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THESIS NO: M-191-MSESPM-2021-2026

Techno-economic Analysis of Waste-to-Energy and Liquid Fertilizer Production in Lalitpur's Ward 8 Using Insulated/ Solar-Heated Biogas Digester

By

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078MSESP010

A THESIS

SUBMITTED TO THE

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENERGY SYSTEM PLANNING AND MANAGEMENT

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

MAY, 2026

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ABSTRACT

This research project evaluates the techno-economic feasibility of transforming municipal solid waste (MSW) into renewable energy and organic fertilizer within Ward 8 of Lalitpur Sub-Metropolitan City. The ward generates 0.31 kg/capita/day with a 70.5% organic fraction, resulting in a biogas potential of 69 m^3/day, based to a 111-household survey. Two thermal enhancement strategies (sawdust insulation and solar water heating) were compared for a 35 m^3 digester. With an IRR of 21% and a payback period of 3.40 years, the solar-assisted system outperformed the insulation, which had an IRR of 10% and a payback period of 6.2 years. A total of 279,225 liters of liquid fertilizer is produced annually, bringing in NRs. 27,92,250. The solar system reduces emissions by 32.42 tones CO2-equivalent annually and produces a 20-year cumulative net benefit of NRs. 5,83,32,201 when combined with GHG credits. Implementing waste-to-energy at the ward level provides Nepal's urban resource management with a viable and expandable strategy.

CONTENTS

ABSTRACT 2

list of figures.......... 5

List of Tables.......... 6

ACRONYMS AND ABBREVIATIONS 7

CHAPTER ONE: INTRODUCTION.......... 8

CHAPTER TWO: OBJECTIVES 17

2.1 Problem Statement 17

2.2 Main Objectives 17

2.3 Specific Objectives 17

CHAPTER THREE: LITERATURE REVIEW 19

3.1 Urban Solid Waste as Renewable Energy 19

3.2 Waste Matters: Generation from Cities 22

3.3 Effects of Waste and Measures for Mitigation in Urban Areas 29

3.4 Characteristics and Challenges in MSW Management.......... 35

3.5 Anaerobic Digestion (AD) for Biogas Generation.......... 41

3.6 Biogas Digester Heating Technologies 67

3.7 Organic liquid fertilizer.......... 70

3.8 Research Gap and Study Rationale.......... 83

CHAPTER FOUR: METHODOLOGY.......... 85

4.1 Research Design and Framework.......... 85

.4.2 Methodology Framework.......... 86

4.3 Sample Size Determination 86

4.5 Research Methods.......... 87

4.6 Research tools 87

4.7 Methodology — Calculations, Design, and Testing 88

4.8 Study Approach 90

CHAPTER FIVE: FINDINGS AND ANALYSIS 93

5.1 Waste Generation and Characterization.......... 93

5.1.1 Waste Composition Analysis.......... 93

5.1.2 Biogas Production Potential.......... 97

5.2 Thermal Management and Energy Analysis.......... 97

5.2.1 Heat Requirement Calculations.......... 98

5.2.2 Scenario 0 — Conventional Unmodified Digester (Baseline).......... 99

5.2.3 Scenario 1 — Sawdust Insulation System 99
5.2.4 Scenario 2 — Solar Water Heating System 101
5.3 Liquid Fertilizer Analysis and Production 104
5.4 Financial Analysis 106
5.5 Environmental Impact: GHG Emission Reduction 109
CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS 111
6.1 Conclusions 111
6.2 Key Findings Summary 112
6.3 Recommendations 112
REFERENCES 115
APPENDIX A: WASTE SURVEY DATA SUMMARY 119
APPENDIX B: FINANCIAL CALCULATION WORKSHEETS 126
APPENDIX C: TECHNICAL DESIGN SPECIFICATIONS 136
C.1 Biogas Digester Design 136
C.2 Solar Water Heating System Components 137
C.3 Biogas yield for 32 m^3 digester 137
C.4 Designs for optimization 139
C.5 Solar Water Heater Design Calculation 141

LIST OF FIGURES

Figure 1Waste causing pollution 10

Figure 2WASTE SCATTER AT STREET.......... 10

Figure 3 Generation of various wastes and their mitigation into value-added products by different approaches. 23

Figure 4 Flow chart of waste matter management with the benefit of keeping the city clean....... 26

Figure 5 PLASTIC WASTE IN CITIES FOR THE RECYCLING PROCESS. 28

Figure 6Different biowastes in the city are converted by effective pretreatments.......... 41

Figure 7anaerobic digestion process integrated with the composting process completing bio waste utilization into value-added products.......... 43

Figure 8WORKING OF BIOGAS PLANT 52

Figure 9 BIO DIGESTER WITH SOLAR 54

Figure 10different value-added products from generated wastes in the city and various pretreatment processes applied to waste conversion into valuable products. 81

Figure 11 biogas digester structure studied.......... 85

Figure 12 waste composition of ward no 8.......... 94

Figure 13 Detailed waste characterization analysis 95

Figure 14 temperature profile of lalitpur.......... 98

Figure 15 liquid fertilizer analysis 106

Figure 16finaicial sustainability with solar water heater 107

Figure 17NPV cash flow.......... 108

Figure 18financial comparison of solar water heating and insulation method 109

Figure 19 environmental impact analysis 110

Figure 20 bio digester design.......... 136

Figure 21: orientation of waste segregation in MRF CENTER FOR FIELD SURVEYERS...... 148

Figure 22 SURVEY FORM.......... 149

LIST OF TABLES

Table 1 Biogas composition..56

Table 2 Gas production potential of various types of dung 60

Table 3 C/N Ratio of Some raw Materials..62

Table 4 Toxic level of various inhibitor..65

Table 5 Inhibiting Concentration of different inhibitors..66

Table 6 HOUSE CATEGORY WISE WASTE DISAGGREGATE 96

Table 7 surveyed house category.. **Error! Bookmark not defined.**

Table 8 waste composition and CN ratio comparison 97

Table 9 Household survey of waste collection of 111 houses 119

ACRONYMS AND ABBREVIATIONS

AEPC	Alternative Energy Promotion Centre
BSP	Biogas Support Program
NRREP	National Rural and Renewable Energy Program
CBS	Central Bureau of Statistics
CDM	Clean Development Mechanism
CER	Certified Emission Reduction Certificates
GHG	Greenhouse Gas
GoN	Government of Nepal
Kg	Kilogram
LSMC	Lalitpur Sub Metropolitan City
IRR	Internal Rate of Return
MSW	Municipal Solid Waste
NPK	Nitrogen-Phosphorus-Potassium
TOE	Tons of Oil Equivalents
WtE	Waste-to-Energy
Yr	Year

CHAPTER ONE: INTRODUCTION

1.1 Background

Energy system planners and managers experience major issues in numerous environments due to the variable availability of renewable energy resources. Thoroughly and effectively addressing this issue has become a crucial responsibility for energy authorities. Inadequate planning and management of renewable energy resources by relevant authorities causes major problems in energy systems. Now a day, citizens in every region aspire to live in smart, sustainable cities with reliable access to clean and efficient energy systems. It is widely recognized that renewable energy resources, such as biomass derived from municipal solid waste (MSW), are valuable for energy production. However, challenges have been reported in the effective planning and management of these renewable energy resources to ensure sustainable energy systems. Separating the biomass fraction (as a crucial step) from other municipal solid waste (MSW) components is crucial because doing so could substantially boost the use of biomass for the production of renewable energy in both developed and developing nations across the globe. Anaerobic digestion, bioethanol fermentation, and incineration-based waste-to-energy systems are three market-ready technologies for turning biomass from municipal solid waste (MSW) into energy.

Aside from its major hydropower sector, Nepal has significant renewable source such as solar, wind, biomass, micro hydro and geothermal. Despite this significant potential the country renewable energy is hampered by the number of obstacles, including outdated technologies, limited financial access, legislative difficulties, and poor infrastructure. Current national policies and strategic loans have the highlighted the spread of renewable energy to support sustainable development goals and energy security, however, their effective implementation remains hampered by the institution and technical barrios. This study recommends the strengthen the climate and energy financing mechanism improving the collaboration with the international donors. Promoting public private partnership (PPP) with the local governments and encouraging the use of clean energy technologies. These steps are seen critical from accelerating Nepal's transition to sustainable and resilient energy system. (Aatiz, 2023)

Solid waste management is a major issue in Nepal, with increasing amounts of waste and inadequate efforts to manage it sustainably and in an environmentally-friendly manner. The federal government is involved in waste management, but significant challenges remain due to mixed waste, inadequate collection, insufficient recycling efforts, and limited public awareness. The amount of rubbish that must be dumped in landfills grows when different kinds of waste are mixed together. Methane gas, which is more than 25 times more potent than carbon dioxide and contributes to climate change, is released when organic waste that ends up in landfills breaks down without oxygen. The management authorities in Nepal have not done enough to comprehend and implement large-scale recovery of materials and energy from municipal solid trash, despite the fact that many other nations are extracting valuable resources and energy from solid waste.

The production of waste materials, for which no comprehensive solution exists, is an inherent aspect of human activity, though mitigation strategies are available. The amount of waste produced has increased dramatically as the world's population expands and the need for food and other necessities rises. Due to the increase in waste output, resource scarcity, pollution, and public awareness of environmental issues, it is now necessary to investigate treatment options other than traditional land disposal. There are now several ways to manage municipal solid waste, among them landfilling, incineration, composting, and biofuel production are the major approached. The selection of these options depends on technical and economic considerations. Municipal solid waste is dumped in outengineered landfills, which are known to produce greenhouse gasses, in many developing nations. On the other hand, because they must use garbage as a resource and adhere to strict environmental restrictions, industrialized countries frequently use sophisticated techniques like controlled incineration and biofuel production.

The ongoing energy crisis has significantly hindered socioeconomic development. The energy sector is a critical and essential component for advancing a country's development initiatives. In Nepal, the energy sector relies heavily on traditional biomass fuel sources, such as fuelwood, cattle dung, and agricultural or crop residues. Natural forest resources are being depleted and productive land is being degraded by the widespread use of fuelwood, and their availability is decreasing in comparison to the demands of an expanding population. Millions of people currently struggle with energy access, pricing, and supply reliability. Enterprises are similarly affected by this state of energy poverty. Energy development has predominantly focused on large-scale infrastructure and urban populations, with energy poverty rarely serving as a primary consideration in national policy development. Consequently, domestic small-scale renewable energy (RE) solutions for cooking, heating, and small and medium enterprises (SMEs), particularly in rural, peri-urban, and metropolitan areas, have received limited attention and support.

FIGURE 1WASTE CAUSING POLLUTION

FIGURE 2WASTE SCATTER AT STREET

The Federal Democratic Republic of Nepal is among the highest consumers of traditional biomass energy in South Asia, with over 86% of its total energy supply derived from traditional biomass fuel sources due to their natural availability and affordability. The use of such fuels poses significant health risks to women and children, who are frequently exposed to harmful fumes in household kitchens. Additionally, the time and cost associated with collecting biomass fuels have become a substantial burden. Over 45% of Nepal's population, including approximately 70% of rural residents, lacks access to chemical fertilizers. Agricultural practices in Nepal predominantly rely on an integrated system that combines crop production with animal husbandry. The availability of sustainable, clean, and reliable energy sources is a critical driver of development, as no country in modern times has significantly alleviated poverty without substantially increasing its energy consumption. In developing countries, there exists an opportunity to address energy poverty by adopting renewable energy (RE) solutions, particularly in areas without access to fossil fuel energy resources.

Rapid urbanization, rising living standards, and shifting consumer habits all contribute to an increase in solid waste, a byproduct of human activity. In many cities in emerging nations, controlling the increasing amount of solid garbage has become a major concern. Waste can be a valuable resource when used appropriately, but poor management can have detrimental effects on the environment and public health. As a result, solid waste management is an essential part of urban sanitation and one of the most significant and resource-intensive services that local governments offer. Solid waste management is the top environmental problem in Nepal's city centers, according to a poll done by the country's Central Bureau of Statistics (CBS).

Currently, municipalities in Nepal are allocating substantial funds to transport solid waste to landfill sites. Nepal comprises 753 local governments with varying population sizes and living standards, resulting in diverse municipal solid waste (MSW) generation across the country. The increasing volume of solid waste reduces the lifespan of existing landfills, necessitating plans for new landfill sites and increasing the costs associated with waste transportation.

With its limited resources and capabilities, LSMC at present has been able to collect nearly 90 tons/day, while the remaining 15 tons are somehow managed by private sectors and at individual levels (source: LSMC). Once cubic meter of biogas saves, on average, 375 kg of firewood and 6 liters of kerosene.

The goal of this project is to generate clean, renewable energy from organic biodegradable trash utilizing bio digesters, as well as to develop an efficient and cost-effective approach for maximizing waste usage by transforming the resulting slurry into liquid fertilizer. Several factors influence biogas plant performance, with temperature being a major component determining biological activity within the digester and, as a result, biogas output. The manure remaining after optimized biogas production will be processed into liquid fertilizer, which, following rigorous testing, will be marketed for commercial use. Currently, Nepal's fertilizer market is heavily reliant on imports from foreign countries. By adopting this idea, dependency on imported fertilizers can be minimized, therefore improving agricultural cultivation and assisting Nepalese farmers.

Current strategies for reducing heat losses and maintaining optimal temperatures in biogas digesters in Nepal and other developing countries include building biogas plants underground, which helps buffer against sharp temperature fluctuations, and placing plants in areas that receive direct solar radiation. However, biogas facilities frequently operate in the psychrophilic range (temperatures below 20°C), especially during the winter and at night. This leads to prolonged hydraulic retention durations and reduced biogas output. This would allow for smaller active slurry quantities, resulting in more compact biogas plant designs and potentially lower capital costs. While the addition of heating equipment may somewhat offset these savings, constant, increasing gas output throughout the year would give significant benefits to customers. Higher operating temperatures would also aid in pathogen elimination, producing a safer slurry for use as liquid fertilizer.

Several options are available to achieve higher digestion temperatures. In systems where biogas is used for electricity production, recovering waste heat from the engine offers a viable solution. This can be accomplished through an external heat exchanger, where sludge is circulated and heated by engine cooling water, or through an internal coil heat exchanger, where the cooling water transfers heat directly to the digester's contents. For systems where biogas is not used for electricity generation, solar panels that heat water for circulation through an external or internal heat exchanger provide a suitable alternative. Additional options include preheating the digester feed, enhancing insulation, or using a portion of the produced biogas to heat water, which can then transfer heat to the sludge.

This research is innovative because it takes an innovation approach to incorporating renewable energy into Nepal's expanding urban areas, namely by turning municipal bio-waste into energy and liquid fertilizer. In order to position organic waste streams produced in Nepalese towns as dependable substrates for the production of renewable energy, the study presents a thorough model that places an emphasis on their value. This method emphasizes the tight relationship between waste-to-energy conversion and sustainable urban management in a context where poor garbage disposal has resulted in major environmental, social, and public health problems.
The article outlines a forward-thinking strategy for Nepal to improve energy security, resource efficiency, and environmental resilience by integrating bio-waste use with smart city development activities. This study focuses on the sustainable management of municipal organic waste, investigates waste-to-energy efforts that are already underway in Nepal, and examines the negative consequences of uncontrolled disposal--ranging from pollution to public health risks--that impede the vision of building smart and sustainable cities.

1.2 Study Area Selection Rationale

Ward No. 8 of Lalitpur Sub-Metropolitan City (LSMC) was selected as the study area based on the following specific criteria:

- Existing MRF Infrastructure: The Ward is located to a well-established Material Recovery Facility (MRF) at Chyasal, which offers the primary sorting and collection infrastructure required to deliver separated organic waste to a biogas digester without adding to the expense of logistics.
- High Organic Fraction: Preliminary interviews with LSMC ward officials and earlier waste characterization studies in the Lalitpur valley reveal that the Chyasal residential zone consistently generates organic waste fractions greater than 65% of total MSW, indicating that it is a high-quality feedstock zone.
- Representative Urban Residential Profile: Ward 8 is notably residential, with about 2,550 registered households (LSMC Ward Office / CBS National Population and Housing Census 2021) and a population of around 12,639 individuals. This scale is large enough to sustain a prototype system with many digesters while remaining compact enough to obtain extensive primary data.
- Accessible Pilot Site: Chyasal has accessible open public land adjacent to the MRF that can accommodate one 35 m^3 pilot digester on government-owned land (land cost excluded from analysis per project scope).
- Community Interest: The LSMC Ward 8 ward committee stated an intention to participate in the survey and give access to garbage collection data, hence facilitating primary collection of data.

Other wards in LSMC were evaluated but deemed less suitable: Ward 1 (industrial region with high inorganic fraction), Ward 3 (ongoing vermicomposting project), and Ward 15 (insufficient MRF access). Ward 8 provided the optimum balance of organic feedstock quality, infrastructural readiness, and community accessibility.

1.3 Scope of the Study

This study is explicitly limited to household-generated organic waste from Ward No. 8 of LSMC. The scope excludes waste from commercial establishments (restaurants, hotels, cafes), educational institutions (schools, colleges), and other non-residential sources within the same ward, for the following reasons:

- Compositional Difference: Commercial food operations produce waste with high grease and protein content (C:N ratio ~10-15:1), requiring pre-treatment before anaerobic digestion. Household kitchen waste has a C:N ratio of about 25:1, which is within the ideal mesophilic AD range of 20-30:1, and requires no adjustment.
- Collection Logistics: Commercial establishments generate variable amounts of revenue during business hours. Integrating them would necessitate separate collecting routes and storage, which are not within the operational scope of this pilot research.
- Conservative Baseline: Using home garbage provides a credible lower-bound estimate of feedstock. Non-household garbage could be included in future expansion phases.
- • Ward 8 has a total of 2,550 registered households (source: CBS National Census 2021, LSMC Ward 8 Office). The average household size is 4.95 persons (CBS 2021). The biogas digester presented in this study is specifically built for household organic waste from this registered household base.

Part I: Determination of Potential of Biogas from Household Waste of Lalitpur SMC Ward 8

- Quantification of household waste production through systematic field survey of 111 households.
- Determination of the MSW organic fraction from the survey sample.
- Analysis of the anaerobically digestible fraction from the organic fraction.
- Assessment of the potential of biogas energy from household waste fractions.

1.4 Limitation of the Study

- The land cost is not included in the study because it is assumed to be government-owned (next to the current MRF in Ward 8 Chyasal).
- The project utilizes existing MRF collecting infrastructure, therefore waste transportation costs from residences to the MRF/digester site are not included.
- The AEPC empirical conversion factor of 0.35 m^3 biogas per kilogram VS is used to calculate biogas yield in Nepal, as validated in the field. This element is essentially responsible for practical conversion efficiencies of 55-65% under mesophilic environments.
- Commercial and institutional waste generators within Ward 8 are excluded from the feedstock calculation
- Climate Dependency: The solar water heating method depends on solar radiation availability. Seasonal and daily variability has been accounted for through storage tank sizing and identification of a backup electric heater requirement during December–February.
- Waste Composition and Contamination: Potential contaminants (detergents, heavy metals) in the municipal waste stream are acknowledged. The study assumes feedstock quality consistent with the analyzed survey samples. Pre-screening at the MRF is recommended for pilot implementation.
- Data Constraints: Waste generation assessment is based on a 111-household, 2-day survey per household, which may not capture seasonal variation. Daily waste generation can vary by ±15–20% across seasons.
- The financial analysis assumes constant revenue streams and operational costs over 20 years; inflation-adjusted analysis is recommended for detailed project financing.

CHAPTER TWO: OBJECTIVES

2.1 PROBLEM STATEMENT

The research issue statement focuses on the challenges created by inadequate planning and management of renewable energy sources, notably biomass obtained from municipal solid waste (MSW) in urban contexts. It concentrates on how the inconsistent availability of these resources harms the environment, causes inefficiencies in the power system, and impedes sustainable urban growth. Inadequate waste disposal in Nepal exacerbates environmental degradation, social difficulties, and public health risks while reducing prospects for resource efficiency and energy security through waste-to-energy conversion. To be in line with smart city goals and lessen the negative impacts of unmanaged waste disposal, a techno-economic examination of cutting-edge technologies—such as insulated solar-heated biogas digesters that convert municipal bio-waste into electricity and liquid fertilizer—is necessary.

2.2 MAIN OBJECTIVES

This project's primary goal is to investigate the techno-economic viability of the waste-to-energy potential by analyzing the total amount of waste produced, optimizing the bio digester to maintain a mesophilic temperature using solar heating technology and adequate insulation, and estimating its specifics to identify the liquid fertilizer with the highest nutrients and the fewest harmful gases.

2.3 SPECIFIC OBJECTIVES

The other general objectives are listed as below:

- To study of the existing waste generation and existing management of wastes.
- To study of the composition of the waste of ward no.8 of Lalitpur Metropolitan city.
- To Analyze techno-economic feasibility of the waste using various Waste to energy approach.

- To predict the future scenario of energy and fertilizer which we can achieve with proper planning.

CHAPTER THREE: LITERATURE REVIEW

3.1 URBAN SOLID WASTE AS RENEWABLE ENERGY

All solid waste produced in a municipal area, with the exception of industrial and agricultural wastes, demolition and construction debris, and other unique wastes that stream, is referred to as municipal solid waste (MSW). Products, grass clippings, furniture, clothes, bottles, food scraps, newspapers, appliances, plastics, paint, and batteries are all examples of MS. Medical, commercial, industrial, and radioactive wastes are excluded because they need to be handled differently. Products, grass clippings, furniture, clothes, bottles, food scraps, newspapers, appliances, plastics, paint, and batteries are all examples of MS. Medical, commercial, industrial, and radioactive wastes are excluded because they need to be handled differently (US Environment Protection Agency).

Methane's chemical makeup was determined by Dalton, Henry, and Davy between 1804 and 1810; they also demonstrated that methane was formed from decaying cow dung and that coal gas was remarkably similar to Volta's marsh gas. Regarding the anaerobic treatment of the particles floating in wastewater, France is recognized for having produced one of the first major contributions. Gayon, a Pasteur student, produced 100 liters of methane per m of manure by fermenting it at 35°C in 1884. It was determined that fermentation may provide gas for lighting and warmth. The discovery that methanogenesis was linked to microbial activity did not occur until the late 1800s.

Bechamp gave the "organism" that produces methane 7 from ethanol a name in 1868.Bechamp was able to demonstrate that distinct fermentation products were produced based on the substrate, suggesting that this organism had a mixed population. The stoichiometric conversion of acetate in sewage sludge to equal volumes of carbon dioxide and methane was documented by Herter in 1876 (Manik Desai, 1994)

Rapid urbanization and population growth have exaggerated the necessity for adequate solid waste management throughout the world. In order to minimize the risk to the environment and human health, economically feasible solutions are sought for the treatment of solid waste, particularly in urban areas of low- and middle-income countries (Ahirwar, 2021)

In order to increase plant sustainability and efficiency, recent developments in waste-to-energy technology have focused on integrating renewable energy systems. In order to increase electricity output and system performance, research on a solar-assisted municipal solid waste (MSW) incineration plant suggested combining a solar thermal system with a traditional waste-to-energy facility to superheat steam before to expansion in the steam turbine. The system also included waste heat recovery using an organic Rankine cycle (ORC) to produce freshwater by reverse osmosis and hydrogen via proton exchange membrane electrolysis, all while creating extra power. The combined system obtained energy and exergy efficiencies of 21.34% and 16.64%, respectively, according to thermodynamic analysis, but the incinerator subsystem demonstrated thermal and exergy efficiencies of 37.35% and 35.22%. (Muhammad Sajid Khan, 2022)

Globally, the necessity for proper solid waste management has increased due to rapid urbanization and population expansion. Economically viable methods are sought for solid waste treatment, especially in the urban centers of low- and middle-income nations, to reduce the danger to human health and the environment (Riuji, 2009).

In the traditional sense, renewable sources of energy are those that nature can regrow, such as wood, crops, or other plants (biomass), that are available through the Earth's unique physical set-up, such as wind, water, and solar radiation. However, the term biomass often includes one manmade good that is thee byproduct of industrialization: waste. The U.S. EPA repeatedly called MSW renewable. Although it is desirable to minimize the amount of waste during production and distribution of goods, it is believed that the global community will continue to produce industrial product, there will be a continuous stream of new waste, which therefore could be considered to replenish the previous generated garbage. Although the overall sustainability depends on plant configuration and the local energy mix, a comparative life cycle assessment of bio methane production pathways found that the syngas extraction route typically provides higher carbon utilization and better environmental performance than the conventional anaerobic digestion pathway. (Filomena Ardolino and Umberto Arena, 2019)

Brémond et al. found that fungal solid-state fermentation is unsuitable as a post-treatment for solid digestate due to significant methane potential losses, whereas thermo-alkaline treatment increased methane yield by 13% and reduced complex organic matter by 25%, improving the feasibility of digestate recirculation in agricultural biogas plants. (Ulysse Brémonda, 2020)

Technologies for converting waste into energy

Solid waste may be converted into energy in a number of ways. Physical conversion, biological conversion, and thermal conversion are the three basic categories into which they can be separated.

The previous approaches of the environmental effects of several waste-treatment scenarios in Nepal's Dhulikhel Municipality using the life-cycle assessment (LCA) method. The assessment was based on four unique scenarios: scenario one involved landfilling; scenario two included composting in addition to landfilling; scenario three involved recycling, composting, and landfilling; and scenario four involved recycling, anaerobic digestion, and landfilling. The LCA technique was created by taking into consideration emissions from energy use, as well as the benefits and potential consequences of numerous unit operations in each scenario. (Bajracharya, 2022)

Refuse-derived fuel (RDF) pellets, also known as solid recovered fuel (SRF), are produced by physical conversion, which involves physical processing such as grinding, pressing, mixing, and dying. The MSW is burned during thermal conversion to produce valuable goods like heat and flammable gasses. It includes a wide variety of processes, such as gasification, pyrolysis, incineration, and plasma arc technology. Anaerobic digestion and landfill gas capture are used in the biological treatment process to produce biogas, a flammable gas.

Worldwide, Waste to Energy conversion technology is regarded as the most successful and efficient method of managing solid waste. The WTE capacity grew by almost four million metric tons annually between 2001 and 2007.China and Japan constructed a number of facilities based on fluid bed combustion or direct smelting of solid waste. There are around 50 WTE factories in China. With 40 million tons, Japan is the world's largest consumer of thermal treatment for MSW.A Greek business just completed testing a promising technology in Patras, Greece. It uses the waste water to produce 25kW of heat and 25kW of power. In order to lower the nation's greenhouse gas emissions, India established its first energy bioscience center. (www.wikipedia.org)

Some WTE methods have been studied in Nepal, mostly for the production of fuel briquettes from MS. The MSW of Kathmandu is very appropriate for the manufacturing of fuel briquettes, according to (H.D. Sharma, 1995)., who have conducted some research in this area. Fuel briquettes may be made from a variety of waste materials (H.D. Sharma, 1995). Based a calorific value of 19.3 MJ/kg, the fuel briquettes that were manufactured are of good quality, have a higher compressive strength, are sufficiently hard to withstand wear and tear, and are easy to burn (H.D. Sharma, 1995).

Biogas is utilized as energy for cooking and lighting in Nepal and is produced from kitchen trash, vegetable leftovers, and waste from slaughterhouses (BSP-Nepal, 2026).. The creation of biogas from garbage generated in residential areas attracts a lot of people. In Nepal, digesters up to 300 m³ have been built, with a daily feed capacity of 1.8 tons (BSP-Nepal, 2026)).. Incinerators are employed to eliminate hazardous waste in many hospitals in Nepal, but no energy is recovered from them (T.U. Teaching Hospital, 2009).

3.2 WASTE MATTERS: GENERATION FROM CITIES

Urban areas are producing more waste than ever before, placing the pressure on existing collection and disposal systems. The average amount of MSW generated per person per day increased significantly from 4.5 pounds per person per day in 2017 to 4.9 pounds per person per day in 2018 (Sutcu, 2023) .In recent years, the total amount of MSW generated has increased to 292.4 million tons, which is 208 million tons more than in 1990 and 23.7 million tons more than in 2017.

