TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS, PULCHOWK

Thesis No: 075/MSCCD/011

“ESTIMATING METHANE GAS GENERATION FROM LANDFILL SITE – A CASE STUDY OF SISDOL LANDFILL SITE, NUWAKOT NEPAL ’’

By
KUSUM DEO

A THESIS

SUBMITTED TO THE DEPARTMENT OF APPLIED SCIENCES AND
CHEMICAL ENGINEERING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTERS OF SCIENCE
IN
CLIMATE CHANGE AND DEVELOPMENT PROGRAMME

Department of Applied Sciences and Chemical Engineering
Institute Of Engineering, Tribhuvan University
Pulchowk Lalitpur, Nepal

September, 2021

COPYRIGHT ©

Head
Department of Applied Sciences and Chemical Engineering
Institute of Engineering
Pulchowk Campus
Lalitpur, Nepal

TRIBHUVANUNIVERSITY
INSTITUTE OF ENGINEERING, PULCHOWK CAMPUS
DEPARTMENT OF APPLIED SCIENCES AND CHEMICAL ENGINEERING

Approval

The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance of the thesis entitled "**Estimating Methane Gas Generation From Landfill Site- A Case Study of Sisdol Landfill Site, Nuwakot Nepal**" submitted by Kusum Deo (075/MSCCD/011) in partial fulfillment of the requirements for the degree of Master of Science in Climate Change and Development.

Supervisors:

Prof. Ram Kumar Sharma, **Ph.D.**
Head of Department
Department of Applied Sciences and
Chemical Engineering
IOE, Pulchowk Campus

Asst. Prof. Shanti Kala Subedi, Ph.D.
Chief, Research and Innovation Unit
Himalaya College of Engineering

Program Coordinator

Prof. Khem Narayan Poudyal, Ph.D.
Program Coordinator
Climate change and Development
Department of Applied Sciences and
Chemical Engineering
IOE, Pulchowk Campus

Committee Chairperson

Prof. Ram Kumar Sharma, **Ph.D.**
Head of Department
Department of Applied Sciences and
Chemical Engineering
IOE, Pulchowk Campus

External Examiner:

Assoc. Prof. Nawaraj Bhattarai, Ph.D.
Head of Department
Department of Mechanical Engineering
IOE, Pulchowk Campus

Date: Sept, 2021

DECLARATION

I hereby declare that the thesis entitled **“Estimating Methane Gas Generation from Landfill Site- A Case Study of Sisdol Landfill Site, Nuwakot Nepal”** has not been previously accepted in substance for any degree and is not being concurrently submitted in candidature for any degree. I state that this thesis is the result of my independent work/investigation, except where otherwise stated. I, hereby, give consent for my thesis, if accepted, to be available for photocopying and understand that any reference to or quotation from my thesis will receive an acknowledgement.

Kusum Deo
075/MSCCD/011
2021

ABSTRACT

Climate change and solid waste management are the two interrelated burning issues globally. Methane gas is one of the most powerful greenhouse gases with a global warming potential having GWP 28 times that of carbon dioxide (CO_2). Landfills are a major source of anthropogenic methane (CH_4) emissions since they are a prevalent method of municipal waste disposal. Because of its exceptional abilities for energy production, CH_4 is not just a source of GHG but also a great source of alternative energy. With the right technology, considerable amounts of energy may be extracted from it. The aim is to determine the total methane emission from the Sisdol landfill under various scenarios and reduction in each scenario. One of the common mathematical models used for estimating the quantity of methane potential and generation is LandGEM software due to its simplicity and precise, site-based estimation of generation of methane. The software was applied in this study to estimate the CH_4 emitted to date and emission in the upcoming years from Sisdol landfill site for six different predictive scenarios: S0, S1, S2, S3, S4 and S5. The Scenarios were developed based on people's perception, feasibility and applicability of each scenario in the future.

After calculation, CH_4 was estimated to be 2283.93 Mg/year for 2021 with 25, 02,999.78 Mg waste in place and 3678.43 Mg/year in 2030 under Business As Usual (BAU). Based on comparative study of each scenario, maximum reduction in methane generation was found under integrated scenario (S5) and minimal was for recycling scenario (S4). Without a doubt, the worst-case scenario resulted in a rise in emissions. As a result, the integrated scenario was determined to be the best option for managing municipal garbage in Kathmandu.

This information will indeed be utilized to determine the optimum solution for municipal waste management for the long-term management of municipal solid waste in Kathmandu. It could be used in the design and planning of waste management solutions, as well as determining the viability of a landfill gas collection system.

ACKNOWLEDGEMENT

First and foremost, I really would like to express my heartfelt gratitude to my supervisors, Dr. Ram Kumar Sharma, Head of Department, Department of Applied Sciences and Chemical Engineering, IOE, Pulchowk Campus, and Dr. Shantikala Subedi, Asst. Professor, Chief, Research and Innovation Unit, Himalaya College of Engineering, for their continuous encouragement, dedication, and keen interest in assisting me with my work. Their prompt assistance, encouragement, meticulous inspection, intellectual advice, and scientific attitude have greatly aided me in completing this assignment.

I owe a debt of gratitude to Dr. Prof. Khem Narayan Poudyal, Programme coordinator, Department of Applied Sciences and Chemical Engineering, for encouraging me to pursue the thesis and for giving the necessary resources and ongoing support during the project.

I would like to appreciate my external Examiner, Dr. Nawaraj Bhattarai for his worthy comments and recommendations for my thesis work.

It is my privilege to thank my colleagues and teachers for suggestions, information, assistance and criticism which helped me a lot.

I would like to thank all the concerned authorities for providing me the required data necessary for this study.

I am very grateful to my family and friends for their life-long sacrifice and unconditional ever-encouraging support for me without which this study would have never been possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CH_4	Methane
CO_2	Carbon Dioxide
DHM	Department of Hydrology and Meteorology
DOC	Degradable Organic Carbon
GHGs	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
LandGEM	Landfill Gas Emissions Model
LFGs	Landfill Gases
LiDAR	Light detection and Ranging
masl	mean Avg. sea level
MSW	Municipal Solid Waste
NAST	Nepal Academy of Science and Technology
SLS	Sisdol Lanfill Site
TNO	The Neatherlands Organisation
UNFCCC	United Nations Framework Convention on Climate Change
US-EPA	United States Environmental Protection Agency
VRPM ORS	Vertical Radial Plume Mapping Optical Remote Sensing

CHAPTER ONE: INTRODUCTION

1.1 Background

Solid waste management is increasingly becoming a critical environmental issue as with an ever increasing global and urbanized population the generation of waste is also remarkably increasing. Especially in developing countries, SWM is one of the essential obligatory functions of the Local Bodies. Globally, the waste generation rate is likely to reach around 2.2 billion tons by 2025. Since history, most of the solid wastes generated are discarded to the landfills instead of alternatively treating it. (Fallahizadeh et al., 2019) which results in landfill gases (LFGs) that generates out of anaerobic degradation of solid wastes (Roodbari et al., 2012; Ahmadian et al., 2013; Jain et al., 2014). Landfills are one of the as a major sources of methane emission. It is estimated that 18% of the global anthropogenic methane is accredited to the waste fraction(Fourier & Morris, 2004) where major greenhouse gases include carbon dioxide, methane, nitrous oxide, water vapor, chlorofluorocarbon gases and ozone. Methane is the main contributor in LFGs, also having global warming potential 28 times greater than CO_2.(Hosseini, S.S. & Yaghmaeian, K. & Yousefi, Nader & Mahvi, 2018). The emission of the GHGs has an adverse effect on the global environment in several ways such as acidification, increasing the amount of heat trapped, higher ambient carbon dioxide concentration, changes in floristic zones and warmer temperatures (Hosseini, S.S. & Yaghmaeian, K. & Yousefi, Nader & Mahvi, 2018). In fact, emission of GHGs could increase the risk of fire, endanger the human health, destroy the vegetation mass around the landfill, pollute and degrade the groundwater resources, affect the climate changes worldwide and produce unfavorable odors (Uri & Saleem, 2014).

Through municipal waste, GHG emission in general is dependent on the organic fraction of MSW and different types of organic wastes own different DOCs (Fourier & Morris, 2004). The emission rate is dependent on the composition of waste, its compaction, and rate degradation of the degradable organic fraction, recirculation of leachates and also the environmental factors (Fourie & Morris, 2004).Due to this fact, methane emission has a spatial variability and measurement of this gas is not easy task to perform. Determination of the amount of emission of methane from landfills is crucial in regards to achieve the purpose of reducing GHGs emissions from none-source and source points. Different studies have retrieved the rate of methane emission from landfills (Chalvatzaki et al., 2015) . However, no exact study has been conducted in the Sisdol landfill site to determine emission rate of methane, total greenhouse gasses, and also the emission per capita for each gas. Various mathematical and scientific models have been used worldwide to determine the LFGs which are based on the different order (zero, first or second order) approaches in the recent years. To estimate landfill gas emissions from municipal solid waste disposal facilities, different models have been devised. IPCC waste model, Vertical Radial Plume Mapping Optical Remote Sensing (VRPM ORS), tracer gases, inverse modeling, differential absorption light detection and ranging (LiDAR), LandGEM (US-EPA), MI micrometeorological eddy covariance (EC), and flux chameleon are just a few of the models available. These systems, however, are not 100 percent efficient and have significant drawbacks, including a lack of all emissions, a small footprint, irregular topography, complexity, uncertainty in the source location, and a high cost. Because of its simplicity and insensitivity to atmospheric instability, LandGEM is the most used and typical model for LFG emission(H. R. Amini et al., 2013). LandGEM model is a simple, relatively good data fit model based on first-order decomposition that was developed by the US- Environmental Protection Agency.

