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# Estimation of Greenhouse Gas Emission and its Mitigation Study in a Community Biogas Plant : A Case Study of "Rastriya Gai Anusandhan Kendra Biogas Plant, Rampur Chitwan"

**by**

**BINIT KAPHLE**

**A THESIS**

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

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Estimation of Greenhouse Gas Emission and Mitigation Study in a Community Biogas Plant: A Case Study of "Rastriya Gai Anusandhan Kendra Biogas Plant, Rampur Chitwan**"** submitted by Mr. Binit Kaphle (078MSREE007) in partial fulfilment of the requirements for the degree of Masters of Science in Renewable Energy Engineering.

…..…………………………………………………………

Supervisor, Asst. Prof. Navin Kumar Jha

Department of Mechanical and Aerospace Engineering

IOE, Pulchowk Campus, TU

……………………………………………………………

External Examiner, Dr. Sunil Prasad Lohani,

Associate Professor, Kathmandu University

…..…………………………………………………………

Committee Chairperson, Dr.Sudip Bhattarai

Department of Mechanical and Aerospace Engineering

IOE, Pulchowk Campus, TU

Date: 28th November, 2023

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# ABSTRACT

Anaerobic Digestion (AD) at digester is considered as an environmentally friendly technology to manage biodegradable waste like cattle dung. However, systematic environmental impact associated with different phases of life cycle of AD at digester is necessary to qualify the technology as environmentally friendly. Several such studies have been carried out in different parts of the world, however, such quantification may not be applicable under Nepalese conditions as the inventory and management of digestate and other technical parameters may be different. Very limited environmental impact studies have been conducted under Nepalese scenario and so the aim of our study is to estimate the greenhouse gases emissions (GHGE) associated with the production of biogas at Rastriya Gai Anusandhan Kendra, Rampur, Chitwan (community biogas plant) systematically, identify the hotspots contributing GHGE and recommend the mitigation strategies of GHGE. ISO 9001 based life cycle assessment (LCA) approach was employed as a methodological framework for the study. Primary inventory data were collected through field visits based on pre structured questionnaire and wherever necessary, secondary data were collected from the official data providing center of the country as well from the published scientific literatures. The operational phase was found to be the major contributor of GHGs emission (89%) whereas such emission is significantly lower in the construction phase (11%). Emission during storage of manure, leakage emission (fugitive as well intentional) and digestate emission were identified as the major hotspots from GHGs emission perspective. Sensitivity analysis was conducted to observe the impact of digestate on the overall GHGs emission associated with the production of biogas. Our findings may be proved effective policy recommendation to the biogas plants developers in Nepal.

**Keywords:** Anaerobic Digestion**,** Life Cycle Assessment**,** Cowdung**,** Digestate

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| | |
|---|---|
| BAU | Business-as-Usual |
| RED | Renewable Energy Directive |
| CBG | Compressed Biogas |
| GoN | Government of Nepal |
| GHG | Greenhouse Gas |
| MoF | Ministry of Finance |
| GWP | Global Warming Potential |
| $CO_2$ eq | Carbon Dioxide Equivalent |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| MOW | Municipal Organic Waste |
| NG | Natural Gas |

# CHAPTER 1: INTRODUCTION

## 1.1 Background of the study

Traditional energy sources including coal, oil, and natural gas are used more frequently as a result of the growing population and fast urbanization. There is a growing need for energy as a result of this increased use of different energy sources. But it also causes problems for the environment, like climate change and global warming [1]. The economy of each nation is greatly influenced by its energy resources. Certain countries have higher taxes and tariffs for traditional fuels due to their centralized energy resources. Research on non-conventional energy sources, such as biomass, wind, solar, hydro, and geothermal energy, is eventually compelled by the impact that rising costs and levies on conventional fuel have on the economies of developing and impoverished nations. Non-conventional energy sources have huge potential to supply the world's energy needs. To preserve the environment and the stability of national economies, a shift from conventional to non-conventional energy-based systems is required. The current global energy demand is accounted for by non-conventional sources to the tune of 15–20% [3]. The majority of the non-conventional energy supply comes from fuelwood, which is used for heating and cooking in developing nations in South America, Asia, and Africa [4]. Approximately 20% of the world's electrical power is produced by hydropower. Two percent of the world's energy needs are met by other renewable energy sources, which include geothermal, solar, wind, bioenergy, and minor hydropower. Current environmental regulations and studies indicate that by 2050, the share of renewable energy sources will rise to 50 percent.

One important component of the nonconventional energy supply is .biomass energy. All organic stuff, such as plants, trees, algae, etc., that essentially uses photosynthesis to gather and store solar energy is referred to as biomass. Bioenergy, also known as biomass energy, is the result of converting biomass into usable forms of energy like heat, electricity, and liquid fuels. After the industrial revolution, effective methods for extracting and burning fossil fuels were created, and fuels like coal, oil, and natural gas gradually replaced biomass. Fossil fuels have supplanted biomass energy, but emerging nations continue to rely on it; at 10 to 14 percent, it is still the fourth-largest energy source, after natural gas (19 percent), coal (21 percent), and oil (33 percent)as the largest primary sources of energy [7]. Nepal relies heavily on biomass to meet its diverse energy needs. In Nepal, the main sources of biomass are animal dung, timber, and agricultural waste. In rural areas, these resources are commonly employed for small-scale electrical generating, cooking, and heating. The promotion of improved cookstoves mitigates deforestation by increasing energy efficiency, lowering interior pollution, and reducing the need for firewood. Methane from manure is captured by biogas digesters for waste management and better energy. Agroforestry raises biomass that is sustainable. Rural electrification is aided by small-scale biomass power facilities. Cleaner cooking fuel is provided by biomass briquettes. Reforestation and tree planting increase biomass resources. In Nepal, balancing biomass use is essential for long-term socioeconomic and environmental benefits.

Nepal, being primarily an agricultural nation with 60.4% of its population involved in this sector (MoF 2021), finds biogas technology well-suited for cooking due to the substantial biomass generated by farming and livestock activities. Approximately 19 lakh households, constituting around 42% of the total households in Nepal, have been identified as having the potential for installing household biogas systems. A recent study has evaluated the biogas potential and the amount of fuelwood savings achievable per household.

. Table 1: Status of Biogas Use [2]

| | Mountain | Hill | Lowland |
|---|---|---|---|
| Annual per capita fuel wood consumption (kg/year) | 712 | 598 | 482 |
| Annual per capita biogas requirement ($m^3$/year) | 155 | 130 | 106 |
| Annual net weight of fresh dung (kg/household/year) | 3501 | 5386 | 7669 |
| Average household size (number of people) | 5.8 | 4 | 4.3 |
| Annual potential biogas production ($m^3$/household/year) | 22 | 49 | 64 |
| Weight of per capita saving of fuel(wood (kg per capital) | 101 | 224 | 292 |
| Percentage share of saving of fuel wood (%) | 14 | 37 | 60 |

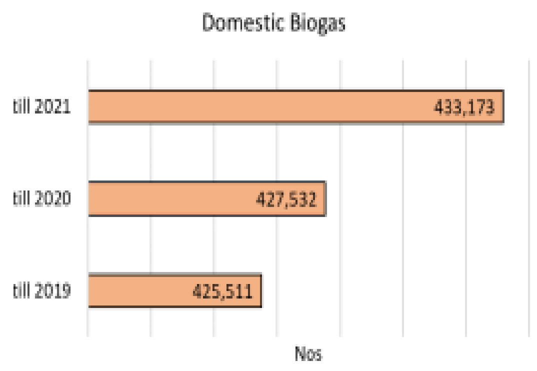
1 $m^3$biogas = 4.57 kg fuel wood ;

1 kg fresh dung = 0.036$m^3$ biogas

The Government of Nepal (GoN) actively supports the installation of biogas plants with different capacities, including 2 cubic meters, 4 cubic meters, 6 cubic meters, and 8 cubic meters, classified as domestic biogas plants. The designs GGC 2047 and its modified version are applied for these plants. The widespread use of domestic biogas plants is seen in nearly all districts, excluding the more remote and less suitable conditions of Manang.