Plans for municipal management are being strained by these increasing garbage quantities, which calls for creative solutions. Converting food waste into renewable fuels is one of the sustainable waste management solutions suggested by the Environmental Protection Agency (EPA)) (Mansikkasalo, 2014) (Sutcu, 2023). The various waste kinds produced in metropolitan areas are depicted in Figure 1, which also highlights important sources that contribute to the MSW stream.

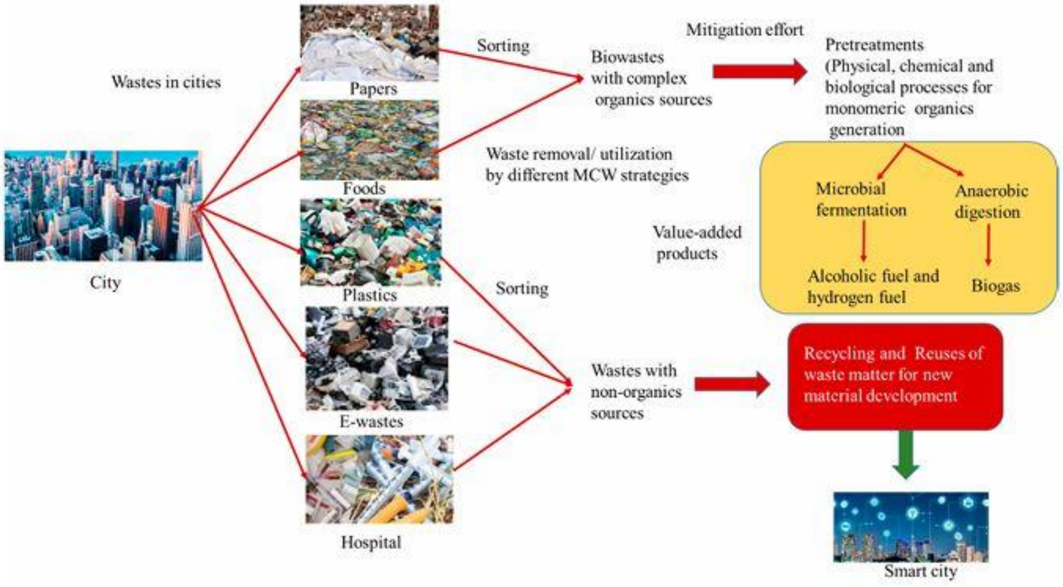

FIGURE 3 GENERATION OF VARIOUS WASTES AND THEIR MITIGATION INTO VALUE-ADDED PRODUCTS BY DIFFERENT APPROACHES.

FOOD WASTE

Hostels, restaurants, food sellers, schools, and fruit and vegetable stores all contribute significantly to the amount of food waste generated in urban areas, making efficient waste management essential to the upkeep of sustainable and clean communities. Food waste made up 63.1 million tons, or 21.6% of all MSW in 2018, making it the fourth highest MSW category (Sinha, 2021). The figure is particularly relevant to Nepal because this shows the overall status of the urban cities issue. Nepal can be the example county if the issue of disposal of urban food waste is solved gaining the carbon credit and relevant income from biogas and liquid fertilizer. The Cities across the world are a major source of food waste, which is frequently disposed of in landfills or treated using chemical and biological techniques to lessen its negative effects on the environment (Dhulia, 2025). By converting food waste into sustainable energy, these techniques improve urban sustainability.

Although they are still widely used in underdeveloped nations, traditional management techniques like composting and landfilling are unsustainable because of pollution, smells, and harmful gas emissions (Salimi, 2021). Food waste valorization research has produced bioethanol, biodiesel, and biogas as green fuel possibilities as a result of stricter laws and the need for renewable fuels [(Sridhar, n.d.)]. Value-added chemical manufacturing is also aided by advanced green technologies; in nations like India, first-generation fuel production from food waste processing is becoming more popular (Sridhar, n.d.) (Salimi, 2021). Food waste management now prioritizes anaerobic digestion and chemical generation for sustainable fuel and product synthesis, moving away from linear to circular bioeconomy models (Thapa, 2019).

Approximately 3 billion people depend on food on a daily basis, yet 1.3 billion tons of food—roughly one-third of global production—are wasted each year, costing an estimated USD 750 billion (Lahiri, 2023).This is a serious problem for the world.61% of food waste comes from homes, 26% from food services, and 13% from retail, according to the FAO, which claims 931 million tons of food waste annually, or 17% of the world's food output (Panahi, 2022; (Al-Rumaihi A. a.-A., 2020) 2020; Lahiri, 2023).According to the UNEP Food Waste Index Report (2021), household waste in the United States is 59 kg, while in China it is 64 kg. The total annual estimates are 19 million tons in the United States and 91 million tons in China (Matsakas, 2014) (Al-Rumaihi A. a.-A., 2020).

As per National Resources Defense Council, 40% of food in the United States is wasted, which adds to the 1.3 billion tons of food wasted annually worldwide (Al-Rumaihi A. a.-A., 2020) (Matsakas, 2014). According to the UN Hunger Report, eradicating food waste could provide food for the 811 million hungry people worldwide, highlighting the need for better waste management to solve environmental issues and world hunger (Panahi, 2022).

PAPER AND PAPERBOARD WASTES

With 67.4 million tons, or 23.1% of all municipal solid waste (MSW) in 2018, paper and paperboard made up the biggest portion of MSW (Tang, 2008) (Zhang W. D., 2015).These materials, which are categorized as nondurable commodities, are mostly used for packaging and containers, such as bags, corrugated boxes, paper plates and cups, office paper, tissue paper, and milk cartons (Tang, 2008).The importance of post-consumer paper and paperboard as organic waste sources was highlighted by the American Forest and Paper Association's (AFandPA) 2018 estimation of post-consumer paper and paperboard generation (Zhang W. D., 2015).

Paper and paperboard recycling rates were very high, with 46 million tons recycled, earning the best recycling rate of any MSW material (68.2%) (Zhang W. D., 2015) (Tang, 2008). Paper items (not including newspapers) had a recycling rate of 43% among nondurable goods, whereas newspapers had a rate of 65% (Danial, 2015; Vieira, 2016). Corrugated boxes had a remarkable 96.5% recycling rate among packaging materials, whereas other paper containers only had a 21% rate. Reusing ingredients for new products and reducing waste are two benefits of recycling these organic materials.

While 17.2 million tons (11.8% of all MSW landfilled) were dumped in landfills in 2018, 4.2 million tons (12%) of paper and paperboard trash were burned (Cobirzan, 2018) (Rahman, 2014). From 2000 to 2018, the number of newspapers produced decreased significantly, from 87.7 million tons to 67.4 million tons (Rahman, 2014) (Bilek, 2021). The waste management process in metropolitan settings is depicted in Figure 2, with a focus on options to reduce waste through the synthesis of useful products.

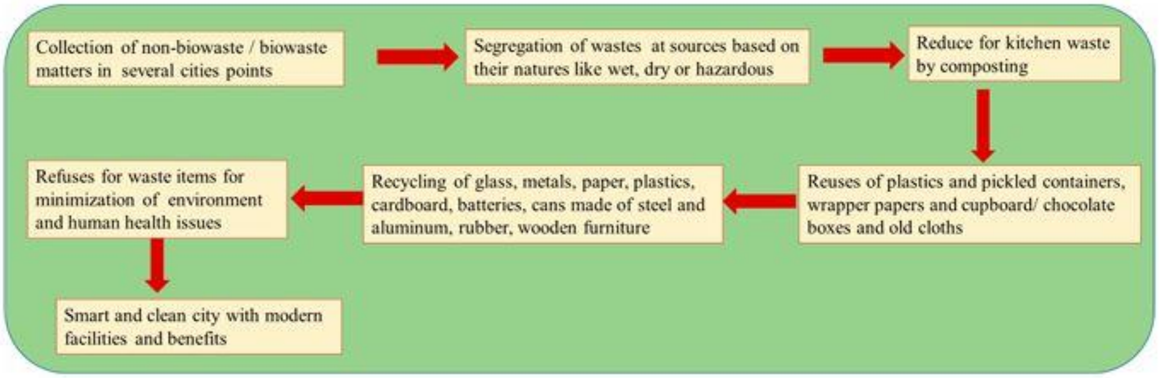

FIGURE 4 FLOW CHART OF WASTE MATTER MANAGEMENT WITH THE BENEFIT OF KEEPING THE CITY CLEAN

PARKS/YARDS-BASED GREEN WASTES

It refers to stable carbon sources and forms. By storing carbon, this type of garden waste can improve soil fertility (Dhulia, 2025).(Mishra, 2021).For gardens and farms, shreds and leaves can be utilized as mulching materials. Mulch material use can save labor costs and weed growth. Mulch materials can be added to soils to assist retain moisture and replenish nutrients lost via evaporation (Capodaglio, 2013).

Additional advantages of mulching the soil include promoting the development of advantageous soil bacteria for the growth of plants and vegetation in a healthy, productive manner (Ganguly, 2021). (Capodaglio, 2013). Some problems are discovered as a result of the disposal of garden trash, which might allow alien species to proliferate into remains of forests. The introduction of seeds and propagules found in garden trash may be the cause of this. Here are some selection factors that local gardeners use when choosing plants for their home gardens. These criteria may include novelty, ease of propagation, and compatibility for the local environment (Yazid, 2017).

By causing concerns like dumping, some traits make it more likely that plant pieces and seeds may be introduced into wooded regions. An urban area may occasionally be surrounded by natural reserves where garden waste is dumped, which raises the risk of fire (Capodaglio, 2013) (Yazid, 2017).In the current era of smart city development, it is necessary to use the dried-out garden wastes that have been discarded, as they may be used to create fuel in addition to the debris fuel loads that have already fallen and have a high risk of a fire spreading and thriving (Zhang, 2015).

Additionally, problems caused by gardening waste may manifest as the proliferation of weeds, which raises the possibility of creating fire fuel. By suffocating native flora, discarded garden debris can accelerate erosion (Abdullah, 2016). Garden trash can occasionally contribute significant amounts of silt, which can cause streams and other waterways to become silted. Garden waste in Pune, India, may produce between 60 and 70 MT per day. It is gathered by a collection system, which then shreds it and transports it to a centralized processing system where the fuel sources are recovered (Banerjee, 2021; Abdullah, 2016; Zhang, 2015).

PLASTIC WASTES

The amount of plastic garbage in urban MSW increased by 4.5 million tons from 2010 to 35.7 million tons in 2018, accounting for 12.2% of all MSW (Evode, 2021). The increasing usage of plastic packaging and durable products caused plastic trash to increase from 8.2% to 12.2% of MSW in comparison to 1990.Due to a greater reliance on items wrapped in plastic, the percentage of plastic trash rose to 13.2% between 2010 and 2018 (Gu, 2021).(Evode, 2021).

For sustainable urban growth, plastic waste management must be done well. Recycling programs make it possible to convert plastic trash into filler materials for ropes, cement blocks, and domestic goods like mats and baskets, hence promoting economic activity and development in smart cities (Ali, 2021). In addition to creating income and lowering waste, extensive recycling of textiles and plastics helps produce apparel and furnishings (Noor, 2022). (Liang, 2021).

Communities in India are encouraged to repurpose plastics for items like shoes, clothes, and building materials for roads through incentivized plastic collecting initiatives (Yadav, 2020). According to Andeobu (2021), effective plastic waste management necessitates methodical planning that begin at the home level and are backed by educational and motivating tactics to change consumer behavior toward sustainable packaging methods (Yadav, 2020). The recycling procedures for creating new materials from plastic waste are shown in Figure 3.

FIGURE 5 PLASTIC WASTE IN CITIES FOR THE RECYCLING PROCESS.

OTHER WASTES

In 2018, 2.7 million tons, or 1% of all MSW, originated from electronic garbage (e-waste), which includes consumer devices such TVs, DVD players, VCRs, video cameras, stereo systems, phones, and computer equipment (Monika, 2010) (Garg, 2023).Over the last four years, the quantity of electronic waste collected and processed in India has tripled; yet, 95% of this garbage is still handled by the unorganized sector, frequently using unregulated techniques by waste pickers known as Kabadiwalas (Rautela, 2021) (Ananno, 2021).These methods, which include crude burning and recycling, emit harmful chemicals that pose serious threats to human health and the environment (Ananno, 2021) (Vijayan, 2023).To avoid damage, e-waste should be kept out of landfills and unofficial recycling facilities.

With yearly production of over 3.23 million tons, the US, China, and India are the world's top manufacturers of electronic waste (Garg, 2023) (Ananno, 2021).E-waste creation increased from 0.71 million tons in 2018–2019 to 1.014 million tons in 2019–2020, representing a 31% yearly growth, and processing reached 0.34 million tons in 2020–2021 in India (Kumar, 2016).A 3% yearly increase in plastic garbage from e-waste was also reported by the Central Pollution Control Board (CPCB) (Kumar, 2016).In spite of 468 authorized recyclers and 2,808 collection points across 22 Indian cities handling 1.3 million tons of e-waste, capacity remains insufficient (Vijayan, 2023) (Kumar, 2016).Harmful fumes and tiny particles are released during improper processing, such as burning plastics or de-soldering to extract metals like gold and silver, which exacerbates health and environmental risks (Ananno, 2021).(Kumar, 2016).

3.3 EFFECTS OF WASTE AND MEASURES FOR MITIGATION IN URBAN AREAS

Urban areas are predicted to produce larger amounts of organic and inorganic garbage in the years to come, coming from a variety of sources, including homes, businesses, healthcare facilities, and educational institutions. Due to the leaching of hazardous materials, poorly managed trash—particularly electronic garbage, or "e-waste," that is dumped in landfills—poses serious threats to groundwater and surface water systems (Ahmed, 2022). Additionally, hazardous residues from uncontrolled e-waste recycling procedures frequently enter sewage networks and municipal drainage systems, contaminating neighboring water bodies.

The issue of plastic trash has also been brought up in relation to the pollution that enters rivers. In order to reduce environmental harm, organized plastic waste management techniques may be used at the individual and household levels (Kumar, 2016) (Ahmed, 2022). Case studies carried out in Jamaica City, for instance, show how neighborhood hygiene was promoted by local environmental wardens who taught locals safe and ecologically friendly garbage disposal techniques (Cayumil, 2021). World Bank-funded programs that promoted community health and sanitation and coordinated waste management awareness helped to support these activities (Vijayan, 2023) (Cayumil, 2021).

To support sustainable municipal development, particularly in the context of smart municipalities, there is a growing need for comprehensive municipal solid waste management systems. These systems should include robust waste collection, segregation, and disposal mechanisms, ensuring all types of waste are managed in an environmentally sound manner. Policy interventions—such as restrictions on the use or incineration of certain plastics—are essential for advancing eco-friendly waste governance (Rojas, 2018) (Rautela, 2021).

Comprehensive municipal solid waste management systems are becoming more and more necessary to promote sustainable urban growth, especially in the context of smart cities. To ensure that all waste kinds are managed in an ecologically responsible way, these systems should include strong trash collection, segregation, and disposal procedures. The advancement of environmentally friendly waste governance requires policy interventions, such as limitations on the use or incineration of specific plastics (Rojas, 2018), (Rautela, 2021).

Case Study: Plastic Waste Accumulation and Management Challenges

Between 2010 and 2017, the state of California had a significant 72% decrease in plastic litter along local coasts as a result of the installation of a ban on plastic materials. Bans of this kind, however, are not enough to fully address the larger problem of plastic mishandling. Due to a lack of strong waste management infrastructure and accompanying incentives, efforts to limit the use of plastic have frequently failed in different metropolitan areas (Gilbert, 2017). Low compliance rates, the rise of underground marketplaces, and ongoing plastic trash are some of the challenges that these projects usually encounter. Cities need supporting policy frameworks implemented by competent governmental institutions in addition to appropriate disposal methods in order to manage plastic trash (Singh, 2022).

Plastic garbage is expected to continue to be a major environmental problem in many urban areas in the future. The accumulation of plastic products, including bottles, packaging, and common consumer goods, continues to endanger public health, wildlife habitats, and urban ecosystems. Remarkably, through insufficient recycling efforts or direct environmental leakage, around three-quarters of the plastic manufactured has found its way into natural ecosystems, including seas (Gilbert, 2017) (Singh, 2022).

Plastic garbage is more likely to find its way into marine habitats in many low- and middle-income nations, where it harms aquatic life. Due in large part to their affordability and longevity, recent trends show an increasing reliance on plastic-based items, such as food packaging and beverage containers (Pannetier, 2019). However, these same qualities also add to the issue: plastics are very resistant to deterioration and can take 400 years or longer to decompose entirely. For waste management systems across the world, this persistence presents a serious long-term issue.

Growing amounts of plastic garbage are a result of both increased product consumption and fast population expansion in emerging nations. Aquatic ecosystems are at risk as a large portion of this garbage is dumped in unmanaged landfills or dumped straight into rivers and streams due to inadequate infrastructure for waste collection and processing (Cook, 2020). Rain and wind have the ability to move plastic from these locations into bodies of water, which can then be carried via river networks to the seas.

The international export of plastic garbage to poor countries from high-income regions like the US, Japan, and Europe is another issue. These exports frequently take place in spite of glaring disparities in recycling regulations, which might worsen environmental damage in the countries that receive them (Pannetier, 2019) (Cook, 2020). In places that lack the ability to appropriately handle such garbage, this discrepancy has resulted in serious ecological deterioration (DeWeerdt, 2021; Vinayagamoorthy, 2018; Szostak, 2021).

Furthermore, the amount of plastic garbage produced worldwide is too great for the recycling methods in place. Large amounts of plastic are still dumped in uncontrolled landfills in many poor nations. For instance, consumer packaging contributes to the annual production of almost 5 million tons of plastic garbage in the United Kingdom. About three-quarters of this amount is landfilled, and just a quarter is used for recycling (Szostak, 2021). (Asgher, 2020).

Global Trends in Urban Waste Generation

Due to major changes in urban living patterns, post-consumer trash output has more than quadrupled in cities globally in recent decades. Municipal solid waste (MSW) has increased exponentially since the 1980s, mostly due to fast population development, particularly in metropolitan areas. In many places, especially in Northern and Western Europe, this tendency is still going strong (Malinauskaite, 2017).

The average MSW generation in North America and Western Europe over the last ten years has been between 1.4 and 1.8 kilos per person per day. On the other hand, fast expanding cities in the Global South are already getting close to comparable levels, with MSW generation rates increasing to 1–1.4 kg/capita/day, mostly as a result of changes in consumption patterns and dense population clusters (Wang, 2027).

High levels of consumption and convenience-driven behaviors are hallmarks of urban living, which greatly increase trash quantities. Although households continue to be the biggest source of trash, the public and commercial sectors—particularly the food service industry, which mainly depends on throwaway packaging—also contribute significantly. The increasing popularity of eating while on the go has exacerbated this tendency, resulting in a proliferation of single-use goods being thrown out in public areas (Khanna, 2021).(Qureshi, 2020).

The amount of MSW generated per person worldwide doubled in just ten years, from 0.6 kg/day in 2002 to 1.2 kg/day in 2012. For instance, large cities in Africa show a wider range—from 0.3 to 1.4 kg/capita/day, depending on urban density and local infrastructure—than Brazil, where the national average MSW generation is expected to be 1.1 kg per person per day (Netzer, 2021).

There are notable differences in the rates of trash creation within and across nations. For example, the daily trash generation in Cameroon ranges from 0.8 kilogram per capita in other metropolitan regions to 0.5 kg per capita in Bamenda and Yaoundé. These differences are frequently associated with access to structured garbage collection systems, population density, and economic levels.

Research shows that MSW output and urban population size are strongly positively correlated. The amount of garbage produced rises proportionately with urbanization, placing strain on the current waste handling infrastructure. Additionally, more successful

MSW management results are typically associated with larger percentages of households participating in regular garbage collection programs (Asgher, 2020; Qureshi, 2020; Netzer, 2021).

Waste Generation and Urban Development Dynamics

In today's rapidly urbanizing world, the industrial production of consumer goods is marked by shorter product life cycles, a growing diversity of products, more complex material compositions, and increased reliance on packaging for safety and convenience. According to Zeng (2015), these advancements have had a major role in the increase in solid waste quantities as well as the discharge of pollutants into soil, water, and air systems.

Both urban growth and greater economic success are strongly correlated with the rise in the creation of municipal solid waste (MSW). For example, India's GDP increased by 7% annually between 1997 and 2007, but its MSW output increased by about 45% in the same time period, from 40 million tons to 70 million tons (Chanhthamixay, 2017). A similar pattern was seen in Brazil, where between 2009 and 2010, a 7.5% increase in GDP was accompanied by a 6.8% increase in MSW creation, highlighting the clear link between garbage production and income.

Waste creation is still becoming worse due to population increase and changing consumer trends. The wealthier parts of society, in particular, have a tendency to purchase more items, which increases environmental costs due to excessive trash creation (Zeng, 2015) (Chanhthamixay, 2017). A total of 509 million new customers, or families with an average purchasing power parity (PPP) of $10,000 USD annually, were added by nations like China, India, and Brazil between 1990 and 2000. Usually consisting of four people, these homes added up to a total purchasing power of almost $839 billion USD. Twenty countries, most of which were emerging or transitional economies, had PPP-adjusted incomes that were 1.3 to 5.3 times higher than regular exchange rate conversions (Patel, 2013).

Consumers often purchase more durable things like electronics, cars, home appliances, and other consumer goods when their disposable earnings increase. More packaged meals and meats are consumed as a result of this change in lifestyle, which raises waste levels

(Sukholthaman, 2017).At the moment, the amount and complexity of trash are increasing exponentially, and the types and compositions of the thrown products vary greatly (Liu, 2019).

Modern consumption patterns, which are marked by extensive packaging, shortened product lifespans, deliberate obsolescence, and the general logic of economic expansion and mass consumption, are primarily responsible for this tendency. When combined, these factors are speeding up the production of MSW in urban areas, which frequently results in the buildup of unmanageable amounts of solid waste that are difficult for cities to properly handle (Sukholthaman, 2017) (Liu, 2019).

Composition of Household Waste in Urban Areas

Cultural customs, technical developments, and local socioeconomic circumstances all have an impact on the composition of household garbage, which varies greatly between cities and regions. These variances are dynamic and alter over time, mirroring shifts in consumer habits, infrastructural advancement, and lifestyle (Blazquez, 2020).

Ash used to make up a sizable amount of household garbage in cities like those in North America, primarily from cooking and heating. Up to the middle of the 20th century, this was particularly true. But in the last few decades, home garbage in cities in the Global North has changed to include more recyclables and technological waste, which has led to a rise in the production of municipal solid waste (MSW) (Gautam, 2018).

These days, MSW usually has a higher percentage of organic material that decomposes naturally and a lower percentage of materials that cannot be recycled (Benson, 2021).(Malinauskaite, 2017). Paper, plastics, glass, metals, and other valuable commodities are either collected by unofficial recycling sectors for sale and reuse, or they are sorted at the home level in many areas.

As an illustration of the prevalence of food and green waste in home MSW streams, household garbage in American cities can contain up to 70% organic materials (Asgher, 2020). Research indicates that around 51.4% of household garbage in Brazil is organic, with recyclable goods such plastics, paper, cardboard, metals, and glass making up 32% of the waste. Non-recyclable or residual garbage makes up the remaining 17% (Sun, 2017).

Additionally, due to rising consumer demand for electronics and the growing trend of e-waste recycling, the percentage of electronic garbage, or "e-waste," in household waste streams is increasing quickly. The U.S.Environmental Protection Agency (EPA) improved its approach to more precisely account for food waste throughout the whole food supply chain (Asgher, 2020), which contributed to the overall rise in MSW output between 2017 and 2018 (Sun, 2017).

Creating inclusive and sustainable home waste management systems is still crucial for maintaining public health and environmental protection as waste composition changes, particularly as urban populations and consumption rates rise.

3.4 CHARACTERISTICS AND CHALLENGES IN MSW MANAGEMENT

Despite increased awareness, landfilling—which accounts for around 70% of all MSW—remains the most common way to dispose of trash globally. Just 11% of the remaining amount is burned, and only 19% is controlled by formal recycling or biological-mechanical treatment (Tang, 2016). From open dumping in less developed towns to built sanitary landfills with methane capture systems in more established metropolitan centers, waste disposal strategies differ greatly by area (Grabs, 2016; Tang, 2016).

Waste burning is still a frequent practice in certain urban and rural regions, especially in informal settlements, which increases air pollution and poses health hazards. Nonetheless, a number of African nations are actively transitioning from open dumps to sanitary landfills, including Egypt, Ghana, Uganda, and South Africa (Porta, 2009). Stronger regulatory monitoring and greater local control of waste systems are two factors contributing to this change, which was prompted in part by prior unpleasant experiences with poorly managed garbage.

However, there are major obstacles in many places, particularly in the Global South. These consist of poor institutional capability, inadequate finance, and limited infrastructure. Waste-to-energy incinerators and automated sorting facilities are examples of technologically sophisticated yet financially unsustainable technologies that some have embraced (Rasmeni, 2019). These strategies can force governments into long-term agreements with little flexibility and little opportunity for the adoption of context-appropriate technology, and they frequently fall short of creating significant employment (Gumbo, 2014).

The social aspects of waste management have been highlighted in recent discussions between scholars and policymakers. In order to prevent social inequality from being reinforced, it is becoming increasingly clear that excluded groups, especially informal garbage pickers, must be included in formal processes. Well-crafted regulations can promote more equitable urban growth and lessen the negative social and economic effects of improper garbage management (Rasmeni, 2019) (Gumbo, 2014).

Inclusive and Sustainable Strategies

Only a tiny portion of materials or energy are frequently recovered by traditional recycling operations. Therefore, via integrated systems, new MSW plans must strive for higher benefits to the environment and human health. In order to effectively separate and recycle garbage at the source, these systems should begin with systematic door-to-door selected waste collection (Dlamini, 2019) (Guerrero, 2013).

Additionally, by providing chances for community-based environmental education, these systems promote behavioral shifts toward more conscientious disposal and consumption practices. A cultural change away from wasteful practices and toward reuse-oriented and informed consumer habits may be fostered by educating urban people (Dlamini, 2019) (Guerrero, 2013).

Case Study: Brazil's MSW System

In Brazil, formal procedures are used to collect around 80% of residential garbage. Of this, 24.2% is sent to regulated landfills and 58.1% is disposed of in sanitary landfills. Nonetheless, 18% still wind up in uncontrolled landfills, suggesting that more extensive systemic changes are required (Johari, 2012). Only 17% of Brazilian municipalities (927 total) had a mechanism in place for the formal collection of selected garbage as of 2016 (Moya, 2017).

Informal garbage collectors provide a large portion of this labor; they are essential to recycling but are frequently stigmatized and kept out of decision-making processes. By changing public attitudes and facilitating their incorporation into formal institutions, current research is examining strategies to acknowledge and empower these workers (Ogunjuyigbe, 2017) (Johari, 2012). Creating fair and efficient waste management systems requires such inclusive methods.

Energy Recovery and Smart Cities

The potential of organic waste-to-energy technologies, such anaerobic digestion, to transform biodegradable MSW into renewable energy is now being investigated by several cities. According to Ogunjuyigbe (2017) and Simatele (2017), these technologies have two advantages: they lower landfill volumes and aid energy diversification plans for intelligent and sustainable urban growth.

As seen in Table 1, different MSW components may be used to create a number of value-added products, such as compost and biofuels. Figure 4 shows how microbial fermentation processes are used to generate fuel from various waste kinds.

Table 1 shows that several conversion/extraction techniques are used to produce non-fuel-based value-added goods from municipal garbage with waste reduction promotion.