The purpose of this study was to determine solid waste generation and composition in the Kathmandu valley, as well as to calculate emissions of GHGs, primarily methane, from the Kathmandu dumping site, Sisdol landfill site, from the year of start to date, and to estimate total emissions of methane compounds over a 15-year period (from 2005 to 2020). In addition, the research focuses on the evolution of different types of differences. LandGEM model was employed to determine the emission rate and total emission till date and under different scenarios.

1.2 Problem Statement

Solid waste management in developing nations presents significant obstacles, not only in terms of system design, but also in terms of public awareness and engagement. Garbage and its management has become a tenacious problem due to a lack of real efforts by town/city authorities, despite the fact that it accounts for the majority of municipal expense. People are primarily concerned with gathering and discarding rubbish away from their homes, regardless of where it goes or the repercussions. The rising rate of urbanization in the Kathmandu Valley is putting enormous strain on the government, which is unable to keep up with the rising demand for solid waste management and waste generation, resulting in a chaotic garbage and sanitation situation. With the exception of a few progressive municipal corporations, most local authorities suffer from a lack of necessary skill and experience, leading in improper solid waste management, resulting in pollution and health risks. Uncollected waste can be found scattered inside communities, footpaths and along the streets. Management of solid waste is extremely poor and the recycling of such wastes is almost negligible. The survey conducted during 2020 revealed that the households in KMC alone generates about 256.50 metric ton of solid wastes every day(Rajbhandary, 2020).Besides, there are hotels, industries, commercial establishments and hospitals producing a large quantity of solid wastes. According to the baseline study of Solid waste management of KMC, total municipal waste generation of KMC alone in 2020 is 513 metric ton per day (Rajbhandary, 2020). Human and ecosystem health is also threatened due to improper handling of solid wastes. Although, in today’s time, almost all the city’s wastes have been disposed at Okharpauwa(Ranabhat, 2015), still there is conflict and it has been a matter of headache for both government and people. The government nearly completely ignores landfill gas generation and methane emissions from waste sites. Even the government's Landfill Site Disposal Scheme is not adequately and successfully implemented. The safe and proper management of solid waste through expert recycling, reuse, and reproduction of the complete solid waste of the Kathmandu Valley is still a long way off due to time constraints.

1.3 Rationale of Study

The goal of this study was to generalize the existing problem and practices of municipal garbage management, as well as their negative impact on the environment. It also emphasizes the importance of solid waste management and the impact of climate change on humans and the environment. It is common knowledge that properly managing environmental issues in today's world is difficult. It is significantly more difficult and complex, especially in developing countries.(E. Amini et al., 2017). A high level of waste collection coverage is linked to good governance because it indicates the city authorities' commitment to keeping the city clean and healthy. Waste management is a pressing issue for all countries throughout the world, as the amount of waste produced is rapidly increasing due to population development. In Nepal, the issue of waste management is not new; it has been a hot topic for a long time, and it has become even more critical in recent years as the country has become more urbanized and industrialized. (Dangi et al., 2011). The major problem is the disposal of the generated waste. The lack of permanent dispose place is now the matter of concern for authority. The study focused on the adverse impact of the unmanaged Landfill Site in the environment and evaluating the best alternatives of solid waste management in future to reduce the adverse effect.

1.3.1 Need of the study

- The study is needed to know the generation of methane gas from the landfill site so that it can be further utilized as an alternative to LPG with certain inventories.
- It is also needed to know the reduction in methane under different predictive scenarios.

1.3.2 Importance of the study

- The study is important to the policy makers and all the stake holders.
- It is also important to the entrepreneurs who wants to invest in collection and use of methane as an alternative fuel.
- It can play an essential role in sustainable planning of solid waste management with different alternatives with reduced GHG emission

1.4 Research Questions

- What amount of waste is generated in Kathmandu valley?
- What amount of methane gas is generated from the Sisdol landfill site till date?
- What amount of methane gas will be generated from the Sisdol landfill site under different scenarios?
- What are the key determinants for the landfill gas emission calculation?

1.5 Objectives

1.1.1 Main Objectives

- To estimate the methane generation from Sisdol landfill site under different scenarios using LandGEM Software.

1.1.2 Specific objectives

- To evaluate the municipal solid waste generation and management methods in Kathmandu valley.
- To assess the feasibility of the LFG recovery plant in Sisdol landfill site.

1.6 Limitations

- The parameters for LandGEM model used in this case are entirely based on the waste composition of Kathmandu valley and climatic condition of Sisdol landfill, so it cannot be generalized for other sites
- The amount of GHG emitted during transportation of the waste to the landfill site is not taken into consideration.
- No lab test was conducted to evaluate the chemical composition of the waste generated.

1.7 Ethical Considerations

In qualitative research, the ethical aspect of the study is a major concern. You have responsibilities as a researcher not only to your research participants, but also to your colleagues and the people who will hear your findings. The four principles of Tom Beauchamp and Jim Childress (1983) are a good place to start when thinking about ethical issues: I Autonomy; respecting individual rights, ii) Beneficence; doing well, iii) Non-maleficence; not harming others, and IV) Justice; especially equity. Consent and confidentiality are two crucial ethical considerations that should be considered in each endeavor. Participants should feel allowed to discuss the researcher's goals for his or her research, but it should not trespass on the participants' debatable minds.

During the research, ethical problems were taken into account. My main concern was that no one would be disturbed during the site inspection and questionnaire survey. Respondents were informed ahead of time about the research's objective and how their opinions, experiences, and expression would be appreciated in the study so that they would pay attention and feel free to answer the questions accurately. Before conducting the sample and site survey, they gave their consent.

1.8 Organization of the Study

The study has been divided in to seven chapters. Each chapter deals with different subject matters.

Chapter one contains brief introduction to thesis, background, statements of the problem along with objective and rationale of the study, limitation of the study, and ethical considerations.

Chapter two deals with the literature review. This chapter also studies the waste management landfill gas, the model used for calculation of the gas i.e. LandGEM model and its parameters.

Chapter three describes about the research methodology which shows the methods of data collection and analysis of the data.

Chapter four deals with the description and details of the landfill site.

Chapter Five studies the collection, tabulation, analysis and calculation of data.

Chapter six deals with the result and discussion of the research.

Chapter seven discuss the summary, conclusion and finally ends with some of the recommendations for further work.

CHAPTER TWO: LITERATURE REVIEW

This chapter provides a review of the relevant literature which is required for the study. Here, the primary concepts are explored and defined.

2.1 Definition of Keywords

Solid Waste: The useless, undesirable, discarded and rejected material resulting from daily activities in the society is termed as solid waste. (Srivastava, 2014)

Solid Waste Management: Srivastava in his paper has also defined solid waste management as “the discipline associated with the control of generation, storage, collection, transfer, processing and disposal of solid waste” (Srivastava, 2014) .

Climate Change: Climate change can be defined as “the change in the state of the climate that can be determined by changes in the mean and/or the variability of its properties, which persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of anthropogenic activity” (UNFCCC, 2011).

Landfill Gas: Landfill gas (LFG) is defined as “a natural byproduct of the decomposition of organic material in landfills” (Mann, John & Wilder, Lynn & Zarus, Gregory & Nickel, 2001).

2.2 Theoretical Background

2.2.1 Methods of Solid waste Management

Municipal solid waste management entails (a) gaining an understanding of the environmental impact of waste generation, collection, transportation, and disposal methods used by a society, and (b) implementing innovative strategies to mitigate that impact. According to (Srivastava, 2014), trash generated in a given area from industrial, residential, and commercial activity can be treated in a variety of ways. The six functional elements that are primarily associated with the management of municipal solid waste from the point of generation to final disposal are waste creation, storage, collection, transportation, segregation and processing, and finally waste disposal(Thapa, 1998). Paper, plastic, glass, metal, and organic trash can all be separated into several categories. Solid waste management and disposal is an important part of environmental hygiene that must be factored into environmental planning. It is usually the generator's responsibility, and it is regulated by local, national, and even worldwide agencies.

Solid waste management can be done in a variety of ways. The following are a few of them:

- **Solid Waste Open Burning:** In the current situation, solid waste open burning is not the best option.
- **Solid wastes sanitary landfills**: Sanitary landfilling of solid wastes is a straightforward, clean, and efficient method. In this approach, layers are squeezed with mechanical equipment before being coated with soil, leveled, and compacted. Microorganisms work on the organic materials and degrade them in a 3 to 5 meter deep trench. In this procedure, the rubbish depth is normally limited to 2m. Facultative bacteria hydrolyze complex organic materials into simpler water soluble organics.
- **Incineration method:** The method of incineration is ideal for combustible waste. This technique entails high operating expenditures and construction. This strategy would be ideal in densely populated areas when land filling sites are few. It can be used to lessen the amount of solid trash that needs to be disposed of.
- **Composting process**: Composting is a popular method in developing nations that is similar to sanitary land-filling. This process separates and composts decomposable organic waste. End products are stable, and yields are good soil conditioners. They can be used as a fertilizer foundation.
- **Disposal by Ploughing into the fields:** Ploughing into the fields is not a frequent method of disposal. In general, these disposals are not environmentally friendly.
- **Disposal by hog feeding**: In Nepal, hog feeding is not a common method of disposal. Garbage dumping into sewers increases by 20-30%, including BOD and TSS.