The Terai and hilly regions are home to the bulk of biogas plants, notwithstanding the difficulties in Manang. Bagmati is the province with the most number of home biogas plants, followed by Province 1, Gandaki, and Lumbini. Geographically, it is clear that the Terai region and the hilly region are home to the majority of biogas plants. The Terai and hilly regions' high feedstock production, as well as the accessibility of warm weather, skilled labor, and building materials, all have an impact on this distribution.

Biogas plants exceeding a capacity of 12 cubic meters are categorized as Large Biogas Plants. This signifies progress in Nepal's biogas technology, achieved through extensive experience with the modified GGC 2047 model and insights gained from various technological practices. The large biogas system encompasses various plant types, ranging from institutional and community-level biogas systems to commercial installations.

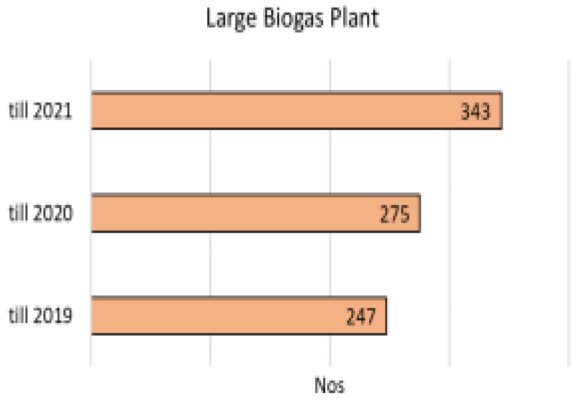



| Province | Installed Share |
|---|---|
| Province 1 | 15.50% |
| Madhesh | 6.30% |
| Bagmati | 25.88% |
| Gandaki | 18.88% |
| Lumbini | 18.85% |
| Karnali | 1.48% |
| Sudurpashchim | 13.11% |

| Region | Installed Share |
|---|---|
| Terai | 51.99% |
| Hill | 46.05% |
| Mountain | 1.96% |

Figure 1: Status of Domestic Biogas Plant in Nepal[2]

Large-scale biogas plants have the potential to be produced from a variety of organic materials, including municipal wastes, but they have not been put in place in significant quantities. Similar to residential biogas plants, the majority of these large biogas plants are located in hilly and Terai districts. Koshi is the province with the greatest concentration of large biogas plants, followed by Bagmati and Gandaki. These provinces have a thriving commercial sector in addition to having effective solid waste management through out the country in the coming years.




| Province | Installed Share |
|---|---|
| Province 1 | 39% |
| Madhesh | 6% |
| Bagmati | 24% |
| Gandaki | 24% |
| Lumbini | 7% |
| Karnali | 0% |
| Sudurpashchim | 1% |

| Region | Installed Share |
|---|---|
| Terai | 52% |
| Hill | 47% |
| Mountain | 1% |

Figure 2: Status of Large Biogas Plant in Nepal[2]

These massive biogas plants are mostly institutional in nature. A small number of biogas plants, including 4,200 m3 plants in Pokhara, 3,750 m3 plants in Nawalparasi, and 3,500 m3 plants in Syangja, have been constructed on a commercial basis.

Energy can be extracted from the biomass in several ways including direct combustion, thermochemical conversion, chemical conversion and biological conversion like anaerobic digestion (AD). AD is a natural biological process that breaks down organic matter by microorganisms in an oxygen-free environment. It is commonly used for the treatment and management of various organic wastes including cattle manure and offers several benefits. Anaerobic digestion produces methane-rich biogas, offering renewable energy for electricity, heating, and vehicles while reducing organic waste volume and capturing methane, aiding climate change mitigation [8]. It also generates nutrient-rich digestate for fertilization, decreasing environmental impact and aiding sustainable waste management, especially in converting manure into compressed natural gas for reduced greenhouse gas emissions in transportation [9, 10]. Success relies on efficient systems, proper management, and adherence to regulations [11, 12].

## 1.2 Problem statement and limitation

The adoption of biogas technology has had a significant impact in Nepal by generating approximately 13,000 green jobs. Moreover, the successful implementation of biogas systems has reached over 2,800 villages out of a total of 3,915, covering all 75 districts in the country [13]. Studies indicate that alongside biogas adoption, there has been a gradual improvement in health and sanitation conditions, and a reduction in deforestation due to decreased reliance on firewood [14, 15]. Notably, efforts are being made to ensure inclusivity in the biogas sector, considering aspects such as caste, ethnicity, and gender, to create a more participative, decentralized, and balanced industry. Waste to Energy (W2E), as a variation of the biogas system, represents a relatively recent energy project adopted in Nepal [16].

Although AD of domestic waste is considered one of the environmentally viable technology of the waste management, environmental impact of the activities associated with whole supply chain of the feed source, construction of digester and its operation & maintenance and application of end products e.g. biogas, digestate should be assessed to qualify the technology as an environmental friendly [17]. For example, the produced biogas during AD of cattle dung is a source of cooking fuel and it has to substitute other form of non-cleaner sources of existing cooking fuel like fossil fuels (kerosene, LPG). Hence, it is necessary to quantify the environmental burden associated with the production of biogas to make sure it should not exceed such environmental burden of the fossil fuel to be substituted by it [18].

Several categories of environmental impact assessments like, global warming potential, ozone layer depletion, acidification etc. are carried out to assess the environmental burden associated with the AD of waste while the study is primarily focused on global warming potential category of environmental impact which is due to greenhouse gases emissions [17]. Several environmental impact assessment studies of AD technology have been carried out in different parts of the world however very limited such studies have been carried out systematically under Nepalese context [16]. Environmental impact of AD under digester is highly influenced by the climatic condition, type of feedstock, operational parameters, sociocultural practices and so such study carried out under any specific context may not be generalized it under another context. So, conducting environmental assessment of biogas production at community level biogas plant (Rastriya Gai Anusandhan kendra) seems essential not only to assess the environmental impact of the plant in particular but also to predict such impact during expansion of the plant and future installment of such biogas plants under similar condition.

Herein we present report on to estimate the GHGs emission associated with the biogas production from cow dung in Rastriya Gai Anusandhan Kendra, Rampur, Chitwan. Estimating GHG emissions from cow dung biogas is crucial for climate mitigation, assessing environmental impact, regulatory compliance, securing funding, raising public awareness, and informed decision-making to promote sustainability in regional scale.

### 1.3. Objectives

The objectives of the research are as follows:

Main Objective

i) To estimate and potential mitigate the GHGE associated with the biogas production at Rastriya Gai Anusandhan Biogas plant.

Specific Objectives

i. To measure and calculate the specific GHG emissions associated with biogas production at the Rastriya Gai Anusandhan Biogas plant.
ii. To identify the key sources and processes within the biogas production system that contribute to GHG emissions.
iii. To propose and implement strategies to reduce and mitigate GHG emissions from the biogas production process.

