methane = 39.8 MJ/M^3 [37]

Energy Per m3 of biogas plant = 0.52 × calorific Value of methane

= 0.52 × 39.8 MJ/m^3

= 20.69 MJ/m^3

Average Daily Energy Output = 1.63 m^3 ×20.69MJ/m^3

= 33.72 MJ

Burner Efficiency calculation

1 ltr of water is taken in a pot and water is boiled by using biogas the result obtained and calculated as:

Volume of water = 1Ltr=1kg

Time to boil = 6min

LHV of Biogas =4144Kcal/m^3

The initial temperature of water =25°c

Final Temperature of water =100 °c

Specific heat of water =1 Kcal/kg/ °c

Energy required to boil 1l of water =mc (T_{final}-I_{nitial}) =1×1× (100-25) =75 Kcal

Biogas Flowrate per minute =0.00679 m^3/min

Biogas consumed in 6 min =0.00679 m^3/min×6min =0.004074 m^3

Total Energy input =Biogas flowrate ×LHV =0.04074 m^3×4144Kcal/m^3=168.82 kcal

Burner Efficiency =$\frac{Useful\ Energy\ Output}{Total\ Energy\ input}$×100%= $\frac{75kcal}{168.82\ kcal}$×100%=44.42 %

Burner Efficiency = 44.42 %

Useable Daily Energy Output = 0.444× 33.72 MJ

= 14.97 MJ

14.97 MJ of useful thermal energy is Produced daily which can be utilized for cooking some food items in the army barrack though the produced gas is not sufficient to meet the daily cooking energy demand of the barrack (28035MJ), it provides some contribution to replace LPG which is the major source of cooking energy in absence of biogas.

4.3 Economic Analysis

In this chapter economic calculations & analysis is carried out by using data collected during study period.

4.3.1 Financial Overview of Plant

The financial model of the biogas plant demonstrates economic sustainability and cost-effectiveness. The total investment of NPR 1,157,458 was covered through a 60% government subsidy (NPR 694,474), 20% labour contribution by barrack staff (NPR 231,491), and 20% support from the Nepal Army (NPR 231,493). The operational costs remain minimal, with maintenance expenses as low as NPR 550, and since the feedstock (human and kitchen waste) is freely available, the plant incurs no fuel costs. With a projected lifespan of 15 years, the plant ensures long-term energy security at minimal expense.

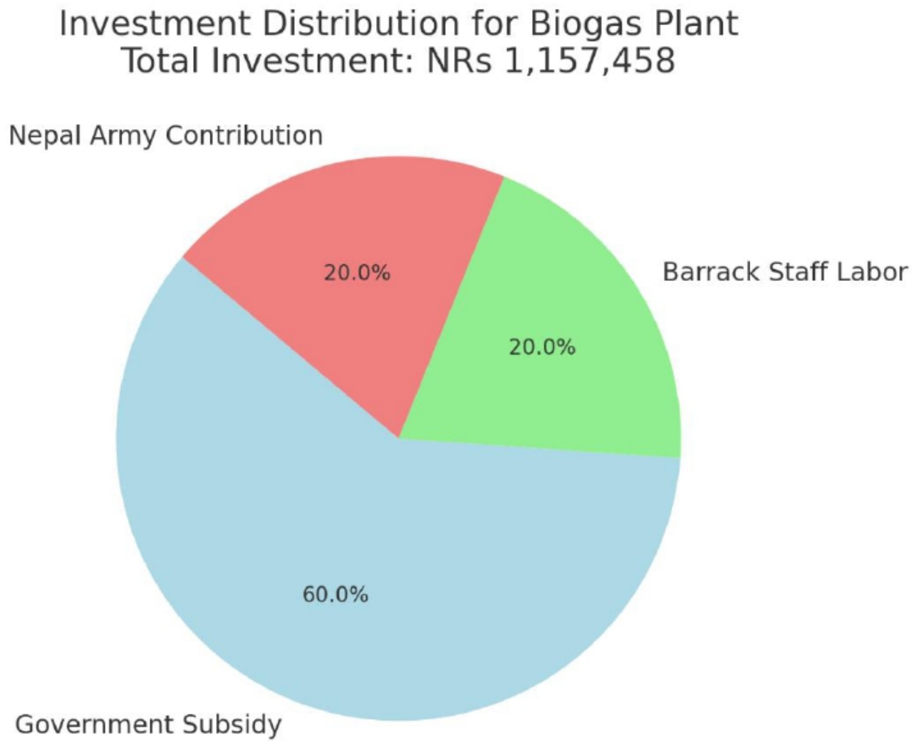

Figure 4.6: Financial Distribution for the Biogas

4.3.2 Levelized Cost of Energy

The levelized cost of biogas energy production is calculated by dividing the total biogas produced over lifetime divided by the total life cycle cost of the biogas plant. LCOE of both Actual Condition and design condition is evaluated as follows

4.3.2.1 Levelized Cost of Energy Actual Condition

The levelized cost of the actual operating condition of the biogas plant is calculated below taking the actual average biogas production during the study period.

Levelized cost of energy (LCOE): $\frac{Total\ Biogas\ Production\ over\ Plant\ Life\ Time}{Total\ Life\ cycle\ cost}$

$$Total\ life\ cycle\ cost\ =\ Initial\ investment\ cost +\ Annual\ Maintenance\ cost +\ fuel\ cost$$

Capital Recovery Factor (CRF) = $\frac{r(1+r)n}{(1+r)n-1}$

r = discount factor

Annualized Investment Cost =Net Investment cost ×CRF

Total Biogas Production = 1.63 × 365 × 15

= 8924.25 m^3

Annual Biogas Production = 1.63 × 365

= 594.95 m^3/year

CRF = [0.1 × (1 + 0.1) ^15] ÷ [(1 + 0.1) ^15 – 1]

= 0.4177 ÷ 3.177

= 0.131

Total Life Cycle Cost = 231,493 + 5,000 + 0

= Rs 236,493

Annualized Investment Cost = 236,493 × 0.131

= Rs 30,980.58

Lifecycle Cost per m^3 = 30,980.58 ÷ 594.95

= Rs 52.07/m^3

Energy Content (MJ/m^3) = 4144 × 0.004184

= 17.33 MJ/m^3

Levelized Cost of Energy (LCOE):

LCOE = 52.07 ÷ 17.33 = Rs 3.00/MJ

4.3.2.2 Levelized Cost of Energy Design Condition

To analyse the levelized cost of biogas production if a biogas plant is operated in design consideration average daily biogas production estimated during design consideration is considered.

Average Daily Production in Design consideration = 7.4 m^3, thus, taking this value in the above calculation

Annual Biogas Production = 7.4 × 365

= 2,701 m^3/year

Total Biogas Production (15 years) = 2,701 × 15

= 40,515 m^3

Lifecycle Cost per m^3 = 30,980.58 ÷ 2,701

= Rs 11.47/m^3

Energy Content:

MJ/m^3 = 17.33

LCOE = 11.47 ÷ 17.33 = Rs 0.66/MJ

Taking this value in the above calculation

4.3.2.3 Levelized Cost of Energy without Government Subsidy

To analyse the levelized cost of biogas production if a biogas plant is constructed without government subsidy, LCOE will be as

Total Life Cycle Cost = 925,967 + 5,000 + 0

= Rs 930,967

Annualized Investment Cost = Rs 930,967× 0.131

= Rs 121,956

Lifecycle Cost per m^3 = Rs 121,956÷ 594.95

= Rs 204.98/m^3

Energy Content:

$MJ/m^3 = 17.33$

LCOE = 204.98 ÷ 17.33 = Rs 11.82/MJ

4.3.3 Energy saving

. Average LPG and cost savings after installation of biogas is calculated by practical method and result are shown in Table 4.3.

Average saving = 1.21kg per day (by Practical Operation)

Cost of 1 cylinder (14.5Kg) of LPG = Rs1950

Cost of 1kg of LPG =Rs137.32

Daily Saving using biogas = Rs 137.32x 1.21

= Rs 138.69

Yearly saving = Rs 166.15× 365

=Rs 60647

Table 4.3: Energy Cost and Savings

S. N	Parameter	Saving	Reference
1	LPG saved per day	1.01 kg	
2	LPG Saved Per Year	507.6kg	
3	Yearly cost Saving	Rs 60647	Rs 1950/14.5 kg

4.3.3.1 Total Energy Consumption for Cooking and Contribution of Biogas

In the barrack, different energy sources like LPG, Electricity and Biogas are used for cooking food. Contribution of different energy sources to the energy mix in cooking is shown in table 4.4.

Table 4.4: Total Energy Consumption in the Barrack for Cooking

S. N		Daily Requirement	Monthly Requirement	Monthly Energy Requirement (MJ)	Contribution in Energy Mix	Reference
1	LPG	16.53 Kg	495.9 Kg	22848.52	81.50%	Calorific Value of LPG is taken 12.38Kwh/kg
2	Electricity	48 Kwh	1440Kwh	5183.67MJ	18.49%	
	Total Energy Requirement Before Biogas Plant installed			28035 MJ	100%	
	Contribution of biogas in Energy mix					
3	Biogas in Actual condition	1.63 m3	48.9 m3	846.72MJ	3.017%	Energy Content from above calculation energy content of biogas 17.33MJ/m^3
4	Biogas in Design Condition	7.4m3	222m3	3841.2 MJ	13.71 %	

The total energy consumptions are cooking contributions are provided in figure 4.7. Sundarijal Arsenal Army barrack uses LPG for cooking energy. After the installation of the biogas plant, some of the required food items are cooked by using biogas, which saves the LPG that was used in the absence of biogas. The total energy requirement for cooking in the barracks is 28,035 MJ per month, with LPG being the dominant energy source (81.5%), followed by electricity (18.49%). After the installation of the biogas plant, its current contribution remains low at 3.01% (847 MJ/month) due to operational constraints. However, if the plant operates at its design capacity, biogas could supply 13.71% (3841 MJ/month) of the total cooking energy demand, significantly reducing reliance on LPG.