Refuse is finely processed in grinders and then deposited in sewers.

- **Fermentation/biological digestion**: Biodegradable waste is composted, and recycling is encouraged whenever practical. Hazardous wastes can be disposed of safely using the appropriate ways.

As mentioned, solid waste disposal is defined as waste disposal and no longer affects society in any negative way. Either the residue is assimilated such that it is no longer identifiable in the environment, such as flying ash from the incinerator, or the waste can be hidden sufficiently effectively so it cannot be located easily (e.g., a covered landfill).

Landfilling is the most common and oldest waste disposal method. Modern landfills have evolved from uncontrolled dumping grounds to advanced garbage treatment and disposal facilities. In many parts of the world, it is still the principal method of managing industrial and municipal solid waste. Since the 1950s, landfills have progressed from open polluting dumps to modern, engineered planned facilities with comprehensive control systems and monitoring routines (Chanton et al., 2011). Despite all of the latest procedures and technological advancements, landfilling is a long-term garbage accumulation that might have negative environmental consequences. (Niskanen et al., 2013).

Landfill gas (LFG) produced from organic waste degradation contributes significantly to global warming, with a composition of 55-60 percent methane (CH_4) and 40-45 percent carbon dioxide (CO_2)(Mann, John & Wilder, Lynn & Zarus, Gregory & Nickel, 2001). The amount of gas produced in a landfill is determined by the waste composition (such as organic content, humidity, nutritional content, and inhibitory chemicals) as well as the age of the garbage (Scheutz et al., 2009a). The generation will continue for centuries after the garbage has been placed, until the majority of the organic material has decayed. The rate at which trash decomposes is determined by the temperature, moisture, landfill cover, and waste type at each location (Christensen, 2011). The Intergovernmental Panel on Climate Change (IPCC) recently revised CH4's global warming potential to 28 or 34, depending on whether carbon storage changes are taken into account (Pachauri, Rajendra K. et al., 2014). The release of methane into the atmosphere, as well as its volatile nature, is a major source of concern(Hardy, 2018). The landfill gas will tend to build within the landfill and, through diffusion and advection processes, will find ways to escape to the atmosphere. Methane, on the other hand, can assist offset the expense of LFG management if it is collected and used properly (Adeyemi, 2013).

2.2.2 Landfill Gas

It's made up of a gas mixture that forms as biochemical waste decomposes in landfills. The quality and quantity of gas produced are mostly determined by the waste composition, particularly the organic portion, moisture content, and landfill age.

Table 1: Components of Landfill gas

(Source: (Mann, John & Wilder, Lynn & Zarus, Gregory & Nickel, 2001))

Components	Percent by Volume	Characteristics
methane	45–60	Methane is a naturally occurring gas. It is colorless and odorless. In the United States, landfills are the single most significant source of man-made methane emissions.
carbon dioxide	40–60	Carbon dioxide is found in modest amounts in the atmosphere naturally (0.03 percent). It has no color, no odor, and is somewhat acidic.
nitrogen	2–5	Nitrogen makes up roughly 79 % of the atmosphere. It has no odor, flavor, or color.
oxygen	0.1–1	About 21% of the atmosphere is made up of oxygen. It has no odor, flavor, or color.
ammonia	0.1–1	Ammonia is a colorless gas that has a strong odor.
NMOCs	0.01–0.6	Organic compounds are NMOCs (i.e., compounds that contain carbon). (Methane is an organic compound, but it is not an NMOC.) Natural NMOCs can occur naturally or be created through synthetic chemical processes.
sulfides	0–1	Sulfides are naturally occurring gases that contribute to the rotten-egg odor of landfill gas mixtures. Even at very low concentrations, sulfides can produce unpleasant odors.
hydrogen	0–0.2	The gas hydrogen is odorless and colorless.

Carbon monoxide	0–0.2	Carbon monoxide is a gas that has no odor and is colorless.

2.2.3 Factors affecting landfill Gas Production

The rate and volume of landfill gas produced at a particular location are determined by the waste's characteristics (e.g., composition and age of the refuse) as well as a number of environmental conditions such as:

- **Waste Composition**: Bacterial decomposition produces more landfill gas when there is more organic waste in the dump. Some types of organic waste provide minerals that help bacteria grow, such as sodium, potassium, calcium, and magnesium. The formation of landfill gas increases when these nutrients are present. Some wastes, on the other hand, include substances that kill bacteria, resulting in decreased gas production. Methane-producing bacteria, for example, can be hindered by excessive salt concentrations in garbage.

- **Oxygen in the Landfill:** Bacteria will begin to create methane only when oxygen is depleted. The longer aerobic bacteria can digest garbage in Phase I, the more oxygen there is in the landfill. More oxygen is available if garbage is loosely buried or disturbed often, allowing oxygen-dependent bacteria to live longer and create carbon dioxide and water for extended periods of time. When aerobic bacteria will be replaced by methane-producing anaerobic microorganisms in Phase III, methane production will commence sooner if the waste is highly compacted. Methane gas is created by anaerobic bacteria only after the aerobic bacteria have used up all of the oxygen in the landfill; consequently, any oxygen left in the landfill will slow methane production. Barometric highs will tend to inject air oxygen into shallow landfill surface soils, potentially affecting bacterial activity. In this case, trash in Phase IV, for example, could briefly revert to Phase I until all of the oxygen is consumed.

- **Moisture Content:** Moisture fosters bacterial growth and carries nutrients and germs to all regions within a landfill, therefore the presence of a specific amount of water in a landfill boosts gas generation. Maximum gas generation is promoted by a moisture level of 40% or more, based on the wet weight of the waste (e.g., in a capped landfill). Because trash compaction raises the density of the landfill materials, it slows gas production by reducing the pace at which water may permeate the garbage. If heavy rain and/or porous landfill covers inject additional water into a landfill, the rate of methane production increases.

- **Temperature.** Warmer temperatures enhance bacterial activity, which accelerates landfill gas production. Bacterial activity is inhibited by colder temperatures. Bacterial activity typically decreases considerably below 50 degrees Fahrenheit (F). In shallow landfills, weather changes have a significantly higher impact on gas production. This is because bacteria in deep landfills, where a thick layer of dirt covers the garbage, are not as well insulated against temperature variations. A capped landfill often keeps a consistent temperature, allowing for maximum gas production. Bacterial activity generates heat, keeping the temperature of a landfill between 77 and 113 degrees Fahrenheit, while temperatures as high as 158 degrees Fahrenheit have been recorded.

- **Age of Refuse**: More gas will be produced by recently buried waste than by older rubbish. Within 1 to 3 years, landfills typically emit significant amounts of gas. Peak gas production normally happens 5 to 7 years after garbage is disposed of. Almost all gas is created within 20 years of garbage disposal; but, minor amounts of gas may continue to be discharged from a landfill for another 50 years or longer. A low-methane yield scenario, on the other hand, predicts that slowly degrading garbage will produce methane in 5 years and continue to emit gas for another 40 years. Depending on when the waste was first placed, different parts of the landfill may be at different stages of decomposition at the same time. The amount of organic material in the trash has a big impact on how long it takes to produce gas.

2.2.4 Methane Production

The organic part of garbage is biodegraded in landfills with the help of microorganisms, releasing methane and carbon dioxide emissions as a result of the decomposition. Decomposition happens in four primary phases over time, as shown in the graphic in figure 1.