# CHAPTER 2: LITERATURE REVIEW

This chapter reviews some of the literature on life cycle assessment of Biogas and CBG.

According to a 2019 study by Cahyani et al., the emissions from small-scale biogas digester installation and maintenance contribute to +18.5 Kt $CO_2$ equivalent. Gasoline and geomembrane HDPE are the main sources of greenhouse gas emissions. However, using biogas in place of fossil fuel (LPG) to power the tapioca drying process could drastically lower greenhouse gas emissions, with a reduction of 296 Kt $CO_2$ equivalent over the course of a single life cycle (15 years) [23].

The electric buses had a global warming potential of 0.11 kg $CO_2$-eq/VKT, while the bio-methane buses had a potential of 0.26 kg $CO_2$-eq/VKT. About half of the effects of eutrophication and acidification caused by biomethane-fueled buses could also be mitigated by electric buses [24].

A study conducted by Felix Raphael et al 2018, explored the use of Nopal, a hardy plant, for biogas production by co-digesting it with dairy cow manure. A life cycle assessment was conducted to evaluate its feasibility, with different scenarios compared. The results showed potential for cleaner energy production, with a lower global warming impact compared to similar feedstocks, making it an environmentally and economically viable solution for reducing greenhouse gas emissions from dairy waste [25].

Another study in 2020 by Anne E. M. and colleagues conducted a Life Cycle Assessment (LCA) of Compressed Biogas (CBG) production from animal manure and municipal organic waste (MOW). The results showed substantial greenhouse gas (GHG) savings (93% to 131%) compared to fossil diesel, meeting the 60% reduction target. However, ammonia emissions from digestate application led to increased acidification and terrestrial eutrophication impacts for CBG from MOW, while producing CBG from manure and addressing manure storage emissions significantly lowered these environmental burdens [26].

While Walter Kloppler and colleagues in 2014, discussed the development of Life Cycle Assessment (LCA) from its early stages in the 1970s and 1980s to its international standardization. This process was initiated by the Society of Environmental Toxicology and Chemistry (SETAC) and led to the publication of LCA guidelines in 1993. It was followed by standardization efforts involving 40 nations under the International Standard Organization (ISO), resulting in the well-known ISO LCA standards (14040ff, 1997-2006). The authors of the book played a role in this development by participating in the German mirror group and reviewing and improving the German translations of these standards [21].

Sıdıka Tuğçe Dağlıoğlu in 2020 elaborated the analysis of Biogas Life Cycle Assessment (LCA) enables the evaluation of environmental consequences in biogas production, as well as the assessment of energy, material needs, and emissions. This allows for the comparison of various scenarios. LCA serves as a valuable tool for engineers and policymakers in understanding the environmental implications of biogas. Hence, this study reviews different LCA approaches, categorized by feedstock and upgrading technologies, and their associated environmental impacts, including global warming potential, eutrophication, and acidification [27].

# CHAPTER 3: MATERIAL AND METHODOLOGY

Life Cycle Assessment (LCA) is a crucial tool for assessing the holistic environmental, social, and economic impacts of products, processes, or systems. When applied to anaerobic digestion (AD), LCA reveals sustainability insights and helps pinpoint environmental "hotspots." It evaluates resource use, such as water consumption and energy inputs, enabling better system design and more efficient resource utilization. Clear communication of AD's environmental benefits can enhance public acceptance and support [18].

ISO 14040 standard (ISO, 2006) based LCA framework was employed as a methodological framework in the study to estimate GHGs emission associated with each phase of life cycle during production of biogas [28, 29]. The framework recommends following four steps to assess the environmental impact: a) goal and scope definitions, b) life cycle inventory, c) life cycle impact assessment, and d) interpretation.

The purpose and scope of the life-cycle assessment (LCA) study must be defined before any evaluation can begin. At this point, the study's aim has been established, along with all of the material and energy fluxes that need to be considered. The definitions must be clarified in detail and need to be appropriate for the intended use. Furthermore, it is imperative to specify and describe the object of research together with the time frame of the study. Time, location, technology, and registration technique define data quality, e.g. measured information or computed information. Impact categories and functional units are finally mentioned. With these.

The EN ISO 14040 [CEN1998] contains detailed statements about the aim and scope defining phase in chapters one to five. Making an organized inventory of the inventory is the second phase in the process. All fluxes of materials and energy, as well as emissions, related to the thing under study during the course of its whole life. Regarding this created model, all of the data are measured, computed, or evaluated with consideration for the data quality specifications stated in the aim and scope description stage. Data about individual steps from the entire process under investigation are, to the greatest extent feasible, gathered in unit processes, which are little, logical segments of the larger process, such as transportation or storing.

An inventory's output includes a list of emissions, resources used, and non-material effects like land use. The inventory result table is referred to as such and is defined in EN ISO 14040 [CEN1998] chapter six. Furthermore, EN ISO 14040's chapter seven describes the fundamental guidelines for analyzing the inventory outcome. These guidelines address accomplishing the specified aim and scope description, evaluating the quality of the data, and assessing findings' lack of assurance. It is crucial to understand that this interpretation only covers the LCA's framework and data—it excludes ecological effects and impact categories stockpile. The inventory analysis is referred to as the "heart" of an LCA by Kaltschmitt & Reinhardt in 1997.

This stage is where all of the fundamental facts needed for further calculations are gathered, which is why it was given this name. Any further findings are the product of computations based on the natural and social sciences and are thus only indirectly related to the thing under inquiry; these data, on the other hand, are directly related to the object under investigation. An effect assessment is conducted in accordance with the recommendations of this study's inventory analysis. As previously said, the outcome of this stage is somewhat tied to the object under examination, which may result in various interpretations of the fundamental information. Even consequently, this effect assessment is done since inventory tables are frequently extensive and challenging to interpret.

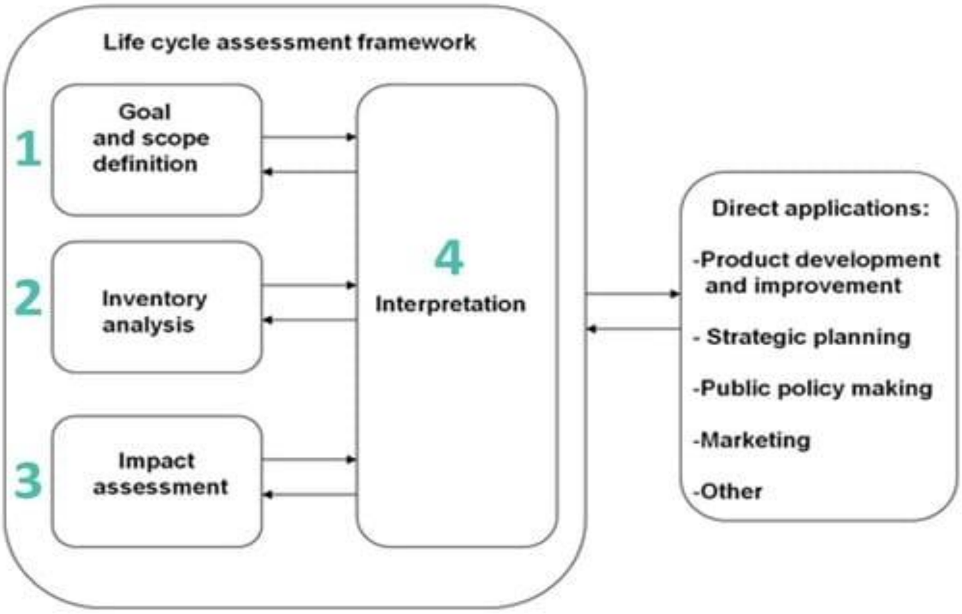



Figure 3: LCA Framework Adapted[30]

The steps followed for our current study are as follows:

### 3.1. Goal and Scope

The goal of our study was to estimate the GHGs emission associated with the biogas production from cow dung and the study is specifically focused in Rastriya Gai Anusandhan Kendra, Rampur, Chitwan.