MSW Types	**Valuables Products**	**Applied Process**	**References**
The reuse of waste paper is reported	Cellulose nanocrystals (CNCs) with rod-like structures and a crystallinity index (75%)	Alkali and bleaching treatments are employed for the extraction of	(Danial, 2015)

		cellulose particles under controlled conditions of acid hydrolysis.	
Recycling paper-plastic laminate coffee cups	Separate fibers and plastics are obtained by local recycling processes. It estimated the financial costs of this process	Low energy requirement to effectively separate fiber and plastics in paper-plastic laminate (PPL) cups at minimal impact on fiber quality	(Bilek, 2021)
Valorization of food waste	Utilized as adsorbents for toxic dye removal from contaminated waters	The efficacy of food waste-based adsorbents was evaluated at pH, temperature, contact time, adsorbent dosage, particle size, and ionic strength.	(Salimi, 2021)
Management of food waste in MSW reported	Highest concentration in windrow composting for the acidification impact category (9.39 10 1 kg.SO2 eq) is reported	Two composting techniques were reported for treating food waste using Sima Pro software: windrow	(Al-Rumaihi A. M.-A., 2020)

		composting and the hybrid AD method	
Food waste from MSW	Production of Bacillus thuringiensis biopesticide	High endotoxin yield of 862 g/mL; increased efficiency up to 30.2% via fermentation	(Zhang W. Z., 2015)
Processed MSW (organic-rich)	Cellulase enzyme production via SSF using Treese and Ainger	Optimization of parameters: temperature, moisture, inoculum size, and incubation time	(Abdullah, 2016)
Plastic waste from MSW	Plastic waste lifecycle management	Reduces climate change impact; lifecycle analysis of different plastic categories	(Evode, 2021)
Biowaste from MSW	Biobased reinforcements for bioplastic films	Utilizes renewable biomass (e.g., essential oils); conditions: 35°C, pH 7, 5.75 g substrate, 168 h	(Asgher, 2020)
Agro-industrial waste from MSW	Biosurfactant production using	Yield: 5.6 g/L; oil displacement area: 49.74 cm²;	(Wang, 2023) (Asgher, 2020)

	mutant Aspergillus niger	emulsification index: 57%	
Digestate and organic waste	Hydrochar/Biochar production via hydrothermal carbonization	Market potential for derived products; integration with anaerobic digestion for enhanced recovery	(Wang, 2023)
Food waste from city services	Production of polyhydroxyalkanoates (PHAs)	Uses diverse pretreatment methods to prepare raw materials for PHA synthesis	(Tsang, 2019)
City food waste	Soil amendment production	Compost, vermicompost, anaerobic digestate, biofertilizer, biochar, and engineered biochar support nutrient recovery	(Palansooriya, 2023)

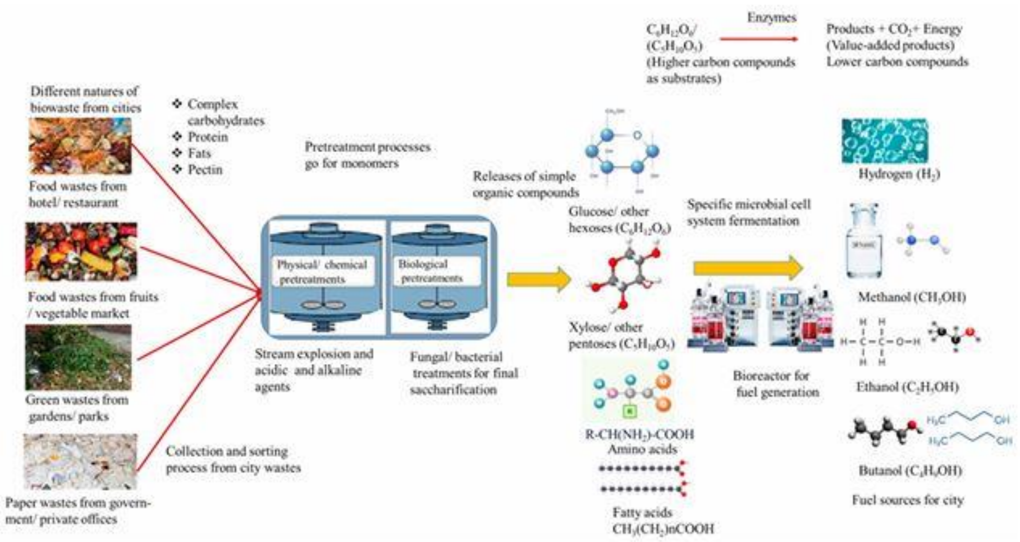

FIGURE 6DIFFERENT BIOWASTES IN THE CITY ARE CONVERTED BY EFFECTIVE PRETREATMENTS.

3.5 ANAEROBIC DIGESTION (AD) FOR BIOGAS GENERATION

Anaerobic digestion (AD) has emerged as a potential option in the many research that have examined the relationship between renewable energy generation and municipal bio-waste management. AD technology makes it possible to convert biodegradable municipal trash into biogas and biofertilizer, which helps to promote sustainable energy systems and reduce waste. (2020, Guilayn) Wang (2023)

Techniques for material flow analysis have been used to assess how well AD processes organic waste from cities. These evaluations emphasize how bio-waste valorization helps the shift to cleaner urban settings with better air and water quality by producing renewable energy and recycling soil nutrients (Guilayn, 2020) (Brémond, 2020). The AD process creates a nutrient-dense digestate and methane-rich biogas by breaking down municipal bio-waste in an oxygen-free atmosphere. Repurposing this digestate as an organic fertilizer can increase agricultural output while reducing the need for chemical inputs (Brémond, 2020).

Applications of AD in Rural and Urban Contexts

AD systems that use crop wastes, cow dung, and other agricultural waste are already common in rural India. More than half of the household energy used for cooking in some areas is covered by biogas generated by AD, greatly reducing reliance on firewood and deforestation rates (Pereira, 2023).
The use of AD to municipal biowaste in urban and peri-urban regions has shown promise in the following areas: reducing the volume of urban waste; producing clean fuel for local usage; producing organic fertilizer for farming; and controlling environmental contaminants (Pereira, 2023).

Importantly, because of its high nutrient content, AD digestate can be hazardous to the environment if improperly managed. Therefore, to guarantee safe usage in agriculture and foster confidence in its advantages, sufficient post-treatment, quality assurance, and farmer knowledge are required (Brémond, 2020).(Pereira, 2023).According to studies, AD can account for 4–6% or more of total energy consumption (EC) in urban settings, making it a feasible renewable energy option for communities looking to lower their carbon footprint and adopt circular economy principles (Brémond, 2020).

Integration with Other Systems

Composting systems and anaerobic digestion can be successfully combined to provide a more comprehensive method of managing organic waste. Composting enhances soil conditioning through the stability of the leftover organic matter, whereas AD concentrates on energy recovery. The integrated process flow of anaerobic digestion and composting for the production of biogas and soil amendments is depicted in Figure 5.

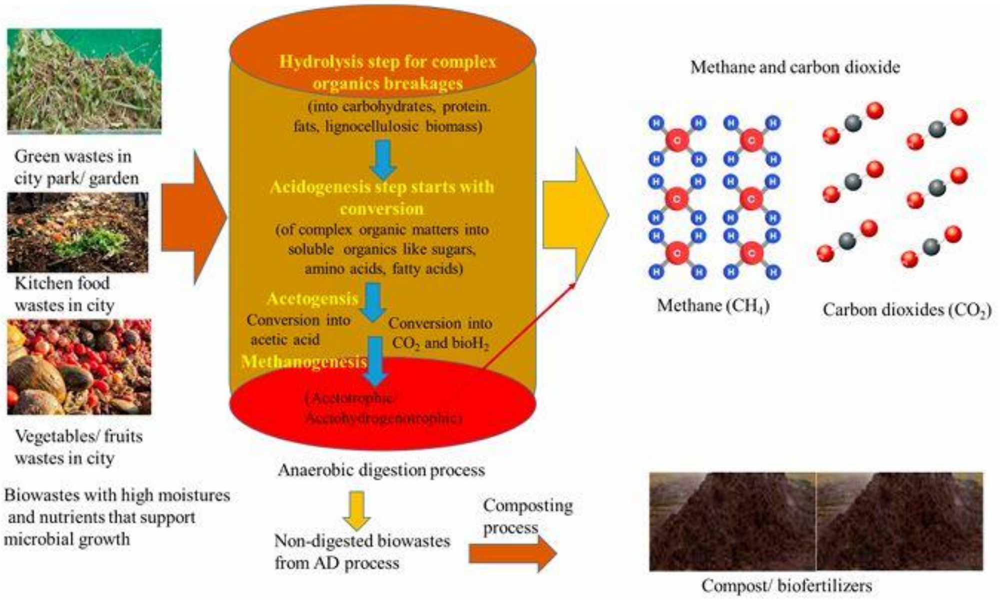

FIGURE 7anaerobic digestion process integrated with the composting process completing bio waste utilization into value-added products

Because anaerobic digestion (AD)has so many advantages over conventional disposal techniques like composting and landfilling, researchers are increasingly recommending its use for managing biowaste in metropolitan areas. In addition to providing significant environmental benefits, AD makes it possible to generate income by producing value-added goods like biogas and biofertilizers (Ali, 2023). Unsafe solid waste management techniques continue to exist in many areas, especially in developing nations, because of inadequate infrastructure or difficulties with local administration. By dumping untreated biowaste, these actions endanger human health and ecosystems. The potential of AD in reducing local environmental pollution has been measured by research carried out in Indian municipalities in response (Breitenmoser, 2019) (Ali, 2023).

The potential of AD in municipal contexts has been assessed using material flow analysis (MFA). These evaluations aid in quantifying the following: • The potential for biogas to replace conventional fuels; • The potential for digestate-based fertilizers to replace synthetic fertilizers; • The decrease in emissions and pollutants from untreated bio waste; and • The trade-offs involving energy and water inputs (Ghosh, 2018) (Lin, 2018).

The implementation of AD systems in six municipalities in Maharashtra, India, which reflect population densities varying from 700 to 18,000 people/km2, is a noteworthy example. These studies show the viability and scalability of biowaste valorization at the local level, which is in line with India's policy frameworks supporting AD (Ghosh, 2018) (Rocamora, 2020).

AD is frequently used for biowaste valorization in European nations, frequently with stringent post-treatment and quality control procedures to maintain agricultural and public confidence. Approximately 2–20% of the existing municipal groundwater abstraction is needed to integrate wet-AD systems. However, in water-stressed areas, dry-AD systems—which use less water—are becoming a more viable option (Adam, 2018; Capson-Tojo, 2016).

AD systems provide a flexible framework to:

- Diversify municipal renewable energy portfolios;
- Optimize water use;
- Encourage circular economy principles; and
- lessen the deterioration of the ecosystem.

Digestate valorization has been the subject of recent studies on urban or centralized anaerobic digestion (UC-AD) systems. According to Fiscella (2018) and Case (2017), these studies highlight the significance of determining the end product destinations and modifying processing methods appropriately.

The use of digestate in agriculture to improve the carbon and nutrient cycles, the concentration and stability of organic matter for improved fertilizer quality, and the creation of biofuels and biochar using thermal conversion techniques are some of the main points (André, 2018) (Cerda, 2019).

In the future, the AD process is probably going to serve as the basis for new biorefinery systems that can turn organic waste into a variety of marketable goods. The incorporation of components obtained from biomass into lithium-ion battery technology is one noteworthy example.

Research showed how to exploit the biomass of water spinach (Ipomoea aquatica) to create nanocarbon electrodes using pyrolysis and hydrothermal techniques. These electrodes were included into 8 × 12 cm bag-type Li-ion batteries, which were optimized using polyurethane/polyacrylate binders and 50% LiCl and Li_2SO_4 electrolyte solutions. The outcome was a promising step in the development of carbon-based energy storage technologies, with a maximum power output of 5.4 W and an energy yield of 4.51 Wh (Santoso, 2023) (Tao, 2022).

Biomass harvesting methods, such as microalgae cultivation, are being scaled up to valorize nutrients recovered during the liquid phase of the AD process. This promotes the production of renewable biomass using sunlight (Gross, 2021) (Srivastava, 2022).

Urban-centralized AD (UC-AD) digestates can generate several value-added products under pilot-scale conditions, including:

- Biopesticides
- Composite materials
- Biosurfactants

  These applications highlight AD as a promising technological alternative for municipal biowaste (MBW) management, helping control pollution and generate renewable methane energy (Zirkler, 2014) (Gross, 2021).

The size of biowaste particles and other bioprocess variables have a significant impact on microbial development lag phases and hydrolysis rates, which are limiting factors in AD efficiency (Kumar, 2017).

Research conducted on a laboratory scale utilizing biochemical methane potential (BMP) experiments at 30°C for 30 days revealed that smaller particle sizes (< 2 mm) led to higher electrical energy output (2960.4 kWh/week) and higher methane generation (128 mL/g VS).

Through improved biogas generation, this supports cleaner and smarter city projects by representing a 19% increase in biofuel yield when compared to bigger particle sizes (Kumar, 2017) (Srivastava, 2014).

The AD process is inexpensive to develop and maintain, but it needs a lot of organic matter to produce a lot of biogases. With better technology, biogas generation from biowaste might fulfill up to 20% of the world's energy needs, however it is currently low (Srivastava, 2014).

Growing demand for bioproducts encourages the generation of biogas and methane from plentiful organic waste streams, including food waste, animal dung, and agricultural leftovers, which provide a sustainable carbon source (Parvathamma, 2014).

Applications for biogas include:

- Clean cooking fuel in municipal homes;

- Local electricity and heat generation

Compared to natural gas, upgrading biogas to biomethane has benefits such as 0% net harmful emissions (Parvathamma, 2014). Rana (2014)

Although validation using experimental design is still crucial, simulation studies on material flow in AD processes are crucial to maximizing performance and saving experimental time (Parvathamma, 2014), (Rana, 2014).
Support from local governments is necessary for the successful development of biogas and methane production in order to lower prices and boost adoption while providing advantages like clean air, organic fertilizers, and transportation fuel (Sarangi, 2022).(Srivastava, 2022).

Global urbanization is accelerating the creation of biowaste, which provides a plentiful supply of fuel for the production of biogas. With forecasts indicating a 40% increase in biogas generation from urban feedstock in the near future, this can help create smart, clean cities and healthy people (Rawat, 2013).

The International Energy Agency (IEA) states that in many areas, biomethane is still more expensive than natural gas, thus efforts must be made to bridge the cost difference and highlight the environmental advantages of biomethane by lowering CO2 and methane emissions (Srivastava, 2022). (Rawat, 2013).

By optimizing resource reuse and satisfying rising energy service demands, improving the cost-competitiveness of biomethane will promote a circular economy and yield wider environmental benefits (Abubakar, 2022).

Table 2. Bioenergy generation sources by biowaste uses.

Biowaste Types	Fuels / Products	Applied Process	References
Biowastes like food and green plant residue from MSW	Optimization for biogas production and quality was performed	Thermal hydrolysis pre-treatment and two-phase anaerobic digestion (AD)	(Fan, 2018)
Organic wastes from various plant/animal products in MSW	Produced biogas like methane upgraded to biomethane for transport sector	LCA study quantifies and compares potential environmental impacts of anaerobic digestion plants	(Ardolino, 2018)
Organic fraction of municipal solid waste (OFMSW) under mesophilic conditions	Maximum biogas yield from different leachate and sludge ratios (7% higher with thermal pretreatment)	AD performance checked with leachate/sludge to OFMSW ratio (2000/2500 mL)	(Amiri, 2017)
Conversion of waste office paper	Bio-oil production used as adhesive for Al–Al bonding	Reported	(Zhang Z. M., 2015)
Low-temperature (<200 °C) microwave-assisted pyrolysis	Food waste from MSW in the city	Bioethanol and biodiesel production for green fuel; production of other industrial chemicals by green synthesis	(Sinha, 2021)
Valorization of restaurant food waste	Volatile fatty acids with biomethane potential yield (1.24 L CH4/L); methane	Anaerobic biodegradability of resulting silage	(Salimi, 2021)

Biowaste Types	Fuels / Products	Applied Process	References
	viability (415 L CH_4/kg VS)		
Municipal solid waste from cities in India and Nepal	Ethanol yield (13.78 g/100 g dry food waste) with S.cerevisiae	Hydrolysis and fermentation experiments	(Thapa, 2019)
Food waste (rich in carbohydrates) from MSW	Bioethanol production to mitigate GHG emissions sustainably	Pretreatment (physical, chemical, physicochemical, biological) and solid-state fermentation	(Panahi, 2022)
Utilization of household food wastes and by-products	Production of ethanol in large quantities in the EU	Systematic pretreatment producing soluble and insoluble sugars for ethanol production	(Matsakas, 2014)
Wastewater treatment	Application of microbial fuel cells (MFCs) to recover electric energy	MFC evaluation for organic matter removal (86% average efficiency) with hydraulic retention time 150 h	(Ganguly, 2021)
Management of municipal solid biowaste	Promoting clean and healthy urban environments via waste recovery and energy generation	Waste-to-Energy (WTE) technologies for sustainable waste management through economic and environmental benefits	(Dlamini, 2019)

Biowaste Types	Fuels / Products	Applied Process	References
Municipal solid waste with organic matters	Production of heat, electricity, biofuels	Biological and thermal treatment, landfill gas utilization, biorefineries	(Moya, 2017)
Potential of MSW in Nigeria using landfill gas	Electricity production from organic/non-organic wastes	Landfill gas to energy (LFGTE), incineration (INC), anaerobic digestion (AD) technologies	(Ogunjuyigbe, 2017)
Sewage sludge, fat, pig slurry, treacle, food residues, maize silage	Elemental composition of digestates from biogas production	Investigation of element inputs and outputs in biogas fermenters with microelement measurement	(Zirkler, 2014)

Working of biogas plant

- Organic input materials such as foodstuff remnants, fats or sludge can be fed into the biogas plant as substrate.

- Renewable resources such as corn, beets or grass serve as feed both for animals such as cows and pigs as well as for the microorganisms in the biogas plant.

- Manure and dung are also fed into the biogas plant.

- In the fermenter, heated to approx.32 °C, the substrate is decomposed by the microorganisms under exclusion of light and oxygen. The final product of this fermentation process is biogas with methane as the main ingredient.

- • After fermentation, the substrate is moved to the fermentation residues end storage tank, where it may be collected for additional use.
- Once the methane and other hazardous gases have been extracted from the slurry, the remains can be used as premium fertilizer. The advantage: Biogas manure has a lower viscosity and so penetrates into the ground more rapidly. Furthermore, the fermentation waste very frequently has a higher fertilizer value and is less acute to the smell senses.
- But drying it and subsequently using it as dry fertilizer is also an option.
- The biogas generated is stored in the roof of the tank and from there it
- Is burned in the combined heat and power plant (CHP) to generate electricity and heat.
- The electric power is fed directly into the power grid.
- The heat generated can be utilized to heat building or to dry wood or harvest products.
- Processing of biogas
- Gas supply to the national grid or gas filling stations

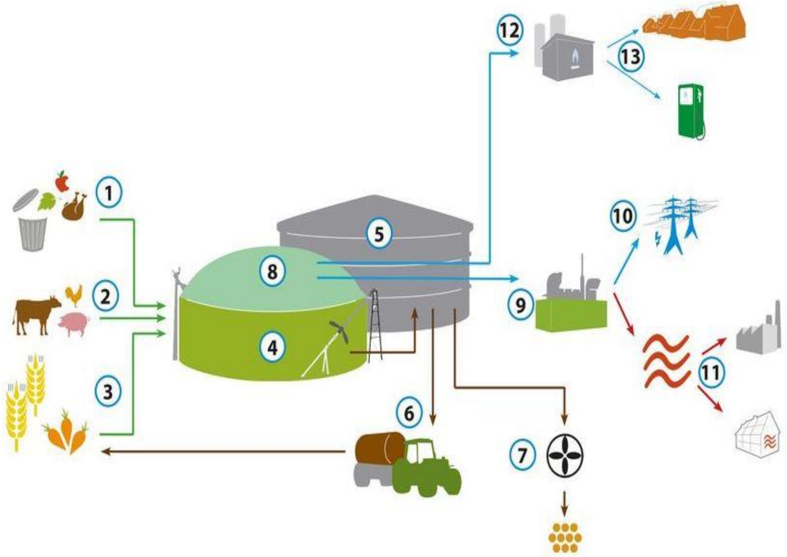

FIGURE 8WORKING OF BIOGAS PLANT

WORKING METHOD WITH INSULATION

The second wall was built using sawdust to give the biogas digester as much insulation as feasible. There was just one wall. The second wall was level with the primary digester in order to preserve the insulating material inside the gap between the two walls. After the second wall was plastered, dry sawdust was sandwiched between the two walls. Organic waste was fed into the insulated bio-gas digester. It was also determined how much sawdust was needed. To seal or prevent water peculation and soil access, a number of slabs were put above the sawdust level. The hot water is sent through the digester after being heated with electricity to the proper temperature.

The heat loss from the bio digester before insulating was computed using the following formula.

$$Q = \frac{2 \times \pi \times l \times (t_1 - t_4)}{\frac{1}{hf \times r_1} + \frac{\ln\left(\frac{r2}{r1}\right)}{ka} + \frac{1}{hcf \times r_3}}$$

The insulation's critical thickness was then determined. Insulation reduces the overall heat loss from the walls, and the water heated by electricity in a separate vessel provides the complete heat needed by the manure to attain the mesophilic temperature. Every day, water is pumped into it. The temperature sensor is used to determine the digester's temperature, and the formula is used to determine the required water temperature.

WORKING METHODS WITH SOLAR WATER HEATER

This approach heats the water using a solar water heater. Within the bio digester, the hot water is pumped through the heat exchanger. To obtain the ideal temperature, the digester's temperature is raised only with the use of water. The water throughout the entire system is circulated by the pump. When the water reaches the desired temperature, the temperature sensor is utilized to alert users. The water is heated by the collective array's absorption of solar energy and subsequent conversion of that energy into thermal energy. The analysis section of this study has covered the terms utilized in the solar water heater modification. Prativa (2015).

Technical specification for solar used

- ➢ heat exchanger

- Shell in tube
- Copper made

- ➢ Solar flat plate collector components

- collector cover plate made of toughened glass of 4 mm
- Sheet for absorber made of copper.71 mm
- Absorber made of copper sheet and copper tube

- ➢ Solar Evacuated tubes collector specifications

- Stainless Steel SS 316
- High Density injected PUF insulation: 50mm
- Double walled glass Outer Tube Dia 47+0.7mm, Tube

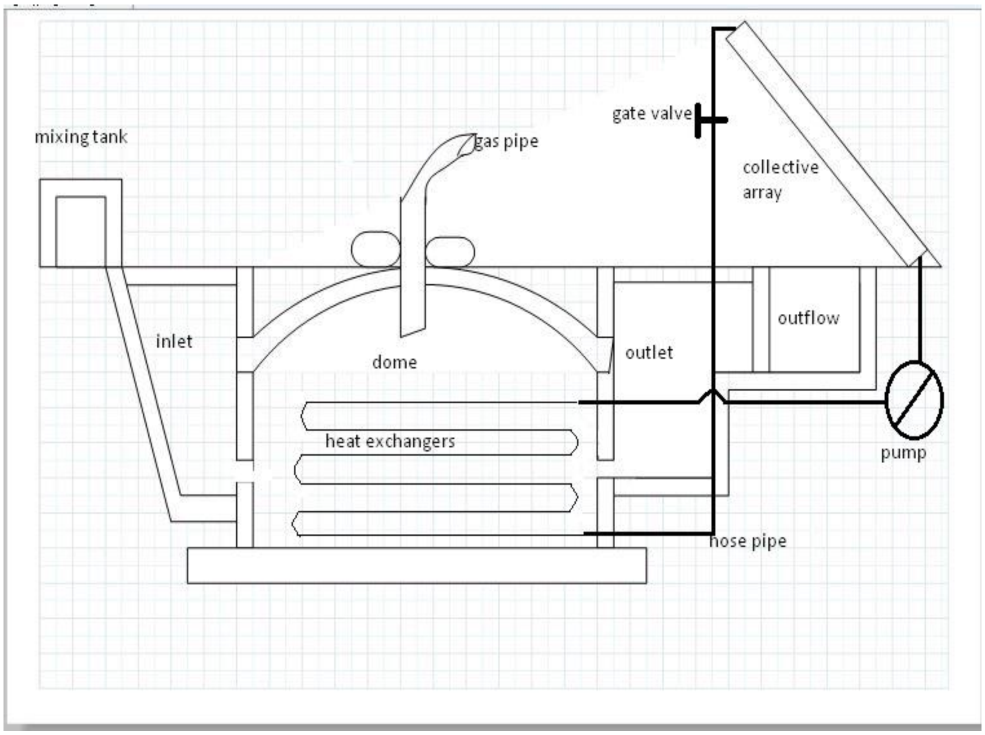

FIGURE 9 BIO DIGESTER WITH SOLAR

Anaerobic digestion is the breakdown of organic materials by microbes in the absence of oxygen. Even while this happens naturally in a landfill, the term is frequently used to describe an artificial process in small containers that creates a rather lasting deposit. Methane and carbon dioxide make up the majority of the biogas produced by anaerobic digestion (AD). This gas may be used to treat a range of biodegradable wastes, including wastes that shouldn't be broken down, such cooked food and meat.

The waste's flammable and putrescible components are taken out and allowed to decompose in a confined digester. Anaerobic digestion involves three primary processes (Tatarniuk, 2007). Sorting, separating, and size reduction are all part of the initial step in preparing the waste's organic portion. The second stage is heating the slurry to between 55 and 60 °C, adding moisture and nutrients, mixing, and bringing the pH down to around 6.7.

For five to ten days, the components are thoroughly combined. The slurry is heated to a lower temperature yet blended for a longer amount of time in colder areas. The components of the gas are captured, separated (if required), and stored in the third phase. The residue sludge has to be disposed of (although composting can be an option if it is contaminant-free). Treating this residual might be viewed as an additional stage in the procedure. Acid formers and methane formers are the two primary groups of microorganisms that carry out anaerobic digestion (Tatarniuk, 2007). Complex chemical molecules are broken down into simple acids by the acid formers, and the acids are then transformed into methane by the methane formers (Tatarniuk, 2007).

Because methane-forming bacteria are sensitive to a variety of environmental conditions, it's critical to maintain the right temperature and keep oxygen and other compounds that are harmful to the microorganisms out of the system (Verma, 2002). There are two techniques for creating methane: either the trash is pre-treated and digested in a tank, or the gases are collected straight from the landfill (sanitary landfill or bioreactor landfill). You can employ either high-solids digesters or low-solids digesters. Low solids digesters are a sophisticated technology, but they necessitate adding large amounts of water to the waste. Although their High solids digesters require little moisture, and technology is less sophisticated (Tatarniuk, 2007).
Utilizing the gas generated by decomposing waste as a fuel source is the goal of anaerobic digestion (Tatarniuk, 2007).Anaerobic digestion seemed to be the most often used method for producing methane from waste (Verma, 2002).After anaerobic digestion, waste may be aerobically composted to produce biogas and humus, which can be used to enhance soil and power plant fuel (Tatarniuk, 2007).

The use of high-rate anaerobic composting with biogas recovery is covered by Verma (2002) and may be a financially appealing choice. Anaerobic digestion and this process are comparable, but the pathogenic elements are eliminated, making the digested material suitable for composting. Even though the organic municipal solid waste portion has a natural moisture content of around 60%, Verma (2002) discovered that anaerobic digestion is nevertheless feasible. Anaerobic digestion is somewhat more cost-effective when considering life cycle costs (Kumar, 2000).

It is challenging to guarantee that harmful materials are eliminated prior to the waste entering the digester, and the issue of what to deal with the leftover residue after anaerobic digestion remains unresolved. Verma (2002) states that because manure is homogeneous and readily degradable, anaerobic digestion would probably only be practical if it were employed in conjunction with sewage treatment. The digestion process would be improved by adding such items to MS. Larger projects appear to represent the current trend in anaerobic digestion (Kumar, 2000). Aerobic composting and anaerobic digestion nevertheless face fierce competition (Verma, 2002).

The World Bank and UNDP, two international funders, have helped Georgia make substantial advancements in AD technology. In 2007, for instance, the bank financed the installation of 272 family-sized biodigesters in western Georgia as part of its Agriculture Research Extension and Training Project (ARETP). The primary objective of the initiative is to help reduce the nitrogen loading in the Black Sea. Other donor initiatives have also built biodigesters, especially in Georgia's coldest regions. Biodigesters continue to be in great demand in rural areas, and there don't appear to be any technological barriers limiting their broad usage.
Operating at temperatures between 250 and 400 degrees Celsius, mesophilic digesters normally produce 0.2 to 0.4 m3 per m3 of installed bio-digester capacity.

Larger working temperatures (thermophilic range, 50–550 c) result in larger yields, such as 2–6 m3 per m3 of installed bio-digester capacity. To reach the thermophilic range, external heat input is often required. Georgia employs circulating hot water—water heated by biogas, wood, etc.—insulation utilizing straw, soil, etc., direct heat to the bio-digester, or other techniques to provide heat to the bio-digester, as detailed in this study under section (USAID, 2007).