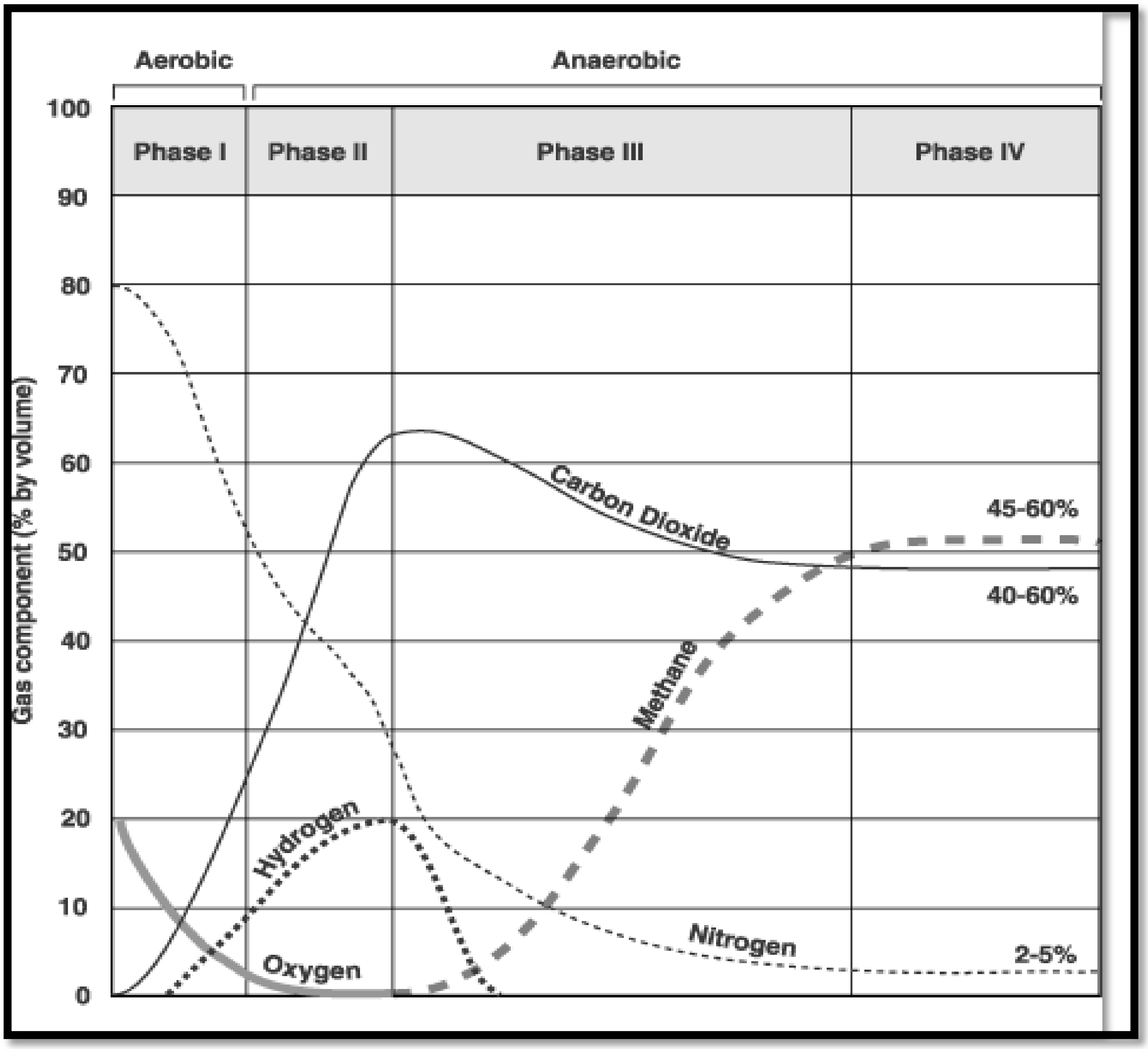


Figure 1: Production Phases of Typical Landfill Gases

(Source: (Mann, John & Wilder, Lynn & Zarus, Gregory & Nickel, 2001))

Phase I: Aerobic bacteria—bacteria that thrive exclusively in the presence of oxygen—consume oxygen while breaking down the lengthy molecular chains of complex carbohydrates, proteins, and lipids that make up organic waste during the first phase of decomposition. Carbon dioxide is the principal output of this process. The nitrogen level of the landfill is high at the start of this phase, but it gradually decreases as the landfill progresses through the four phases. Phase I will continue until all available oxygen has been used up. Depending on how much oxygen is present when the waste is disposed of in the landfill, Phase I decomposition can take days or months. The amount of oxygen in the waste will vary depending on how loose or compressed it was when it was buried.

Phase II: After the landfill's oxygen supply has been depleted, Phase II decomposition begins. Bacteria transform chemicals produced by aerobic bacteria into acetic, lactic, and formic acids, as well as alcohols such as methanol and ethanol, using an anaerobic process (a process that does not require oxygen). The landfill deteriorates into a highly acidic environment. When the acids react with the moisture in the garbage, certain nutrients dissolve, making nitrogen and phosphorus available to the landfill's growing number of bacteria species. Carbon dioxide and hydrogen are gaseous byproducts of these reactions. Microbial processes will revert to Phase I if the landfill is disturbed or if oxygen is introduced into the waste in any way.

Phase III: Decomposition in Phase III begins when anaerobic bacteria devour the organic acids produced in Phase II and produce acetate, an organic acid. As a result of this process, the landfill becomes more neutral, allowing methane-producing bacteria to establish themselves. Bacteria that produce methane and acid have a symbiotic, or mutually beneficial, connection. Acid-producing bacteria produce chemicals that are consumed by methanogen bacteria. Methanogen bacteria consume carbon dioxide and acetate, which would be hazardous to acid-producing bacteria if there was too much of it.

Phase IV: When the composition and production rates of landfill gas stay roughly stable, phase IV decomposition begins. By volume, Phase IV landfill gas typically contains 45 percent to 60 percent methane, 40 percent to 60 percent carbon dioxide, and 2 percent to 9 percent other gases such sulfides. In Phase IV, gas is produced at a constant rate for around 20 years; however, gas will continue to be discharged for another 50 years or more after the waste is buried (Crawford and Smith 1985). If there are more organics in the waste, such as in a landfill that receives more than usual volumes of domestic animal waste, gas generation could last longer.

2.2.5 Methane generation Model

In basic terms, landfill gas models summarize the complicated changes that occur during waste decomposition in order to estimate methane generation over time. Methane generation at landfills is typically estimated using a first-order kinetic equation based on trash amounts over time, waste composition, and other factors (Fallahizadeh et al., 2019; Kristanto & Koven, 2019; J. Park & Shin, 2001). Methane production is supposed to decline steadily and linearly over time in first-order models, proportional to the breakdown of organic matter in any given year and the remaining fraction of organic matter from prior years (Atabi et al., 2014). The amount of gas produced by each year's trash decreases exponentially until it is totally degraded (Sil, A., Kumar, S., and Kumar, 2014). According to these model assumptions, landfill gas would gradually decrease after closure. Denmark, the Netherlands, and the United States are currently using first-order models such as TNO, Belgium, and Land GEM (Atabi et al., 2014).

2.2.6 LandGEM model

The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that may be used to predict total landfill gas, methane, carbon dioxide, non-methane organic compounds, and individual air pollutants emissions rates from municipal solid waste landfills. (Hosseini, S.S. & Yaghmaeian, K. & Yousefi, Nader & Mahvi, 2018; USEPA- United States Environmental Protection Agency, 2005). For estimating emissions from the breakdown of landfilled waste in MSW landfills, LandGEM is based on a first-order decomposition rate equation. The defaults in the model are based on real data from landfills in the United States. When available, field test data can be used instead of model defaults. LandGEM is a screening tool, which means that the better the input data, the better the results. The available data on waste quantity and composition, variation in design and operation practices over time, and changes that occur throughout time all have an impact on the emissions potential. Changes in landfill operation, such as operating under wet circumstances via leachate recirculation or other liquid inputs, will result in more gas being produced at a faster rate. For establishing emission inventories and determining CAA application, defaults for this sort of operation are being established to include in LandGEM alongside defaults for typical landfills (no leachate or liquid inputs) (USEPA- United States Environmental Protection Agency, 2005).

LandGEM uses the following first-order decomposition rate equation to estimate annual emissions over a time period that is specified.

Equation 1 : First Order Decomposition rate Equation

$$\mathbf{Q = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \frac{M_i}{10} \exp\left(-kt_{ij}\right)} \qquad (1)$$

Where,

Q = annual methane generation in the year of the calculation (m^3 /year)

i = 1 year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1 year time increment

k = methane generation rate ($year^{-1}$)

Lo = potential methane generation capacity (m^3/Mg)

M_i = mass of waste accepted in the ith year (Mg)

t_{ij} = age of the jth section of waste mass M_i accepted in the ith year (decimal years, e.g., 3.2 years)

2.2.7 Model Parameters to run the LandGEM

The appropriate choice of assumption, in terms of the constants of the CH_4 generation potential (L_0) and CH_4 generation rate (k), is the fundamental requirement for obtaining modeling results that are as similar as feasible to actual gas production (J. K. Park et al., 2018). L_0 denotes the total volume of CH_4 produced from a given amount of dumped material. The k value determines how long CH_4 is anticipated to be produced from a given waste stream (H. R. Amini et al., 2012). These variables are highly influenced by the chemical constitution of the waste, its characteristics, and the state of the process (e.g., waste density, pH, and moisture content). As a result, estimating the L_0 and k values requires a detailed analysis and critical estimation of the bio-chemical attributes of wastes that considers the control of LFG emissions (J. K. Park et al., 2018).

Method for Determining L_0

The amount of CH4 that can be created per unit mass of trash under idealized conditions for CH4 generation is known as the L0 of wastes (J. K. Park et al., 2018). The L0 is frequently used to refer to the highest quantity of CH4 produced per unit mass of waste under anaerobic environments, or the ultimate CH4 output. In general, L0 values can be calculated using a variety of methods, including the stoichiometric method (Machado et al., 2009; Mor et al., 2006; Sanderson et al., 2008); experimental methods (Cho et al., 2012; Jeon et al., 2007; Tolaymat et al., 2010); model fitting or regression analysis using gas data (Amini et al., 2012; Wang et al., 2013a); and the IPCC model (Govindan and Agamuthu, 2014; Kumar et al., 2004; Thompson et al., 2009).

The IPCC (2006) model uses characteristics of the waste (DOC and DOC_f) and the landfill site (MCF and F) to prediction CH_4 generation. In the IPCC (2006) model, L_0 can be calculated using equation 2:

Equation 2: IPCC Methodology for calculation of methane Generation potential

$$\mathbf{L_0 = DOC \times DOC_f \times MCF \times F \times \frac{16}{12}} \qquad (2)$$

Where,

DOC = the organic carbon in waste that is accessible to biochemical decomposition.