These findings highlight the potential of biogas as a renewable alternative, emphasizing the need for optimized plant operation to maximize its impact on energy sustainability within the barracks.

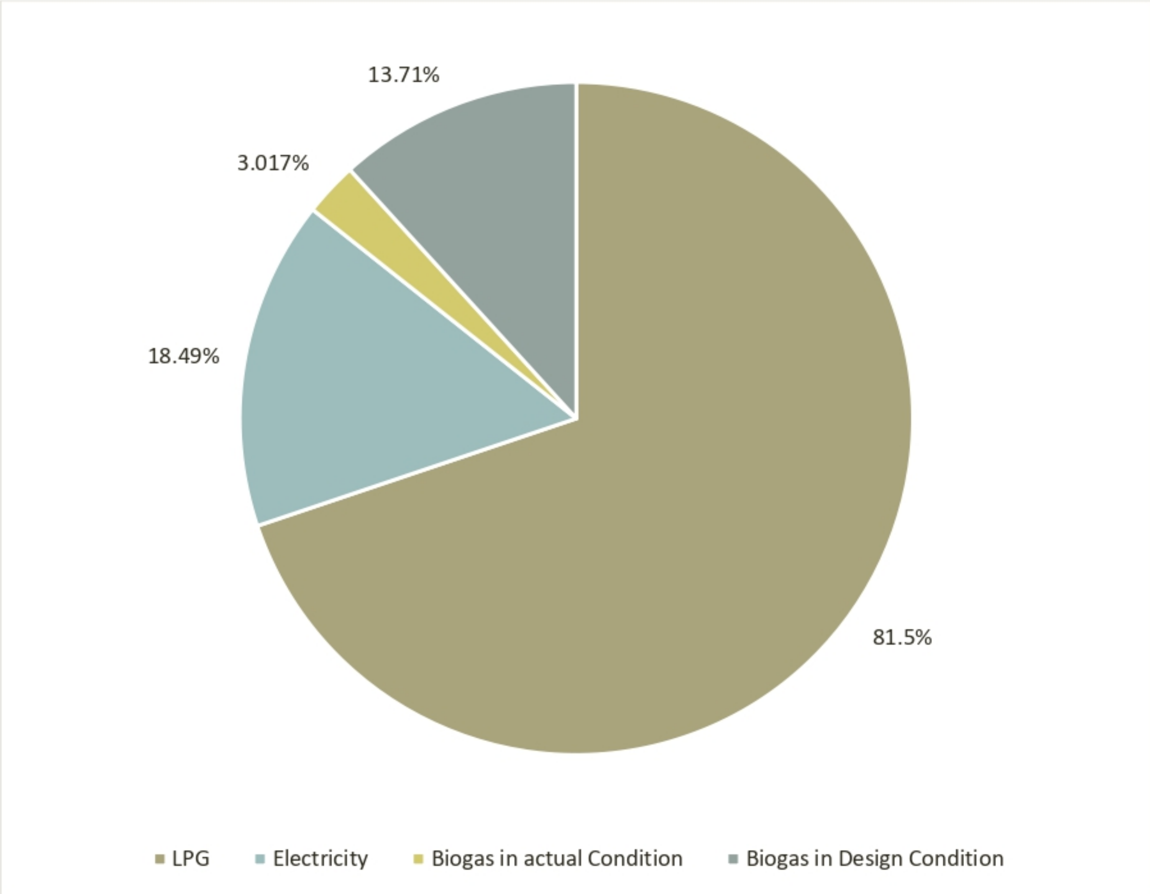

Figure 4.7: Contribution of Energy Required for Cooking

4.4 Environmental Analysis

Different environmental & health related issues & contributions of bio-gas for environmental benefits are discussed and analysed in this chapter

4.4.1 CO2 Saving and Greenhouse Gas Emission Reduction

Burning of Fossil fuels like LPG and different greenhouse gases like CO2. The use of biogas in replacement of LPG saves the emission of those gases in the environment brings financial benefit. The CO2 equivalent by the data during this study is shown in Table 4.5.

Table 4.5: CO2 equivalent calculation of biogas plant

Calculation of Co2 Equivalent		
Average Weight of Mixed Feedstock	27.26	kg
Conversion Factor	2.2	Kg of CO_2 Equivalent
Total co2 Equivalent	0.059	Tons of CO_2 Equivalent
Total co2 equivalent /annum	21.88	Tones of CO_2 Equivalent
Rate of Per tones of Co2 Equivalent	7	USD
Total Cost Saving	153.16	USD per Annum

Table 4.6: CO2 Savings from LPG Replacement

Calculation of Co2 Equivalent by LPG replacement		
Average Weight of LPG Saving	1.01	kg
Conversion Factor	2.98	Kg of CO_2 Equivalent
Total CO2 Equivalent	0.003	Tons of CO_2 Equivalent
Total CO2 equivalent /annum	1.09	Tones of CO_2 Equivalent
Rate of Per tones of Co2 Equivalent	7	USD
Total Cost Saving	7.69	USD per Annum

The study estimates that the total CO_2 equivalent emissions per annum from feedstock amount to 21.88 tons, with a total cost saving of USD 153.16. Additionally, the cost savings from CO_2 reduction due to LPG replacement are USD 7.69 per annum. These findings highlight the environmental and financial benefits of biogas utilization, emphasizing its potential to reduce greenhouse gas emissions while providing economic advantages through fuel cost saving. Moreover, if the biogas plant operates at its design capacity (7.4 m^3/day) instead of the actual capacity (1.63 m^3/day), the CO_2 savings would increase from 21.88 tons to 99.33 tons per annum, with total cost savings rising from USD 153.16 to USD 695.33. Additionally, cost savings from LPG replacement would grow from USD 7.69 to USD 34.91 per annum.

Likewise, the biogas plant reduces methane emissions by capturing and utilizing methane that would otherwise release into the atmosphere. With a daily biogas production of 1.63 m^3 (actual) and 7.4 m^3 (design) at 52% methane content, the methane emissions avoided are 0.106 kg/day and 0.48 kg/day, respectively. This roughly translated to 38.8 kg/year under actual conditions and 176.2 kg/year under design conditions, with carbon credit savings as $ 16.3 to 74, on an annual basis. This reduction highlights the plant's role in mitigating methane emissions, enhancing environmental sustainability, and improving waste-to-energy efficiency.

4.5 Comparison of Actual Performance with Design Consideration

Different technical parameters like feedstock, biogas production, useful energy output in actual condition is compared with design condition parameters to see the actual performance of plant

4.5.1 Comparison of Technical Parameters

Technical parameters related to technical assessment during study period and that of design condition is shown in Table 4.7.

Table 4.7: Comparison of Actual and Design Technical Parameters

S. N	Parameter	Unit	Actual Value	Design Value
1	Feedstock (Kitchen Waste)	kg/day	4.00	28.00
2	Feedstock (Human Waste)	kg/day	23.33	90.00
3	Feedstock (Cow Dung)	kg/day	0.00	118.00
4	Biogas Production	m^3/day	1.63	7.40
5	Solid Slurry Production	kg/day	27.00	382.00
6	Useful Energy Output	MJ/day	14.97	84.20

The table 4.7 presents a comparative analysis of actual operational data against design projections. The comparison reveals substantial deviations between actual and design values, particularly in feedstock availability. The recorded inputs for kitchen waste (4 kg vs. 28 kg), human waste (23.33 kg vs. 90 kg), and cow dung (0 kg vs. 118 kg) were significantly lower than the design estimates. This directly contributed to reduced biogas production of 1.63 m³/day while the design condition had 7.4 m³/day, subsequently reducing solid slurry output by 14 times and useful energy generation nearly 6 folds, as shown in figure 4.8. These findings suggest the necessity of adjustments in feedstock management and operational strategies to enhance efficiency.

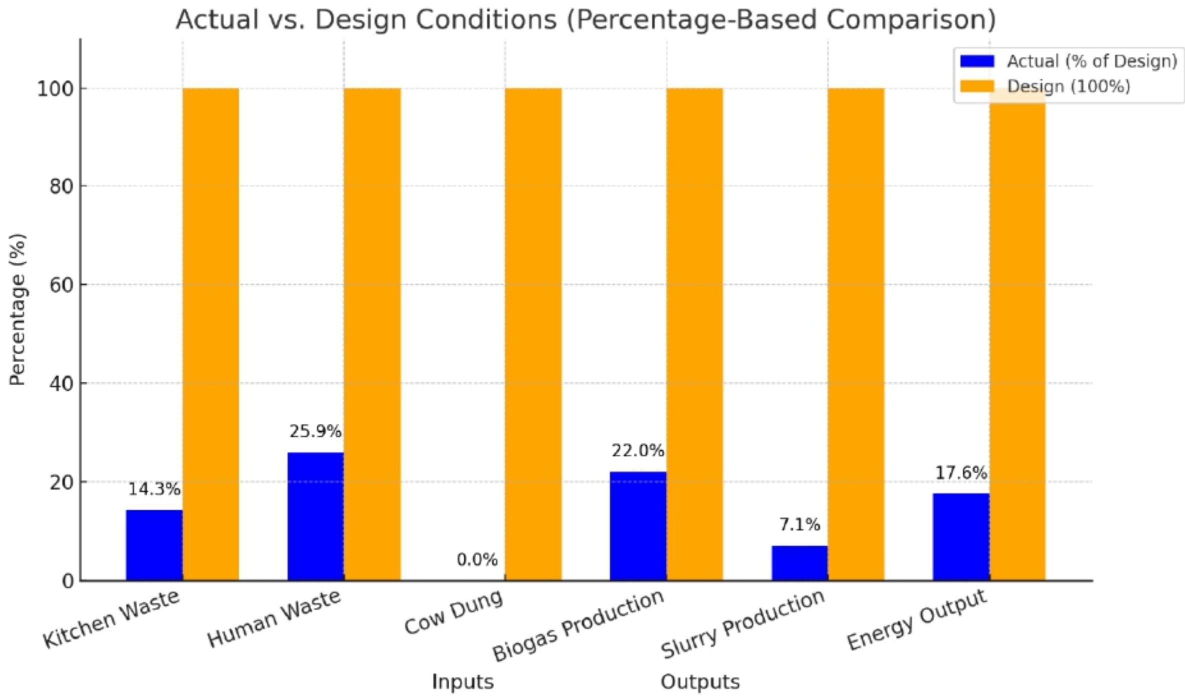

Figure 4.8: Actual Vs Design Comparisons for Inputs and Outputs for the Plant

4.5.2 LCOE Comparison

LCOE of plant in design and actual running condition is shown in Table 4.8.