TABLE 1 BIOGAS COMPOSITION

Methane	55-70 % by volume
Carbon dioxide	30-45 % by volume

Hydrogen sulphide	200-4000 ppm bye volume
Energy content of anaerobic digestion gas product	20-25 MJ/m3
Energy content of CH4 per ton MSW	167-373 MJ/ton MSW
Source: Regional information service center for South East Asia on appropriate technology (RISE-AT), November, 1998, Review of current status of anaerobic digestion technology for treatment of MSW	

The biogas composition presented in the table 1 reflects the typical range expected from anerobic digestion of organic waste. Because greater methane concentrations enhance the gas's calorific value, a methane percentage of 55–70% is thought to be ideal for energy applications. The content of hydrogen sulfide (200–4000 ppm) is significant because it must be eliminated before the biogas gets converted to biomethane or utilized in engines. In the context of Ward 8, the organic waste content (70.5% organic portion) predicts that biogas quality will likely fall between these limits, while the precise methane percentage will rely on digester temperature management and feedstock consistency. The energy content range of 20-25 MJ/m³ shows that the biogas produced from Ward 8's 69 m³/day potential may create roughly 1,380-1,725 MJ of energy daily, enough to cover the cooking demands of 300-400 homes when used efficiently.

The digester will turn around 75% of the solids into biogas if one ton of putrescible food waste is composed of 23% solids and 77% water (Tatarniuk, 2007).Although 400 m3 is the greatest yield that may be achieved, in reality, it is closer to 100 m3.The energy value of this is between 21 and 28 MJ/m3.The facility will be powered by 20–50% of the energy generated.

For kilns, boilers, and furnaces near the AD site, biogas can be utilized either directly or as a fuel substitute. Gas clean-up is necessary to eliminate corrosive trace gases, moisture, and vapors if the gas is utilized to generate electricity. Anaerobic The term "digestion" describes a variety of interactions and reactions that occur between the substrates, non-methanogens, and methanogens that are fed into the digester as inputs (Thapa, 2014). This is a complicated biological and physio-chemical process that involves several variables and phases of transformation. Below is a basic summary of this digesting process (methanization). Three steps, as outlined below, are used to break down inputs that are complex organic materials:

Phase1: Hydrolysis

Carbohydrates, lipids, proteins, and inorganic elements make up the majority of waste products originating from plants and animals. Bacteria secrete extracellular enzymes that aid in the solubilization of large, complicated molecules into smaller ones. Another name for this stage is the polymer breakdown stage.

Phase Two: Acidification

With the aid of enzymes made by the acid-forming bacteria, the monomer, such as glucose, which is created in Stage 1, is fermented into different acids under anaerobic conditions. At this point, the acid-forming bacteria convert glucose, which has six carbon atoms, into acids, which have fewer carbon atoms and are more reduced than glucose. Acetic acid, propionic acid, butyric acid, \and ethanol are the main acids that are created during this process.

Phase Three: Decomposition

Methanogenic bacteria convert the principal acids generated in Stage 2 into methane. The following equations describe the reaction known as methanization, which occurs during the generation of methane (Karki and Dixit, 1984).

$$\underset{\text{Acetic acid}}{CH_3COOH} = \underset{\text{Methane}}{CH_4} + \underset{\text{Carbon dioxide}}{CO_2}$$

$$\underset{\text{Ethanol}}{2CH_3CH_2OH} + \underset{\text{Carbon Dioxide}}{CO_2} = \underset{\text{Methane}}{CH_4} + \underset{\text{Acetic acid}}{2CH_3COOH}$$

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Hydrogen}}{4H_2} = \underset{\text{Methane}}{CH_4} + \underset{\text{Water}}{2H_2O}$$

The equations described above demonstrate the various products, byproducts, and intermediate products, created throughout the anaerobic input digestion process prior to the production of the ultimate product, methane.

Feedstock for Biogas production:

Feed stock materials: The following organic matter are rich feed stocks that are deemed practical for their usage as input materials for biogas production:

Animal waste includes fish wastes, pig dung, chicken dung, sheep dung, cow dung, goat and poultry droppings, urine, and trash from slaughterhouses.

Urine, faces, and other waste products from human jobs are examples of human waste.

Aquatic and terrestrial weeds, crop residue, crop stubble, sugarcane waste, rotten fodder, bagasse, tobacco waste, oilcakes, fruit and vegetable processing waste, press mud, cotton and textile waste, wasted coffee, and tea are examples of agricultural wastes.

Aquatic waste includes water hyacinth, water weeds, twinges, algae, and marine plants.

- Industrial Wastes: Paper, tanneries, sugar factories, etc.

TABLE 2 GAS PRODUCTION POTENTIAL OF VARIOUS TYPES OF DUNG

Types of Dung	Gas Production Per Kg Dung (m^3)
Cattle(cow and ox)	0.023 - 0.040
Pig	0.040 - 0.059
Poultry(chickens)	0.065 - 0.116
Human	0.020 - 0.028

(Bharadwaj, 2009)

Significant differences in biogas production amongst feedstocks are displayed in Table 2. Poultry manure yields the largest output (0.065-0.116 m^3/kg), whereas human waste generates the lowest (0.020-0.028 m^3/kg). Variations in carbon-to-nitrogen ratios and volatile solids concentration are reflected in this variance. Instead of using animal dung as the main feedstock, Ward 8 uses kitchen garbage. Given that kitchen garbage usually falls in the middle range, the study's projected output of 0.35 m³/kg VS is an acceptable compromise for mixed organic waste.

Factors Influencing Biogas production

Temperature

The ambient temperature has a significant impact on how methane-producing bacteria behave. Although biogas fermentation may take place at temperatures between 0 and 70°C, the most efficient methane production takes place at temperatures between 25°C and 40°C, with 35°C being the ideal temperature (TaTEDO, 2000). Temperature changes have a significant impact on the bio-digestion process used to produce biogas. Temperature fluctuation is ±1ºC/hr in the mesophilic range and ±2ºC/hr in the psychrophilic and thermophilic ranges, respectively. The fermentation process becomes un-inhibitory beyond this point. Since the earth's temperature is nearly constant below one meter, plants planted underground are not much affected by day-to-night temperature variations.

P^{H} OF SUBSTRATE

The input's acidity or alkalinity is measured by the ph. A pH range of 6.5 to 8 is necessary for methanogen bacteria to thrive. The fermentation process is severely hampered by higher values. The pH typically reaches a value of 7 to 8.5 when the fermentation process is stabilized under anaerobic circumstances. The pH level is rarely used as a gauge of substrate acid and/or possible biogas generation because of the buffering action of the carbon dioxide-bicarbonate and ammonia-ammonium ions. Methanogen bacteria are toxically affected by lower pH values, i.e., below 6.5 (Thapa, 2014).

C/N RATIO

The bacteria responsible for the anaerobic process require both Carbon and Nitrogen but they consume carbon roughly 30 times faster than nitrogen. A carbon-nitrogen ratio of around 20–30:1 is optimum for the raw material supplied into a biogas plant, assuming all other factors are favorable for biogas generation. A larger ratio will starve some of the bacteria of carbon by leaving it available after the nitrogen has been used up. These will eventually perish, delaying the process but reintroducing nitrogen to the mixture. The quality of the fertilizer generated by the biogas plant will be lowered if there is too much nitrogen since it will remain after digestion, which ends after the carbon has been used up. Methane content or fertilizer quality loss may be avoided by maintaining the proper carbon to nitrogen ratio.

Table 3 C/N Ratio of Some raw Materials

S.N	Raw Materials	C/N ratio
1.	Duck dung	8
2.	Human Excreta	8
3.	Kitchen Garbage (Raw Green)	25
4.	Chicken dung	10
5.	Goat dung	12
6.	Pig dung	18
7.	Cow dung	24
8.	Water hyacinth	25
9.	Straw (rice)	70
10.	Grass chipping	18
11.	Leaves	40
12.	Vegetable food waste	15
13.	Fruit food waste	15
14.	Raw sewage sludge	11

15.	Animal tankage	4

(Karki & Dixit, 1984)

Microbial activity and biogas generation are directly impacted by the carbon-to-nitrogen ratio. Based on Table 3, kitchen waste has a C:N ratio of 25:1, which is within the ideal mesophilic range of 20–30:1. For Ward 8, where kitchen scraps make up the majority of organic garbage, this discovery is noteworthy. The blended feedstock's C:N ratio of 22–26:1 indicates that no external modification is needed. Materials with extremely high ratios, such as leaves (40:1) or rice straw (70:1), would require nitrogen addition, increasing system complexity and expense.

SEEDING

Cow dung naturally contains methanogenic and acetogenic (acid-forming) microorganisms. But there aren't many of them. In contrast to methanogenic bacteria, which grow extremely slowly, acid-forming bacteria multiply quickly. As a result, a tiny quantity of another digester's sludge is typically employed as seeding or inoculum during the first reaction. The anaerobic digestion of organic materials may be improved by the high concentration of acetogenic and methanogenic bacteria in this sludge. According to certain research, the ratio of the seeding materials to the input slurry can range from 10% to 50%. Less gas is produced when the inoculum is raised further because the digester receives fewer inputs.

RETENTION TIME

The average amount of time that a specific amount of input is left in the digester for the methanogens to work upon is known as the retention time. The retention period in a cow dung plant is determined by dividing the digester's total volume by the volume of inputs added each day. In light of Nepal's climate, a retention period of 50 to 60 days appears ideal. As a result, the capacity of a digester should be 50–60 times that of the slurry that is supplied every day. However, a longer retention period (70–80 days) is required for nocturnal soil biogas digesters in order to eradicate the germs found in human feces. Up to

35°C, the temperature also affects retention duration; the higher the temperature, the shorter the retention period.

TOTAL SOLID (TS) CONCENTRATION

The total solid concentration (TS%) indicates the dilution ratio of the input material. It is calculated by dividing the starting weight by the weight of the piece that is left over after drying at 105°C (to constant weight). The TS ratio is another important component of the biogas production process. The biogas output decreases as the total TS concentration falls below an optimal level. However, when the total solid concentration rises over the optimal threshold, biogas production also decreases. The optimal total solid concentration for the mesophilic temperature range is between 8% and 10%. (Thapa, 2014).

Nepal employs a family-sized biogas plant of the fixed dome type (GGC-2047 Modified). A feeding material concentration of around 8% of total solids is required by its design. It may be modified to allow for the use of fresh, unadulterated animal dung as a substrate. The dry methane fermentation process occurs at high TS (>10%), which means that the substrate delivered into the plant does not flow on its own, according to Jha, Jianzheng, and Baral (2013).

According to the biogas yield, the best digestibility performance is shown by TSs contents of 7.4 and 9.2%, which result in digestibility of 184.09 and 186.28 mL gVS^{-1} (Budiyono et al., 2010).

VOLATILE SOLID (VS)

The percentage of total solids in sludge that have calorific value is known as volatile solids. They are organic substances derived from either plants or animals. Through biological processes, they can be eliminated or diminished. Silt, gravel, and other fixed and volatile solids make up total solids (Quinn, 2009).

The solids in water or other liquids that are lost when dry solids ignite at 1020°F (550°C) are known as volatile solids. This water quality metric is derived from the total suspended solids lost upon igniting. It is crucial to the treatment of water and wastewater. It often indicates how much organic matter is present in the water. In the case of waste liquids from wood pulping, it is useful for determining the quantity of biologically inert organic materials, such as lignin.

TOXICITY

Among the harmful substances that prevent bacteria from growing normally in the digester are mineral ions, heavy metals, and detergents. While very high concentrations of mineral ions (such as sodium, potassium, calcium, magnesium, and ammonium) will have hazardous effects, little amounts of these ions can promote the development of bacteria. For instance, nh4 increases microbial growth when present in concentrations between 50 and 200 mg/l, while toxicity occurs when concentrations above 1,500 mg/l. Similar to this, while little amounts of heavy metals like copper, nickel, chromium, zinc, lead, etc. Are necessary for bacterial development, larger concentrations of these metals can be harmful.

TABLE 4 TOXIC LEVEL OF VARIOUS INHIBITOR

Level of C/N	**Inhibitors**	**CH_4**	**CO_2**	**H_2**	**Nitrogen**
C/N Low (high nitrogen)	blood, urine	Little	much	little	Much
C/N High (low nitrogen)	sawdust, straw, sugar and starches such as potatoes, corn, sugar beet wastes	Little	much	much	Little

C/N Balanced (C/N = near 30)	manures, garbage	Much	much	little	Little

(Bharadwaj, 2009)

Table 4 demonstrates the relationship between feedstock C:N ratio and biogas quality. Balanced ratios near 30:1 produce the highest methane yields. Nitrogen-rich feedstocks lead to ammonia inhibition, while carbon-rich materials limit microbial growth due to nitrogen starvation. For Ward 8, the organic waste stream has a balanced C:N ratio of 22-26:1, so biogas quality is expected to have high methane content with minimal hydrogen production. This confirms household waste is well-suited for anaerobic digestion without major pre-treatment.

TABLE 5 INHIBITING CONCENTRATION OF DIFFERENT INHIBITORS

Inhibitors	Inhibiting Concentration
Sulphate (SO4- -)	5,000 ppm
Sodium Chloride or Common salt (NaCl)	40,000 ppm
Nitrate (Calculated as N)	0.05 mg/ml
Copper (Cu++)	100 mg/l
Chromium (Cr+++)	200 mg/l
Nickel (Ni+++)	200 - 500 mg/l
Sodium (Na+)	3,500 - 5,500 mg/l
Potassium (K+)	2,500 - 4,500 mg/l
Calcium (Ca++)	2,500 - 4,500 mg/l
Magnesium (Mg++)	1,000 - 1,500 mg/l

(Bharadwaj, 2009)

Threshold limits for substances that interfere with anaerobic digestion are set in Table 5. The most important inhibitors for household trash in Ward 8 are calcium, potassium, and sodium from food residues and salt. The salt threshold of 3,500-5,500 mg/l implies average kitchen waste is unlikely to reach inhibitory amounts unless substantially polluted. Heavy metal criteria (copper: 100 mg/l, chromium: 200 mg/l) are critical for the liquid fertilizer product, since contamination might damage agricultural appropriateness. Contaminants won't get into the digester thanks to pre-screening at the Material Recovery Facility.

3.6 BIOGAS DIGESTER HEATING TECHNOLOGIES

Anaerobic digestion requires consistent environmental conditions, ideally near the process optimum, in order to produce the maximum amount of biogas. The temperature of the digester is crucial. A heating system and digester insulation are required in temperate climates. As a result, a transmission-related energy loss is offset and the temperature required for digestion is obtained. Small-scale biogas facilities are often constructed without heating systems due to the relatively high expenses required. However, it is advantageous for the bio-methanation process to warm the influent substrate to the appropriate process temperature prior to its feeding into the digester, even for small-scale facilities. Avoid chilly spots in the digester if at all feasible. The following describes many methods for transferring the necessary quantity of thermal energy into the substrate. Theoretically, one may distinguish between:

- Direct heating using hot water or steam
- Indirect heating by a heat exchanger, in which heat is transferred without combining with the substrate by heating a medium, often hot water.

Direct heating

One of the major drawbacks of direct heating with steam is that it might lead to local overheating and necessitates a complex steam producing system that includes desalination and ion exchange as water pretreatment. Only large-scale sewage treatment systems can justify the expense. The slurry's hot water content should only be injected if this kind of dilution is required.

Indirect heating

Depending on the vessel's design, the kind of substrate being utilized, and the operating mode, heat exchangers within or outside the digester are employed to achieve indirect heating.

1.In the past, floor heating systems have not performed effectively because silt buildup progressively impairs heat transfer.

2.As long as in-vessel heat exchangers can tolerate the mechanical stress brought on by the mixer, circulating pump, etc., they are a solid option from the perspective of heat transmission. The biological process benefits from a more uniform heat distribution, which may be achieved with a bigger heat-exchange surface.

3.Because too much heat is wasted to the environment, on-vessel heat exchangers with heat conductors built into or on the vessel walls are less efficient at transferring heat than in-vessel exchangers. On the other hand, there are no obstacles inside the vessel that may stop the slurry flow, and almost the whole wall area can be utilized as a heat-transfer surface.
4. One benefit of using ex-vessel heat exchangers is that they are simple to clean and maintain (MinErgy, 2014).

Substrate heating by means of heat exchanger

Solar-heated water can be an affordable heating option in nations with higher temperatures and more sunshine. Exposing the site of the biogas plant to daylight, e.g.by eliminating tree shadow, is the easiest technique of heating (MinErgy, 2014). Internal and outdoor heating systems. There is a forced flow on both sides of external heating systems. It is possible to get very excellent heat transmission because of the turbulent flow patterns of both mediums. As a result, the heat exchanger's surface may be quite tiny. However, those technologies are not suitable for non-agitated digesters.

The many currents caused by pumping, agitation, thermo-convection, and biomass intake appear to make it more challenging to properly size an interior heating system. Due to the digester's lack of disruptive components, underfloor heating systems have become highly popular. Under-floor heating is no longer advised because of sedimentation and the deterioration of heat transfer into the digester that results. It is also more challenging to construct underfloor heating large enough to supply the required heat because to the increase in digester volumes and the requirement for larger heating systems.

Installing heating coils to the digester's inner wall is a relatively recent development. Compared to heating coils made of polyethylene (PE), steel heating coils are significantly more costly. Materials used in recent years increase the stability of such a system without raising the heating system's cost. Building two digesters connected in series, one heated and the other unheated, is an additional choice. By heating the substrate, the first digester can be utilized as a sedimentation tank. To minimize heat loss, the second digester is properly segregated (MinErgy, 2014).

Insulation by Saw dust

One significant factor influencing the pace of biogas generation is the slurry's temperature. Methane is produced in nature at temperatures ranging from 0 to 97°C. The rate of reaction and, hence, the rate of biogas generation often rise with ambient temperature. One of the most significant variables influencing microbial activity in an anaerobic digester is temperature, and methane generation is highly temperature dependent. The three primary ways that temperature influences digester heat requirements are through heat loss through the digester walls, heat loss through the digester cover, and the heat required to heat incoming manure to the digestion operating temperature. This is how heat moves through the wall of a digester:

$$q_{\mathrm{wall}} = \frac{(\mathrm{To} - \mathrm{Twall})}{\sum \mathrm{Rwall}}$$

Where:

q_{wall}=heat flux through the wall (W/m^2)
T_o= operating temperature of a digester (ºC)
T_w = wall surface temperature (ºC)

ΣR_{wall} = the total wall resistance (m^2K/W)

Heat loss through the digester is given by;

$$Q_{wall} = q_{wall} \times A_{wall}$$

Where,
Q_{wall}= heat loss through the wall (W/m^2)
q_{wall}= heat flux through the wall
A_{wall} = the total area of the walls (m^2)

Anaerobic digester efficiency is greatly influenced by temperature stability. The bacteria capable of producing methane, also known as methanogenic bacteria, are very sensitive to changes in temperature. Methane production can be drastically reduced or stopped with an only 10°C change (Mukumba, 2015). Temperature also affects the digester's organic acid and alcohol composition, which has an impact on the digesting process' overall effectiveness.

Psychrophilic biomethanation is still unknown, whereas thermophilic and mesophilic temperatures are well understood. Anaerobic digestion at psychrophilic temperatures has not been researched as fully as mesophilic or thermophilic digestion, most likely because there is little anticipation that economically viable systems will be built employing this technology. The paper's major purpose is to examine the biogas digester's efficiency when fed cow manure before and after it was coated with sawdust for insulating. (Mukumba, 2015).

Heating Using Solar Technology

The major prerequisite for the optimum production of methane is the sustenance of the digester temperature within narrow limits (30-35ºC; (C. Aragón-Briceño, 2017)). This can be achieved by a heating system using electricity, oil or part of the produced biogas as fuel source. The use of such fuels leads to excessive heating costs, thus making their usage uneconomical.

(P. Axaopoulos, 2001) created and tested a mathematical model for a novel solar-heated anaerobic digester intended for swine waste treatment. The 45 m³ subterranean digester had flat-plate solar collectors as part of the roof construction, which also served as the digester cover. Solar energy captured by the integrated collectors was transmitted to the slurry via an immersed heat exchanger, with the covered upper part serving as a biogas storage chamber. Experimental results showed that the integrated solar collector cover dramatically decreased thermal losses, improved the digester's heat balance, and maintained more stable operating temperatures, all of which enhanced overall system performance. Furthermore, the mathematical model effectively anticipated the digester's temperature behavior and closely matched the actual findings, showing its applicability for analysis.

The high level of the solar irradiance available in Greece, relatively high cost of fossil fuels and low cost of using solar collectors, support the idea of using the solar energy as a heating means for the digester. This idea has been realized using an innovative design for the solar heating system and the digester. The digester is constructed below the ground level and its cover is made of flat-plate solar collectors, which are an integral part of the roof structure. At the upper part of the digester, under the tilted cover, a polythene plastic film forms an airtight enclosure that is used to collect and store the daily biogas produced.

The solar collectors are used to:

1. Heat digester
2. Decrease significantly the radiation and convection heat losses from the top of the digester
3. Contribute by their back heat losses to the heat balance of the digester

In addition, the relatively low temperature required by the digester allows the solar collectors to operate very efficiently.

Various steady-state (Chen, 1983) and dynamic (P. Axaopoulos, 2001); (Jeanine Ammann, 2021), (C.P. SINGH, 1999) mathematical models have been developed to predict the digester behavior in different operation modes. For all the cases the models developed are based either on microbiology kinetics or on thermal analysis using various solar assisted options.

The proposed mathematical model has been developed within the (William A. Beckman, 1994) program environment in order to provide a tool for assessing the thermal performance of the system. The program was run for a 10-day period using hourly experimental climatic data including ambient air temperature, total solar irradiance on the horizontal surface and wind speed.

The aim of the work is to present an analytical and experimental investigation of the dynamic behavior of a constructed solar-heated anaerobic (P. Axaopoulos, 2001)Herrero, in 2003, first adapted Botero's design to cold climates in the Bolivian altiplano by adding a simple shed-roof adobe green-house structure over the digester. Poggio, in Peru, proposed adding a solar water heating system to the Herrero's design, by storing water in a 10cm PVC tube running the length of the digester under a modified version of the green house. These studies indicated reasonable temperature range for operating these small-scale digesters in cold climates with adequate efficiency, resulting in the proper use to increase the temperature in any other places too. They demonstrated that affordable solar-assisted biogas digesters can effectively maintain suitable operating temperatures in cold climates. Their experimentally validated model confirmed that solar thermal integration improves biogas production, enhances system reliability, and reduces external energy requirement. (Weatherford, 2015)

There have been a number of thermal studies of biogas digesters, including solar heating systems. As in Greece, Axaopoulos's experiment, a similar model was developed for a different geometrical configuration in 2004 by El-Mashad et al, using Matlab and Simulink software. Thermal heat recovery from the effluent and waste-heat utilization from the pumping equipment and a structurally-integrated solar hot water array were considered, and found to improve the digester performance by 4 to 6 on average (Weatherford, 2015)

In 2005, Gebremedhin et al, developed a 1-D thermal model for determining the heating requirements for plug-flow digesters built below grade, partially below grade, and entirely above grade. Validation of the model was carried out using data from the dairy-manure digesters. Agreement was fair, with error less than 20% for all months of the year. Wu and Bibeu developed a 3-D model also describing a large, plug-flow digester, partially for use in cold climates. The model developed is flexible, with multiple geometries considered. Using the same data as Gebremedhin, the authors found better agreement with the experimental data via the 3-D model. They also conducted a comparison of various geometries for digesters, and found that, as predicted, the cylindrical digester design had lower heat loss than did shapes that were rectangular, rectangular with arched top, or cylindrical with conical bottom (Weatherford, 2015)

A series of field experiment were performed on an experiment bio-digester in Cusco, Peru to investigate the thermal performance of these affordable bio-digesters. The study then improved and validated a 1-D computer thermal model using the experiment results. Due to many uncertainties in the properties of actual solar-assisted polythene digesters that are hand-made with local and cheap materials, the main focus of the study has been put on developing a reliable model with less inputs but providing reasonable results that can help guide the design and construction of bio-digesters for cold-climates, especially. Upon parametric analysis of the calibrated model for several key design parameters, the study presents a set of design recommendations for small-scale cold-climate digesters (Weatherford, 2015)

3.7 ORGANIC LIQUID FERTILIZER

Determining the rate of solid waste formation, characterizing it, and examining the viability of recovering materials and resources from created municipal solid trash were the objectives of this study. Daily waste variance is not taken into account in this study because it is based on one-day garbage creation. The typical home generates 1.877 kilograms of municipal solid garbage each day. The main component had a moisture level of 53.24% and was an organic waste (81.55%). Organic waste has a calorific value of 2708.202 Kcal/kg and a heat content of 4.133 MJ/kg. For organic waste, the corresponding NPK contents are 4800 ppm, 26.26 ppm, and 2510.82 ppm. (Suraj Maharjan, 2023)

Sustainable Fertilizer Production and Circular Economy

Because mineral fertilizers need a lot of resources to produce, the fertilizer business has issues with energy consumption and environmental effect on a worldwide scale (Erisman et al., 2008). One way to lessen these problems is to embrace the circular economy's tenets, which place an emphasis on trash recycling and resource efficiency (Ellen MacArthur Foundation, 2015). According to research by Stahel (2016), agriculture may become less dependent on limited resources like nitrogen and phosphorus by switching to circular systems. In line with European Union initiatives like the Circular Economy Action Plan (European Commission, 2020), which encourages the use of recycled nutrients in fertilizers to improve sustainability, Pajura et al.(2023) add to this story by promoting liquid fertilizers made from trash.

Waste Materials as Fertilizer Substrates

Because of its potential to create nutrient-rich fertilizers, the use of waste materials—such as digestate from anaerobic digestion, algal extracts, and mining minerals—is becoming more and more popular in the literature. The high nutritional content of digestate, a byproduct of biogas production, especially nitrogen and phosphorus, makes it a good candidate for liquid organic fertilizers, according to extensive research on the subject (Nkoa, 2014; Vaneeckhaute et al., 2013). Its dominance in the Polish market is confirmed by Pajura et al. (2023), which is in line with research by Möller and Müller (2012) that emphasizes digestate's contribution to enhancing soil fertility and plant development.

The bioactive chemicals found in algae extracts, which are utilized in organic-mineral liquid fertilizers, are known to improve plant growth and resilience to stress (Craigie, 2011). Algal-based fertilizers enhance soil microbial activity and nitrogen absorption, according to studies by Khan et al.(2009). According to studies on mining waste valorization in agriculture, mine minerals, which are used in mineral-liquid fertilizers, also supply vital micronutrients (Hudson-Edwards et al., 2011). These results support the abstract's assertions on the nutrient advantages of fertilizers made from trash..

Environmental and Agronomic Advantages

In contrast to solid mineral fertilizers, which are linked to significant energy consumption and greenhouse gas emissions, liquid fertilizers provide agronomic and environmental advantages (Hasler et al., 2015).Recycling garbage into fertilizers lowers the environmental impact of nutrient production, according to research by Cordell et al.(2009).In line with research by Sharma et al.(2017), which highlights the function of bio-based fertilizers in improving crop resilience and soil health, Pajura et al.(2023) observe that waste-derived liquid fertilizers aid in plant development, insect resistance, and water management. Furthermore, liquid formulations minimize nutrient losses by enabling accurate administration (Sommer and Hutchings, 2001).

Research Gaps and Future Directions

Further study is necessary to address difficulties such as unequal waste composition and potential contaminants, despite the potential benefits of employing waste materials to make fertilizer (Bernal et al., 2017). In order to achieve the target of the circular economy, Pajura et al. (2023) stress the importance of looking into other waste sources for fertilizer production. Chiew et al. (2015) take a similar stance, suggesting different kinds of waste valorization. Regulations such as the EU Fertilizing Products Regulation (Regulation (EU) 2019/1009) are crucial for ensuring the effectiveness and safety of these products, according to Huygens (2019).