DOCf = the fraction of DOC that can decompose.

MCF = the CH_4 correction factor for aerobic decomposition.

F = CH_4 volume concentration in the gas

16/12 is the molecular weight ratio of CH_4 and C

2.2.8 Method for Determining K

For landfilled waste, the k value is the biodegradation half-life value in years1. Attempts have been made to determine the k value, which governs the rate at which CH_4 is formed. Despite the fact that the organic component of each waste type is thought to decay at distinct rates (Thompson et al., 2009), most models use a single overall value for k. With increasing moisture contents and higher temperatures, the k value rises (Baldwin et al., 1998; Ishii and Furuichi, 2013). Because all of the research landfills were located in Florida, which has relatively high annual precipitation rates, Amini et al. (2012) reported identical k values for the wet cell (0.10 yr1) and traditional landfill (0.08 yr^1). According to Barlaz et al. (2010), there is no obvious link between k and wet weight water content. This is most likely owing to the variability of water content in different waste material fractions, as well as uneven wetting caused by channelized flow, which results in a wide range of water contents over the lateral and vertical dimensions of a landfill. The rate of deterioration is determined by the depth, density, pH, climate, and moisture content of the waste (Levis and Barlaz, 2011; Machado et al., 2009; Sormunen et al., 2013). These circumstances also have an impact on the DOCf. The k values at the field scale are projected average rates for a traditional landfill scenario (k = 0.04 yr^{-1}).

Garg et al. (2006) indicate that precipitation is the most important parameter to estimate the k value. Thus, the k value for a bulk waste can be calculated based on precipitation rates (US EPA, 2004):

Equation 3: Calculation of Methane generation rate constant

$$\mathbf{k = \left(3.2 \times 10^{-5} \times annual\ precipiation\ in\ mm\right) + 0.01} \qquad \textbf{(3)}$$

The US EPA (2004) provides default values based on an emission factor, which is a k of

0.04 yr^{-1} above 25 inches (635 mm) of precipitation for emission inventories that are considered more representative of MSW landfills where no leachate recirculation is occurring (Faour et al., 2007).

2.3 Solid Waste Management in Nepal

Nepal's urban development has been chaotic and unplanned, and this, along with the haphazard and mismanaged growth of the industrial and commercial sectors, as well as unplanned settlement, has resulted in a deterioration, particularly in the urban living environment(ADB, 2013). As the population of cities grows, so does the demand for municipal trash management, which is becoming a severe problem for local governments.

Local bodies are responsible for the building, operation, and administration of infrastructure for the collection, treatment, and final disposal of Municipal Solid Waste (MSW) under Nepal's Solid Waste Management Act of 2011. (Sharma, 2020). Solid trash generation is increasing every year in all municipalities and emerging cities, owing to rapid urban population expansion and changing lifestyles. The majority of municipalities, including recently established municipalities, have no SWM initiatives planned (Sharma, 2020). According to Sharma, over 80% of municipalities constituted after the country's federalization in 2013 lack adequate physical infrastructure and mechanisms for garbage management and record keeping.

2.4 Solid Waste Management in Kathmandu Valley

The household trash generation rate in KMC is 180 grams per capita per day, according to (Rajbhandary, 2020). Total household garbage created per day is 256.50 metric tons per day, based on the estimated population of KMC in 2020 (1,424,581, UN Population projection). According to the ADB 2013 research, the average of institutional and commercial trash creation is 50 percent. The rate of municipal garbage generation was expected to be 360 grams per capita per day, and municipal waste generation was estimated to be.

Waste is collected from residential areas, government offices, street maintenance, roads, and government hospitals by municipalities. KMC alone disposes of an estimated 419 metric tons of waste each day at the Sisdol landfill site, with other municipalities contributing the remaining 781 tons.

The main issues with solid waste management in Kathmandu were a big pool of abandoned waste on Kathmandu's streets, a lack of competent staff, a restricted area for transfer stations, a lack of law enforcement, the government's inability to sustain creative schemes, and a lack of oversight. The flow of municipal garbage in Kathmandu Valley is seen in Figure 2.

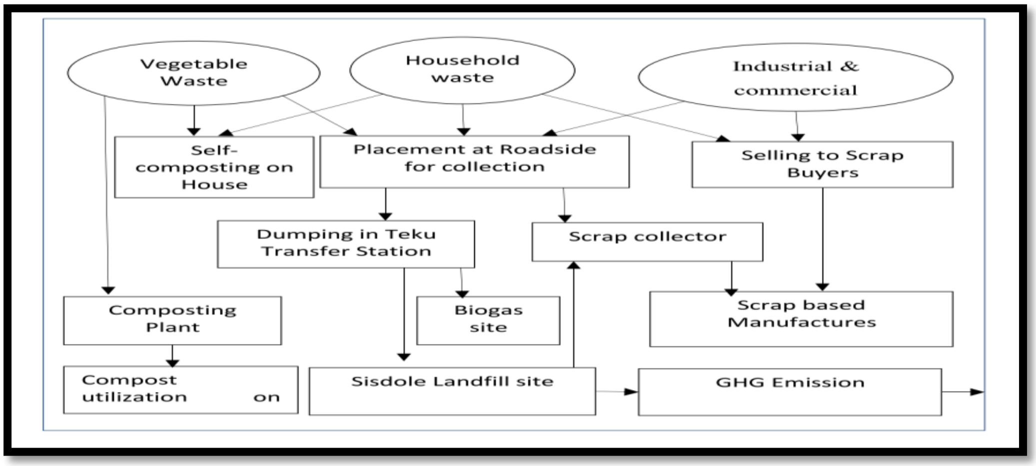


Figure 2: Municipal waste flow of Kathmandu (Source: (Khadka et al., 2020)

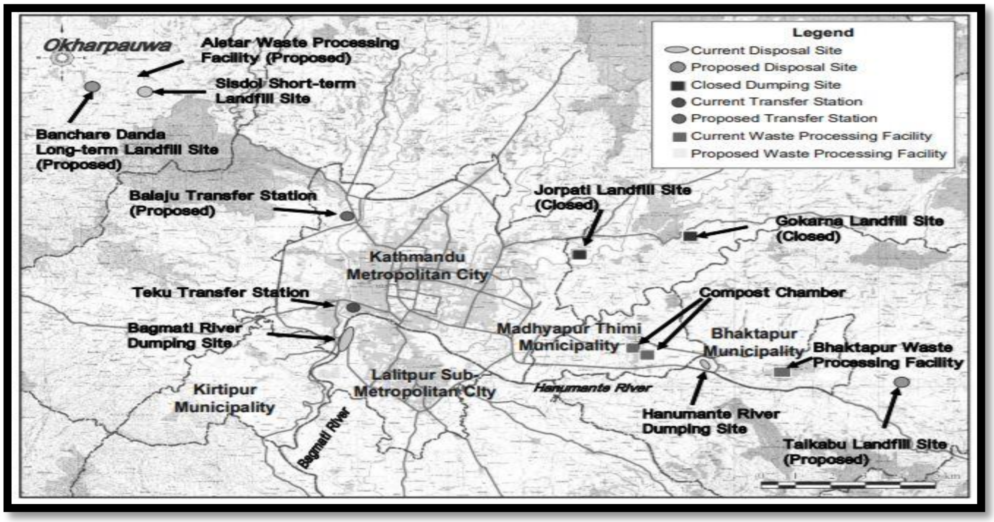


Figure 3: Different Landfill Sites (closed and operating) of Ktm

2.5 Estimation of Landfill Gases (Case Studies and Past work)

According to a study conducted on the site by the Nepal Academy of Science and Technology (NAST), rubbish disposal has harmed the ecology in eight locations, including Okharpauwa, Jeetpur Aletar, and Deurali. With the help of the Waste Management and Resources Mobilization Center, the NAST conducted an environmental impact analysis in the area. For the study, 56 locations in and around the dump site were chosen. During the research, surface and ground water, soil, and microorganisms were all tested. For the first time in the country, an Alfactrometer, a device for measuring foul odors, was also employed in the study. Improvements to the waste management process, as well as the separation of disposable and non-disposable garbage before bringing solid waste to be disposed of, were among the report's recommendations. (RSS: 17 June 2011)

(Khadka et al., 2020) utilized the IPCC model and the NV Afvalzong Multiphase model to estimate the quantity of methane produced by the Sisdol landfill using the model's default values. According to their analysis, the landfill generates 15,136 m^3 of total methane in typical conditions.

Several studies have calculated the GHG potential for various landfill sites across the world using various models, according to the literature. Using the LandGEM model, S.S. Hosseini et al. calculated total gas and methane emissions from a landfill in Hamedan (west Iran) from 2011 to 2030. After 20 years, the results showed that 4.371108 m^3 of methane would be created, with the majority (4.053106 m^3) occurring in the first year. Furthermore, the Hamedan landfill site has a methane production capability of 107 m^3/Mg (Hosseini, S.S. & Yaghmaeian, K. & Yousefi, Nader & Mahvi, 2018).

Similarly, Farideh Atabi (Atabi et al., 2014) used the Land GEM Mathematical Model to calculate methane and carbon dioxide emissions in the Kahrizak Landfill Place, which has been a dumping site for daily solid waste of about 7000 ton/day for the previous 40 years. The higher the value of k, the faster the methane generation rate increases and eventually decays over time, according to their findings. It also indicates that greenhouse gas emissions were lowered greatly by using gas-recovery and recovering energy from landfills with a 75 percent efficiency.