Table 4.8: LCOE of Different Energy Sources for Cooking

S. N	Parameter	LOOE Rs/MJ
1	Biogas Plant in Actual Operating Condition	3
2	Biogas Plant in Design Consideration	0.66
3	Biogas Plant Without Government Subsidy	11.82
3	Electricity	2.68
4	LPG	2.97

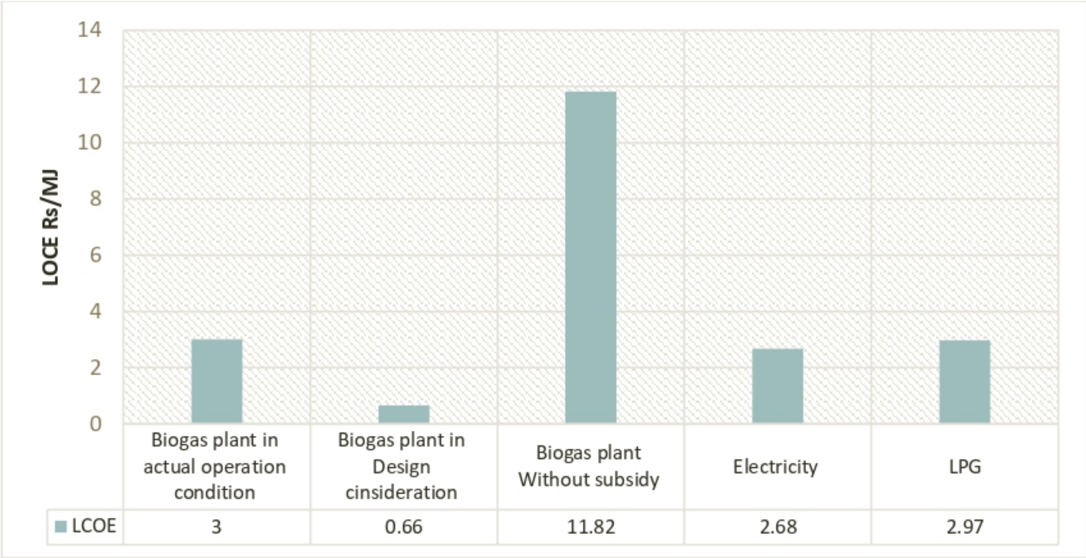

Figure 4.9: LCOE Comparison

The LCOE of biogas in actual conditions is Rs3/MJ, which is slightly higher than electricity Rs Rs2.68/MJ and LPG Rs2.97/MJ in Nepal (2024), as shown in figure 4.9. However, if the plant operates at its design capacity of 7.4 m³/day, the LCOE would drop to Rs0.66/MJ, making it significantly more cost-effective. If the plant is constructed without government subsidy LCOE raised to Rs 11.82/MJ which is much higher than other energy alternatives. This indicates that underutilization of plant capacity leads to higher costs. Optimizing feedstock supply and ensuring full-capacity operation would enhance economic feasibility, making biogas a sustainable and cost-efficient alternative for institutional cooking. Much higher LCOE without subsidy strongly indicate biogas plants is not sustainable without government subsidy.

4.5.3 GHG Saving and Cost saving Comparison

Table 4.9: GHG Savings and Cost Saving Comparisons

S. N		Co2 Actual condition	Co2 Design condition	Ch4 Saving Actual Condition	Ch4 Saving Design Condition
1	Saving /Annum	21.88	99.3	38.8	176.2
2	Cost Saving /Annum	USD 153.16	USD 695.33	USD 16.3	USD 74

The analysis of the biogas production data indicates a significant performance gap between the actual and design conditions for both CO_2 and CH_4 savings, as well as the corresponding cost savings. In terms of CO_2 reduction, the actual savings (21.88) are much lower than the design condition (99.3), resulting in a shortfall of 77.42 units. Similarly, CH_4 savings show a marked underperformance, with actual savings (38.8) falling far behind the designed value (176.2), a difference of 137.4 units. This gap directly impacts the expected cost savings, which are only around 22% of the projected figures for both CO2 (USD 153.16 vs. USD 695.33) and CH4 (USD 16.3 vs. USD 74).

These discrepancies suggest that the biogas plant is not operating at optimal efficiency, potentially due to factors such as suboptimal feedstock quality. Environmental factors like temperature fluctuations and feedstock variability could also contribute to lower biogas yields.

4.6 Correlation and Regression Analysis

During the study, it was seen that during summertime gas production increased significantly so Correlation and regression Analysis between Temperature and biogas yield was done to see the impact of temperature on biogas yield result of the analysis is summarized below.

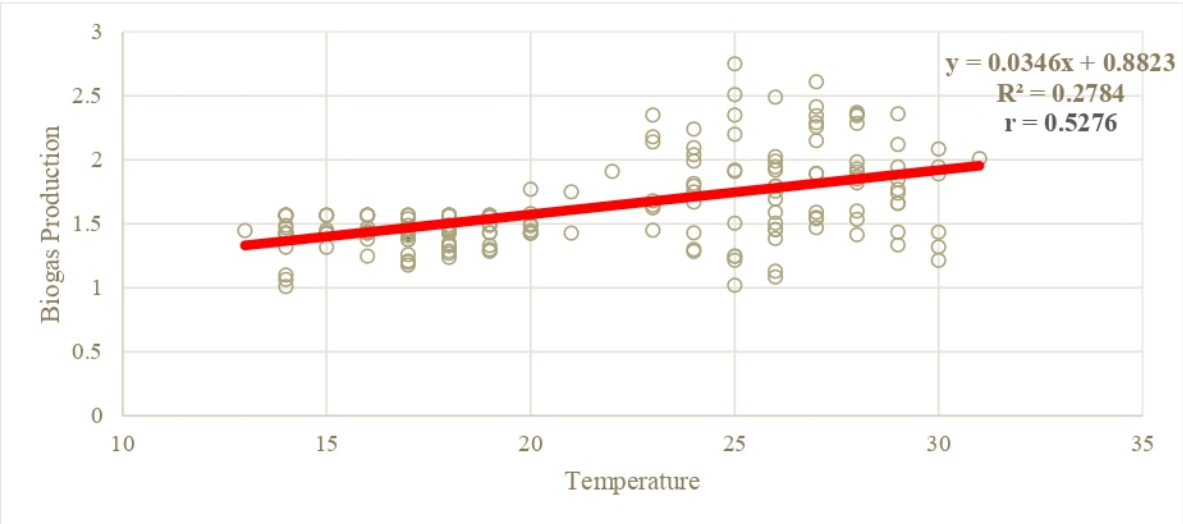

Figure 4.10: Correlation and Regression Analysis

4.6.1 Analysis of the Results

1. **Equation: $y=0.0346x+0.8823$**

- This equation represents the linear relationship between temperature and biogas production.
- The slope (0.0346) indicates that for each 1°C increase in temperature, biogas production increases by 0.0346 units.

2. **R^2=0.2784 (Coefficient of Determination)**

- This value indicates that only 27.84% of the variation in biogas production is explained by temperature.
- The remaining 72.16% is influenced by other factors such as feedstock composition, pH, retention time, microbial activity, and environmental conditions.
- A low R^2 suggests that temperature alone is not a strong predictor of biogas production, and additional variables should be considered for a better model.

3. **r=0.5276 (Karl Pearson Correlation Coefficient)**

- This value suggests a moderate positive correlation between temperature and biogas production.
- Since r is closer to 0.5 than to 1, the relationship is not very strong, meaning that while temperature affects biogas production, other factors play significant roles.
- The positive sign confirms that as temperature increases, biogas production also increases.

4.7 Sensitivity Analysis

The sensitivity analysis of the Sundarijal Arsenal Biogas Plant reveals that feedstock quantity is the most influential factor affecting biogas production. With a baseline yield of 1.63 m^3/day from 27.26 kg/day of feedstock (efficiency 0.060 m^3/kg), increasing input to the design value of 123 kg/day could raise output to 7.4 m^3/day (a 354% increase), though capped by the plant's capacity. This underscores feedstock scarcity as the primary limitation, with current input at just 11.5% of design.

Temperature moderately impacts yield, with a 33.8% range (1.36–1.91 m^3/day) across 15–40°C. The gentle linear increase aligns with a reported correlation of 28% as shown in

(Refer Appendix B), suggesting thermal optimization (e.g., maintaining 30–40°C) could mitigate winter drops but offers limited gains compared to feedstock.

pH shows significant sensitivity, with a 50.3% yield range (1.09–1.91 m^3/day) from 5.5–7.5. The baseline slurry pH of 7.3 is near optimal, but acidic kitchen waste (pH 5.7) risks reducing efficiency if unbalanced, making pH management crucial for stability.