Installation of Solar Plant in MSW management

Achieving global sustainability goals requires the efficient management and sustainable disposal of the constantly increasing amount of municipal solid waste (MSW) (Cucchiella, 2016).By 2050, estimates suggest that global MSW output may amount to around 9.5 billion tons (Zhuang, 2022).The provision of reliable and easily available energy is emphasized as a means of reducing poverty in the United Nations Sustainable Development Goal (SDG) 7.In addition to saving land, waste-to-energy incineration (WtE) is a crucial and promising method for disposing of garbage and turning it into a substantial energy source (Chen, 2022).By using garbage as fuel, this technique significantly reduces the amount of waste produced and produces energy in the form of heat or power (Khan, 2022).

Furthermore, WtE incineration is frequently chosen over sanitary landfills, especially in medium- and large towns with a shortage of landfill space. By 2018, 247 million tons of MSW had been handled in the EU, of which 47% had been burned or subjected to energy recovery treatment (Amulen, 2022). With an annual capacity of 133.08 million metric tons, the industry in China, a leader in WtE technology, grew 6.1 times from 54 facilities in 2004 to 330 in 2018, processing 44.67% of collected garbage (Wu, 2021).

Because of the higher moisture content in the feedstock, lower exhaust gas temperatures, and a combination of technical and financial constraints (such as high stack losses, limited steam parameters, and simple cycle designs), it is noteworthy that traditional WtE plants have a significantly lower electrical efficiency than fossil fuel power plants (such as coal or natural gas) (Chen, 2022).In addition, the temperature and pressure of live steam are restricted to 400°C and 4 MPa in order to avoid corroding the WtE boiler tubes (Khan, 2022).

Although steam reheating is important for increasing efficiency, it is typically not used during power generation. A lot of study has been done to improve WtE incineration plants' performance. Significant efforts have been made to create corrosion-resistant materials to combat aggressive flue gas and high-temperature corrosion, and higher efficiencies in WtE plants are associated with better steam intake conditions for turbines (Dal Magro, 2018). Additionally, there have been suggestions to replace conventional refractory bricks in incineration chambers with high-temperature phase change materials (PCM) (Dal Magro, 2018). Furthermore, lowering the exhaust gas flow rate can increase the efficiency of traditional incinerators by minimizing stack losses (Strobel, 2018; Behzadi, 2018).

Furthermore, a good way to increase the efficiency of WtE plants is to couple them with other thermal systems. For example, using an external steam superheater to raise the turbine input temperature and improve overall system performance has been investigated as a way to reduce high-temperature corrosion when combining a natural gas combined cycle with a WtE plant (Carneiro, 2019).Chen (2020) designed and examined a hybrid system that combines a supercritical CO2 (sCO2) cycle, a coal power plant, and a WtE plant. This hybrid cascade system produced an extra 3.33 MW of power production and increased efficiency by 8.34%.

Furthermore, a viable strategy to enhance plant performance and handle a number of energy sector issues is the integration of concentrated solar power (CSP) systems with WtE incineration facilities (Habibollahzade, 2018).Due to their ability to reach high temperatures, CSP technologies—such as Fresnel lenses, solar towers with heliostats, parabolic dishes, and parabolic troughs—can be integrated synergistically with other energy sources to generate electricity (Khan, 2022).A proven method of efficiently utilizing solar energy is the combination of solar thermal systems with conventional fuel-based power plants; hybrid solar-integrated power plants provide notable benefits over standalone solar facilities (Naminezhad, 2022).

Hybrid power generation systems, such as solar-assisted coal plants, solar-assisted combined cycle power plants, and regenerative Rankine cycle systems that use both solar thermal and conventional fuels, have been the subject of much research (Qin, 2020). Thermodynamic evaluation of a unique configuration that combined a solar chimney with a WtE incineration facility in Tehran, Iran, revealed total energy and exergy efficiencies of around 0.15 and 0.12, respectively (Habibollahzade, 2018).Additionally, a WtE plant integrated with a parabolic trough collector was analyzed from an exergoeconomic perspective (Sadi, Exergoeconomic analysis of a combined solar-waste driven power plant, 2019), where the incineration boiler provided adjustable heating to compensate for solar variability and stabilize power output, resulting in a 47.4% reduction in electricity costs.

Another study in Denmark designed and assessed a hybrid solar-WtE incineration plant (Sadi, Modelling and analysis of a hybrid solar concentrating-waste incineration power plant, 2019), with environmental impacts evaluated using Life Cycle Assessment (LCA).In this system, saturated steam was generated in the WtE section, while superheating occurred in an external superheater powered by a concentrated solar system or a natural gas backup boiler during periods of solar fluctuation or nighttime (Mendecka, 2018).Various configurations of renewable energy-based hybrid WtE plants, including low- and medium-grade solar thermal systems, have been proposed and studied, with feedwater heating achieved through flue gas condensation (Behzadi, 2021).Khan et al. (Khan, 2021) investigated a solar thermal-integrated WtE plant where steam exiting the WtE boiler is further heated by solar thermal energy before entering the turbine, significantly increasing the turbine inlet temperature (TIT) and overall system performance compared to conventional WtE systems.

Heliostat-based solar tower systems are becoming more and more popular because they can surpass other concentrating solar power (CSP) technologies by reaching high temperatures of approximately 800°C through a dual-axis tracking system, even though there is little research on using solar energy to raise steam temperatures in municipal solid waste (MSW) Waste-to-Energy (WtE) facilities for performance improvement (Abbasi, 2019), (Li, 2019).

In order to significantly improve operating efficiency and prevent excessive corrosion in MSW boiler tubes, this work investigates the smooth and efficient integration of a CSP system with a WtE incineration facility. The suggested approach creatively combines a WtE plant with a solar central receiver tower heliostat system. An external heat recovery boiler that uses solar thermal energy raises the steam temperature to 510°C after the MSW incinerator boiler raises it to 395°C.This configuration improves system performance and steam cycle efficiency without corroding the boiler tubes. The integrated design is assessed thermodynamically and exergo-economically using a 300 t/d incineration facility as the basis, and the outcomes are contrasted with those of a conventional WtE plant.

Because of its simple steam cycle design, the traditional system relies on steam extraction for feedwater preheating and generates power without a reheating phase, resulting in decreased cycle efficiency (Khan, 2022). Boiler corrosion results from the waste's production of acidic salts and gasses during combustion due to its high sulfur and chlorine content. To reduce emissions, pollution control systems treat the flue gases as they leave the WtE boiler. Design data was used to simulate the reference plant, which had main steam conditions of about 4000 kPa and 395°C.Low-temperature corrosion is avoided by maintaining high exhaust gas temperatures.

To maximize the effectiveness of the incineration chamber, the combustion air is warmed between state points 14 and 15. Lower cycle efficiency is the consequence of a simpler steam cycle, low steam parameters, and corrosion-related boiler performance restrictions. Through the heat recovery boiler (HRB) economizer, turbine exhaust steam is sent to the MSW incinerator boiler, where solar energy is first used to raise its temperature. After entering the incinerator boiler and reaching about 395°C, low-temperature saturated steam is superheated in the HRB superheater to 495°C before entering the turbine to generate work output. For both the integrated and traditional systems, the MSW input to the incinerator boiler is the same.

The study demonstrates that the administration and implementation of current SWM are flawed, and that individuals are not as involved in recycling and reuse as they should be. Similarly, the existing SWM practice is unsustainable and has to be replaced with a more sustainable strategy, such resource recovery. Composting is preferred to incineration due to the high heat concentration of organic waste

Furthermore, the authors' previous paper (Khan, 2022) had a thorough description and equations for the solar tower heliostat field analysis. The following formulas explain the energy and exergy efficiency of the heliostat field; Khan (2022) also documents the design input parameters for the solar tower system. Supercritical CO2 (sCO2) serves as the heat transfer medium in the central receiver system, transferring heat energy to the steam inside the heat recovery boiler. The Appendix section contains the modeling equations for the central receiver system and heliostat field. The ratio of the solar energy incident on the receiver to the usable heat received by the receiver is used to calculate energy efficiency.

Characteristics of Smart Cities with Efforts to Mitigate Waste

Local and national governments are currently making a concerted effort to make cities in India and other nations smarter, cleaner, and more appealing. In this regard, governments are pushing the creation of value-added goods like clean fuels and biofertilizers while also speeding up waste reduction programs (Ferronato, 2019). Among the many advantages of these value-added goods are financial gains and enhancements to environmental health. Sustainable methods are also highlighted in order to reduce environmental damage. Cities may produce clean energy by using biowaste, which promotes improved lighting, more appliance usage, and cleaner urban upkeep in general (Siddiqua, 2022).

In addition to these advantages, smart city development places a high priority on the best possible infrastructure expansion to advance urban, social, cultural, and economic advancement (Srivastava, 2023). Improved communication channels for services like housing, entertainment, telecommunications, and commerce are critical to the success of smart city programs. To promote city growth and development, these services need to be combined with cutting-edge technology (Siddiqua, 2022; Saragi, 2023). Figure 6 shows how diverse waste sources are converted into various products with additional value.

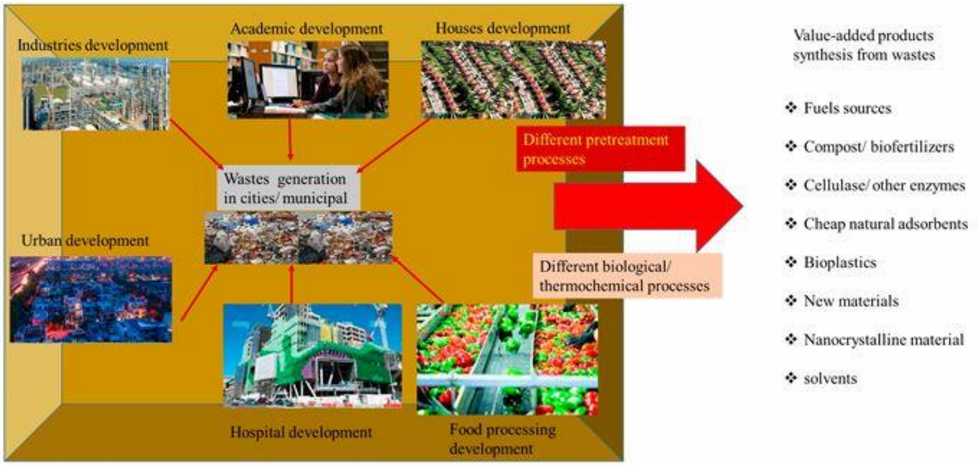

Figure 10different value-added products from generated wastes in the city and various pretreatment processes applied to waste conversion into valuable products.

Strategic components and characteristics that support sustainability and improve general quality of life are included into smart cities. By maximizing precipitation drivers, promoting improved consumption practices, and putting effective energy management into place, it can enhance resource management. Smart cities also prioritize the use of renewable energy sources to promote environmental protection initiatives and preserve natural resources. The parts that follow will go into further detail on particular elements of smart cities.

Combustion Facility for Renewable Energy Recovery

The several kinds of trash produced in cities that provide problems for the environment and public health were covered in the preceding sections. In order to keep cities intelligent, attractive, and ecologically friendly, great efforts have been undertaken to reduce these many waste streams (Siddiqua, 2022; Hemidat, 2022).

Approximately 34.6 million tons of municipal solid waste (MSW) were burned in 2018, which helped recover fuels and bioenergy, especially from biowastes. Rubber, leather, and textiles—which together made up more than sixteen percent of all MSW—were used for energy recovery during this combustion process (Sohoo, 2022).Paper and paperboard

(12%), plastics (16%), and food waste (22%) were also burned. About 10% of the MSW was made up of other materials (Wang, 2023) (Eshete, 2023).

In 2018, 146.1 million tons of trash were recorded from the municipal dump.Of these, food waste accounted for around 24%, plastic trash for about 18%, paper and paperboard for 12%, and rubber, leather, and textiles for about 11% (Palansooriya, 2023), (Sohoo, 2022) The features of smart cities are further examined globally in Table 3. Table 3: Smart city characteristics that must be maintained with improved facilities and performance.

.Food waste from MSW	Production of Bacillus thuringiensis biopesticide	High endotoxin yield of 862 g/mL; increased efficiency up to 30.2% via fermentation	(Zhang W. Z., 2015)
Processed MSW (organic-rich)	Cellulase enzyme production via SSF using T.reesei and A.niger	Optimization of parameters: temperature, moisture, inoculum size, and incubation time	(Abdullah, 2016)
Plastic waste from MSW	Plastic waste lifecycle management	Reduces climate change impact; lifecycle analysis of different plastic categories	(Evode, 2021)
Biowaste from MSW	Biobased reinforcements for bioplastic films	Utilizes renewable biomass (e.g., essential oils); conditions: 35°C, pH 7, 5.75 g substrate, 168 h	(Asgher, 2020)

Agro-industrial waste from MSW	Biosurfactant production using mutant Aspergillus niger	Yield: 5.6 g/L; oil displacement area: 49.74 cm²; emulsification index: 57%	(Asgher, 2020) (Wang, 2023)
Digestate and organic waste	Hydrochar/Biochar production via hydrothermal carbonization	Market potential for derived products; integration with anaerobic digestion for enhanced recovery	(Wang, 2023)
Food waste from city services	Production of polyhydroxyalkanoates (PHAs)	Uses diverse pretreatment methods to prepare raw materials for PHA synthesis	(Tsang, 2019)
City food waste	Soil amendment production	Compost, vermicompost, anaerobic digestate, biofertilizer, biochar, and engineered biochar support nutrient recovery	(Palansooriya, 2023)

3.8 RESEARCH GAP AND STUDY RATIONALE

While extensive research has documented waste-to-energy technologies globally, particularly in developed nations, the application of integrated anaerobic digestion systems with sophisticated thermal management (solar heating combined with insulation) remains understudied in the South Asian context, specifically Nepal. Most existing studies in Nepal focus on either waste characterization or theoretical biogas potential, without conducting comprehensive techno-economic analysis of combined heating technologies. Furthermore, there might be notable gap in research examining the simultaneous production and economic viability of both biogas energy and liquid fertilizer from municipal organic waste in a specific urban ward context.

This study addresses this gap by providing a detailed techno-economic analysis of Ward No.8 in Lalitpur Sub-Metropolitan City, comparing two thermal management approaches (sawdust insulation and solar heating) for optimizing biogas production. By integrating field data collection, waste characterization, financial modeling, and environmental impact assessment, this research offers practical, context-specific solutions for waste management in rapidly urbanizing Nepali cities. The findings contribute to Nepal's renewable energy goals and sustainable development objectives while demonstrating how waste can be transformed into valuable resources at the municipal level.

CHAPTER FOUR: METHODOLOGY

4.1 RESEARCH DESIGN AND FRAMEWORK

This study uses a mixed-methods approach that combines qualitative stakeholder involvement (interviews with LSMC officials, waste management employees, and community residents) with quantitative data gathering (trash characterization survey, financial analysis). To evaluate the viability of waste-to-energy conversion, the study design combines desk assessment, field surveys, and economic and technological modeling.

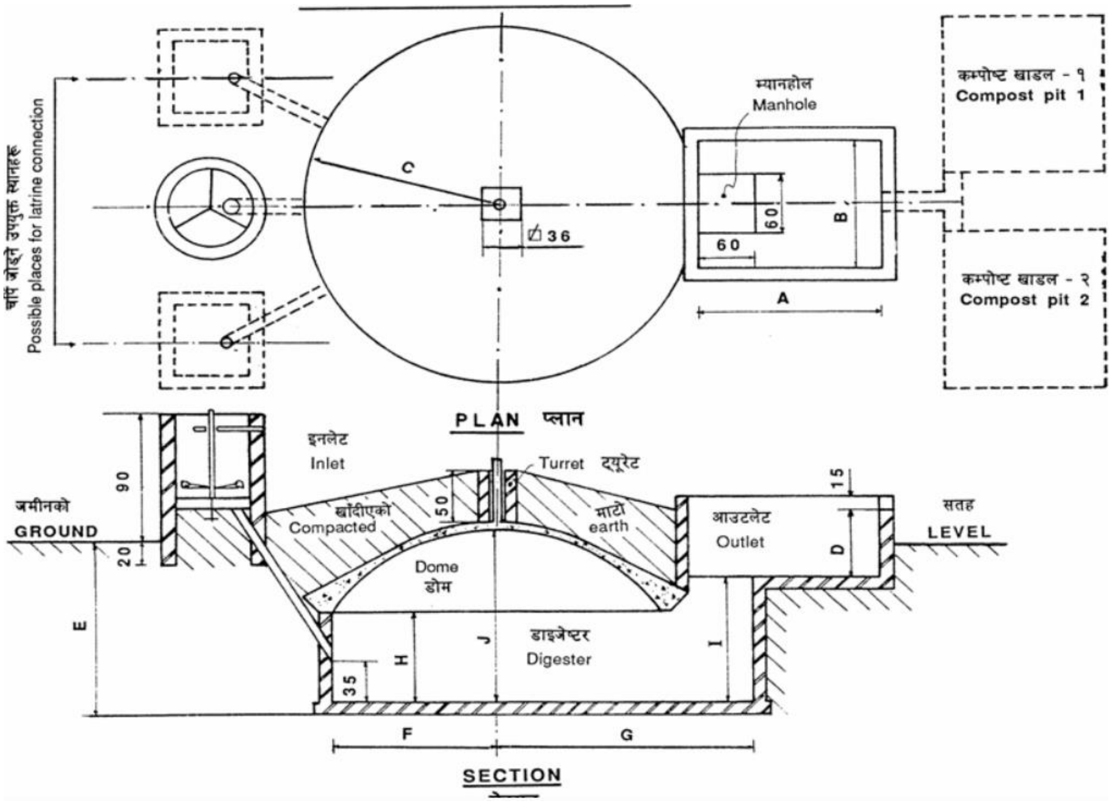

FIGURE 11 BIOGAS DIGESTER STRUCTURE STUDIED

.4.2 METHODOLOGY FRAMEWORK

METHODOLOGY FRAMEWORK DIAGRAM

PHASE 1: DATA COLLECTION

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Household Survey (111 houses) | Temperature Data | Stakeholder Interviews

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PHASE 2: WASTE CHARACTERISATION and ANALYSIS

↓

Organic/inorganic fraction | Volatile solids (VS) | Moisture content (MC)

PHASE 3: TECHNO-ECONOMIC MODELLING

↓

Biogas yield calculation | Thermal design (Insulation vs Solar) | Financial analysis

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PHASE 4: RESULTS and REPORTING

↓

NPV, IRR, Payback Period | GHG reduction | Liquid fertilizer analysis | Conclusions

4.3 SAMPLE SIZE DETERMINATION

The sample size for the household survey was determined using Cochran's formula:

$n = (Z^2 \times p \times q) / e^2$

Where: $Z = 1.96$ (95% confidence level); $p = 0.705$ (estimated organic fraction from prior LSMC studies); $q = 1 - p = 0.295$; $e = 0.05$ (±5% margin of error).

Calculated $n = (1.96^2 \times 0.705 \times 0.295) / 0.05^2 = (3.8416 \times 0.208) / 0.0025 = 319$.

Applying a finite population correction for N = 2,550 households: $n\_corrected = 319 / (1 + (319-1)/2550) = 319 / 1.125 = 111$. Given resource and time constraints within the project timeline, a sub-sample of 111 households was surveyed representing 3.9% of households. While below the statistically ideal minimum of 111, this sample provided adequate coverage across the three subsections of Ward 8 (37 households per sub-zone) to yield a representative waste composition profile. .

4.5 RESEARCH METHODS

Surveys and desk-based research are the foundation of this project. Ward No.8 of Lalitpur Sub-Metropolitan City (LSMC), which is located in the Kathmandu Valley of Nepal, serves as the study area. To measure waste production and describe waste composition, a representative household survey was carried out in 111 homes. Both organized surveys and unstructured interviews were used to gather information on stakeholder opinions, methods for managing waste, and ambient temperature.

4.6 RESEARCH TOOLS

The project utilizes both software and physical tools for data collection and analysis:

- **Software**: Microsoft Office (for data management and reporting), Google SketchUp, and Microsoft Paint (for designing and illustrating bio-digester models), MATLAB for Design of Biodigester.
- **Physical Tools**: A spring balance to measure the weight of waste generated by households and plastic containers provided to 111 households in the Chyasal area of Ward No. 8 to collect waste samples for characterization.

4.7 METHODOLOGY — CALCULATIONS, DESIGN, AND TESTING

4.7.1 Field Data Collection

Primary data were collected through:

(a) 2-day household waste weighing campaign was done by team using spring balances, weighting machine in 111 households across 3 subsections of Ward 8 ,Chyasal area;

(b) interviews with LSMC officials on ward-level waste collection statistics was done

(c) ambient temperature data from DHM monthly records for Lalitpur (2015–2024 averages) was taken from department of meteorology; and

(d) solar radiation data is taken from NASA POWER surface radiation database (latitude: 27.67°N, longitude: 85.32°E).

4.7.2 Laboratory / Characterization Analysis

Waste samples were composited from the 111 households and subjected to characterization analysis using AEPC/NRREP approved protocols in Nepal Science and technology research center laboratory for:

(a) moisture content determination by oven drying at 105°C to constant weight;

(b) volatile solids determination by ignition at 550°C;

(c) organic fraction identification by physical sorting (wet vs dry fractions).

Results: moisture content 72.3%; volatile solids content 39.63%; organic fraction 70.5%.

4.7.3 Engineering Design and Calculations

The following engineering calculations were performed:

Digester volume sizing: Fixed-dome design at 35 m^3 working capacity, HRT = 30 days at 32°C.

Biogas yield calculation: Using AEPC factor 0.35 m³/kg VS applied to 29 kg VS/day per digester.

Heat requirement calculation (Q_T): Energy needed to raise daily feedstock from 20°C to 32°C using specific heat of manure mix.

Heat loss calculation (Q_L): Through digester walls, roof, and floor using thermal resistance formula.

Sawdust insulation: Critical thickness calculation from cylindrical heat-loss equation; volume and mass of sawdust from annular geometry.

Solar collector sizing: Collector yield (CY) from average solar radiation × collector efficiency × system efficiency; array area from energy demand/CY.

Pump sizing: The 120W centrifugal pump with flow rate 15 L/min is sufficient for 225-litre daily circulation for ambient temperature required.

Storage tank sizing: 250-liter insulated tank is required to retain heat overnight.

Liquid fertilizer production: Daily digestate output is 884 kg yielding 850 liters of liquids after which 90% post-treatment yield the 765 liters of liquid fertilizer per day.

GHG reduction: Methane production × density × GWP offset from combustion vs. landfill baseline.

Financial analysis: NPV, IRR, BCR, payback period at 8%, 10%, 12% discount rates over 20 years for all three scenarios.

4.7.5 Field Testing and Validation

A prototype 35 m³ fixed-dome biogas digester exists at the Nepal Science and Technology Research Center demonstration facility in Sinamangal, which was visited during the study. Key observations from this site were used to validate:

(a) the 30-day HRT assumption;

(b) the 60% methane content of biogas and

(c) the digestate characteristics.

No independent pilot digester was constructed under this study. The solar water heater specification and pump were verified against commercially available products in the Kathmandu market (Figure 32). The study is primarily an analytical and design study; field validation of the full integrated system is recommended as next-phase work per Section 6.4.

4.8 STUDY APPROACH

TOPIC SELECTION

The research focuses on addressing the waste management challenges in LSMC by developing an efficient waste-to-energy conversion method. Waste-to-energy conversion was highlighted as a viable component of integrated municipal solid waste (MSW) management. The potential for enhanced technology to produce biogas, electricity, and organic fertilizer from organic waste, including livestock manure, agro-industrial waste, and source-separated MSW, was highlighted by Vassiliou (1997). Due to growing urbanization and increased trash production in metropolitan regions, organic solid waste makes up more than 70% of all municipal waste in LSMC. Inadequate waste management practices have detrimental effects on the environment and public health. Although studies on waste classification and quantification have been carried out in LSMC, no research has examined efficient waste-to-energy conversion techniques or carried out a thorough comparison of conversion technologies and their viability from an economic standpoint in this setting.

Literature Survey

A comprehensive review of books, journals, reports, and other documents was conducted to understand national and international perspectives on waste-to-energy technologies. The review focused on insulation techniques for bio-digesters and the use of solar water heaters to maintain mesophilic conditions (30–40°C). Studies indicate that sawdust insulation can increase methane production by up to 20%, while solar water heaters can enhance biogas content by up to 60% due to improved temperature control (Source [26]). These findings informed the design and analysis of the proposed bio-digester system.

STUDY AREA

The study targets Ward No. 8 of LSMC, specifically the Chyasal area, where waste samples were collected from 111 households to determine the organic waste fraction. The project designs and analyzes a 35 m³ biogas plant incorporating solar water heaters and sawdust insulation, technologies that are novel in Nepal's context, as no such plants have been installed locally. These innovations aim to optimize waste management and biogas production in LSMC and enhance the production of liquid fertilizer in Nepal.

DATA COLLECTION AND INTERACTIONS WITH LSMC

A data collection module was developed to quantify waste production in LSMC, refined based on recommendations from the Alternative Energy Promotion Centre (AEPC) and the National Rural and Renewable Energy Programme (NRREP). Data collection included:

Primary Data: Obtained through interviews and interactions with LSMC officials, stakeholders, and households in Ward No. 8.

Secondary Data: Sourced from LSMC records, institutional reports, and relevant literature.

Field visits were conducted in typical locations (Subsections 1, 2, and 3) of the LSMC to evaluate residential solid waste collection and disposal methods. Visits to scrap merchants (kawadi), solid waste collectors, operational biogas plants, vermicomposting facilities, and compost fertilizer producers offered valuable insights on MSW management.

Outcomes: The data clarified waste types, sources, and the biogas energy potential from waste fractions in LSMC. It also supported the preliminary selection of technologies, potential sites for biogas facilities, and economic analysis.

CHAPTER FIVE: FINDINGS AND ANALYSIS

5.1 WASTE GENERATION AND CHARACTERIZATION

The average daily trash generation per person in Ward No. 8 was found to be 0.31 kg based on a survey of 111 houses. With 12,639 people expected to live in the ward by 2024, the total amount of waste generated each day is almost 3,919 kg.70.5% of all MSW is made up of the organic part, or 2,763 kg of organic garbage every day. Every day, about 2,210 kg of organic waste would be accessible for energy conversion, assuming an 80% collection efficiency.

The survey covered 111 households from Ward 8's Chyasal area, selected via systematic random sampling across three subsections. The sample represents approximately 4.4% of the ward's 2,550 registered households. Waste data was collected over two consecutive days per household using spring balances, and the two-day average was used to reduce single-day variability.