The size of the digester in the plant is 200 $m^3$ and fixed dome digester has been used in the plant for digestion of cattle dung from around 200 number of cows. Daily 3000 kg of cow dung is mixed with equal amount of water and continuous feeding is done on daily basis.


Figure 4:Digester at the site

Figure 5: Site Location at Rampur, Chitwan

### 3.2. Functional Unit and System Boundary

One important idea that is used to specify the goal and parameters of the assessment is the functional unit. It acts as a reference number for the particular service or function that a system or product is offering at the time of analysis. This cases the fixed-dome household digester and offers a standard against which all LCI data, both input and output, are adjusted. In this case, the FU is producing 1 m3 of biogas, which is normally utilized for cooking. Pipelines are used to deliver the produced biogas to the consumer, who solely uses it as cooking fuel. A useful lifetime of 20 years was taken into consideration, assuming it operates 360 days a year to account for brief stoppages caused by faults or during maintenance, as advised during field investigations. [31]

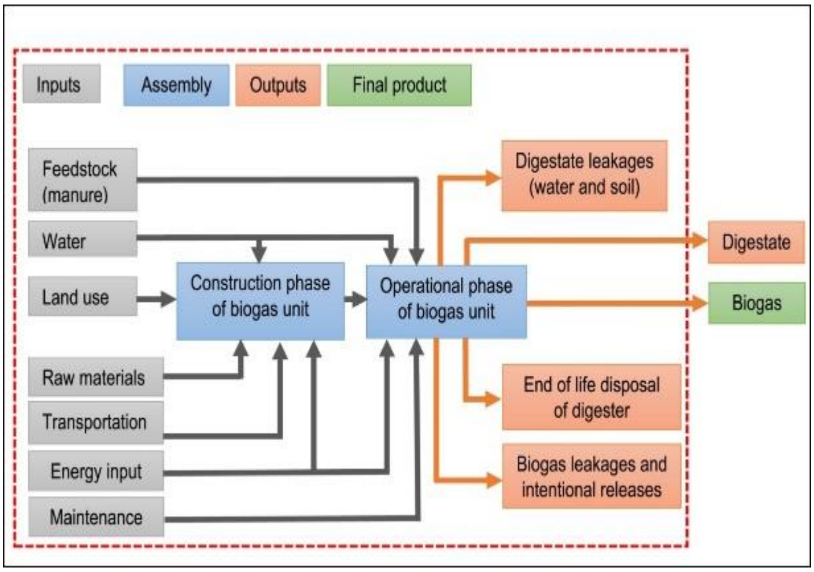



Figure 6: System Boundary of Overall Plant [49]

The components of the product/system life cycle that are included in or not included from the analysis are defined by the system boundary, along with the related processes and activities. This fixed dome digester unit is analyzed, taking into account all major inputs and outputs, transportation, land use, and pertinent emissions to the air, water, and soil. The system boundary also includes the phases of demolition, waste processing, and recycling. Dictate is produced in addition to biogas, and due to its high nutrient content, it can be either disposed of as waste or utilized as a coproduct or system byproduct (biofertilizer). It is typically disposed of in agricultural fields that are not close to water bodies, either directly into the aquatic environment or through lagoons. This is because of its high water content.

## 3.3. Inventory Analysis

Inventory data of the biogas plant was collected from the Anusandhan Kendra, Rampur, Chitwan based on the pre-structured questionnaire and associated GHGs emission were estimated based on IPCC guidelines and other published scientific literatures [33].

Table 2: Net amount and weight of the description according to survey

| S.N | Description | No/Amount | Weight |
|---|---|---|---|
| 1 | Block | 11000(162m$^3$) | |
| 2 | Bricks | 12000 (24 m$^3$) | |
| 3 | Cement | | 2000 kg |
| 4 | Sand | | 10000 kg |
| 5 | 8 Inch Steel Pipe | 26 m (340 kg) | 340 kg |
| 6 | 8 Inch PVC Pipe | 12 m (28.5kg) | 28.5 kg |
| 7 | 28 Inch Steel Pipe | 24 m (108 kg) | 108 kg |
| 8 | 3 Inch PVC Pipe | 6 m (5.4 kg) | 5.4 kg |
| 9 | 17 Inch Steel Pipe | 0.6 m (20 kg) | 20 kg |
| 10 | Fencing Wire | 70 m$^2$ | |
| 11 | 5 Inch Steel Pipe | 128 m | 1042 kg |
| 12 | Transportation (Local For raw materials) | 10 km (Distance between Narayangarh to Rampur) | |
| 13 | Square Pipe (Steel) | 500 m | 5070 kg |
| 14 | Other iron Materials | | 500 kg |
| 15 | Gravel (Stone) | 800 m$^3$ | |
| 16 | Corrugated Sheet | 1500 m$^2$ | 30000 kg |
| 17 | Water (Per Day) | 5100 l | |
| 18 | Feedstock (Per Day) | | 3000 kg |
| 19 | Electricity Consumption by machineries | 1000 units | |
| 20 | Digestate (60% used as liquid fertilizer) | | 4860 kg |
| 21 | Digestate (40% used after drying)` | | 3240 kg |

# CHAPTER 4: RESULTS AND DISCUSSIONS

## 4.1. Life Cycle Assessment

Time constraints, the complexity of each system (commercial biogas production, storage, distribution, use, and end-of-use waste, i.e., biogas digestate generation systems), and the abundance of nutrients involved precluded a comprehensive cradle-to-grave analysis. However, every LCA component—most notably inventory analysis—was applied to every system. To make analysis and discussion easier, the system was divided into two main sub-systems: (a) the construction phase, which also includes the unit's disposal/recycling after its useful life, and (b) the operational phase, which also includes biogas/digestate leakages. Across all categories, the construction phase contributes significantly less than the operational phase. This was expected given that: (i) The building materials required to construct the biogas digester are commonly believed to be carcinogenic, mutagenic, or reproductively toxic substances; and (ii) the biogas unit has a 25-year lifespan overall.