The C/N ratio has the least effect, with a 15.6% range (1.36–1.63 m^3/day) across 11–32. The baseline slurry C/N of 19.99 is near the optimal 20–30, indicating minimal adjustment is needed unless extreme imbalances arise.

Overall, feedstock quantity drives the largest potential improvement, while temperature and pH are secondary factors for operational refinement. The analysis highlights the need to boost feedstock to at least 123 kg/day (where yield hits 7.4 m^3/day) and optimize conditions to enhance sustainability.

Table 4.10: Sensitivity Analysis Table

Variable	**Range**	**Biogas Yield (m^3/day)**	**% Change from Baseline**
Feedstock (kg/day)	15	0.90	-44.8%
	27.26 (base)	1.63	0%
	236 (design)	7.40 (capped)	+354%
Temperature (°C)	15	1.36	-16.6%
	25 (base)	1.63	0%
	40	1.91	+17.2%
pH	5.5	1.09	-33.1%
	7.3 (base)	1.63	0%
	7.5	1.91	+17.2%
C/N Ratio	11	1.36	-16.6%
	19.99 (base)	1.63	0%
	32	1.50	-8.0%

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The biogas plant is operating at only 22% of its capacity, mainly due to shortage of feedstock. While human and kitchen waste are utilized to operate the system, feedstock available is far less than was estimated at the design stage, resulting in lower-than-expected biogas production. Thus, it can be concluded from the study that if a biogas plant can be run in its design condition, it can be a sustainable source of energy for cooking energy for a barrack.

Seasonal variation directly influences biogas yield, with summer yields higher (1.81 m^3/day) and winter yields lower (1.44 m^3/day) due to temperature fluctuations. Correlation analysis ($R^2 = 0.2784$, $r = 0.5276$) however indicates that temperature is not the only factor to represent biogas yield, but that feedstock composition, pH balance, and retention time are equally crucial factors.

Techno-economic analysis shows that biogas is cost-competitive with the Levelized Cost of Energy (LCOE) of biogas at the current capacity of operation is Rs 3/MJ, slightly more than electricity (Rs 2.68/MJ) and LPG (Rs 2.97/MJ). However, if the plant operates at the design capacity, the LCOE would reduce to Rs 0.66/MJ, making biogas the lowest energy source for the barrack's cooking demand.

The plant is also significant in waste management in reducing kitchen and human excrement disposal issues and CO_2 emission reductions by 21.88 tons per year, hence yielding overall cost savings of USD 153.16 per year. However, slurry applications are low, limiting potential organic farm applications.

In conclusion, this study highlights the potential of the institutional biogas plant to achieve technical, economic, and environmental sustainability, though this is contingent on optimal operational conditions. Technically, the plant can meet energy demands when operated at full capacity and with a consistent feedstock supply. Economically, running the plant at its design capacity leads to a significant reduction in the Levelized Cost of Electricity (LCOE), making it a more cost-competitive option compared to other energy sources. However, the importance of government subsidies cannot be overlooked, as the LCOE increases substantially in their absence. Environmentally, the biogas plant offers valuable contributions to waste management and the reduction of CO_2 emissions, supporting broader sustainability objectives.

5.2 Recommendations

To enhance the sustainability and efficiency of the biogas plant, waste collection should be expanded to include market waste and agricultural residues to ensure a steady feedstock supply. Co-digestion with nitrogen-rich waste should be introduced to balance the carbon-to-nitrogen (C/N) ratio, improving digestion efficiency and methane production. Thermal insulation or heating mechanisms should be implemented to maintain optimal temperatures in winter, preventing seasonal fluctuations in biogas yield.

The plant should operate at its design capacity (7.4 m^3/day) to lower the Levelized Cost of Energy (LCOE) and improve economic sustainability. To increase human waste as feedstock, all the possible toilets inside the barrack should be connected to the digester. Additional sources of organic waste, such as agricultural residue and kitchen waste, should be explored to fulfill the feedstock requirement to run it at optimal loading. Slurry should be repurposed as organic fertilizer within the barracks or for local agricultural use, ensuring efficient resource utilization. CO_2 removal techniques should be explored to increase methane concentration above 52%, improving biogas quality and energy efficiency for cooking and heating applications

LOCE of biogas produced without government subsidy is much higher than other energy alternative, so it is recommended to policymakers to continue government subsidy to sustain institutional biogas plant like this.

Thus, to ensure sustainability, it is recommended to: (i) expand and diversify feedstock sources, (ii) maintain optimal temperature and C/N ratio for digestion efficiency, (iii) utilize slurry as fertilizer, (iv) improve biogas quality through CO_2 removal, and (v) continue government subsidies to offset high LCOE at partial loads.

Future Work

This study lays the groundwork for developing a national framework to assess the sustainability of all types of biogas plants (domestic, institutional, and commercial) in Nepal. Although these systems vary in scale and ownership, they share core operational features such as anaerobic digestion, feedstock dependence, and similar performance metrics. This makes a unified assessment framework feasible, with adjustments for underlying differences. Future work can apply the step-wise methodology used in this study, enhanced with Multi-Criteria Decision Analysis (MCDA) or other ranking methods to account for the multiple indicators and varying priorities across different biogas plant types.

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Appendix A Questioner

General information

1	Name of Institution		
2	Type of institution		
3	Location	Province	
		District	
		Municipality	
		Ward no	

1. Technical

A	**Plant Details**		
1	Model		
2	Size		
3	Date of Construction		
4	Application /Purpose of biogas Installation	Cooking	
		Lighting	
		Agricultural fertilizer	
B	**Construction**		
1	Construction materials	Brick	
		Stabilized cement brick	
		Stone	
		Other Please specify	
2	Gas pipes	GI	
		PVC	
		PPR	
		Other Please Specify	
3	Location of plant	Sunny	
		Partly sunny	
		Shadow	
4	Distance of water source from plant (m)		

5	Diameter of Main Gas outlet (m)			
6	Distance of plant from kitchen			
7	Type of appliances used	Stove	No of stove/lamp	Type of Stove/lamp
		Lamp if used for electricity		
C	**Technical And Operational Data**			
1	PH Value Testing the Slurry			
2	Temperature	Ambient		
		Inside digester		
3	Gas Pressure			
4	What is the composition of biogas produced (Please Specify)	Methane (CH_4)		
		Carbon dioxide(CO_2)		
		Nitrogen(N_2)		
		Hydrogen Sulphide (H_2S)		
		Others		
5	Types of feeding materials	Cattle Dung		
		Kitchen Waste		
		Human Waste		
		Others if Please specify		
6	Is there a screening system before feeding of feeding material			
7	How is the Availability and sources of feed material?	From institute	From outside of the institute	
			Yes	No
			If yes	
			Collected	Purchased
8	Feedstock specification	PH		
		CN Ratio		
		Chemical composition if analyzed		

9	Quantity of feeding material/day (kg)	Cattle dung		
		Food Waste		
		Human Waste (toilet)		
		Other if used specify		
10	Feeding liquid	Quantity of urine		
		Quantity of water		
11	Water to feedstock Ratio			
12	Feedstock storage condition	Covered		
		Exposed to weather		
13	Expected life of biogas plant before up gradation			
14	What is the Existence /condition and cleanliness of the biogas system components (please tick)	Yes		
		Very good	Good	Bad
	Inlet +mixer			
	Outlet +compensation chamber			
	Dome			
	Stirrer			
	Water drain			
	Gas flow meter			
	Pressure Gauge			
	Gas Pipe (Diameter)			
	Main Gas Valve			
	Hose pipe			
	Stoves and other appliances			

D. Gas Consumption

	Meals cooked/Day	Winter		
1		Breakfast	Lunch	Dinner

		Type of meal cooked (kg)	**Time taken to cook**	**Gas Consumption (m^3)**	**Type of meal cooked (kg)**	**Time taken to cook**	**Gas Consumption (m^3)**	**Type of meal cooked (kg)**	**Time taken to cook**	**Gas Consumption (m^3)**
		Summer								
		Type of meal cooked (kg	**Time taken to cook**	**Gas Consumption (m^3)**	**Type of meal cooked (kg)**	**Time taken to cook**	**Gas Consumption (m^3**	**Type of meal cooked (kg**	**Time taken to cook**	**Gas Consumption (m^3)**
2	Total number of hrs biogas utilized for cooking/day	Morning			Day			Evening		
3	Total number of people served/day in average									

E. Technical Problem and Maintenance

1	What are the problems faced with operating the system?	**Type of Problem**	**Frequency /period**	**Action taken**
2	Is there any Maintenance for these components before?	Item	Frequency of maintenance	Action taken
		Main Gas Valve		
		Water drain		
		Gas valve		
		Appliances		
		Other		
3	Who is responsible	Institutional technician	Hired from outside	Technician from other organization

	for the maintenance				
4	Functional status please specify leaks	Leaks	Yes	No	
		Broken parts	Yes	NO	
		Blockages	Yes	No	
		Others if yes please specify problem	No	Yes	
5	If the plant is non-operation after installation till now what is the reason please tick	Crack	Digester	Yes	No
			Inlet chamber	Yes	No
			Inlet pipe	Yes	No
			Dome	Yes	No
			Gas pipe outlet	Yes	No
		Blockage	Inlet	Yes	No
			Digester	Yes	No
			Outlet	Yes	No
			Gas Pipe	Yes	No
			Water trap	Yes	No
			Overflow	Yes	No
		Stove Damage		Yes	No
		Cum formation		Yes	No
		Lack of interest		Yes	No
		Lack of water for dilution		Yes	No
		Lack of feed materials		Yes	No
		Others please specify (if yes)	Yes	No	