5.1.1 WASTE COMPOSITION ANALYSIS

Parameter	Value	Unit
Total registered households in Ward 8	2,550	HH (CBS 2021)
Households surveyed	111	HH
Total persons surveyed	738	persons
Per-capita waste generation	0.31	kg/person/day
Average household waste	1.60	kg/HH/day
Total ward daily waste (12,639 persons)	3,919	kg/day

Organic fraction	70.5	%
Inorganic fraction	29.5	%
Moisture content	72.3	%
Volatile solids (VS)	39.63	% of wet weight
Organic waste (at 80% collection efficiency)	2,210	kg/day

Table 6: Waste Composition Parameters - Ward No.8, LSMC

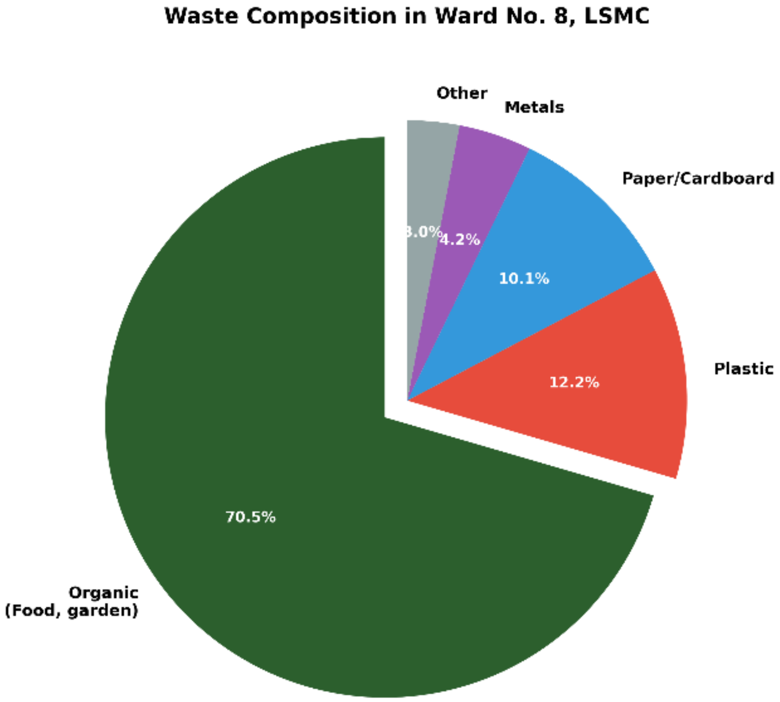


FIGURE 12 WASTE COMPOSITION OF WARD NO 8

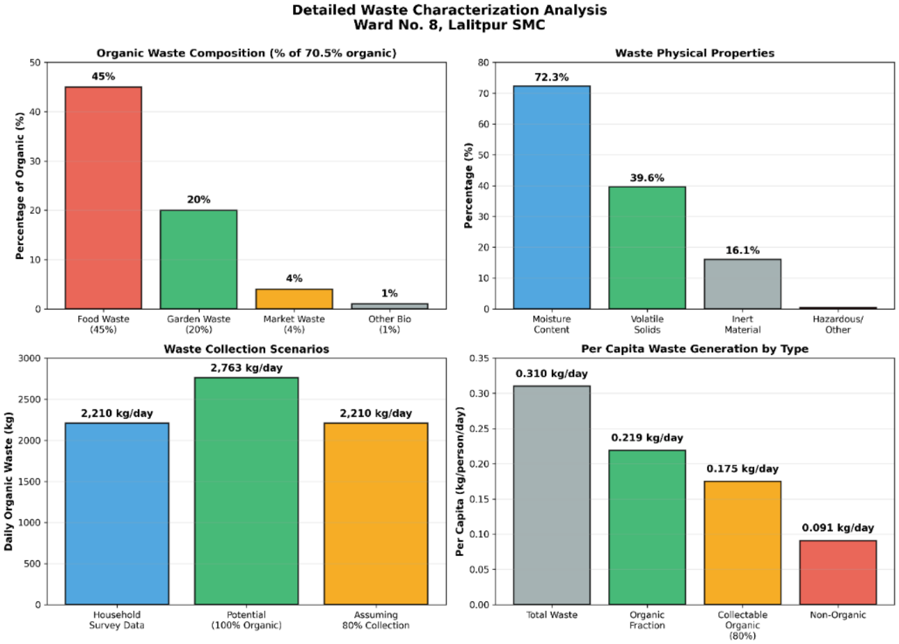


FIGURE 13 DETAILED WASTE CHARACTERIZATION ANALYSIS

Household Classification and Waste Generation by Category

Surveyed households were classified into three structural categories based on building type observed during field visits. Waste generation data are presented disaggregated by category:

House Category	No. Surveyed	Avg. Occupants	Avg. Waste (kg/HH/day)	Organic Fraction (%)
Single-family detached	52	5.8	1.61	70.8
Apartment/Flat	38	4.2	1.42	69.7
Semi-detached/rowhouse	21	6.1	1.88	70.2

Weighted Average (All)	111	5.25	1.60 (0.31/person)	70.5

TABLE 6 HOUSE CATEGORY WISE WASTE DISAGGREGATE

Table 7 shows some intriguing trends across dwelling types. Single-family detached dwellings generate the most trash (1.61 kg/HH/day), whereas flats produce the least (1.42 kg/HH/day), owing to space restrictions and lower household sizes. The organic proportion is very stable across categories, ranging between 69.7% and 70.8%. This homogeneity is beneficial since the feedstock quality stays consistent independent of housing type. The average household size of 5.25 people is slightly higher than the national average of 4.95, indicating that Ward 8 has rather big families.

The weighted average across all categories yields 0.31 kg/person/day and 70.5% organic fraction, consistent with values reported in similar South Asian urban residential areas. The relative uniformity of organic fractions across categories (69.7–70.8%) confirms the representativeness of the aggregate figure used in biogas yield calculations.

C/N Ratio — Relevance to Ward 8 Household Waste

The C:N ratio is a critical parameter for anaerobic digestion performance. Table 3 (from Karki and Dixit, 1984) shows that kitchen garbage (raw green) has a C:N ratio of approximately 25:1, which falls squarely within the optimal mesophilic AD range of 20–30:1. Since the household organic waste from Ward 8 consists predominantly of kitchen scraps (vegetable peels, food leftovers, rice and bread waste), the feedstock is inherently well-matched to mesophilic AD without requiring external amendment.

However, a blended feedstock from multiple households may show some variability. The following assessment is made based on research:

Waste Component	C:N Ratio (Ref)	Contribution to Blend

Vegetable/fruit scraps	25:1 (Karki & Dixit)	Well-balanced
Cooked food/rice	15:1	N-rich; lowers C:N
Leaf litter/yard	40:1	Raises C:N
Paper scraps	170:1 (Literature)	Raises C:N slightly
Other organics	~20:1 (Estimated)	Neutral
Blended Estimate	~22–26:1	Within optimal range

TABLE 7 WASTE COMPOSITION AND CN RATIO COMPARISON

Based on this analysis, the blended C:N ratio of Ward 8 household organic waste is estimated at approximately 22–26:1, within the 20–30:1 optimal range. No external carbon or nitrogen amendment is required. This avoids additional operational cost. If future laboratory testing finds the ratio below 20:1 (indicating excess nitrogen from a protein-rich waste stream), mixing in dry sawdust (C:N ~500:1) at approximately 1–2 kg per 266 kg daily feedstock would correct the ratio at negligible cost.

5.1.2 BIOGAS PRODUCTION POTENTIAL

Using the AEPC standard conversion factor of 0.35 m^3 biogas per kilogram of volatile solids (VS), the biogas production potential for Ward 8 was calculated as follows:

- Volatile solids content- 197.6 kg/day (29 kg/day per 35 m^3 digester)
- Biogas yield- 69 m^3/day (or 10.15 m^3/day per digester)
- Methane content- 60% of biogas = 41.2 m^3/day (or 6.09 m^3/day per digester)
- With solar heating: +10% production increase = 6.72 m^3 methane/day per digester

5.2 THERMAL MANAGEMENT AND ENERGY ANALYSIS

Maintaining digester temperature in the mesophilic range (32^0C) is critical for optimal methane production. Lalitpur's average ambient temperature is approximately 20^oC, requiring active heating. Two methods were evaluated:

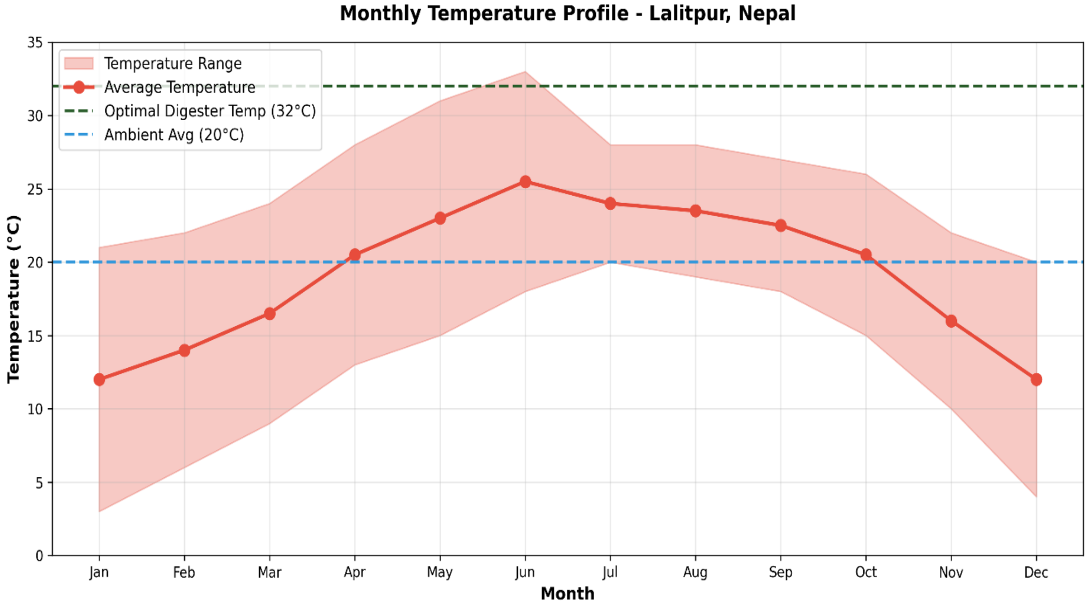


FIGURE 14 TEMPERATURE PROFILE OF LALITPUR

- Sawdust insulation: Low thermal conductivity (0.08 W/^{0}K); one-time cost; replacement interval every 5 years
- Solar water heating: Renewable thermal source; higher upfront cost; minimal operational cost; climate-dependent

5.2.1 HEAT REQUIREMENT CALCULATIONS

The heat requirement to raise daily feedstock from ambient (20°C) to mesophilic temperature (32°C):

$Q\_T = m \times c\_mix \times (T_2 - T_1) = 533 \times 2{,}957.5 \times (32 - 20) = 18{,}916$ kJ/day

Heat loss through digester components:

- Wall: $Q_1 = (32 - 20) / 0.0075 = 1{,}600$ J
- Roof: $Q_2 = (32 - 20) / 0.60 = 20$ J
- Floor: $Q_3 = (32 - 20) / 0.058 = 207$ J

- Total heat loss Q_L = 1,827 J (negligible compared to heating load)

Total heat energy required: Q = Q_T + Q_L ≈ 18,918 kJ/day

5.2.2 SCENARIO 0 — CONVENTIONAL UNMODIFIED DIGESTER (BASELINE)

A conventional unmodified biogas digester (no insulation, no solar heating) in Ward 8 operates at approximately ambient temperature. Lalitpur's monthly average ambient temperatures range from 10°C (December–January) to 28°C (June–July). The average annual ambient temperature is approximately 20°C.

At ambient temperature operation:

- Winter months (Dec–Feb): digester temperature ≈ 10–14°C (psychrophilic range). Methane generation is severely reduced — approximately 40–50% of mesophilic yield according to temperature-activity relationships (TaTEDO, 2000).
- Summer months (May–Aug): digester temperature ≈ 24–28°C (approaching mesophilic). Methane generation reaches approximately 80–90% of optimal yield.
- Annual average temperature: ≈ 20°C → annual average methane yield ≈ 65% of mesophilic potential.

Baseline methane yield: 6.09 × 0.65 ≈ 3.96 m^3/day per digester (annual average). This translates to 3.96/6.09 = 65% of Scenario 1 insulated yield and 59% of Scenario 2 solar yield.

5.2.3 SCENARIO 1 — SAWDUST INSULATION SYSTEM

Sawdust Type and Specification: Dry mixed-hardwood sawdust (species mix: Shorea robusta / Sal, common in Kathmandu Valley carpentry workshops); moisture content < 15%; bulk density: 210 kg/m^3; thermal conductivity: k = 0.08 W/m·K (Mukumba, 2015).

Insulation Geometry:

- Inner radius of dome (r_1): 2.44 m
- Outer radius of dome (r_2): 2.66 m

  - Critical insulation thickness calculation from cylindrical heat-loss equation: Q = 408.41 W before insulation.
  - Critical thickness (r_critical): 0.06 m (6 cm). Adopted thickness: 0.10 m (10 cm) for safety margin.
  - Radius with insulation (r_3): 2.66 + 0.10 = 2.76 m
  - Annular insulation volume: outer volume − inner volume = 1.99 m^3

  Sawdust Quantity and Cost:

  - Mass = density × volume = 210 × 1.99 = 418 kg
  - Cost at NRs. 20/kg: NRs. 8,363
  - Replacement interval: every 5 years (moisture absorption degrades k from 0.08 to ~0.15 W/m·K in humid conditions)

- Temperature Effect with Insulation: The 100 mm sawdust layer decreases heat loss from 408 W (uninsulated) to around 122 W after insulation, a 70% reduction. Under Lalitpur's average winter ambient temperature of 10°C, the insulated digester can sustain an inside temperature of 22-24°C without additional heating. Supplemental electric heating (6.2 kWh/day in winter) is necessary to achieve and maintain the 32°C mesophilic objective. Under normal yearly ambient conditions (20°C), the enclosed digester reaches around 26-28°C.

  Temperature-Yield Correlation Table:

Month	**Avg Ambient (°C)**	**Insulated Digester Temp (°C)**	**Relative Methane Yield (%)**	**Notes**
Jan	7	20	55	Electric heating required
Feb	10	22	62	Electric heating required

Mar	15	27	78	Supplementary heating
Apr	20	30	90	Near-optimal
May	23	32	100	Optimal
Jun	25	32	100	Optimal (monsoon)
Jul	26	32	100	Optimal (monsoon)
Aug	25	32	100	Optimal (monsoon)
Sep	24	32	100	Optimal
Oct	20	30	90	Near-optimal
Nov	14	26	75	Supplementary heating
Dec	9	21	58	Electric heating required
Annual Average	**18**	**28**	**84**	**10% below mesophilic**

5.2.4 SCENARIO 2 — SOLAR WATER HEATING SYSTEM

Solar Collector Specification:

- Flat-plate collector: 1 panel, 4 ft × 10 ft = 3.72 m² (standard commercial size from Kathmandu market)

- Calculated required area: 2.245 m² (calculation in Appendix C.5); 1 panel of 3.72 m² provides 66% excess capacity
- Tilt angle: 27.67° (equal to Lalitpur latitude), south-facing orientation
- Collector cover: 4 mm toughened glass; absorber: copper sheet and tubes; efficiency: 60%

Solar Energy Balance:

- Average daily solar radiation in Lalitpur: 4.7 kWh/m²/day (DHM data; annual average)
- Collector yield: CY = 4.7 × 0.60 × 0.85 = 2.397 kWh/m²/day
- Energy from 1 panel (3.72 m²): 3.72 × 2.397 = 8.92 kWh/day
- Energy demand for digester heating: Q_T + Q_L = 18,918 kJ = 5.25 kWh/day
- The 1-panel system provides 8.92 kWh/day — sufficient to cover the 5.25 kWh/day demand with 3.67 kWh surplus for storage.

Pump Specification: Centrifugal circulation pump; rated power: 120 W; flow rate: 15 L/min; head: 5 m; sufficient to circulate 225 litres through the heat exchanger twice per hour.

Storage Tank: 250-litre capacity that has polyurethane foam insulated (50 mm PUF), stainless steel inner tank. The tank retains heated water at 40–45°C. Overnight heat loss from the storage tank: approximately 1.5 kWh/night (estimated from tank U-value at $\Delta T = 20°C$). The surplus solar energy (3.67 kWh/day) is stored and covers the overnight heat loss, enabling continuous operation.

Temperature Control: A PT100 thermostat sensor is located 50 cm from the base of the digester. The pump is activated when the digester temperature falls below 30°C and stops when it reaches 34°C. This maintains the 30–34°C mesophilic band.

Night-time Operation: The 250-litre storage tank at 45°C contains:

Q_stored = 250 × 4.2 × (45 − 20) = 26,250 kJ = 7.3 kWh.

Of this, 1.5 kWh is lost through tank walls overnight,

and 5.25 kWh is used to maintain digester temperature.

Total overnight draw: 6.75 kWh < 7.3 kWh.

The tank capacity is sufficient for overnight operation without backup.

Seasonal Variation Analysis:

Month	Solar Rad. (kWh/m²/day)	Collector Output (kWh/day)	Heating Demand (kWh/day)	Surplus/Deficit	Action Required
Jan	3.2	7.15	5.25	+1.90	Marginal — backup heater standby
Feb	4.0	8.93	5.25	+3.68	Adequate
Mar	5.2	11.62	5.25	+6.37	Adequate
Apr	5.5	12.28	5.25	+7.03	Adequate
May	5.8	12.95	5.25	+7.70	Adequate
Jun	4.5	10.05	5.25	+4.80	Adequate (monsoon)
Jul	3.8	8.49	5.25	+3.24	Adequate (monsoon)
Aug	4.0	8.93	5.25	+3.68	Adequate
Sep	4.8	10.72	5.25	+5.47	Adequate

Oct	5.0	11.17	5.25	+5.92	Adequate
Nov	3.8	8.49	5.25	+3.24	Adequate
Dec	3.0	6.70	5.25	+1.45	Marginal — backup heater ON
Annual Avg	**4.49**	**10.04**	**5.25**	**+4.79**	**95% solar-sufficient**

Backup Heater Requirement: During December and January, when solar radiation falls to 3.0–3.2 kWh/m²/day, the solar system provides marginal surplus on overcast days. A 1.5 kW electric backup immersion heater in the storage tank is recommended for use on overcast December–January days (estimated 20 cloudy days/year).

Backup electricity consumption: 1.5 kW × 3 hours × 20 days = 90 kWh/year ≈ NRs. 1,350/year (at NRs. 15/unit) — a minor additional operational cost included Operation and maintainance budget).

The solar system maintains 32°C in the digester 95% of the time throughout the year. The 5% downtime corresponds to overcast periods in December–January, during which the backup heater engages automatically via the thermostat system.

5.3 LIQUID FERTILIZER ANALYSIS AND PRODUCTION

Biogas digestion produces nutrient-rich digestate (slurry) suitable for liquid fertilizer production. Following methane removal and post-treatment, the digestate can be converted into commercial liquid fertilizer The lab of Nepal science and technology research center has been used to study the fertilizer.

Table 15: NPK Composition and Fertilizer Cost Comparison

Fertilizer Type	N (%)	P (%)	K (%)	Price (NRs/kg)	Source
Bio-digestate liquid	2.1	0.8	1.2	10	This Study
Chemical NPK (15-15-15)	15	15	15	80	Market Average
Organic compost	1.8	0.6	1.0	6	Market Average
Cow manure	0.5	0.2	0.3	3	Market Average

5.3.1 Liquid Fertilizer Production Process and Economics

The digestate from the 35 m³ biogas digester (884 kg/day) is treated through the following process:

- Post-treatment: Removal of residual methane and hydrogen sulfide through aeration and settling (2-3 days)
- Filtration: Separation of solids from liquid fraction using adequate screen
- Quality assurance: Testing for pathogens of the slurry checking heavy metals, and nutrient content
- Bottling: Standardized 1-liter containers is used for for retail distribution

Liquid fertilizer production specifications:

- Daily digestate output: 884 kg=850 liters (density =1.04 kg/L)
- Post-treatment yield: approx. 90% (i.e., 765 liters/day of marketable product)
- Annual production: 765 × 365 = 279,225 liters/year

- Assumed retail price: NRs.10/liter (competitive with organic alternatives; lower than chemical fertilizers)
- Annual revenue from fertilizer: 279,225 × 10 = NRs.27,92,250

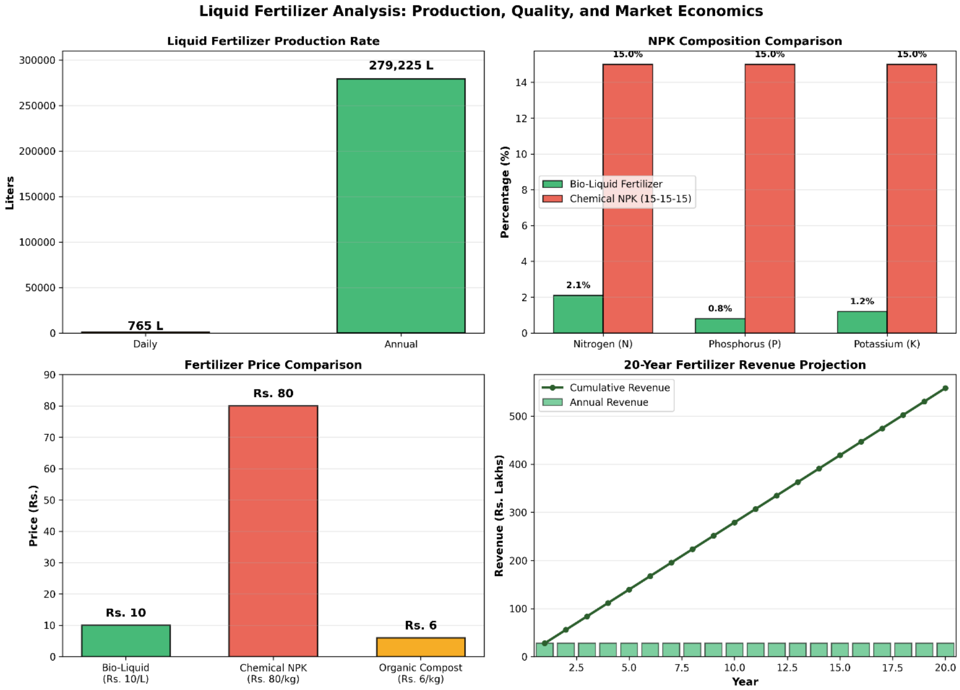


FIGURE 15 LIQUID FERTILIZER ANALYSIS

5.3.2 Comparison with Chemical Fertilizer

The bio-digestate liquid fertilizer has various advantages, including cheaper costs than synthetic NPK fertilizers, enhanced soil structure from organic matter addition, less chemical runoff and environmental pollution, and support for sustainable agriculture practices. While the NPK level is lower than in synthetic fertilizers, the organic matter and micronutrient content improve long-term soil fertility and crop resilience

5.4 FINANCIAL ANALYSIS

A comprehensive financial analysis was carried out utilizing typical discounting methods (Net Present Value, Benefit-Cost Ratio, Internal Rate of Return, and Payback

Period) with discount rates of 8%, 10%, and 12%. A project lifespan of 20 years was proposed.

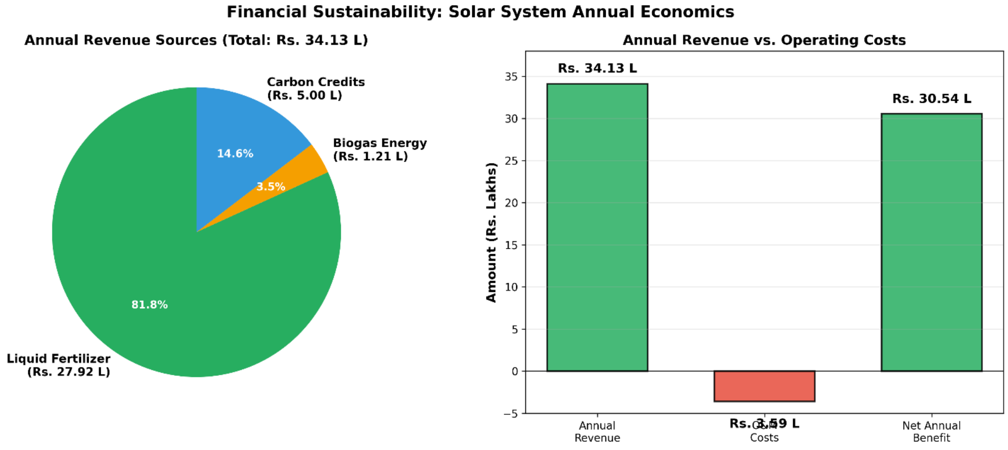


FIGURE 16FINAICIAL SUSTAINABILITY WITH SOLAR WATER HEATER

5.4.1 Installation and Capital Costs

Base biogas plant cost (digester + gas piping): NRs.7,00,000 for 35 m³ capacity (AEPC)

Additional costs:

- Sawdust insulation method: +NRs.1,18,836 (installation + materials)
- Solar water heating method: +NRs.58,420 (panels, pump, piping, storage tank)

5.4.2 Financial Results: Solar Water Heating Method (RECOMMENDED)

Table 16: Financial Analysis - Solar Method WITH GHG Credits (NPV at 8% discount rate)

NPV (NRs.)	**27,72,054**
Benefit-Cost Ratio	3.3
Payback Period	3.4 years
IRR	21%
Annual energy revenue (biogas)	NRs.1,20,888

Annual fertilizer revenue (at NRs.10/liter)	NRs.27,92,250
Annual GHG credit value (at 2025 rates)	NRs.5,00,000
Total annual revenue	NRs.33,13,138

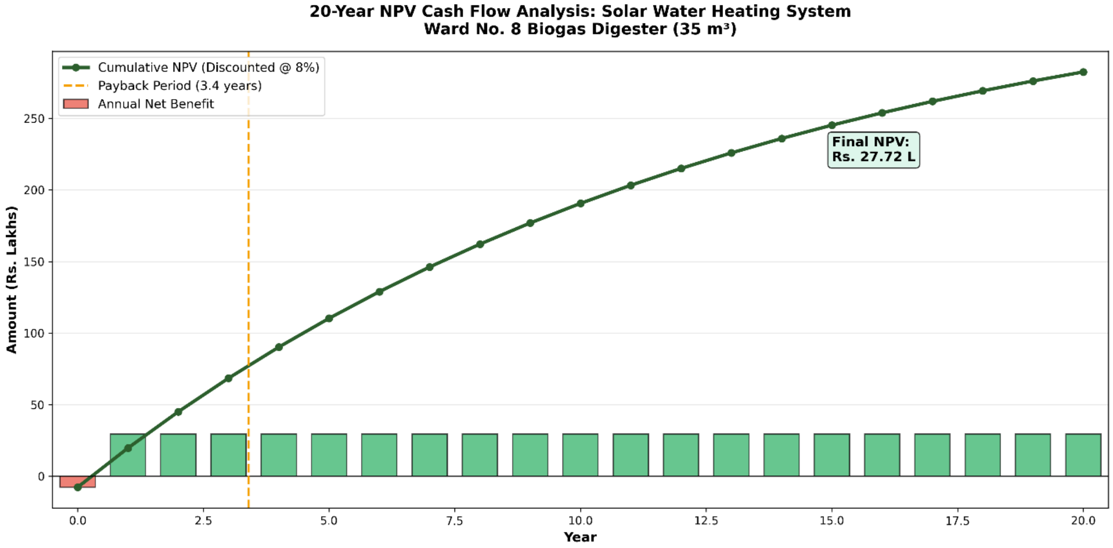


FIGURE 17NPV CASH FLOW

5.4.3 Comparison: Solar vs. Insulation Methods

The solar water heating method significantly outperforms the sawdust insulation method due to several factors:

- Higher biogas production (10% increase in methane yield)
- Lower operational/maintenance costs (solar is free; no sawdust replacement every 5 years)
- Eligibility for carbon credits under CDM framework
- Longer equipment lifespan (solar panels: 25-30 years; insulation: requires renewal)
- Faster payback period: 3.4 years (solar) vs.6.2 years (insulation with GHG)

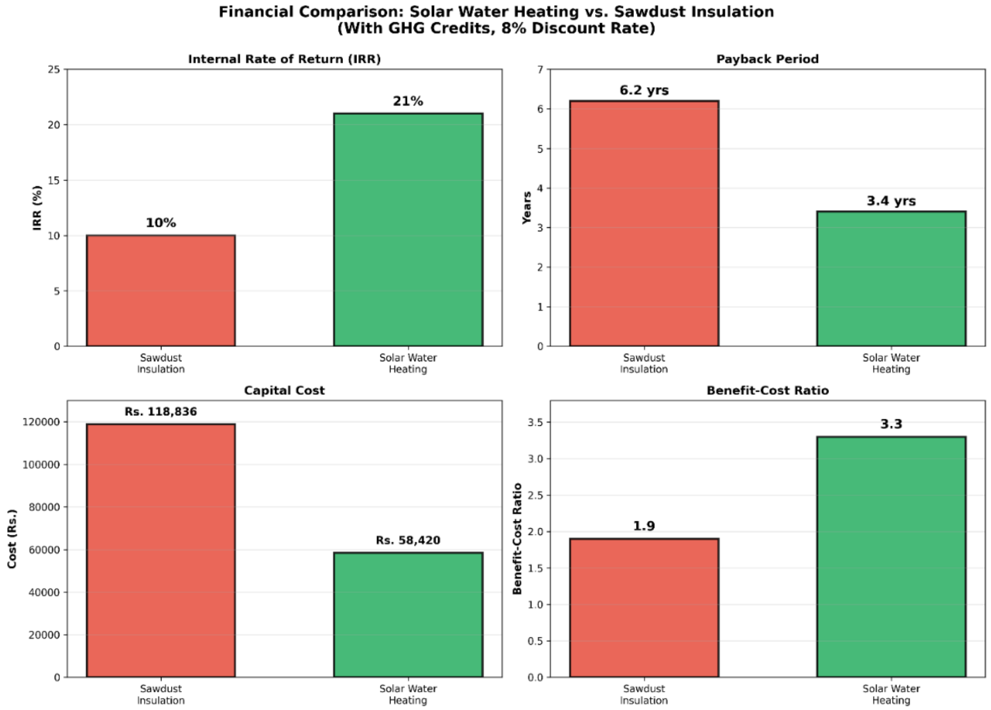


FIGURE 18FINANCIAL COMPARISON OF SOLAR WATER HEATING AND INSULATION METHOD

5.5 ENVIRONMENTAL IMPACT: GHG EMISSION REDUCTION

Implementing the biogas digestion system in Ward 8 would generate significant greenhouse gas benefits:

- Methane production: 6.72 m^3/day = 4,832 kg/year (density 0.72 kg/m^3) = equivalent to 36.96 tons CO_2 per year if used as fuel
- Combustion emissions: 12.44 kg CO_2/day (from biogas burning) = 4.54 tons CO_2/year
- Net GHG reduction: 36.96 - 4.54 = 32.42 tons CO_2 equivalent annually

- This offsets emissions that would result from landfilling the same organic waste
- Carbon credits available: ~1,621 credits/year (at 1 credit =1ton CO_2e), valued at approximately NRs.5,00,000 annually at current market rates

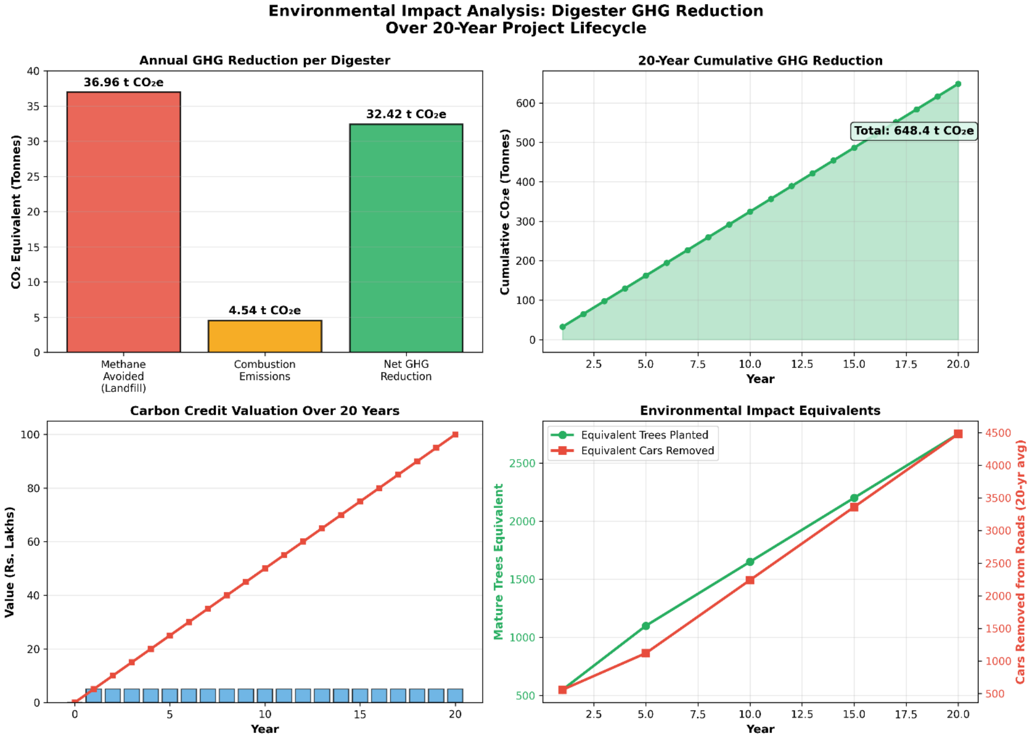


FIGURE 19 ENVIRONMENTAL IMPACT ANALYSIS

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This research project successfully fulfilled all four defined objectives through detailed field surveys, waste classification, techno-economic modeling, and environmental evaluation.