Table 3: Carbon emission of production of 1 $m^3$of biogas

| S.N | Description | Carbon Emission ( Functional Unit 1 m3) | Unit | LCA Data Refrence |
|---|---|---|---|---|
| 1 | Block | 0.043749511 | kg $CO_2$ eq | [33] |
| 2 | Bricks | 0.01192955 | kg $CO_2$ eq | [34] |
| 3 | Cement | 0.00109589 | kg $CO_2$ eq | [35] |
| 4 | Sand | 0.051585127 | kg $CO_2$ eq | [36] |
| 5 | 8 Inch Steel Pipe | 0.000471076 | kg $CO_2$ eq | [37] |
| 6 | 8 Inch PVC Pipe | 0.000174681 | kg $CO_2$ eq | [37] |
| 7 | 28 Inch Steel Pipe | 3.32524E-05 | kg $CO_2$ eq | [37] |
| 8 | 3 Inch PVC Pipe | 3.30975E-05 | kg $CO_2$ eq | [38] |
| 9 | 17 Inch Steel Pipe | 2.77104E-05 | kg $CO_2$ eq | [37] |
| 10 | 5 Inch Steel Pipe | 0.014445417 | kg $CO_2$ eq | [37] |

| | | | | |
|---|---|---|---|---|
| 11 | Square Pipe (Steel) | 0.007024579 | kg $CO_2$ eq | [37] |
| 12 | Other iron Materials | 0.000567515 | kg $CO_2$ eq | [38] |
| 13 | Gravel | 0.000494716 | kg $CO_2$ eq | [39] |
| 14 | Initial Feeding | 0.33816047 | kg $CO_2$ eq | [40] |
| 16 | Electricity Consumption by machineries | 0.004696673 | kg $CO_2$ eq | [41] |
| 17 | Digestate (60% used as liquid fertilizer) | 2.082857143 | kg $CO_2$ eq | [42] |
| 18 | Digestate (40% used after drying)` | 0.617142857 | kg $CO_2$ eq | [43] |

The total carbon emission for producing 1 $m^3$ of biogas is calculated as 3.17 kg CO2 eq. The major contributions came from the digestates and the initial feeding that is done during the operational period.

## 4.2 Emissions during construction phase

Table 4: Carbon emission during construction phase

| S. N | Description | Qty | Carbon Emission ( Per Unit) | Total Carbon Emission | Unit | LCA Data Refrence |
|---|---|---|---|---|---|---|
| 1 | Block | 11000(22$m^3$) | 345 kg $CO_2$ eq | 7590 | kg $CO_2$ eq | [33] |
| 2 | Bricks | 12000 (178 $m^3$) | 635 kg $CO_2$ eq | 113030 | kg $CO_2$ eq | [34] |
| 3 | Cement | 20000 kg | 0.7 kg $CO_2$ eq | 14000 | kg $CO_2$ eq | [35] |
| 4 | Sand | 80000 kg | 6.59 kg $CO_2$ eq | 527200 | kg $CO_2$ eq | [36] |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | 8 Inch Steel Pipe | 26 m (340 kg) | 1.77 kg $CO_2$ -eq | 601.8 | kg $CO_2$ eq | [37] |
| 7 | 8 Inch PVC Pipe | 12 m (28.5kg) | 7.83kg CO2-eq | 223.155 | kg $CO_2$ eq | [38] |
| 8 | 28 Inch Steel Pipe | 24 m (108 kg) | 1.77 kg $CO_2$ -eq | 42.48 | kg $CO_2$ eq | [37] |
| 9 | 3 Inch PVC Pipe | 6 m (5.4 kg) | 7.83kg $CO_2$-eq | 42.282 | kg $CO_2$ eq | [37] |
| 10 | 17 Inch Steel Pipe | 0.6 m (20 kg) | 1.77 kg $CO_2$ -eq | 35.4 | kg $CO_2$ eq | [37] |
| 11 | 5 Inch Steel Pipe | 1280 m (10426 kg) | 1.77 kg $CO_2$ -eq | 18454.02 | kg $CO_2$ eq | [37] |
| 12 | Square Pipe (Steel) | 500 m (5070 kg) | 1.77 kg $CO_2$ -eq | 8973.9 | kg $CO_2$ eq | [37] |
| 13 | Other iron Materials | 500 kg | 1.45 Kg $CO_2$ - eq | 725 | kg $CO_2$ eq | [38] |
| 14 | Gravel (Stone) | 800 $m^3$ | 237 kg $CO_2$ Eq | 189600 | kg $CO_2$ eq | [39] |

The GWP of the materials used to build the plant is determined to be 167591.23 kg CO2 equivalent. It is not necessary to heat these plants to maintain the ideal temperatures for AD reactions because they are located in a subtropical area with generally high ambient temperatures. This implies that the effect of operating these plants in this way on GWP can be disregarded.

The mining and processing of raw materials is primarily responsible for the impact categories during the construction phase. Burnt solid bricks account for the largest portion, closely followed by cement and, to a lesser degree, mining sand and gravel. Clay must be mined and transported in order to produce bricks, which necessitates the use of fossil fuels—typically diesel—and energy-intensive brick drying. Carbon emission of the materials required for the construction and operational phase is shown in the table.