3. Economic

<table>
<tr><td rowspan="2">1.</td><td rowspan="2">What is the total investment cost of the biogas plant installation (NRS)</td><td colspan="4">Institution Investment</td><td colspan="2">Government Subsidy</td></tr>
<tr><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>2.</td><td>Total maintenance cost up to now</td><td colspan="6"></td></tr>
<tr><td rowspan="3">3.</td><td rowspan="3">What is the operational cost per month ?</td><td colspan="3">Cost of Feedstock if purchase</td><td colspan="3"></td></tr>
<tr><td colspan="3">Cost of spare parts if changed</td><td colspan="3"></td></tr>
<tr><td colspan="3">Other if any</td><td colspan="3"></td></tr>
<tr><td rowspan="6">4.</td><td rowspan="6">What are the energy consumption pattern for cooking before and after the biogas plant is installed?</td><td colspan="2">Quantity used</td><td></td><td colspan="3">Expenditure</td></tr>
<tr><td></td><td>Before</td><td>After</td><td colspan="2">Before</td><td>After</td></tr>
<tr><td>Fire wood</td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>LPG (cylinder)</td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Kerosene(LTR)</td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Electricity (Kwh)</td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">If there any saving on waste management after biogas plant is installed? please specify</td><td colspan="3">Saving on human waste management</td><td colspan="3">Saving on</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td rowspan="3">6</td><td rowspan="3">Do the slurry is utilized as a fertilizer</td><td>Yes</td><td>No</td><td colspan="4">If yes who is the user</td></tr>
<tr><td></td><td></td><td colspan="2">Institution itself</td><td colspan="2">Others</td></tr>
<tr><td></td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>7</td><td>If slurry is utilized as fertilizer by others do they pay if yes please specify the income from fertilizer</td><td colspan="6"></td></tr>
</table>

4. Environmental

1	How is the food waste is managed before biogas plant is installed	Dumped in open environment	dumped in closed environment to make organic fertilizer	Managed to municipal landfill side	Other please specify
2	How the effluent slurry is utilized	Used as a fertilizer	Thrown in open environment	Send to the municipal landfill	Other please specify
3	Is there any health impact after installation of biogas plant	Are there any change interns of cleanliness in the kitchen	Are there any change interims of cleanliness in the surrounding of plant	Are there any increase in eye infection	Are there positive impact on reduction of insects
4	Are there any hesitation to use biogas because of toilet connection	Yes			
		No			
5	Do you think there has been any health impact for the people in charge of cooking after installation of plant	Yes (please specify impact if yes)			No

5. General impact

<table>
<tr><td rowspan="3">1</td><td rowspan="3">Are there any change in time for cooking per day since you started to use biogas</td><td rowspan="3">No</td><td colspan="2">Yes</td></tr>
<tr><td>Increased (Hour/day)</td><td>Decreased Hour/day)</td></tr>
<tr><td></td><td></td></tr>
<tr><td>2</td><td>Are there any change in terms of cleanliness</td><td>No</td><td colspan="2">Yes (please specify)</td></tr>
<tr><td>3</td><td>How has biogas change life in your institution</td><td colspan="3"></td></tr>
<tr><td>4</td><td>Is your institution satisfied with the performance of biogas plant</td><td colspan="2">Yes</td><td>No</td></tr>
<tr><td>5</td><td>Are you recommend other institution to install similar type of institutional biogas plant</td><td colspan="2">Yes</td><td>No</td></tr>
<tr><td rowspan="6">6</td><td rowspan="6">Have you experienced any advantages of biogas over other energy sources for cooking</td><td colspan="3">No</td></tr>
<tr><td colspan="3">Less costly</td></tr>
<tr><td colspan="3">Comfortable and easy to operate</td></tr>
<tr><td colspan="3">Environmental friendly</td></tr>
<tr><td colspan="3">Energy efficient</td></tr>
<tr><td colspan="3">Other please specify</td></tr>
</table>