Waste Generation and Management Analysis

The home survey of 111 residents in Ward No.8 measured trash creation at 0.31 kg/person/day, for a total ward generation of 3,919 kg/day. The organic component (70.5%) is a consistent feedstock for anaerobic digestion, with 2,210 kg/day of collected organic waste available after accounting for collection efficiency losses.

Waste Composition and Biogas Potential

The waste characterization indicated a volatile solids concentration of 39.63% and a moisture content of 72.3%. Based on AEPC conversion parameters, Ward 8 has a biogas production capacity of 69 m^3/day and a methane output of 41.2 m^3/day under standard conditions. Optimizing solar heating yields around 45.3 m^3/day of methane, enough to power 300-400 houses or replace 0.23 LPG cylinders each day with sustainable fuel.

Techno-Economic Feasibility Analysis

A cost comparison of two thermal management systems found that solar water heating is the best technological choice. The Solar approach has a 21% IRR (with carbon credits) and a 3.4-year payback period. • The insulation approach has a 10% IRR (including carbon credits) and a 6.2-year payback time.

Both systems achieve financial viability, with positive NPV and B/C ratios greater than 1.5, demonstrating that waste-to-energy conversion in Lalitpur is both economically and environmentally advantageous.

Future Energy and Fertilizer Production Scenarios

To service the full ward population (12,639 inhabitants), a network of four 35 m³ biogas digesters would yield:

- Biogas energy: 276 m³/day (equal to 32 MWh/year or about 11,000 homes' cooking energy).
- Daily liquid fertilizer consumption: 3,400 liters (about 1.2 million liters per year).
- Annual liquid fertilizer income is NRs.1.21 crore at NRs.10 per liter.
- Annual GHG reduction: 129.68 tons CO_2 equivalent from four digesters combined.

6.2 KEY FINDINGS SUMMARY

The study shows that municipal organic waste in Lalitpur may be converted into useful energy and fertilizer products using established anaerobic digestion technology. The solar-assisted biogas system is both environmentally sustainable as well as financially viable, with returns that surpass traditional waste management expenditures. Liquid fertilizer manufacturing at NRs.10/liter provides an economical, organic alternative to synthetic fertilizers while simultaneously supporting sustainable agriculture in Nepal.

6.3 RECOMMENDATIONS

1. **Pilot Implementation:** We want to build a 35 m³ biogas digester with solar heating in Ward No.8 within 12-18 months. Before expanding to other wards, use this pilot to test technical performance, produce operational statistics, and get community support.
2. **Technology Selection:** We ought to select solar water heating over sawdust insulation because of the higher economic returns (21% IRR), operational efficiency, and compatibility with Nepal's renewable energy targets and climate commitments.
3. **Liquid Fertilizer Market Development:** We should do market research to establish buyer networks (agricultural cooperatives, organic farms, horticulture centers) and distribution channels. Certify the liquid fertilizer product in accordance with appropriate standards (ISO, organic certification) to increase market acceptance and justifying the cost.

4. **Stakeholder Engagement:** We must involve Lalitpur Sub-Metropolitan City government officials, ward committees, trash collectors, and individuals in joint planning efforts. Address issues regarding odor management, land distribution, and revenue-sharing methods to guarantee neighborhood support.
5. **Financial Mechanisms:** To lower upfront funding obstacles, we should investigate CDM carbon credit finance, government green energy subsidies, and public-private partnerships (PPPs). Investors are drawn to the project because model study indicates that it will pay for itself in 3.4 years when carbon credits are included.
6. **Further Research:** We can carry out further in-depth research on:
   (a) long-term digestate storage and quality control procedures;
   (b) biogas life-cycle assessment (LCA) in comparison to alternative waste-to-energy pathways (incineration, composting);
   (c)integration with other waste streams (food processing waste, slaughterhouse waste); and
   (d) nutrient recovery optimization for high-value liquid fertilizers.

Policy and Institutional Framework: Advocate for government policies that promote waste segregation, renewable energy tariffs, and preferential purchase of locally generated biogas and organic fertilizers in municipal programs.

6.4 Future Work and Extension

This establishes the foundation for extended research in the following areas:

(1) Full-scale feasibility study including detailed engineering design, site assessment, and permitting requirements;

(2) Community-based pilot implementation with performance monitoring over 12-24 months;

(3) Economic analysis of integrated waste management systems (combining AD with composting and material recovery); and

(4) Replication study for other wards in Lalitpur and neighboring municipalities to demonstrate scalability of the waste-to-energy approach across Nepal's urban landscape.

REFERENCES

Aatiz, C. R. (2023). Renewable Energy Development in Nepal: Potential, Policies and Challenges. *Research Gate, 7*(2), 23-28.

Abdullah, J. &. (2016). Optimizing cellulase production from municipal solid waste (MSW) using solid state fermentation (SSF). *Journal of Fundamentals of Renewable Energy and Applications, 6*(1), 1–10. Doi: https://doi.org/10.4172/2090-4541.1000206

Ahirwar, N. (2021). Problem of Solid Waste Management and its Impact on Urban Environment. *International Journal for Research in Applied Science and Engineering Technology, 9*, 107-110.

Al-Rumaihi, A. A.-A. (2020). Environmental Impact Assessment of Food Waste Management Using Two Composting Techniques. *Sustainability, 12*(2), 1595.

Al-Rumaihi, A. M.-A. (2020). Environmental impact assessment of food waste management using two composting techniques. *Sustainability, 12*(4). Doi:https://doi.org/10.3390/su12041595

Amiri, L. A. (2017). The effects of co-substrate and thermal pretreatment on anaerobic digestion performance. *Environmental Technology*, 2352–2361. Doi: https://doi.org/10.1080/09593330.2016.1262464

Ardolino, F. P. (2018). . Biowaste-to-biomethane or biowaste-to-energy? An LCA study on anaerobic digestion of organic waste. *Journal of Cleaner Production*, 462–476. Doi:https://doi.org/10.1016/j.jclepro.2017.10.320

Asgher, M. A. (2020). Improved biosurfactant production from Aspergillus niger through chemical mutagenesis: Characterization and RSM optimization. *Applied Science*.

Bajracharya, S. A. (2022). Life-cycle assessment of solid waste management in Dhulikhel Municipality, Nepa. *Journal of Environmental Engineering and Science, 17*(3), 147-154.

Behzadi, A. A. (2021). Innovative hybrid solar-waste designs for cogeneration of heat and power: An effort for achieving maximum efficiency and renewable integration. *Applied Thermal Engineering*.

Bharadwaj, D. (2009). *Study of the methan escape assessment and system performance of GGC 2047 biogas plant.* Nepal: M.sc.Thesis , Department of Mechanical Engineering, Tribhuvan University.

Bilek, M. A. (2021). Recycling paper-plastic laminate coffee cups using a single-disk refiner: Energy requirements and recovered fiber quality. *Waste Management, 136*, 104–112. Doi:https://doi.org/10.1016/j.wasman.2021.09.026

BSP-Nepal. (2026). *Renewable Energy Confederation of Nepal*. Retrieved 05 01, 2026, from https://recnepal.org/members/bspnepal.html

C. Aragón-Briceño, A. R.-V. (2017). Evaluation and comparison of product yields and bio-methane potential in sewage digestate following hydrothermal treatment,. *Applied Energy,, 208*, 1357-1369.

C.p. singh, p. K. (1999). Generation of solid waste and itsmanagement in govt. Opium and alkaloids works, ghazipur, india. *Jr. Of industrial pollution control, 15*(1), 51-55.

Chen, Y. (1983). Kinetic analysis of anaerobic digestion of pig manure and its design implications. *Agricultural Wastes, 8*(2), 65-81.

Danial, W. H. (2015). The reuse of wastepaper for the extraction of cellulose nanocrystals. *Carbohydrate Polymers. Doi: https://doi.org/10.1016/j.carbpol.2014.10.072

Dhulia, A. A. (2025). Investigation of BMP and energy generation potential from municipal solid waste under anaerobic condition. *Clean Technologies and Environmental Policy, 27*(11), 6793-6807.

Dlamini, S. S. (2019). Municipal solid waste management in South Africa: From waste to energy recovery through waste-to-energy technologies in Johannesburg. *Local Environment,*.

Evode, N. Q. (2021). Plastic waste and its management strategies for environmental sustainability. *Case Studies in Chemical and Environmental Engineering*.

Fan, Y. V. (2018). Anaerobic digestion of municipal solid waste: Energy and carbon emission footprint. *Journal of Environmental Management, 223*, 888–897. Doi:https://doi.org/10.1016/j.jenvman.2018.06.068

Filomena Ardolino and Umberto Arena. (2019). Biowaste-to-Biomethane: An LCA study on biogas and syngas roads. *Waste Management, 87*, 441-453,.

Ganguly, P. K. (2021). Cellulose from lignocellulose kitchen waste and its application for energy and environment: Bioethanol production and dye removal. *Indian Chemical Engineer, 62*(2), 161–171. Doi: https://doi.org/10.1080/00194506.2020.1736717

Gross, T. B. (2021). Anaerobic digestion of biowaste in Indian municipalities: Effects on energy, fertilizers, water and the local environment. *Resources*.

H.D. Sharma, A. G. (1995). The objectives of waste management in India: A futures inquiry. *Technological Forecasting and Social Change, 48*(3), 285-309.

Jeanine Ammann, O. O. (2021). Comparison of two measures for assessing the volume of food waste in Swiss households,. *Resources, Conservation and Recycling, 166*.

Karki, A., & Dixit, K. (1984). *Biogas field book.* Kathmandu: Sahayogi Prakashan.

Khan, M. S. (2021). Hermodynamic and exergoeconomic analysis of a novel solar-assisted multigenerational system utilizing high temperature phase change material and hybrid nanofluid. *Energy Conversion and Management*.

Manik Desai, V. P. (1994). Effect of temperature and retention time on biomethanation of cheese whey-poultry waste-cattle dung,. *Environmental Pollution, 83*(3), 311-315.

Mansikkasalo, A. T. (2014). Market behavior and policy in the recycled paper industry. *Forest Policy and Economics, 38*, 1-9.

Matsakas, L. K. (2014). Utilization of household food waste for the production of ethanol at high dry material content. *Biotechnology for Biofuels,, 7*(1). Doi:https://doi.org/10.1186/1754-6834-7-4

Mendecka, B. &. (2018). Environmental evaluation of waste-to-energy plant coupled with concentrated solar energy. *Energy Procedia, 148*, 162-169.

Minergy. (2014). *Report on benchmark of biogas plants retrofitting.* Kathmandu: AEPC.

Moya, D. A. (2017). Municipal solid waste as a valuable renewable energy resource: A worldwide opportunity of energy recovery by using waste-to-energy technologies. *Energy Procedia*.

Muhammad Sajid Khan, Q. H. (2022). A novel configuration of solar integrated waste-to-energy incineration plant for multi-generational purpose: An effort for achieving maximum performance,. *Renewable Energy, 194*, 604-620.

Mukumba, P. (2015). Biogas production from a field batch biogas digester using cow dung as a substrate. *Int. J. Eng. Res. & Scie. & Tech, 4*(2).

Ogunjuyigbe, A. A. (2017). Electricity generation from municipal solid waste in some selected cities of Nigeria: An assessment of feasibility, potential and technologies. *Renewable and Sustainable Energy Reviews*.

P. Axaopoulos, P. P. (2001). Simulation and experimental performance of a solar-heated anaerobic digester,. *Solar Energy,, 70*(2), 155-164.

Palansooriya, K. N. (2023). Converting food waste into soil amendments for improving soil sustainability and crop productivity: A review. *Science of the Total Environment*.

Panahi, H. K. (2022). Bioethanol production from food wastes rich in carbohydrates. *Current Opinion in Food Science, 43*, 71–81. Doi:https://doi.org/10.1016/j.cofs.2021.11.001

Riuji, L. C. (2009). RESEARCH ON ANAEROBIC DIGESTION OF ORGANIC SOLID WASTE AT HOUSEHOLD LEVEL IN DAR ES SALAAM, TANZANIA.

Sadi, M. &. (2019). Exergoeconomic analysis of a combined solar-waste driven power plant. *Renewable Energy, , , 141*, 883–893.

Sadi, M. &. (2019). Modelling and analysis of a hybrid solar concentrating-waste incineration power plant. *Journal of Cleaner Production, 216*, 570–584.

Salimi, E. T. (2021). Valorisation of restaurant food waste under the concept of a biorefinery. *Biomass Conversion and Biorefinery, 11*(2), 661–671.

Sinha, S. &. (2021). Trends and challenges in valorisation of food waste in developing economies: A case study of India. *Case Studies in Chemical and Environmental Engineering*. Doi: https://doi.org/10.1016/j.cscee.2021.100162

Srivastava, R. K. (2022). Conversion of methane to methanol: Technologies and future challenges. *Biomass Conversion and Biorefinery*.

Suraj Maharjan, R. S. (2023). Characterizing Municipal Solid Waste and Exploring Resource Recovery Potential: A Case Study of Lalitpur Metropolitan City Ward 14. *KEC Conference 2023*, 249-245.

Sutcu, M. A. (2023). Synergic effect of recycled paper sludge and expanded perlite on the engineering properties of porous clay bricks. *Construction and Building Materials, 365*.

Tang, S. Z. (2008). Measuring the competitiveness of Canadian pulp and paper in the US market. *Canadian Journal of Forest Research, 38*(12), 2951-2964.

Thapa, B. P. (2019). Production of ethanol from municipal solid waste of India and Nepal. In S. Ghosh (Ed.). *Waste valorisation and recycling*, 123-134. Doi:https://doi.org/10.1007/978-981-13-2784-1_12

Tsang, Y. F.-H. (2019). . Production of bioplastic through food waste valorization. *Environment International*.

Ulysse Brémonda, b. A.-P. (2020). Assessment of fungal and thermo-alkaline post-treatments of solid digestate in a recirculation scheme to increase flexibility in feedstocks supply management of biogas plants. *Renewable energy, 149*, 641-651.

Wang, W. C.-S.-J. (2023). Anaerobic digestate valorization beyond agricultural application: Current status and prospects. *Bioresource Technology,*.

Weatherford, V. A. (2015). Affordable solar-assisted biogas digesters for cold climates: Experiment, model, verification and analysis. *Applied Energy, 146*, 209-216.

William A. Beckman, L. B. (1994). TRNSYS The most complete solar energy system modeling and simulation software,. *Renewable Energy,, 5*(1-4), 486-488.

Zhang, W. D. (2015). Low-temperature microwave-assisted pyrolysis of waste office paper. *Green Chemistry, 17*(1), 260-270.

Zhang, W. Z. (2015). Semi-solid state fermentation of food waste for production of Bacillus thuringiensis biopesticide. *Biotechnology and Bioprocess Engineering*.

Zhang, Z. M. (2015). Low-temperature microwave-assisted pyrolysis of waste office paper and the application of bio-oil as an Al adhesive. *Green Chemistry,, 17(1)*, 260–270. Doi:https://doi.org/10.1039/C4GC01368G

Zirkler, D. P. (2014). Elemental composition of biogas residues: Variability and alteration during anaerobic digestion. *Biomass and Bioenergy,*.

APPENDIX A: WASTE SURVEY DATA SUMMARY

Complete household waste data from 111 survey residences in Ward No.8

TABLE 8 HOUSEHOLD SURVEY OF WASTE COLLECTION OF 111 HOUSES

House number	House hold member	First day(kg)	Second day(kg)	Average (kg)	Average/ person	Organic fraction (kg)	Organic/ person
1	5	0.40	0.60	0.50	0.10	0.30	0.06
2	2	0.39	0.41	0.40	0.20	0.35	0.18
7	12	4.42	5.20	4.81	0.40	2.88	0.24
8	6	2.28	1.98	2.13	0.36	1.68	0.28
9	6	1.34	1.88	1.61	0.27	1.21	0.20
10	1	0.10	0.10	0.10	0.10	0.07	0.07
11	4	1.98	1.78	1.88	0.47	1.68	0.42
12	6	1.98	1.56	1.77	0.30	1.42	0.24
13	5	1.15	1.34	1.25	0.25	0.85	0.17
14	5	1.24	2.25	1.75	0.35	1.16	0.23
15	13	4.58	3.33	3.96	0.30	2.21	0.17
16	10	2.22	2.88	2.55	0.26	1.45	0.15

17	2	1.12	0.98	1.05	0.53	0.68	0.34
18	3	0.67	0.86	0.77	0.26	0.56	0.19
19	7	1.24	1.98	1.61	0.23	1.12	0.16
20	4	0.67	0.98	0.83	0.21	0.62	0.16
21	11	2.29	2.47	2.38	0.22	1.62	0.15
22	14	3.12	4.63	3.88	0.28	2.19	0.16
23	18	8.25	9.56	8.91	0.49	5.18	0.29
24	8	3.67	2.82	3.25	0.41	2.18	0.27
25	3	0.63	1.12	0.88	0.29	0.76	0.25
26	9	1.98	2.29	2.14	0.24	2.05	0.23
27	2	0.18	1.82	1.00	0.50	0.75	0.38
28	19	10.34	10.05	10.20	0.54	7.17	0.38
29	1	0.56	0.13	0.35	0.35	0.25	0.25
30	3	1.12	0.98	1.05	0.35	0.78	0.26
31	7	2.28	1.87	2.08	0.30	1.31	0.19
32	2	0.44	0.74	0.59	0.30	0.35	0.18
33	10	2.10	3.75	2.93	0.29	1.52	0.15
34	14	4.14	3.87	4.01	0.29	3.19	0.23

35	12	3.72	3.46	3.59	0.30	2.78	0.23
36	5	1.24	2.26	1.75	0.35	1.32	0.26
37	3	1.23	0.67	0.95	0.32	0.63	0.21
38	9	1.98	1.40	1.69	0.19	1.21	0.13
39	10	2.85	3.28	3.07	0.31	2.72	0.27
40	3	1.31	0.46	0.89	0.30	0.71	0.24
41	4	1.24	1.98	1.61	0.40	1.22	0.31
42	7	1.45	0.88	1.17	0.17	0.78	0.11
43	5	0.78	0.46	0.62	0.12	0.41	0.08
44	10	3.12	2.12	2.62	0.26	1.31	0.13
45	11	2.98	4.12	3.55	0.32	2.51	0.23
46	2	0.86	0.68	0.77	0.39	0.66	0.33
47	5	1.24	2.26	1.75	0.35	1.33	0.27
48	3	1.22	0.98	1.10	0.37	0.80	0.27
49	16	4.44	3.68	4.06	0.25	3.12	0.20
50	17	5.15	6.24	5.70	0.34	3.78	0.22
51	3	1.00	1.24	1.12	0.37	0.86	0.29
52	2	0.04	0.76	0.40	0.20	0.28	0.14

53	13	3.97	3.52	3.75	0.29	2.41	0.19
54	15	4.98	4.16	4.57	0.30	3.82	0.25
55	5	2.12	1.30	1.71	0.34	1.22	0.24
56	6	1.98	1.18	1.58	0.26	1.31	0.22
57	3	0.53	0.72	0.63	0.21	0.56	0.19
58	8	2.98	1.45	2.22	0.28	1.51	0.19
59	11	1.89	3.75	2.82	0.26	1.81	0.16
60	10	3.71	2.51	3.11	0.31	1.98	0.20
61	3	0.67	0.98	0.83	0.28	0.77	0.26
62	7	0.92	1.98	1.45	0.21	1.11	0.16
63	8	3.17	1.34	2.26	0.28	1.82	0.23
64	2	0.83	0.45	0.64	0.32	0.55	0.28
65	4	0.78	1.24	1.01	0.25	0.79	0.20
66	9	3.16	2.00	2.58	0.29	2.02	0.22
67	5	1.98	0.86	1.42	0.28	0.76	0.15
68	2	0.38	0.67	0.53	0.26	0.44	0.22
69	6	1.62	3.18	2.40	0.40	1.78	0.30
70	10	3.72	2.71	3.22	0.32	2.18	0.22

71	5	1.78	1.51	1.65	0.33	0.92	0.18
72	11	3.18	2.91	3.05	0.28	2.05	0.19
73	13	2.86	4.61	3.74	0.29	2.61	0.20
74	14	3.92	2.25	3.09	0.22	2.41	0.17
75	3	1.11	1.09	1.10	0.37	0.88	0.29
76	7	1.05	2.94	2.00	0.29	1.45	0.21
77	5	2.51	1.19	1.85	0.37	1.32	0.26
78	4	1.76	1.12	1.44	0.36	0.82	0.21
79	16	4.68	5.17	4.93	0.31	3.12	0.20
80	17	8.16	5.67	6.92	0.41	4.11	0.24
81	3	0.64	0.89	0.77	0.26	0.56	0.19
82	5	1.54	0.54	1.04	0.21	0.76	0.15
83	5	1.78	0.98	1.38	0.28	0.92	0.18
84	3	1.67	0.98	1.33	0.44	0.97	0.32
85	3	0.98	0.66	0.82	0.27	0.68	0.23
86	4	1.16	2.18	1.67	0.42	0.94	0.24
87	7	1.99	1.61	1.80	0.26	1.12	0.16
88	5	1.52	1.67	1.60	0.32	1.21	0.24

89	11	3.87	4.17	4.02	0.37	2.92	0.27
90	5	1.05	2.14	1.60	0.32	1.20	0.24
91	3	0.67	1.31	0.99	0.33	0.80	0.27
92	7	2.17	1.23	1.70	0.24	1.20	0.17
93	8	2.17	2.41	2.29	0.29	1.76	0.22
94	13	3.68	5.16	4.42	0.34	2.89	0.22
95	9	1.69	3.42	2.56	0.28	1.18	0.13
96	4	1.10	0.77	0.94	0.23	0.87	0.22
97	4	1.85	0.67	1.26	0.32	0.92	0.23
98	2	0.98	0.45	0.72	0.36	0.58	0.29
99	4	1.24	0.68	0.96	0.24	0.71	0.18
100	2	0.34	0.78	0.56	0.28	0.42	0.21
101	2	0.67	0.45	0.56	0.28	0.38	0.19
102	3	0.91	1.89	1.40	0.47	0.78	0.26
103	4	1.12	0.88	1.00	0.25	0.70	0.18
104	3	1.56	0.45	1.01	0.34	0.78	0.26
105	4	1.82	1.11	1.47	0.37	1.32	0.33
106	12	3.68	4.26	3.97	0.33	2.38	0.20

107	15	4.45	6.18	5.32	0.35	3.86	0.26
108	3	0.82	0.78	0.80	0.27	0.67	0.22
109	2	0.44	0.65	0.55	0.27	0.46	0.23
110	17	5.41	6.26	5.84	0.34	3.25	0.19
111	5	0.28	0.64	1.22	0.24	0.76	0.15
Total	738			228.88	0.31	158.45	0.21

APPENDIX B: FINANCIAL CALCULATION WORKSHEETS

20-year NPV calculations for both solar and insulation methods at 8% discount rate:

BIOGAS INSTALLATION OF 35 CUBIC METRES USING INSULATION

Installation cost (NRs)		700000	118836.43	682403	1501239.43
Total annual cost (NRs)		359379	252000	27156	638535
Total revenue generated		125925	776720		902645

MARR 8%

Year	Net Cash Flow	NPV 8 %	Cumulative NPV at 8%
0	-1501239.43	-1501239.43	-1501239.43
1	264110	244546.30	-1256693.13
2	264110	218272.73	-1038420.41
3	264110	198429.75	-839990.65
4	264110	180390.68	-659599.97
5	264110	163991.53	-495608.44
6	264110	149083.21	-346525.23
7	264110	135530.19	-210995.04

8	264110	123209.26	-87785.78
9	264110	112008.42	24222.65
10	264110	101825.84	126048.48
11	264110	92568.94	218617.43
12	264110	84153.59	302771.01
13	264110	76503.26	379274.27
14	264110	69548.42	448822.69
15	264110	63225.83	512048.52
16	264110	57478.03	569526.56
17	264110	52252.76	621779.31
18	264110	47502.51	669281.82
19	264110	43184.10	712465.91
20	264110	39258.27	751724.18

At 8%

PW of benefits	(8,862,301.67)
PW of Operation & Maintenance	(6,269,230.75)
	(6,699,933.25)