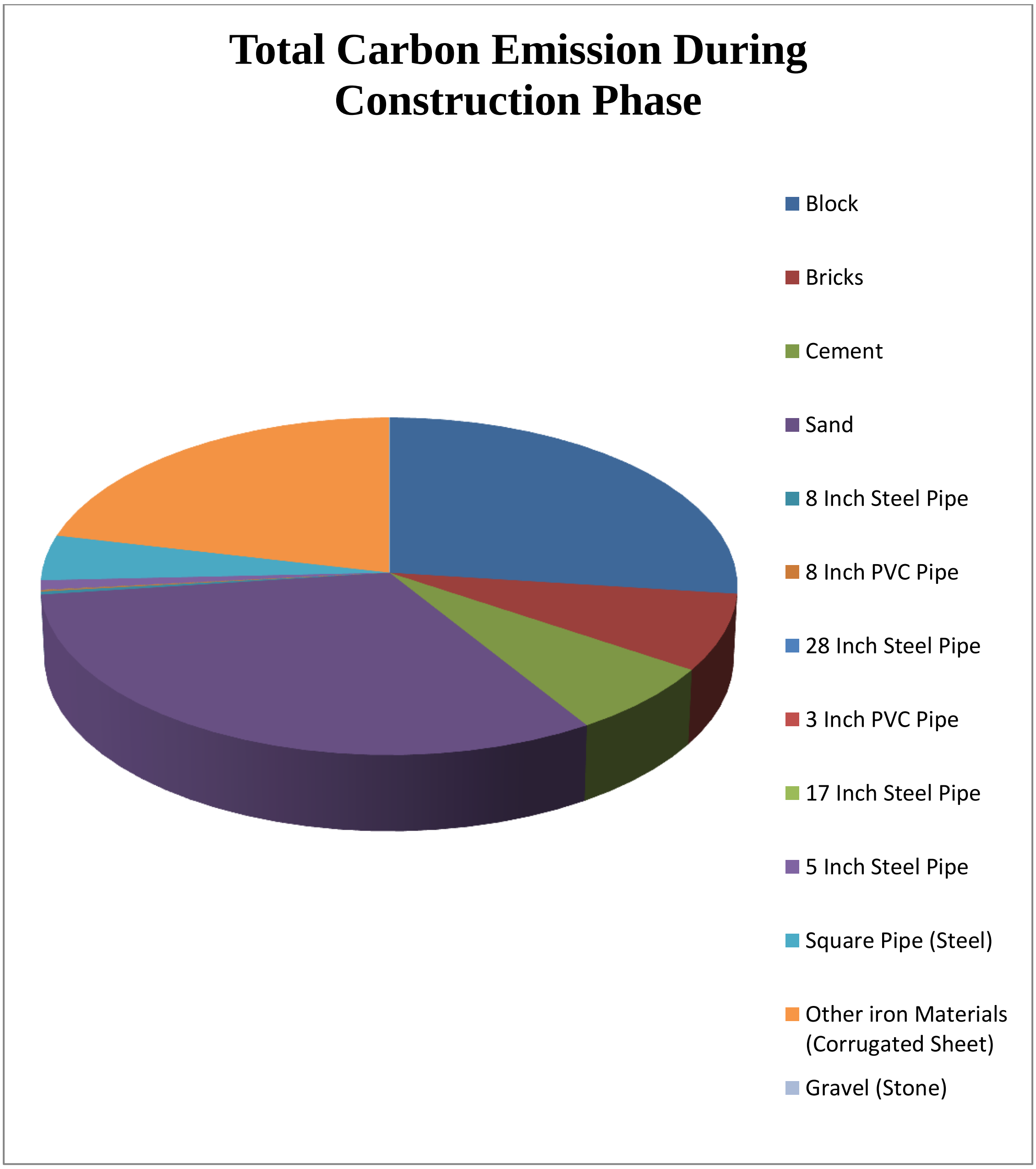



Figure 7: Carbon Emission during Construction Phase

### 4.3. Anaerobic digestion process

The anaerobic digester receives a slurry made from the combination of manure from the AD feedstock and water [11]. Digestate and biogas are the primary and secondary products of the biochemical conversion process. There are no more emissions or leftovers. The biogas is used as fuel, mostly for cooking, and the digestate is returned to the land as a nutrient-rich fertilizer [32]. In the digester, a 1:1 mixture of manure and water is used to promote bacterial degradation. 10,000 kg of cattle dung must be added to the plant as an initial input when it is first started, according to the standard 200 $m^3$ scale used in this LCA study. After that, 2700 kg of manure are utilized as input daily.

Biogas produced by manure yields 0.037 $m^3$ $kg^{-1}$, with $CO_2$ (39.90%) and $CH_4$ (60%) making up the majority of the composition. This shows that 105 kg of gas, mostly carbon dioxide, are produced daily from the 3000 kg of dung input. Of this, 55 kg of the gas is methane. Since the manure is considered a waste product and the water required for manual mixing comes from the nearby boring, this material has no embodied energy.

Because of the original charge, the GWP is 432000 kg $CO_2$ equivalent. The quantity of feedstock added daily to keep the digester running is known as the daily charge. The daily biogas production of a 200 m3 plant results in a GWP of 9600 kg $CO_2$ equivalent. Given an AD plant's 25-year lifespan, the lifetime yield production amounts to 43800000 kg of dung, calculated as follows: daily × 360 days/year × 25 years.

Table 5: Carbon Emission During Operational Phase

| **S.N** | **Description** | **Qty** | Carbon Emission (Per Unit) | Total Carbon Emission | Unit | LCA Data Reference |
|---|---|---|---|---|---|---|
| 1 | Initial Feeding | 135000 kg | 3.2 kg CO2 -eq | 432000 | kg $CO_2$ eq | [40] |
| 2 | Electricity Consumption by machineries | 1000 units per month | 0.02 kg $CO_2$ eq | 20 | kg $CO_2$ eq | [41] |
| 3 | Digestate (60% used as liquid fertilizer) | 4860 kg | 0.139 kg $CO_2$ eq | 675.54 | kg $CO_2$ | [42] |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | eq | |
| 4 | Digestate (40% used after drying) | 3240 kg | 0.060 kg $CO_2$-eq | 194.4 | kg $CO_2$ eq | [43] |

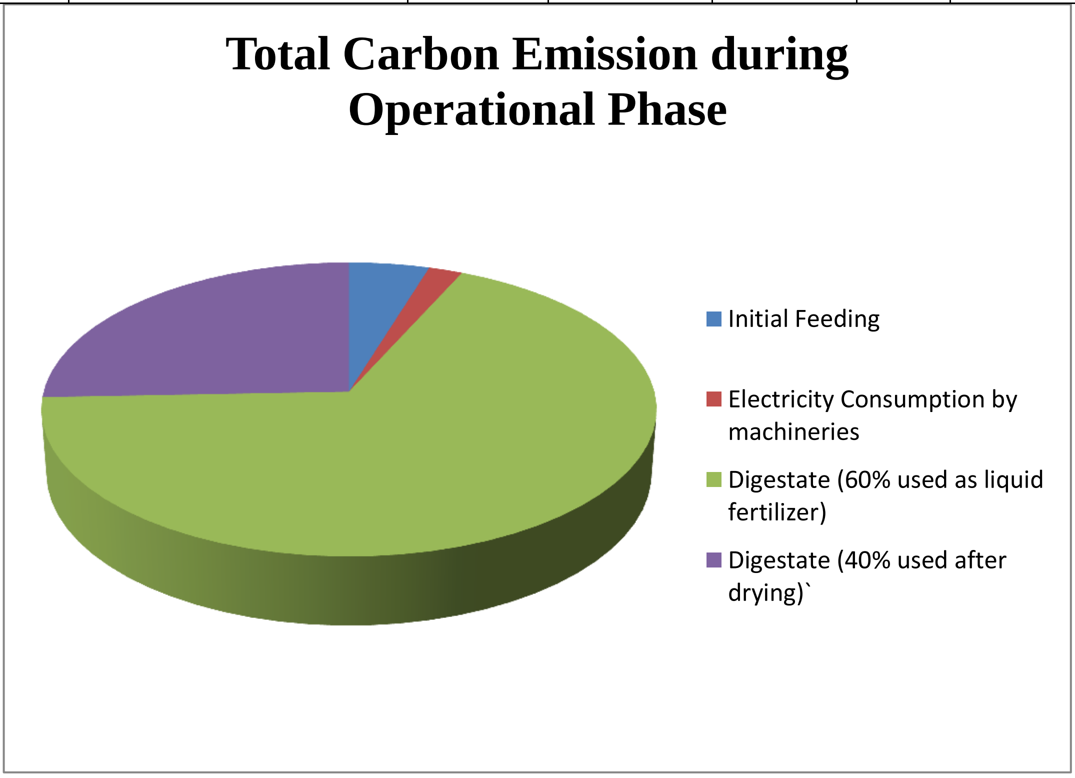



Figure 8: Carbon Emission During Operational Phase

A GWP of 3528206 kg CO2 equivalent is obtained from this. The combined contribution from the initial charge and lifetime charge is the total impact. A 200 m3 plant running for 25 years will have a GWP impact of 3528206 kg CO2 equivalent (including the impact of the initial charge) due to the biogas. Methane is converted to CO2 when the methane-rich biogas is burned as fuel.

The emissions during the operational phase is due to the slurries that is available after the production of biogas. The emissions due to the digestate can be reduced by using the slurries as the fertilizers. Also some emissions can be reduced by controlling the leakages.

Hence, the operational phase contributes about 89% of GHG emissions whereas the constructional phase contributes about 11% of GHG emissions. This result is similar to the research (Mohammad et al, 2022) conducted in India, Tamil Nadu which concluded that the constructional phase contributed to about 9% and operational phase contributed to about 91% of overall GHG emissions. The results nearly compliances with the above study. This is due to the availability of the materials being same and the conditions present in those above mentioned areas.

### 4.4. Digestate Management:

Digestate is a byproduct of the anaerobic digestion process, which is commonly used to break down organic materials like agricultural residues, food waste, and sewage sludge to produce biogas (a mixture of methane and carbon dioxide) . It consists of the solid and liquid residues left behind after the biogas has been extracted. The impact of digestate and its potential to replace chemical fertilizers can vary depending on several factors, including its nutrient content, handling, and application methods.