Appendix B Sensitivity Analysis Graphs

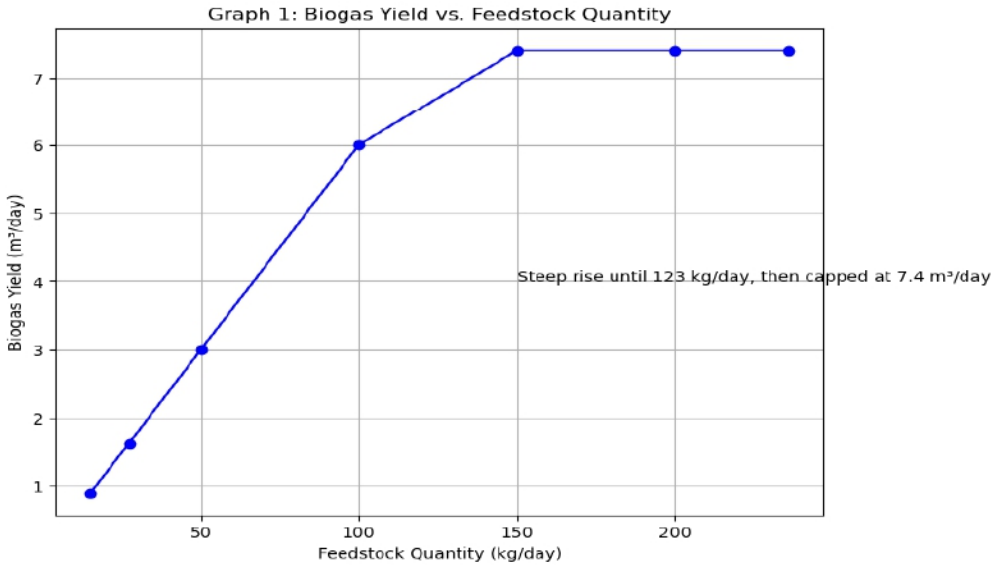

Figure 1: Biogas Yield VS Feedstock Quantity

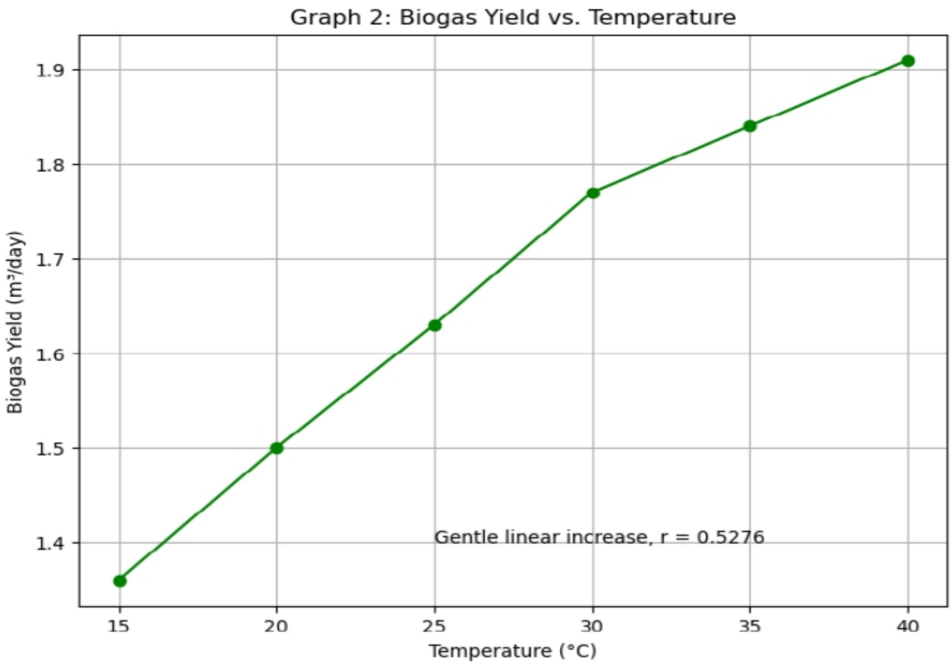

Figure 2 Biogas Yield VS Temperature

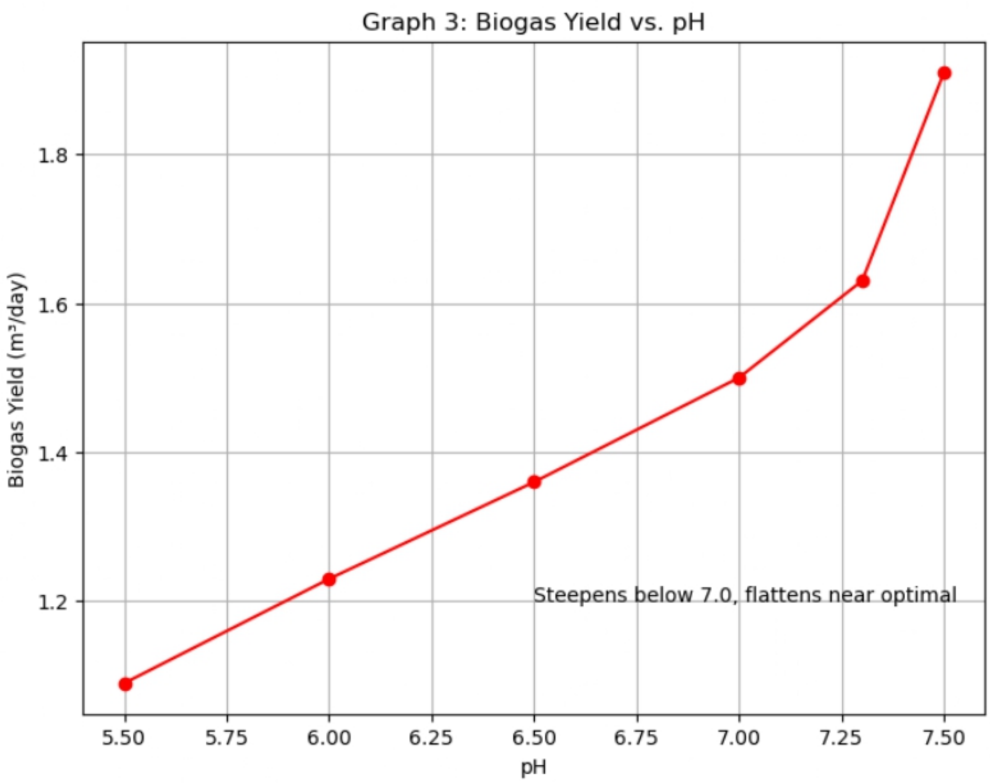

Figure 3 Biogas Yield VS pH

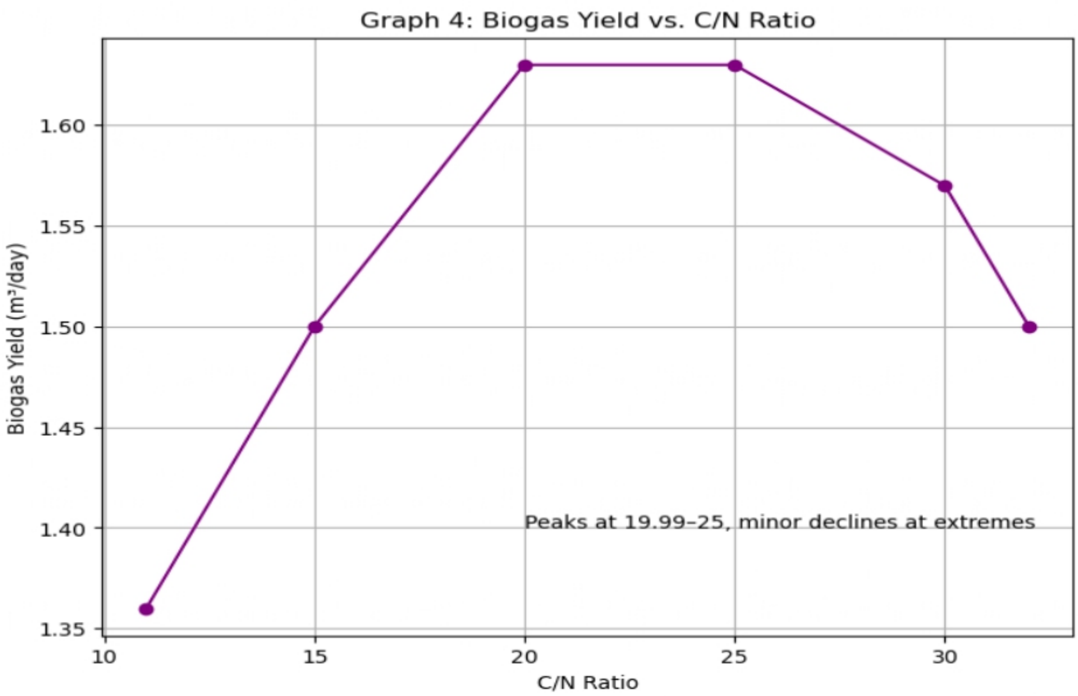

Figure 4 Biogas Yield VS C/N Ratio

Appendex C: Bio Gas Consumption Related Data

S.N	DATE	Total gas Produced in day (m3)	Numbers reside inside barrack	TEMPERATURE (^{o}C)	Kitchen waste WEIGHT (Kg)	Feedstock from toilet Kg (taking o.4gm person)	Total feedstock Per day (Kg)
1	8/1/2080	1.427	70	5	5	28	33
2	8/2/2080	1.427	65	5	5	26	31
3	8/3/2080	1.427	45	5	4	18	22
4	8/4/2080	1.238	47	4	5	18.8	23.8
5	8/5/2080	1.484	60	3	4	24	28
6	8/6/2080	1.553	73	4	5	29.2	34.2
7	8/7/2080	1.563	65	4	3	26	29
8	8/8/2080	1.3	70	3	6	28	34
9	8/9/2080	1.35	66	5	4	26.4	30.4
10	8/10/2080	1.43	55	4	3	22	25
11	8/11/2080	1.47	44	3	5	17.6	22.6
12	8/12/2080	1.33	90	5	4	36	40
13	8/13/2080	1.5	75	4	5	30	35
14	8/14/2080	1.54	66	5	3	26.4	29.4
15	8/15/2080	1.45	77	2	4	30.8	34.8
16	8/16/2080	1.33	54	2	5	21.6	26.6
17	8/17/2080	1.48	64	4	2	25.6	27.6
18	8/18/2080	1.49	60	3	7	24	31
19	8/19/2080	1.4	76	5	6	30.4	36.4
20	8/20/2080	1.46	55	4	5	22	27
21	8/21/2080	1.33	73	3	4	29.2	33.2
22	8/22/2080	1.2	74	3	7	29.6	36.6
23	8/23/2080	1.21	64	3	2	25.6	27.6
24	8/24/2080	1.47	67	4	4	26.8	30.8
25	8/25/2080	1.26	87	3	5	34.8	39.8
26	8/26/2080	1.44	96	5	2	38.4	40.4
27	8/27/2080	1.38	87	2	4	34.8	38.8
28	8/28/2080	1.27	77	5	3	30.8	33.8
29	9/2/2080	1.566	67	5	5	26.8	31.8
30	9/3/2080	1.466	55	4	4	22	26
31	9/4/2080	1.453	56	5	3	22.4	25.4
32	9/5/2080	1.317	53	4	4	21.2	25.2
33	9/6/2080	1.427	45	4	4	18	22
34	9/7/2080	1.427	44	3	4	17.6	21.6
35	9/8/2080	1.317	44	4	6	17.6	23.6
36	9/9/2080	1.427	51	5	4	20.4	24.4
37	9/10/2080	1.427	45	6	5	18	23

38	9/11/2080	1.317	43	4	4	17.2	21.2
39	9/12/2080	1.427	44	3	4	17.6	21.6
40	9/13/2080	1.427	46	5	3	18.4	21.4
41	9/14/2080	1.427	47	5	3	18.8	21.8
42	9/15/2080	1.317	53	4	4	21.2	25.2
43	9/16/2080	1.566	52	4	3	20.8	23.8
44	9/17/2080	1.566	41	3	4	16.4	20.4
45	9/18/2080	1.566	66	3	5	26.4	31.4
46	9/19/2080	1.566	67	4	4	26.8	30.8
47	9/20/2080	1.487	49	3	4	19.6	23.6
48	9/21/2080	1.408	47	4	5	18.8	23.8
49	9/22/2080	1.178	44	5	4	17.6	21.6
50	9/23/2080	1.566	41	4	5	16.4	21.4
51	9/24/2080	1.566	53	3	6	21.2	27.2
52	9/25/2080	1.566	36	4	4	14.4	18.4
53	9/26/2080	1.487	41	6	7	16.4	23.4
54	9/27/2080	1.487	49	5	2	19.6	21.6
55	9/28/2080	1.248	53	4	5	21.2	26.2
56	9/29/2080	1.566	54	3	6	21.6	27.6
57	10/1/2080	1.487	89	4	5	35.6	40.6
58	10/2/2080	1.566	83	4	6	33.2	39.2
59	10/3/2080	1.566	75	5	4	30	34
60	10/4/2080	1.566	72	3	3	28.8	31.8
61	10/5/2080	1.566	80	4	4	32	36
62	10/6/2080	1.427	81	5	4	32.4	36.4
63	10/7/2080	1.427	97	4	4	38.8	42.8
64	10/8/2080	1.427	104	2	5	41.6	46.6
65	10/9/2080	1.427	105	3	5	42	47
66	10/10/2080	1.427	76	4	4	30.4	34.4
67	10/11/2080	1.427	75	5	6	30	36
68	10/12/2080	1.669	102	3	4	40.8	44.8
69	10/13/2080	1.35	108	4	4	43.2	47.2
70	10/14/2080	1.566	102	6	5	40.8	45.8
71	10/15/2080	1.566	111	4	4	44.4	48.4
72	10/16/2080	1.566	113	5	4	45.2	49.2
73	10/17/2080	1.566	74	4	4	29.6	33.6
74	10/18/2080	1.566	70	5	5	28	33
75	10/19/2080	1.566	117	7	4	46.8	50.8
76	10/20/2080	1.566	102	6	4	40.8	44.8
77	10/21/2080	1.566	100	4	5	40	45
78	10/22/2080	1.566	112	6	5	44.8	49.8
79	10/23/2080	1.566	73	7	5	29.2	34.2
80	10/24/2080	1.45	77	7	4	30.8	34.8
81	10/25/2080	1.566	77	6	4	30.8	34.8

82	10/26/2080	1.566	73	7	5	29.2	34.2
83	10/27/2080	1.46	74	9	6	29.6	35.6
84	10/28/2080	1.498	115	9	5	46	51
85	10/29/2080	1.498	103	13	7	41.2	48.2
86	11/1/2080	1.47	112	5	5	44.8	49.8
87	11/2/2080	1.48	83	10	6	33.2	39.2
88	11/3/2080	1.43	88	9	4	35.2	39.2
89	11/4/2080	1.447	112	4	6	44.8	50.8
90	11/5/2080	1.288	96	11	4	38.4	42.4
91	11/6/2080	1.288	102	13	4	40.8	44.8
92	11/7/2080	1.286	119	9	5	47.6	52.6
		1.45	72.17	4.78	4.45	27.86	33.48