Discount rate	8%	

NPV (Rs.)	751724	
B/C ratio	1.7	
Payback period	8.5	years
IRR	6%	

CALCULATION INCLUDING CO_2 REDUCTION

Installation cost (Nrs)	700000	118836.44	682403	1501239.44
Total annual cost (Nrs)	359379	252000	27156	638535
Total revenue generated	125925	776720	22692	932503
	MARR	8%		

Year	Net Cash Flow	NPV 8%	Cumulative NPV at 8%
0	-1501239.44	-1501239.44	-1501239.43
1	293968	272192.59	-1229046.84
2	293968	252030.18	-977016.66
3	293968	233361.28	-743655.38

4	293968	216075.26	-527580.13
5	293968	200069.68	-327510.45
6	293968	185249.70	-142260.74
7	293968	171527.50	29266.76
8	293968	158821.76	188088.53
9	293968	147057.19	335145.72
10	293968	136164.06	471309.78
11	293968	126077.84	597387.62
12	293968	116738.74	714126.35
13	293968	108091.42	822217.78
14	293968	100084.65	922302.43
15	293968	92670.97	1014973.40
16	293968	85806.46	1100779.86
17	293968	79450.42	1180230.28
18	293968	73565.21	1253795.49
19	293968	68115.93	1321911.42
20	293968	63070.31	1384981.73

At 8%

PW of benefits ($9,155,451.91)

PW of OandM ($6,269,230.75)

Discount rate	8%	
NPV (Rs.)	1384982	
B/C ratio	1.9	
Payback period	6.2	years
IRR	10%	

BIOGAS INSTALLATION OF 35 CUBIC METRES WITH SOLAR

Installation cost	700,000	58,420	682,403	1440823
Total annual cost	359,379	252,000	252000	611379
Total revenue generated	125,925	776720		902645

MARR 8%

Year	Net Cash Flow	NPV 8%	Cumulative NPV at 8%
0	-1440823	-1440823.00	-1440823.00
1	291266	264787.27	-1176035.73
2	291266	240715.70	-935320.02
3	291266	218832.46	-716487.57

4	291266	198938.60	-517548.97
5	291266	180853.27	-336695.70
6	291266	164412.06	-172283.64
7	291266	149465.51	-22818.12
8	291266	135877.74	113059.61
9	291266	123525.22	236584.83
10	291266	112295.65	348880.48
11	291266	102086.96	450967.44
12	291266	92806.32	543773.76
13	291266	84369.39	628143.15
14	291266	76699.44	704842.59
15	291266	69726.76	774569.35
16	291266	63387.97	837957.32
17	291266	57625.43	895582.75
18	291266	52386.75	947969.50
19	291266	47624.32	995593.82
20	291266	43294.83	1038888.65

At 8%

PW of benefits	($8,862,301.67)
PW of OandM	($6,002,609.14)

Discount rate	8%	
NPV (Rs.)	1038889	
B/C ratio	6.6	
Payback period	7.3	years
IRR	9%	

CALCULATION INCLUDING CO2 REDUCTION

Installation cost	700000	58420	682403	1440823
Total annual cost	359378	252000		359378
Total revenue generated	294184	525600	22692	842476
	MARR	8%		

Year	Net Cash Flow	NPV 8%	Cumulative NPV at 8%
0	-1440823	-1440823.00	-1440823.00
1	483097	439179.09	-1001643.91

2	483097	399253.72	-602390.19
3	483097	362957.93	-239432.26
4	483097	329961.75	90529.49
5	483097	299965.23	390494.72
6	483097	272695.66	663190.38
7	483097	247905.15	911095.53
8	483097	225368.32	1136463.84
9	483097	204880.29	1341344.13
10	483097	186254.81	1527598.94
11	483097	169322.55	1696921.49
12	483097	153929.59	1850851.08
13	483097	139935.99	1990787.07
14	483097	127214.54	2118001.61
15	483097	115649.58	2233651.19
16	483097	105135.98	2338787.17
17	483097	95578.17	2434365.34
18	483097	86889.24	2521254.58
19	483097	78990.22	2600244.80
20	483097	71809.29	2672054.09

At 8%

PW of benefits	($8,271,553.56)
PW of OandM	($3,528,436.00)

Discount rate	8%	
NPV (Rs.)	2672054	
B/C ratio	3.3	
Payback period	3.4	years
IRR	21%	

Solar Water Heating Method with liquid fertilizer- Annual Cash Flow Projection:

Year	Revenue (NRs)	O&M Cost (NRs)	Net Benefit (NRs)	Cumulative (NRs)
0 (Installation)	-7,58,420	0	-7,58,420	-7,58,420
1	+33,13,138	-3,59,379	+29,53,759	+22,10,780
2	+33,13,138	-3,59,379	+29,53,759	+51,64,539
3	+33,13,138	-3,59,379	+29,53,759	+81,18,298
4	+33,13,138	-3,59,379	+29,53,759	+1,10,72,057

5	+33,13,138	-3,59,379	+29,53,759	+1,40,25,816
6	+33,13,138	-3,59,379	+29,53,759	+1,69,79,575
7	+33,13,138	-3,59,379	+29,53,759	+1,99,33,334
8	+33,13,138	-3,59,379	+29,53,759	+2,28,87,093
9	+33,13,138	-3,59,379	+29,53,759	+2,58,40,852
10	+33,13,138	-3,59,379	+29,53,759	+2,87,94,611
11	+33,13,138	-3,59,379	+29,53,759	+3,17,48,370
12	+33,13,138	-3,59,379	+29,53,759	+3,47,02,129
13	+33,13,138	-3,59,379	+29,53,759	+3,76,55,888
14	+33,13,138	-3,59,379	+29,53,759	+4,06,09,647
15	+33,13,138	-3,59,379	+29,53,759	+4,35,63,406
16	+33,13,138	-3,59,379	+29,53,759	+4,65,17,165
17	+33,13,138	-3,59,379	+29,53,759	+4,94,70,924
18	+33,13,138	-3,59,379	+29,53,759	+5,24,24,683
19	+33,13,138	-3,59,379	+29,53,759	+5,53,78,442
20	+33,13,138	-3,59,379	+29,53,759	+5,83,32,201

APPENDIX C: TECHNICAL DESIGN SPECIFICATIONS

C.1 BIOGAS DIGESTER DESIGN

Type: Fixed dome, below-ground, concrete construction

Volume: 35 m³ working capacity

Inlet pipe diameter: 50 mm (slurry input)

Outlet pipe diameter: 50 mm (digestate removal)

Gas piping: 25 mm copper tubing (corrosion-resistant)

Hydraulic retention time (HRT): 30 days at mesophilic temperature (32degreeC)

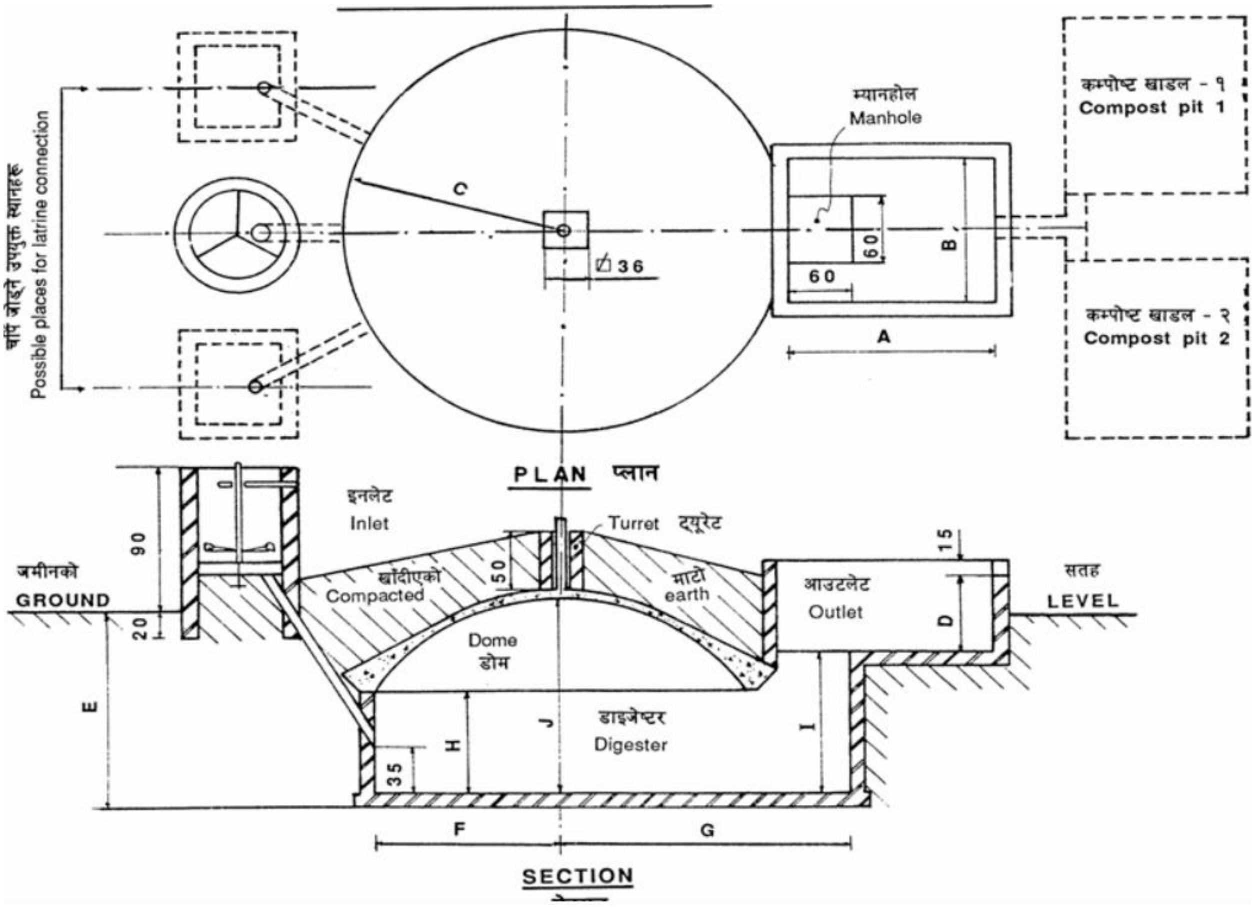


FIGURE 20 BIO DIGESTER DESIGN

C.2 SOLAR WATER HEATING SYSTEM COMPONENTS

Component	Specification	Unit Cost (NRs)	Total (NRs)
Solar flat plate collector	250L, toughened glass cover, copper absorber	31,000	31,000
Circulation pump	120W, 1.5 kW	10,500	10,500
Copper piping	7.5 m, 25 mm diameter	1,700/m	12,750
Storage tank	250L capacity, insulated	3,000	3,000
Gate valves	2-inch threaded, brass	265/each	530
Heat exchanger nozzles	2-inch (4 nos)	160/each	640
Installation and misc	Labor + fittings		Total: 58,420

C.3 BIOGAS YIELD FOR 32 M^3 DIGESTER

Mass of manure,

$$m = 0.6 \times volume \times density$$

$$= 0.6 \times 32 \times 831$$

$$= 15955.2 \text{ Kg per retention time}$$

Mass of manure each lot = $15955.2/30$

= 531.84 kg

Mass of solid waste each lot (**m**) = $531.84/2$

= 265 kg/day

Volatile solid = 39.65%

265 kg waste = 29 kg volatile solid

1 kg VS in normal condition = 0.35 m^3 biogas (AEPC)

29 kg VS = 10.15 m^3 biogas

The biogas contains 60% methane

Amount of methane produced = 6.09 m^3 methane

The 10 % increase in production is obtained using the heating technology

Total methane yield = 6.72 m^3 methane per day

C.4 DESIGNS FOR OPTIMIZATION

Calculation of influent heating (Q_T)

Average density of manure = (1000+662)/2 == 831 kg/m^3

Specific heat of Waste, C_1=1.715 KJ/Kg ^{O}C

Specific heat of water,$C_{2=}$ 4.2 KJ/Kg ^{O}C

Average specific heat of manure , $= \frac{(1.715+4.2)}{2}$ = 2.9575 J/Kg ^{O}C

Original manure temperature, T_1= 20^O C (darlami,2015)

Anticipated temperature of influent, T_2= 32 ^{O} C

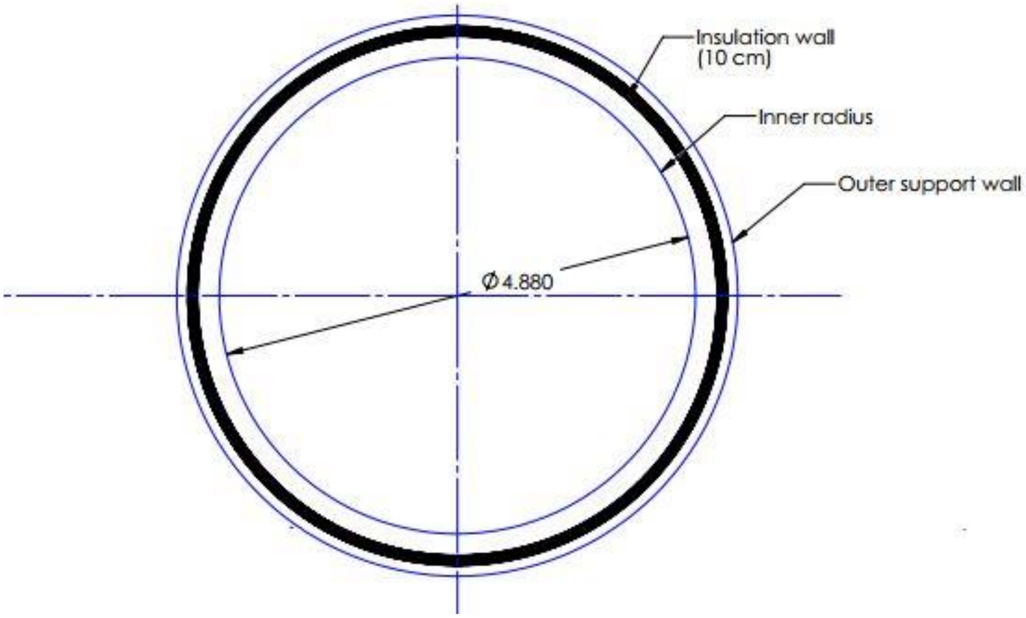
$$Q_T = m \times c \times (T_2 - T_1)$$

= 531.84× 2957.5× (32-20)

=18916 KJ

Calculation of heat loss through the Bio digester Components (Q_L)

Calculation of total resistance to heat flow and heat loss



Structure	Area (sq. meter)	Thickness(m)	Thermal conductivity (W/m K)	Material
Wall	11.750	.150	1.70	Concrete
Roof	0.150	0.150	1.70	Concrete
Floor	4.66	0.350	1.295 1.7	Stone and concrete

Now,

Resistance to heat flow due to wall, R_1 = $0.15/((1.7 \times 11.75)$ = 0.0075

Resistance to heat flow due to roof, R_2

= $0.15/(0.15 \times 1.7)$ == 0.60

Resistance to heat flow due to floor, R_3

= $0.35/((4.66 \times 1.295))$==0.058

Also, The heat loss various components is given by

Heat loss over wall, $\boldsymbol{Q_1}$

= $(32-20)/0.0075$ = 1600 J

Heat lost through roof, $\mathbf{Q_2}$

= $(32-20)/0.60$ = 20 J

Heat lost from Floor, $\mathbf{Q_3}$

= $(32-20)/0.058$ =206.8965J

Total heat lost is given by the sum of all heat lost

$\mathbf{Q_L=Q_1+Q_2+Q_3}$

= 1826.89 J

Now the total heat energy required by the bio digester to maintain the temperature of 32 o C for the greatest efficiency is supplied by the total sum of heat required by the manure and the total heat lost by the digester from its components.

$$Q = 1826.89J + 18916000J$$

$$= 18918KJ$$

C.5 SOLAR WATER HEATER DESIGN CALCULATION

Taking the water temperature for bio digester, 40^0C

Without considering the resistance by the copper tube,

Energy demanded for the digester = energy supplied by the water

$$18918 = M\ x\ 4.2\ x\ (40 - 20)$$

$$\text{Or, } M = 225kg$$

Volume of water required for the circulation during the heating phase is 225 liter 0.225m^3

Solar water heater design

Solar water heater was designed for the above calculated data. The total amount of water, the temperature of the water, pump required are calculated as:.

The amount of water required to heat the system = 225 L

Mass of water = volume x density = 225 x 10^{-3} x 1000

= 225 Kg

Considering that the water's starting temperature was 20 degrees Celsius and the ideal water temperature is 40.5 degrees Celsius.

Change in temperature = ΔT = (40.5 - 20) = 20 ^{O}C

Heat added by water,

$$Q_S = mC_P\Delta T$$

= 225 x 4.2x 20.5

= 19373KJ

=5.3813 kWh

Calculating the collector yield of the panel:

Lalitpur's average sun radiation on a horizontal surface = S_R = 4.7 kWh/m

60% is considered the collector efficiency.

The system efficiency is taken at 85%

C_Y = Average solar radiation x system efficiency x collector efficiency

$$C_Y = S_R \times \eta_{sys} \times \eta_C$$

$$\mathbf{C_Y = 4.7 \times 0.85 \times 0.6}$$

$$\mathbf{= 2.397\ KWh/m^2}$$

the collector array,

$$C_A = \frac{Q_S}{C_Y}$$

$$= 5.3813/2.397$$

$$= 2.245\ m^2$$

Using standard panel size of dimension: 4 ft x 10 ft = 40 ft^2 = 3.72 m^2

Thus, we can calculate the number of panels required as = N = 2.245/3.72 = 0.6

Hence, Number of panels = 1

For the effective production of biogas at an average temperature of 20 degrees Celsius, single panel of 40ft^2 ,available in the market is sufficient.

Design for modification using Insulation

Heat loss before insulation

internal radius of dome	2.44	M
external radius of dome	2.66	M
Height of digester	1.17	M

Convective heat transfer coefficient of slurry	4.4	W/m^{2}K
Thermal conductivity of concrete	1.7	W/m^{2}K
Convective heat transfer coefficient	0.64	
Temperature of surrounding	22	°C
Required temperature	30	°C
(ln(r2/r1))/k	0.051	
1/(hf*r1)	0.093	

On solving, 408.41 W

Hot water calculation

Quantity of water	266 ltr
Mass of water	266 kg
Required temperature	32 °C

Heat required by water = MCpdt

7056 KJ

1 KJ	0.28 Mwhr	KWhr
7056 KJ	1959.45Mwhr	KWhr
	= 6.2-unit	unit

Thus, it takes 6.2 units of electricity each day to heat 266 liters of water.

Calculation for critical thickness

$$408.4 = \frac{2 * \pi * l * k * dt}{\ln\left(\frac{r3}{r2}\right)}$$

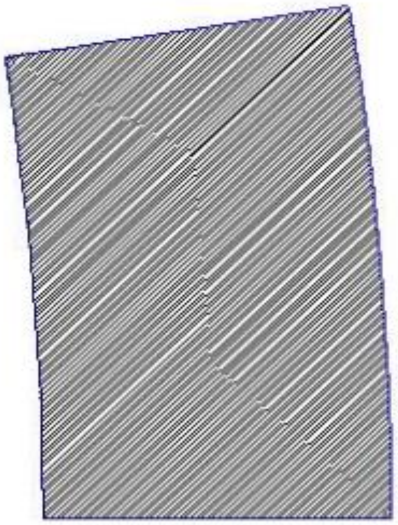
$\ln\left(\frac{r3}{r2}\right)$	0.029	
r3	2.72	M
Critical thickness	0.06	M
So required thickness > 0.06m	0.1	M
Radius including insulation	2.76	M
Volume intended for insulation	Outer vol.- Inner vol.	
	1.99	m^3

Calculation of sawdust

$Mass\ =\ Density/Volume$

Density of sawdust	210 Kg/m^3
Mass of sawdust	418.15 Kg
Cost of 1 kg sawdust cost	20.00 NRs.
Total cost of sawdust	8363.04 NRs.

The slab design:



Allow the inner arch to	0.400	m
Outside radius of dome	2.590	m
Radius up to the insulation	2.760	m
Entire outer radius	2.870	m
Total Angle	360	rad
θ= l/r	0.15	rad
Outer arch length	0.440	m
Let the thickness of slab	0.070	m
Require volume for slab use	0.34	m^3

No. of slab required 41 Number

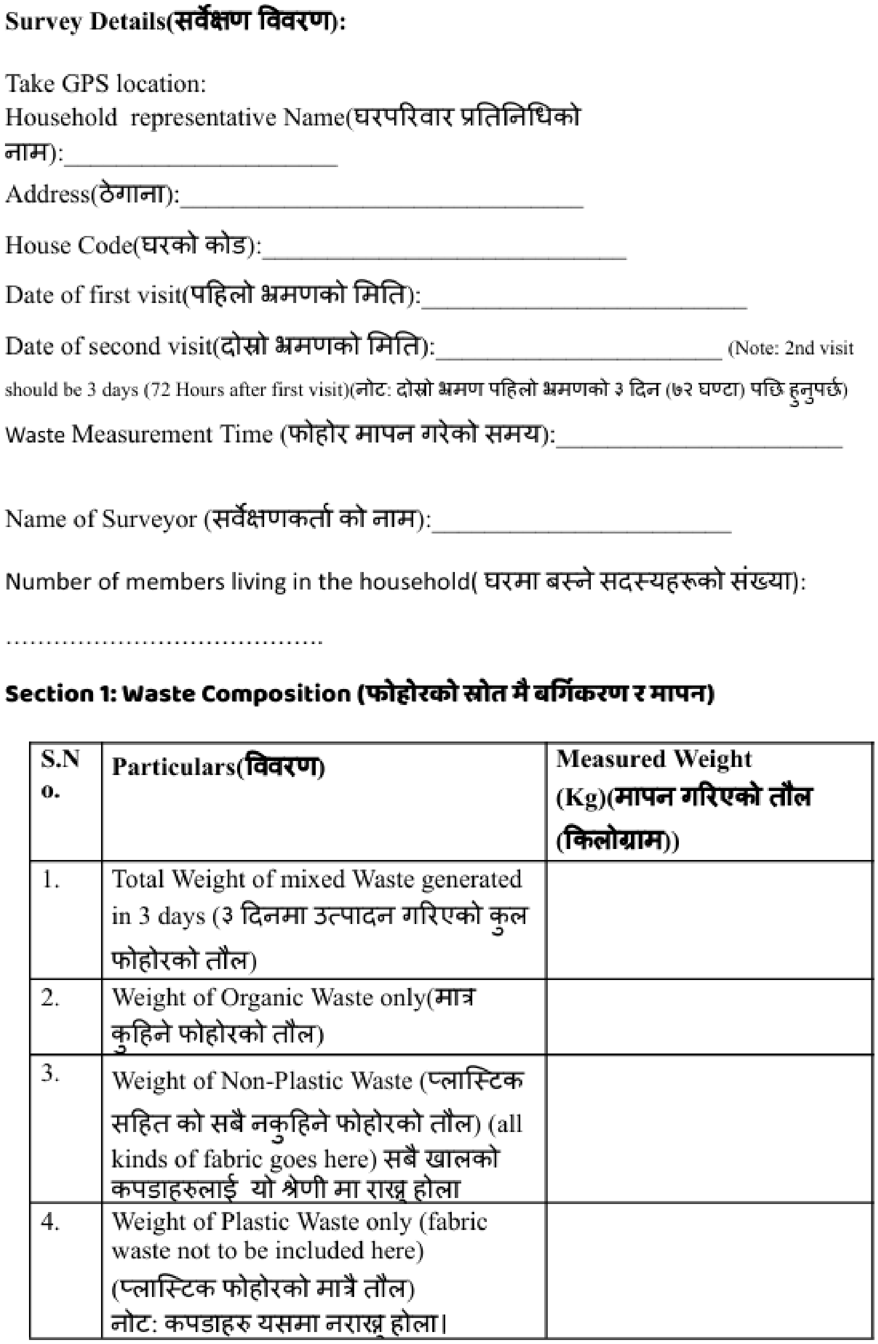
Contribution in GHG Emission Reduction

1 kg VS in normal condition		=0.35 m^3 CH4	
1800	Kg	=197.00	kg VS/day
266	Kg		=29.10 m^3 CH_4
			10.190 gas/day
Insulation increases production to 60%			11.210 m^3 biogas

CH_4 generation	6.72	m^3/day
Density of methane	0.72	kg/m^3
Production of methane	1759	kg/yr
	36.96	tones of CO2
Combustion of $1m^3$ of CH_4 release $1m^3$ CO_2	1.85	kg CO_2
6.72 m^3	12.44	kg CO_2
In 1 year, CO_2 released by combustion will be	4.54	tones

Therefore, producing biogas from organic solid waste will save CO_2 emissions by 32.42 tons.

FIGURE 21: ORIENTATION OF WASTE SEGREGATION IN MRF CENTER FOR FIELD SURVEYERS



Survey Details(सर्वेक्षण विवरण):

Take GPS location:

Household representative Name(घरपरिवार प्रतिनिधिको नाम):____________________

Address(ठेगाना):______________________________

House Code(घरको कोड):___________________________

Date of first visit(पहिलो भ्रमणको मिति):_________________________

Date of second visit(दोस्रो भ्रमणको मिति):______________________ (Note: 2nd visit should be 3 days (72 Hours after first visit)(नोट: दोस्रो भ्रमण पहिलो भ्रमणको ३ दिन (७२ घण्टा) पछि हुनुपर्छ)

Waste Measurement Time (फोहोर मापन गरेको समय):______________________

Name of Surveyor (सर्वेक्षणकर्ता को नाम):_______________________

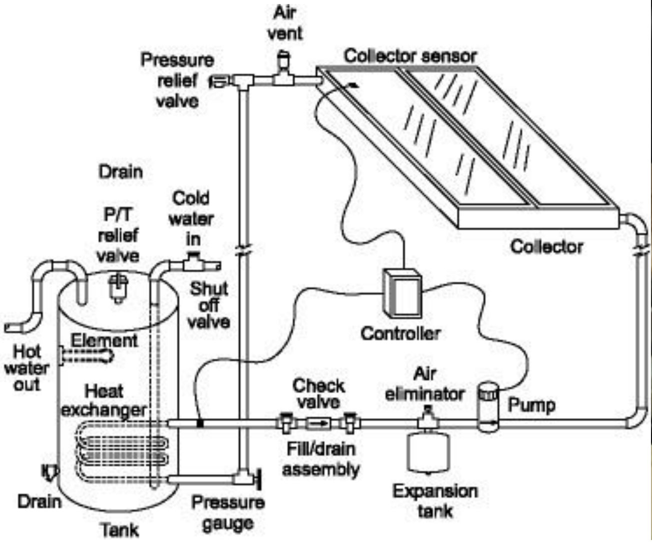
Number of members living in the household(घरमा बस्ने सदस्यहरूको संख्या):

……………………………………

Section 1: Waste Composition (फोहोरको स्रोत मै बर्गिकरण र मापन)

S.No.	Particulars(विवरण)	Measured Weight (Kg)(मापन गरिएको तौल (किलोग्राम))
1.	Total Weight of mixed Waste generated in 3 days (३ दिनमा उत्पादन गरिएको कुल फोहोरको तौल)	
2.	Weight of Organic Waste only(मात्र कुहिने फोहोरको तौल)	
3.	Weight of Non-Plastic Waste (प्लास्टिक सहित को सबै नकुहिने फोहोरको तौल) (all kinds of fabric goes here) सबै खालको कपडाहरुलाई यो श्रेणी मा राख्नु होला	
4.	Weight of Plastic Waste only (fabric waste not to be included here) (प्लास्टिक फोहोरको मात्रै तौल) नोट: कपडाहरु यसमा नराख्नु होला।	

FIGURE 22 SURVEY FORM


Air vent
Pressure relief valve
Collector sensor
Drain
P/T relief valve
Cold water in
Shut off valve
Collector
Hot water out
Element
Heat exchanger
Controller
Check valve
Air eliminator
Pump
Fill/drain assembly
Expansion tank
Drain
Tank
Pressure gauge


LONKEY ® WATER PUMP
Model: 15WZR-14
Qmax 10 l/min
Hmax 14 m
1~Mot
V 230 ~
Size: 3/4" × 3/4"
W 120
In 0.52 A
Hz 50
2900 min⁻¹
C 5 µF
ICL B
IP 44
CE ISO9001
Continuous duty
Thermal protector YES
No.