The nutrient content of digestate can vary depending on the feedstock used for anaerobic digestion. It typically contains essential plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K), along with micronutrients. The nutrient composition can make it a valuable source of plant nutrients for agriculture. It also contains organic matter, which can improve soil structure, water retention, and microbial activity. This can lead to improved soil health and fertility over time. Using digestate as a fertilizer can help reduce the environmental impact associated with chemical fertilizers. Chemical fertilizers can contribute to nutrient runoff and water pollution, while digestate can release nutrients more slowly, reducing the risk of nutrient leaching and pollution. To replace chemical fertilizers effectively, the nutrient content and composition of digestate must match the nutrient requirements of the crops being grown. This may require additional processing or blending of digestate to ensure it provides the right balance of nutrients. Proper application methods are crucial when using digestate as a fertilizer. It can be applied directly to fields, but it may need to be treated or processed to reduce pathogens and weed seeds. Appropriate application rates and timing should also be considered to maximize its effectiveness. It's important to conduct research and monitoring to assess the impact of digestate on soil quality, crop yield, and environmental factors. This helps optimize its use and ensure that it provides the desired benefits. Digestate from biogas production can have a positive impact on agriculture by providing nutrients and organic matter to improve soil health and reduce the reliance on chemical fertilizers. However, successful integration into agricultural practices requires careful consideration of nutrient content, handling, and application methods, as well as compliance with local regulations.

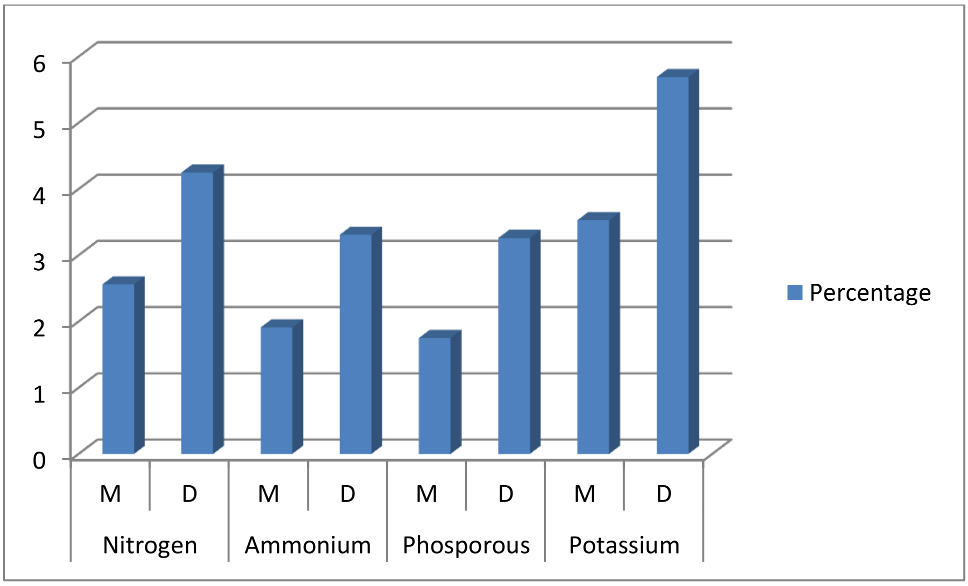



Figure 9: Comparison of the  fertilizer nutrient of cattle manure and the processed digestate, M – cattle manure used for production of biogas; D –digestate [35]

Over a period of 100 years, the global warming potential (GWP) of nitrous oxide ($N_2O$) is 265–298 times greater than that of $CO_2$. Since there is most likely not as much nitrogen in the soils that Nepalese farmers use, adding nitrogen from biogas effluent might not have the same detrimental effects on the environment. Cow dung has a nitrogen percentage (by weight) of 1.29, while synthetic fertilizers (such as urea-$NH_2$-CO-$NH_2$) have a nitrogen content of 46%. With a global warming potential of 2.79 kg $CO_2$ equivalent, 1 kg of inorganic nitrogen requires 44.94MJ of energy to produce. For potassium, the figures are 3.78MJ and 0.35 kg CO equivalent, and for phosphorus, they are 6.95MJ and 0.74 kg CO2 equivalent. The biogas plant's effluent slurry typically contains 1.6% nitrogen, 1.5% phosphorus, and other nutrients as plant fertilizers. Further study is necessary to support these numbers, though, as they are not commonly acknowledged in the published literature [44].

Table 6: Sensitivity analysis of the amount of use of digestate to replace the Chemical Fertilizer (Urea) on daily basis of feed to the digestate

| Per(%) | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Digestate Amt (kg) | 810 | 1620 | 2430 | 3240 | 4050 | 4860 | 5670 | 6480 | 7290 | 8100 |
| Carbon Emission (kg $CO_2$ eq) | 112.5 | 225.1 | 337.7 | 450.3 | 562.9 | 675.5 | 788.1 | 900.72 | 1013.31 | 1125.9 |
| Urea Equivalent $CO_2$ eq | 48.6 | 97.2 | 145.8 | 194.4 | 243 | 291.6 | 340.2 | 388.8 | 437.4 | 486 |
| Dry Digestate (Remaining in kg) | 2430 | 2160 | 1890 | 1620 | 1350 | 1080 | 810 | 540 | 270 | 0 |
| Carbon Emission | 194.4 | 172.8 | 151.2 | 129.6 | 108 | 86.4 | 64.8 | 43.2 | 21.6 | 0 |
| $CO_2$ emission saving | -145.8 | -75.6 | -5.4 | 64.8 | 135 | 205.2 | 275.4 | 345.6 | 415.8 | 486 |

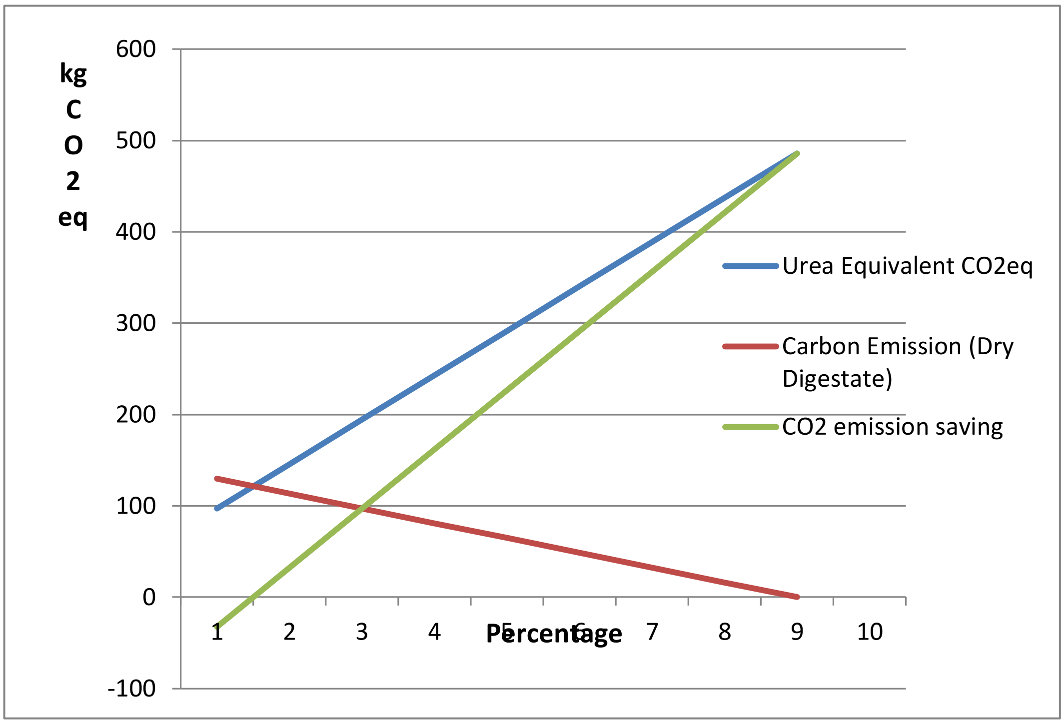



Figure 10: Sensitivity Analysis of Using Digestate as Fertilizer

At present, only 60% of digestate from the dome is used as fertilizer in the agricultural land whereas 40% of digestate is left as usual and it has huge impact in the environment. This digestate can replace and hence it can help in mitigating the carbon emission due to the chemical fertilizers.