Bio Gas Consumption Related Data

S. N	DATE	BIO GAS RUN PERIOD		gas flow meter reading (m3)	ITEMS COOKED (in kg)			toal gas flow meter reading (m3)	total reading of a day	Numbers Reside inside barrack	lpg gas saved per day(kg)	Kitchen waste WEIGHT (Kg)	Feedstock from toilet Kg (taking o.4gm person)	Total feedstock Per day (Kg)
		MORNING (AM)			PULSE	BEANS	BOILED EGG(pcs)							
1	1/1/2081	5:00	6:50	0.422	4	2	80	1.284	1.13	71	1.13	4	21.3	25.3
2	1/2/2081	5:15	6:40	0.837	5		180	1.783	1.55	101	1.55	3	30.3	33.3
3	1/3/2081	5:15	6:50	0.837	5		60	0.923	1.247	108	1.247	4	32.4	36.4
4	1/4/2081	5:25	6:30	0.837	5		160	1.583	1.247	64	1.247	2	19.2	21.2
5	1/5/2081	5:00	6:50	0.644	3	2	165	1.61	1.285	68	1.285	5	20.4	25.4
6	1/6/2081	5:00	6:45	0.837	3	1	180	2.46	2.14	96	2.14	3	28.8	31.8
7	1/7/2081	5:00	6:40	1.075	5	2	160	1.805	2.24	69	2.24	5	20.7	25.7
8	1/8/2081	5:00	6:50	0.756	3	2	100	1.303	1.535	72	1.535	4	21.6	25.6
9	1/9/2081	5:30	6:40	0.837	4	3	180	2.046	2.025	105	2.025	4	31.5	35.5
10	1/10/2081	5:00	6:50	0.837	4		100	0.493	1.3	87	1.3	3	26.1	29.1
11	1/11/2081	5:00	6:00	0.644	5	2	160	1.663	1.455	85	1.455	3	25.5	28.5
12	1/12/2081	5:00	6:45	0.837	3	1	160	1.476	1.455	106	1.455	5	31.8	36.8
13	1/13/2081	5:00	6:40	0.756	5	3	160	2.007	1.99	97	1.99	3	29.1	32.1
14	1/14/2081	5:00	6:45	0.731	5	2	160	1.885	1.645	72	1.645	5	21.6	26.6
15	1/15/2081	5:00	6:50	0.644	4	2	60	1.074	1.415	75	1.415	5	22.5	27.5
16	1/16/2081	5:00	6:50	0.837	4	3	160	1.592	1.54	107	1.54	4	32.1	36.1
17	1/17/2081	5:00	6:40	0.837	5	2	60	0.923	1.435	103	1.435	3	30.9	33.9
18	1/18/2081	5:00	6:50	0.715	5	3	130	1.803	1.845	78	1.845	5	23.4	28.4
19	1/19/2081	5:00	6:20	0.643	3	2	135	1.609	1.505	78	1.505	6	23.4	29.4
20	1/20/2081	5:00	6:04	0.493	5	1	125	1.354	1.085	116	1.085	4	34.8	38.8
21	1/21/2081	5:10	6:50	0.953	3	2	125	1.171	1.385	78	1.385	4	23.4	27.4
22	1/22/2081	5:00	6:45	0.532	3	3	130	1.611	1.505	83	1.505	3	24.9	27.9
23	1/23/2081	5:00	6:55	0.715	5	2	130	1.681	1.695	121	1.695	4	36.3	40.3
24	1/24/2081	5:00	6:40	0.837	5	3	125	1.698	1.985	106	1.985	4	31.8	35.8
25	1/25/2081	5:00	6:50	0.837	5	2	80	1.251	1.77	100	1.77	4	30	34
26	1/26/2081	5:00	6:50	0.837	5	2	150	1.698	2.49	93	2.49	3	27.9	30.9
27	1/27/2081	5:00	6:40	0.953	5	2	150	1.776	1.91	107	1.91	4	32.1	36.1
28	1/28/2081	5:00	6:50	0.644	4	2	80	1.284	1.45	77	1.45	3	23.1	26.1

29	1/29/2081	5:00	6:40	0.837	4	3	150	1.817	1.99	73	1.99	5	21.9	26.9
30	1/30/2081	5:00	6:50	0.837	5	2	145	1.554	1.58	107	1.58	4	32.1	36.1
31	1/31/2081	5:00	6:40	0.837	5	3	150	1.898	2.04	106	2.04	3	31.8	34.8
32	2/1/2081	5:00	6:50	0.837	5	3	160	1.85	2.075	107	2.075	5	32.1	37.1
33	2/2/2081	5:00	6:40	0.837	5	3	150	1.898	2.04	99	2.04	3	29.7	32.7
34	2/3/2081	5:00	6:50	0.837	5	3	180	2.128	2.119	101	2.119	4	30.3	34.3
35	2/4/2081	5:00	6:40	0.837	5	2	150	1.776	1.89	105	1.89	4	31.5	35.5
36	2/5/2081	5:00	6:50	0.534	5	3	155	1.897	1.215	97	1.215	4	29.1	33.1
37	2/6/2081	5:00	6:40	0.715	5	2	150	1.776	1.74	75	1.74	3	22.5	25.5
38	2/7/2081	5:00	6:50	0.837	5	3	100	1.537	1.75	82	1.75	3	24.6	27.6
39	2/8/2081	5:00	6:00	0.837	5	3	155	1.897	1.6	97	1.6	3	29.1	32.1
40	2/9/2081	5:00	6:40	0.837	5	2	150	1.554	1.59	96	1.59	4	28.8	32.8
41	2/10/2081	5:00	6:50	0.837	5	3	70	1.373	1.89	80	1.89	4	24	28
42	2/11/2081	5:00	6:40	0.731	5	2	180	0.715	1.32	82	1.32	3	24.6	27.6
43	2/12/2081	5:00	6:30	0.644	5	2	140	1.786	1.335	62	1.335	5	18.6	23.6
44	2/13/2081	5:00	6:40	0.783	4	3	145	1.388	1.43	62	1.43	4	18.6	22.6
45	2/14/2081	5:00	6:00	0.837	5	2	150	1.554	1.59	85	1.59	4	25.5	29.5
46	2/15/2081	5:00	6:00	0.756	4	3	150	1.817	1.87	61	1.87	3	18.3	21.3
47	2/16/2081	5:00	6:00	0.926	6	1	105	1.348	1.66	95	1.66	3	28.5	31.5
48	2/17/2081	5:15	6:00	0.926	6	3	132	1.136	2.01	96	2.01	3	28.8	31.8
49	2/18/2081	5:15	6:00	0.832	8	2	210	1.91	2.085	69	2.085	3	20.7	23.7
50	2/19/2081	5:25	6:00	0.644	4	2	200	2.056	1.66	69	1.66	3	20.7	23.7
51	2/20/2081	5:00	6:00	0.926	6	2	200	2.195	2.15	109	2.15	5	32.7	37.7
52	2/21/2081	5:00	6:00	0.926	6	3	210	2.338	2.345	98	2.345	5	29.4	34.4
53	2/22/2081	5:00	6:00	0.926	6	2	210	2.104	1.895	99	1.895	3	29.7	32.7
54	2/23/2081	5:00	6:00	0.926	6	4	200	2.005	1.85	97	1.85	3	29.1	32.1
55	2/24/2081	5:30	6:00	0.926	6	3	210	1.87	2.345	115	2.345	2	34.5	36.5
56	2/25/2081	5:00	6:00	0.592	8	2	225	2.46	1.93	62	1.93	3	18.6	21.6
57	2/26/2081	5:00	6:00	0.944	8	2	235	2.45	2.285	64	2.285	4	19.2	23.2
58	2/27/2081	5:00	6:00	0.643	3	3	235	1.923	1.435	108	1.435	4	32.4	36.4
59	2/28/2081	5:00	6:00	0.926	6	4	230	2.209	1.945	99	1.945	4	29.7	33.7
60	3/1/2081	5:00	6:00	0.926	6	3	225	2.35	2.36	105	2.36	4	31.5	35.5
61	3/2/2081	5:00	6:00	0.926	6	2	230	2.209	1.945	103	1.945	4	30.9	34.9
62	3/3/2081	5:00	6:00	0.783	6	3	235	2.41	2.095	108	2.095	5	32.4	37.4

63	3/4/2081	5:00	6:00	0.926	6	2	240	2.314	1.945	92	1.945	4	27.6	31.6
64	3/5/2081	5:00	6:00	0.926	8	2	230	2.1	2.415	90	2.415	4	27	31
65	3/6/2081	5:00	6:00	1.166	6	3	80	1.461	2.26	73	2.26	3	21.9	24.9
66	3/7/2081	5:00	6:00	0.592	6	2	180	1.867	1.02	69	1.02	3	20.7	23.7
67	3/8/2081	5:10	6:00	0.783	6	3	60	1.357	1.77	106	1.77	4	31.8	35.8
68	3/9/2081	5:00	6:00	1.065	6	2	160	1.954	2.18	99	2.18	3	29.7	32.7
69	3/10/2081	5:00	6:00	0.643	4	2	165	1.814	1.67	110	1.67	4	33	37
70	3/11/2081	5:00	6:00	0.926	3	5	180	2.252	1.5	72	1.215	5	21.6	26.6
71	3/12/2081	5:00	6:00	0.926	6	1	160	1.763	1.795	75	1.795	3	22.5	25.5
72	3/13/2081	5:00	6:00	0.926	6	3	100	1.682	1.92	66	1.92	4	19.8	23.8
73	3/14/2081	5:00	6:00	0.926	6	1	180	1.883	1.47	67	1.47	5	20.1	25.1
74	3/15/2081	5:00	6:00	0.926	6	3	200	0.926	1.92	58	1.92	5	17.4	22.4
75	3/16/2081	5:00	6:00	0.832	6	2	160	1.954	1.815	52	1.815	5	15.6	20.6
76	3/17/2081	5:00	6:00	0.644	4	3	160	1.926	1.755	49	1.755	5	14.7	19.7
77	3/18/2081	5:00	6:00	0.926	4	2	160	1.592	1.625	48	1.625	3	14.4	17.4
78	3/19/2081	5:00	6:00	0.926	6	1	160	1.763	1.795	52	1.795	5	15.6	20.6
79	3/20/2081	5:00	6:00	0.926	6	3	160	1.357	2.2	55	2.2	3	16.5	19.5
80	3/21/2081	5:00	6:00	0.926	6		160	1.763	1.795	56	1.795	4	16.8	20.8
81	3/22/2081	5:00	6:00	0.926	6		160	1.022	1.75	69	1.75	5	20.7	25.7
82	3/23/2081	5:00	6:00	1.388	6	2	130	1.6	2.51	72	2.51	4	21.6	25.6
83	3/24/2081	5:00	6:00	0.667	4	2	135	1.61	1.68	74	1.68	4	22.2	26.2
84	3/25/2081	5:00	6:00	0.977	6	3	125	1.787	2.35	75	2.35	3	22.5	25.5
85	3/26/2081	5:00	6:00	0.977	6	3	125	1.787	2.35	66	2.35	6	19.8	25.8
86	3/27/2081	5:00	6:00	0.977	6		130	1.558	2.2	53	1.91	5	15.9	20.9
87	3/28/2081	5:00	6:00	0.977	6	3	130	1.892	2.36	54	2.36	5	16.2	21.2
88	3/29/2081	5:00	6:00	0.977	8	2	125	1.961	2.37	51	2.37	6	15.3	21.3
89	3/30/2081	5:00	6:00	1.224	4	2	180	1.179	1.82	64	1.82	5	19.2	24.2
90	3/31/2081	5:00	6:00	0.657	6	2	150	1.854	1.905	65	1.905	5	19.5	24.5
91	4/1/2081	5:00	6:00	0.978	6	2	150	1.854	2.29	66	2.29	5	19.8	24.8
							Average gas produced		**1.81**	83.45	1.80	**3.95**	**25.03**	**28.99**

Appendix C: Lab Test Report

SWAT/F/C/04
Version no: 01
Issue no: 02
Revision no: 04
Effective date: 2024/01/20

Soil Water and Air Testing Laboratories Pvt. Ltd.
VAT No: 605928743
Tel: +977-01 4249480
Email: swatlab2017@gmail.com
PO Box: 25752, Kathmandu, Nepal
Bulbule Marga 10, Thapagaun, Kathmandu, Nepal

ANALYSIS REPORT

Name of Client:	Mahesh Ghimire	**Lab Code:**	25/01-1781 (1)
Collector:	Manak Chaudhary	**Location:**	Sundurijal
Source:	Slurry	**Sampled By:**	Client
Sampling Date:	2025/01/27	**Test Performance Date:**	2025/01/27-2025/02/03
Receipt Date:	2025/01/27	**Issued Date:**	2025/02/03

Parameters	Results	Unit	Method
Physical Parameters			
pH	7.3	-	Electrometric method, 4500 H+ B, APHA-AWWA-WEF, 24th Edition, 2023
Total Solids	4396	mg/L	Total Solids Dried at 103°C-105°C, 2540 B. APHA-AWWA-WEF, 24th Edition, 2023
Volatile Solids	66.38	mg/L	Fixed and Volatile solids ignited at 550 °C, 2540 E APHA AWWA, WEF, and 24th edition
Chemical Parameters			
C: N Ratio	19.99	-	

American Public Health Association, AWWA=American Water Works Association, Water Environment Federation

Note:

1. This report is based on the sample submitted to this laboratory by the client.
2. The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.
3. Statements of conformity have been made without taking Measurement Uncertainty into account except when specifically requested by the customer.

Analyzed By	Checked By	Authorized By
Aalekh Bhattarai	Prabina Shrestha	Er. Lokesh Sapkota

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Bulbule Marga 10, Thapagaun, Kathmandu, Nepal

ANALYSIS REPORT

Name of Client:	Mahesh Ghimire	**Lab Code:**	25/01-1781 (2)
Sample Collection in Lab:	Manak Chaudhary	**Location:**	Sundarijal
Source:	Kitchen Waste	**Sampled By:**	Client
Sampling Date:	2025/01/27	**Test Performance Date:**	2025/01/27-2025/02/03
Receipt Date:	2025/01/27	**Issued Date:**	2025/02/03

Parameters	Results	Unit	Method
Physical Parameters			
pH	5.7	-	Electrometric method, 4500 H+ B, APHA-AWWA-WEF, 24th Edition, 2023
Total Solids	10,190	mg/L	Total Solids Dried at 103°C-105°C, 2540 B. APHA-AWWA-WEF, 24th Edition, 2023
Volatile Solids	72.37	mg/L	Fixed and Volatile solids ignited at 550 °C, 2540 E APHA AWWA, WEF, and 24th edition
Chemical Parameters			
C: N Ratio	32.35	-	-

American Public Health Association, AWWA=American Water Works Association, Water Environment Federation

Note:

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2. The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.
3. Statements of conformity have been made without taking Measurement Uncertainty into account except when specifically requested by the customer.

Analyzed By
Aalekh Bhattarai

Checked By
Prabina Shrestha

Authorized By
Er. Lokesh Sapkota

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Bulbule Marga 10, Thapagaun, Kathmandu, Nepal

ANALYSIS REPORT

Name of Client:	Mahesh Ghimire	**Lab Code:**	25/01-1781 (3)
Sample Collection in Lab:	Manak Chaudhary	**Location:**	Sundarijal
Source:	Human Waste	**Sampled By:**	Client
Sampling Date:	2025/01/27	**Test Performance Date:**	2025/01/27-2025/02/03
Receipt Date:	2025/01/27	**Issued Date:**	2025/02/03

Parameters	Results	Unit	Method
Physical Parameters			
pH	6.4	-	Electrometric method, 4500 H+ B, APHA-AWWA-WEF, 24th Edition, 2023
Total Solids	3480	mg/L	Total Solids Dried at 103°C-105°C, 2540 B. APHA-AWWA-WEF, 24th Edition, 2023
Volatile Solids	58.1	mg/L	Fixed and Volatile solids ignited at 550 °C, 2540 E APHA AWWA, WEF, and 24th edition
Chemical Parameters			
C: N Ratio	11.25	-	-

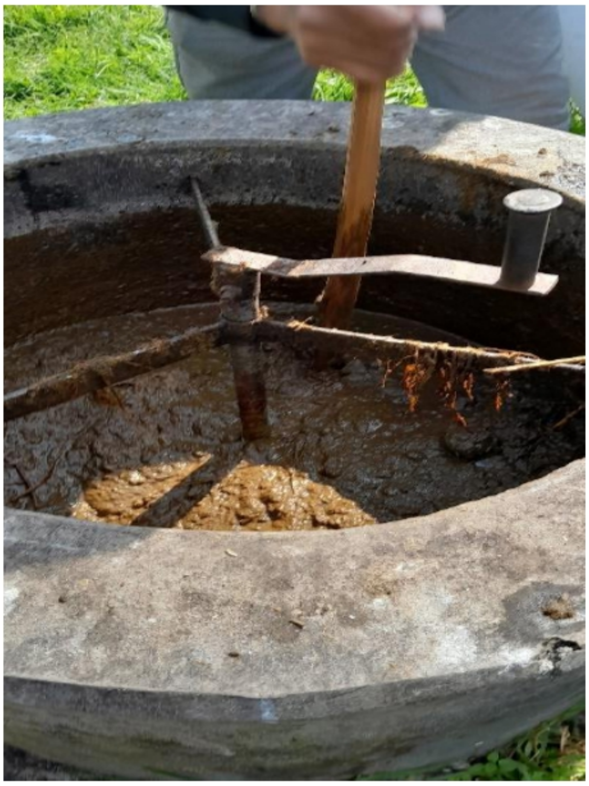
American Public Health Association, AWWA=American Water Works Association, Water Environment Federation

Note:

1. This report is based on the sample submitted to this laboratory by the client
2. The integrity of the sample and results are dependent on the quality of sampling. The results refer only to the parameters tested of the samples provided/collected for analysis.
3. Statements of conformity have been made without taking Measurement Uncertainty into account except when specifically requested by the customer.

Analyzed By	Checked By	Authorized By
Aalekh Bhattarai	Prabina Shrestha	Er. Lokesh Sapkota

Appendex D: Related Photos

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O2 22.39 %
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80
60
40
20


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Mahesh Kumar Ghimire

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Tribhuvan University

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Gmail **mahesh ghimire <mahesh56056056@gmail.com>**

[IOEGC16] Editor Decision

Kobid <conference-noreply@ioe.edu.np> Fri, Mar 28, 2025 at 7:42 AM
To: Mahesh Kumar Ghimire <mahesh56056056@gmail.com>, Navin Kumar Jha <navin.jha@pcampus.edu.np>

Mahesh Kumar Ghimire, Navin Kumar Jha:

We are pleased to inform you that your manuscript titled "Sustainability_Assessment_of_Institutional_Biogas_Plant_in_Kathmandu_Case_Study_of_the_Sundarijal_Arsenal_Biogas_Plant" submitted to 16th IOE Graduate Conference is **Accepted** for presentation in the Conference as well as inclusion in the Peer-Reviewed Proceedings.
Please note that inclusion in hard copy proceedings is contingent upon your timely response to further edits, if any, during the publication process.

With Warm Regards,
IOEGC-16 Editorial Team