There is an international issue with the decline of rural habitats and natural systems. This is a result of careless animal waste disposal, excessive use of chemical pesticides and fertilizers, and overuse of land and forests. Digestate from AD plants has been successfully applied to improve crop cultivation, according to research [45, 46]. Since carbon, hydrogen, and oxygen are released as biogas, the amount of nitrogen in digestate is higher than that of fresh dung. Compared to one kilogram of fresh manure, one kilogram of digestate contains 0.5 kg more nitrogen. In addition to lowering reliance on chemical fertilizers, using digestate as an organic fertilizer can enhance soil structure. This can address soil degradation issues in regions where dung was previously used as a fuel source for burning. For the household, using less artificial fertilizer results in financial savings [47]. The SimaPro program undervalues the advantages of using AD because it ignores these factors [48]. According to the above estimate, the savings come from using 1 t of digestate as fertilizer instead of 0.06 t of $CO_2$ equivalent from chemical fertilizer. If we are able to use all of the digestate—roughly 116800 t-during the plant's lifetime, it will be able to replace 7008 t CO2 equivalent from the chemical fertilizer.

# CHAPTER 5: FINDINGS

The major findings during the research can be summarized as follows:

1. The total carbon emission for the production of 1 $m^3$ of biogas is calculated as 7.9 kg $CO_2$ eq.
2. The main contributor towards the GHG emission is during the operational phase rather than the constructional phase.
3. The major hotspot for the GHG emissions during the operational phase come from the digestates i.e the slurries.
4. The emissions from the digestates can be minimized such that it can replace the chemical fertilizers.
5. The dry digestate that is stored and kept sepereately can be later used to make vermicomposts so that it also can help in removing chemical fertilizers.

# CHAPTER 6: CONCLUSION

GHG Emission of the plant using this method was estimated to be 3528206 kg $CO_2$ eq. The total carbon emission for producing 1 $m^3$ of biogas is calculated as 3.17 kg $CO_2$ eq.The operational phase was found the major contributor of GHGs emission (89%) whereas such emission is significantly lower in the construction phase (11%).

Sensitivity analysis was performed to examine the effects of digestate on the total amount of greenhouse gases (GHGs) released during the production of biogas. Our research may be proved a beneficial policy recommendation to Nepal's biogas plant developers and other stakeholders. Different types of materials which are locally available could be used such as building materials which could lead to less GHG emissions during the construction phase of Biogas plant. The digestate remained after the production of biogas could be used as the fertilizer and hence these fertilizers could be later processed as a vermicompost plant which will eventually have a higher nutrient content. So, the dependence on chemical fertilizers could eventually be minimized. Consumption of digestate may mitigate GHGs emission associated with the synthetic fertilizer.

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# ANNEXES

**Questionnaire during the field visit**

1. What is the total land area of the plant?

2. How many separate smaller sheds are present in the farm?

3. What is the size of the shed in the farm? (Include the construction parts and other factors)

4. How many cattle are present in the farm?

5. How many people work in the farm?

6. How much amount of grass and other food materials are given to the cattle?

7. How much dung is collected in a day from the farm to the biogas plant?

8. What percentage of dung is sent to the digester?

9. How much amount of dung and slurry is directly use as the fertilizer?

10. How is dung sent to the digester? Manually or by using machine?

11. What is the length and size of the canal from which dung is sent to the digester?

12. What is the approximate amount of materials used in building the canal?

13. What is the size of the digester? Volume wise. ( It includes the amount of brick, cement, sand and other construction materials) Also include the number of people involve in the process)

14. What is the size of the cover of the digester and the material involved in it?

15. What is the length of pipe which carry slurry? (Specification of pipe)

16. What is the size of the slurry collecting area? ( It includes the amount of brick, cement, sand and other construction materials)

17. What are the total types of pipe involving in the whole process of producing biogas?

(It involves every type like material of pipe like PVC or iron of pipe and their specifications)

18. What are the process involving in the digester? (Air over pressure and Gas Over Pressure Valve, Heater) and electricity consumed if not known then try to gather the size specification of pumps and machinary

19. What is the specification of the machines involving in the digesters? (All data including the size, capacity and the power consumption)

20. What is the area and the materials required in building the shed for the machines? ( It

includes the amount of brick, cement, sand and other construction materials and the grill)

21. What are the specifications of the gas collector/balloon? (Size, Material, Gas Holding

Capacity, Working Mechanism)

22. What is the specification of heater?

23. What is the specification of $H_2S$ filter? How is it operated?

24. What is the specification of Buffer Tank ?

25. What is the specification of Compressor?

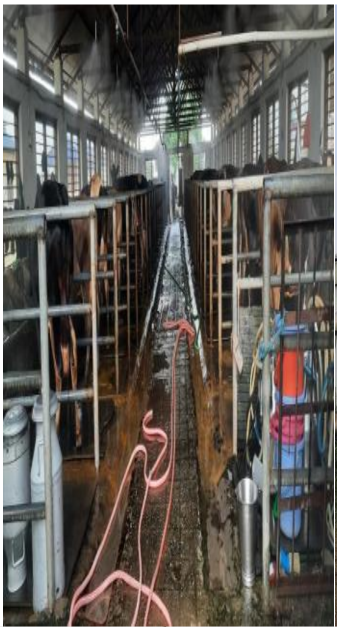
26. What is the specification of Surge Tank?

27. What percentage of methane in biogas can be obtained from the above purification process?

28. How much gas is produced in a day?

29. How much gas is wasted in a day?

## **Photographs during Field Visit**





# Estimation of Greenhouse Gas Emission and its Mitigation Study in a Community Biogas Plant : A Case Study of “Rastriya Gai Anusandhan Kendra Biogas Plant, Rampur Chitwan”

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Institute of Engineering
डीनको कार्यालय
OFFICE OF THE DEAN

GPO box- 1915, Pulchowk, Lalitpur
Tel: 977-5-521531, Fax: 977-5-525830
dean@ioe.edu.np, www.ioe.edu.np
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Date: November 26, 2023

**To Whom It May Concern:**

This is to certify that the paper titled "***Environmental Impact Assessment of Biogas Plant: A Case Study of "Rastriya Gai Anusandhan Kendra Biogas Plant, Rampur Chitwan""*** (Submission# **590**) submitted by **Binit Kaphle** as the first author has been accepted after the peer-review process for presentation in the 14th IOE Graduate Conference being held during Nov 29 to Dec 1, 2023. Kindly note that the publication of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon the author's presence for presentation during the conference and timely response to further edits during the publication process.

Bhim Kumar Dahal, PhD
Convener,
14th IOE Graduate Conference