(Kaushal & Sharma, 2016) had used IPCC Default, FOD methodology, and LandGEM model, version 3.02 for determining methane from the Panki Open Dump Site in Kanpur, India. For the period 2010-2030, the annual average CH4 emission rates from Panki open dump site were found to be 197.33, 24.27, and 25.14 Gg, respectively, by IPCC Default approach, FOD, and LandGEM, with LandGEM delivering the best result among the 3 models.

According to the findings of a research conducted by Kavoussi et al. (2011), gas production rates in 2016, 2021, and 2031 will be 140, 325, and 438 $m3h^{-1}$, respectively, and gas production will continue with a slighter gradient from 2026. According to recent research, the gas emission rate per ton of MSW is between 120 and 300 m^3 (Hosseini, S.S., Yaghmaeian, K., Yousefi, Nader, and Mahvi, 2018). Kumar et al. (2004) compared the total CH4 generation using the default approach and the modified triangular method, and found that both methods produce roughly the same amount of CH_4. The prefeasibility assessment for the Deonar and Okhla dump sites was prepared using LandGEM, which was adopted by the USEPA in 2005.

(Issn et al., 2017) also used the LandGEM model to predict the amount and type of landfill gases produced over a 30-year period (from 2016 to 2045) in Jiroft, which had a population of 120,746 people and a per capita waste generation of 1.08 kg/day person, with research demonstrating that in 2045, approximately 3 million tons of waste will be disposed in municipal landfills in Jiroft, and the total amount of produced gas, will be 32, 994 ton/year, 8813ton/year, 24,181ton/year, and 378.8 tons/year, respectively.

Since the LandGEM model was designed in US conditions, (Sil, A., Kumar, S., and Kumar, 2014) modified it to an Indian situation. In terms of methane generation, the equation was re-modeled in terms of Indian conditions, and the model was validated with different landfill sites in India. According to their conclusions, the LandGEM model is exclusively utilized for anticipating methane potential from landfill sites, particularly for finance modeling for the CDM mechanism, and it can be readily re-modeled to reflect the country's present situation by altering the model's input parameters (Sil, A., Kumar, S. and Kumar, 2014).The efficiency was calculated by dividing the quantity of methane acquired from landfill operating records by the quantity estimated using the LandGEM model

(Taylor et al., 2014). The landfills' underperformance was related to open burning of early-stage LFG, LFG escape from fractures in high-density polyethylene covers, and excessive amounts of leachate within a landfill site, according to the findings. As a result, this research presented an integrated LFG collection system that could eliminate leachate while also collecting gas from landfills that contain high-moisture waste.

CHAPTER THREE: RESEARCH METHODOLGY

In this chapter the methodological approach for the research is explained.

3.1 Research Methodology

3.1.1 Sampling method

The Sisdol landfill site was chosen for this study since it is Nepal's largest dumping ground. As a result, the research used the Purposive Sampling Method. This study covers a small geographic area and only involves a few families. In addition, questionnaires and inquiries are conducted with a select group of persons, including the area manager, KMC environmental department officials, social workers, and local activists.

3.1.2 Data Collection

This study is based on the quantitative data collection and analysis. Both primary and secondary types of data are collected during the study.

a. **Primary data**: Primary data is critical for giving the researcher with firsthand, in-depth knowledge and understanding of the solid waste management issue. Field surveys, interviews, and observation are used to get this information.

b. **Secondary data**: To understand what has already been done in the field of solid waste management, substantial relevant secondary data on elements of solid waste management and the Integrated Solid Waste Management model has been gathered and thoroughly analyzed. It is gathered from both public and unpublished sources such as journals, articles, research reports, and dissertations, among others.

The data from the Sisdol landfill was acquired first, followed by the data from the Environment Management Department and the Solid Waste Management Association Nepal. In addition, the demographic data was gathered based on the population annual growth rate throughout time.

3.1.3 Data Analysis

The essential variables, such as prospective methane production capacity, constant methane value, and content (percent by volume), were calculated and entered into the software and the methane emissions were estimated as a result. The mass of garbage dumped and the methane generation capacity are used by LandGEM to calculate the mass of methane produced. Future annual trash was anticipated based on population growth and waste creation rates for the following ten years. Different scenarios for future municipal waste management were created, and the amount of methane released in each scenario was computed. A comparative analysis was conducted using several calculations, and best practices were recommended for the future.

3.1.4 Scenario generation

Different scenarios were created based on assessments of various solid waste management options in the Kathmandu valley. The future GHG emissions under these scenarios were estimated and compared to the Business as Usual scenario in order to determine the decrease in emissions in each case and to recommend the valley's best solid waste management plan. The study of people's perceptions of waste segregation, interest in and possibility of composting organic wastes, and organizations' involvement in it served as the foundation for scenario development. Similarly, the feasibility and viability of landfill gas recovery inventory at the landfill site, as well as the effectiveness of recycling and recovery of recyclable trash. Various stakeholders were interviewed in order to do this. To assess the possibility of composting and recycling, work by active private businesses such as Doko Recylcers, Khalisisi.com, Praramva Boitech, and Blue waste to Value was reviewed.

3.2 Selection of Methane Generation Model

The first stage in determining the technical and economic feasibility of any LFGE project is to calculate the amount of LFG (particularly methane) that can be gathered. In most cases, no active collection system is deployed, and no LFG flow data exists to indicate a collection rate that can be achieved. As a result, while developing an LFG flaring or energy project, a model to estimate LFG collection is a must-have tool. Selecting a suitable model for evaluating LFG and methane generation is the first and arguably most significant stage in the modeling process. LandGEM, IPCC, NV-Afvalzong multiphase model, and GMI country-specific LFG models are only a few of the publicly available models.

Various models necessitate data on current garbage levels, composition, and disposal techniques that span decades. Due to a lack of sufficient data at the Sisdol site, the actual IPCC model and other models that require specifics cannot be utilized to estimate methane emissions. As a result, a modified model was employed. The LandGEM model has been changed. It is a first-order decay model based on IPCC mathematics and default assumptions that estimates methane generation, recovery, and emission on specific landfills with limited waste composition data. Different types of trash contain differing proportions of organic stuff that decompose at different rates. The LandGEM model has the advantage of being able to account for normal waste composition. Furthermore, among the traditional models frequently referenced in different literature, the LandGEM has interesting advantages for our study because it has shown good agreement with field measurements and the ability to take into account the landfills location in a tropical area for various studies, albeit in a rough way. For example, three alternative landfill gas emission models were utilized in Greece in research undertaken by Paraskaki and Lazaridis [and Chalvatzaki and Lazaridis]: the triangle model, the stoichiometric model, and a first order model the Landfill Gas Emissions Model (LandGEM). The LandGEM presented the best results after comparing field observations with the output of three models. As a result of numerous literature reviews and data availability, the LandGEM model was chosen for the investigation.

3.3 Research Framework

A research framework is a diagram that depicts the study goal and the steps that must be followed to attain it (Verschuren & Doorewaard, 2010). The research framework is created by a series of steps that are used to accomplish the study goals, as indicated in figure 4 below:

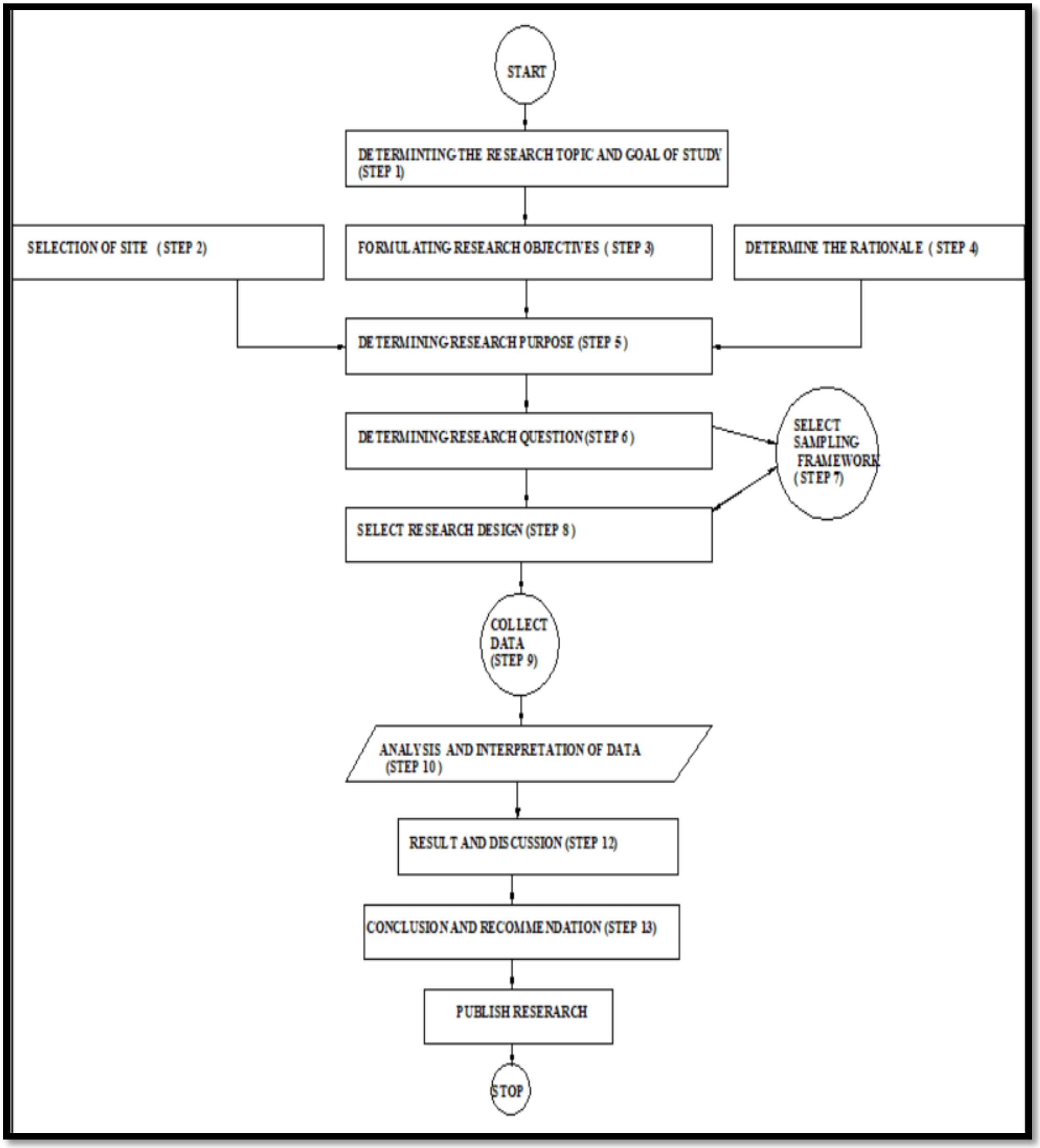


Figure 4: Overall Research methodology Framework

3.4 Conceptual Framework

The conceptual framework depicts what one should expect to find during their investigation. It identifies the study's relevant factors and plots out how they might interact (Swaen, 2021). Figure 5 illustrates the conceptual framework:

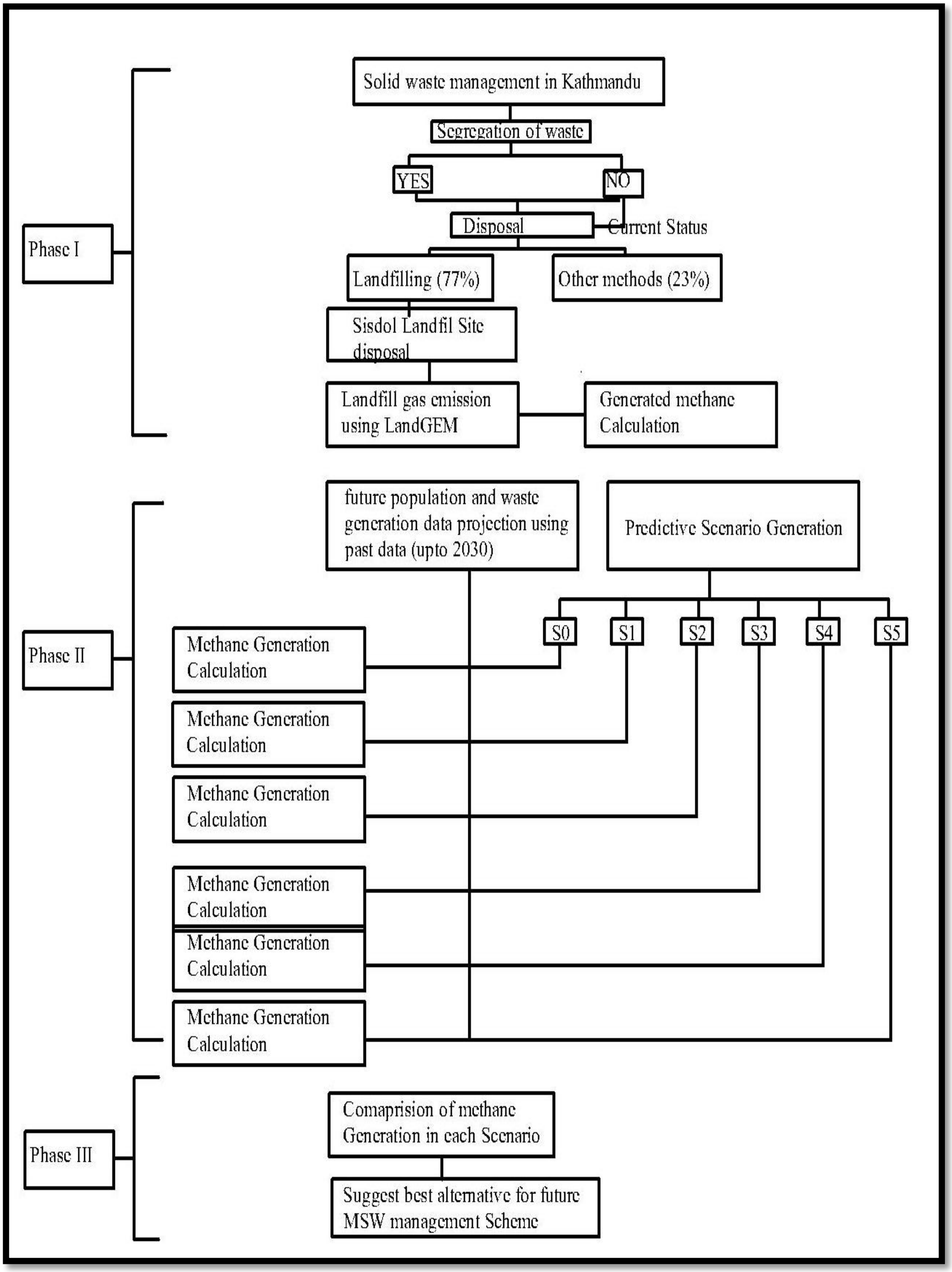


Figure 5: Conceptual framework of the research

3.5 Research Design Matrix

Quantitative approach was used for estimation of methane and other landfill gases from the landfill site under different scenarios. Research design matrix showing approach for data collection and calculation are listed in table no. 2:

Table 2: Research Design Matrix for data collection and Analysis

S. N.	Objective	Research questions	Data to be collected analyzed	Source of information	Output
1.	**To estimate the amount of waste generated in Kathmandu**	What are the key determinants for the landfill gas emission calculation?	Climatic Condition of the Landfill Site Amount of waste generated per capita Population and Growth rate	Data from DHM CBS KMC Questionnaire survey, Interview	Total amount of waste generated
		What are the possible methods of Municipal waste management in Kathmandu?	Feasibility of different source People's perception	Questionnaire survey, Interview, Literatures from past researches	Feasible alternatives for SWM
2.	**To estimate the amount of methane generated under different scenarios**	What amount of methane gas will be generated from the Sisdol landfill site under different scenarios?	Methane generation rate and potential Calculation for model Input	Calculation based on site location and composition of waste generated	Amount of methane generated under various scenarios

CHAPTER FOUR: STUDY AREA

4.1 Study Area

At an elevation of 1,150 meters, the Sisdol landfill site is located about 24 kilometers northwest of Kathmandu on the northern bank of the Kolpu River in Okharpauwa in Kakani Rural Municipality Ward 2 in Nuwakot district. Between 27° 46' north latitude and 85°13' east longitude, the VDC is located. SWMRMC divided the Sisdol landfill site into two valleys; valley 1 was developed as a semi-aerobic landfill initially, with essential upgrading works carried out as part of the study's pilot project. SWMRMC was in charge of waste dam raising, fencing, power supply preparation, office building, and administrative utilities. The valley 1 began operations on June 5, 2005, using these facilities (ADB, 2013). It gets MSW from Kathmandu and Lalitpur Metropolitan Cities, Bhaktapur Sub Metropolitan City, Kirtipur, and Mayapur Thimi municipalities in Kathmandu Valley (Basnyat et al., 2020). Figure 6 represents the research area's location:

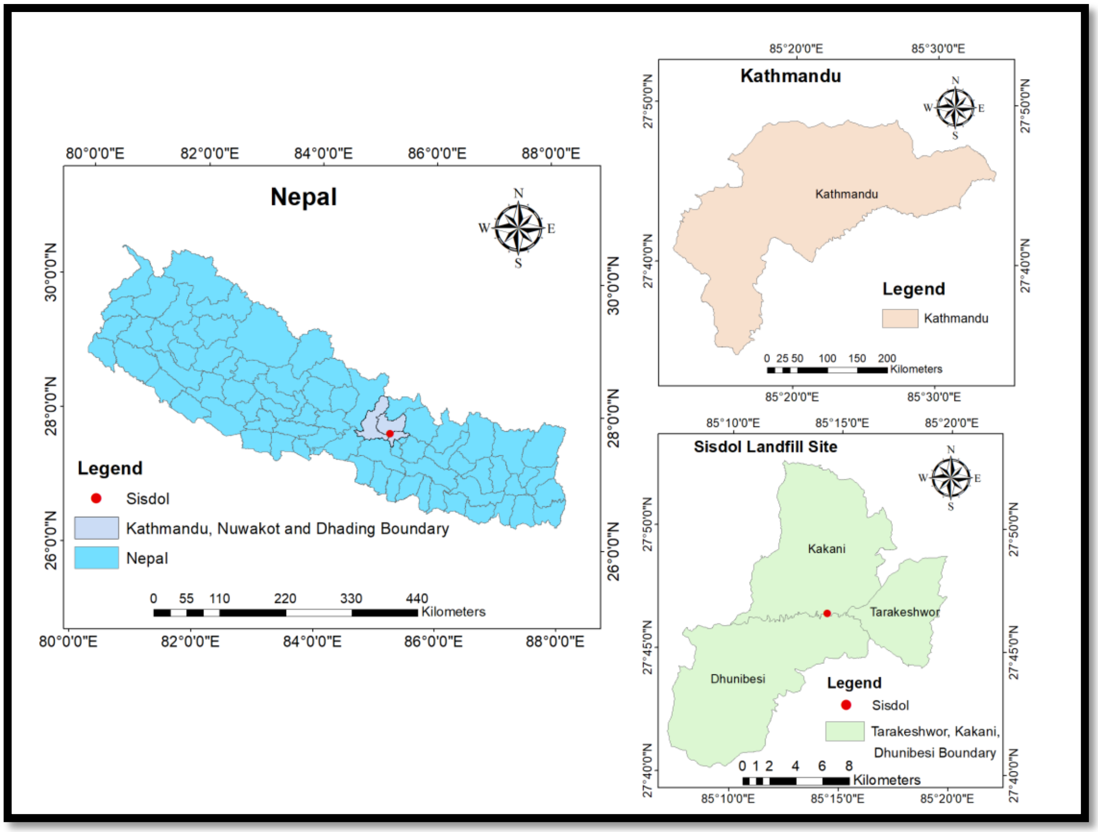


Figure 6: Site location (Sisdol Landfill)

The proposed SLS (minus the 5 ha waste processing plant) spans a total area of 15 ha, with the actual landfill covering 2 ha, the site protection/buffer zone covering 12 ha, and other waste management facilities covering the remaining 1 ha. SLS had two valleys during the design phase: Valley I, which covered 11,200 m2 and had a volume capacity of 166,085 m3, and Valley II, which covered 9,501 m2 and had a volume capacity of 108,910 m3 (Bijay & Ajay Kumar, 2011). The landfill system is semi-aerobic, according to "the report on the solid waste management for Kathmandu valley" from September 2005.

Figure 7: Sisdol landfill

Wastes were thrown into the neighboring Aaletar landfill site when the valleys were completely overloaded. This dump site in Aaletar was later filled and closed as well. The management team had no choice but to fuse the already filled Valleys to dispose of the garbage further as shown in figure 7 because the planned Bancharedanda Landfill could not take off even after the filling of Aaletar to date. Unlike the previously utilized clay lining in Valleys I and II, the newly utilized site is unlined (Basnyat et al., 2020).

4.2 Topography and Climatic Condition of the Area

Topography

Sisdol is in Ward 4 of thi4.2.1s VDC's many villages. It is located in a narrow, wellprotected valley with a small catchment area. Geographically, it follows the abandoned Kolpu Khola's path and is surrounded on all sides by steep hill spurs. The valley has two openings, one to the east and the other to the south, each 50 to 75 meters wide. In the south, north, and west, the valley bottom is gently, flat ground, ending in ridge slopes reaching 20 degrees in grade. Prime agricultural land dominates the site. Kolpu Khola is one of its sub-watershed areas (Study et al., 2002).

Climatic Condition

The climate at the site is mild subtropical, with substantial monsoon rainfall occurring between June and September with a total annual average rainfall of 1111.1mm (2020) (https://www.worldweatheronline.com). This statistic is based on the Kakani rainfall station in the Kolpu Khola basin, which may fluctuate depending on rainfall at the bottom of the hill. It has a tiny watershed, and the river's outflow runs through flat terrain. The yearly average temperature at the summit of the hill in Kakani is 11°C, with high temperatures of 14°C in July and minimum temperatures of 5°C in January (data 2020).

4.3 Land Use pattern

It is suitable for agriculture from a topographic standpoint. As a result, agricultural land accounts for 60.30 percent of the village's land, while non-irrigated land accounts for 10.05 percent. Similarly, forest land accounts for 18.65% of the total land area, with the remainder consisting of other types of land, such as pasture land. However, due to the continued discharge of solid waste, the fertile area has become unproductive.

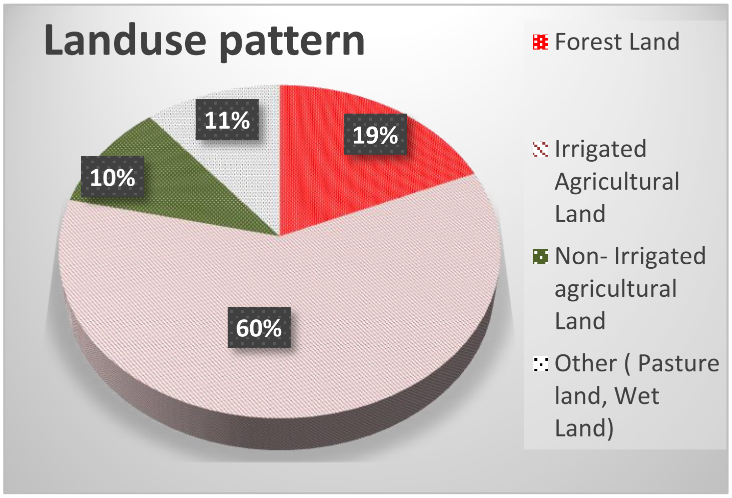


Figure 8: Land use Pattern

CHAPTER FIVE: DATA COLLECTION AND ANAYSIS OF DATA

In this chapter, the methods of data collection, and analysis of the data for the calculation and estimation of the landfill gas is shown.

5.1 Sisdol Landfill Site Data

Table 3: Sisdol landfill Data

(Source: (Adhikari et al., 2013; Bijay & Ajay Kumar, 2011; *sisdol report*, n.d.; Urban Development Ministry, 2015))

Sisdol Landfill Site	
Country	Nepal
Site location	Sisdol , Okharpauwa
Latitude	27° 46’ north
Longitude	85°13’ east
Elevation	1,150 masl
Average maximum Temperature	14° C
Average Minimum Temperature	5° C
Average Annual Precipitation	1111.1 mm
Availability of site - Specific Waste Composition Data	Yes
Type of Landfill	Semi- Aerobic Landfill
Year of opening of landfill site	2005
Area of site	15 ha
Built Design Capacity	
Valley 1	166,085 m^3
Valley 2	108,910 m^3

5.2 Demographic and Solid Waste Data

According to (Adhikari et al., 2013; Dangi et al., 2011; Korenaga, 2007) municipal waste generation per capita in 2005 when the landfill site was just started was of KMC and LSMC was 0. 416 kg/ day, similarly that of Bhaktapur was 0.16 kg/day and for Mayapur

Thimi and Kirtipur was 0.266 kg/day with total generation of 434.9 metric ton/day (434.9Mg/day) municipal waste with total population of 790,000. With increase in population and urbanization in Kathmandu valley, the waste generation rate increased gradually, increasing the amount of daily waste. According to (Rajbhandary, 2020), the municipal waste generated in KMC alone per capita in 2020 was 0.36 kg/day with total waste generation 513 metric ton/day. According to City Planning Commission Thapathali, total waste disposed to landfill site is 1200 ton/day. The average density of waste measured at household level is 340 gm/ltr that at transfer station is 114 gm /ltr and similarly at Sisdol landfill Site is 142 gm/ltr (Rajbhandary, 2020). As shown in Table 4, based on the result regarding the components of MSW in Kathmandu Valley, the highest amount of waste in Sisdol landfill site is related to organic followed by plastics and plythene bags, textiles, paper and glass followed by e-waste, metal, rubber and other mixed wastes.

Table 4: Total Population and Waste generated in Kathmandu over years

(Source(ADB, 2013; CBS, 2020; Rajbhandary, 2020)

year	**Population (Nos)**	**waste Generated (Mg/year)**
2005	790000	158738.50
2006	822000	163818.13
2007	855000	169060.31
2008	890000	174470.24
2009	927000	180053.29
2010	965000	185815.00
2011	1004000	191761.08
2012	1045000	197897.43
2013	1088000	204230.15
2014	1133000	210765.51
2015	1179000	217510.01
2016	1227000	224470.33
2017	1277000	231653.38
2018	1330000	239066.29
2019	1376000	246716.41
2020	1424000	254611.33

Table 4 shows the total population and total waste generated in Kathmandu from year 2005 to 2020.the population of Kathmandu was 7, 90,000 in 2005 which was haphazardly increased to 14, 24,000 by 2020. The data shows annual population growth rate of 4 % from year 2005 to 2015 which now reduced to 3.5% annual population growth rate and at present, according to UN World Urbanization Prospects the annual population growth rate is 3.4%(United Nations, 2020). Also, the total waste generated in 2015 was 158,738.50 Mg/Year which increased by nearly 3.2 % resulting in generation of 254611.33 Mg/Year in 2020.

Based on the past data of the population growth and the waste generation rate, the trend was analyzed. Figure 9 shows the yearly population growth trend and the yearly waste generation trend of Kathmandu valley. It shows that there is a strong linear relationship between population growth and waste generation with a coefficient of regression R^2=0.99.

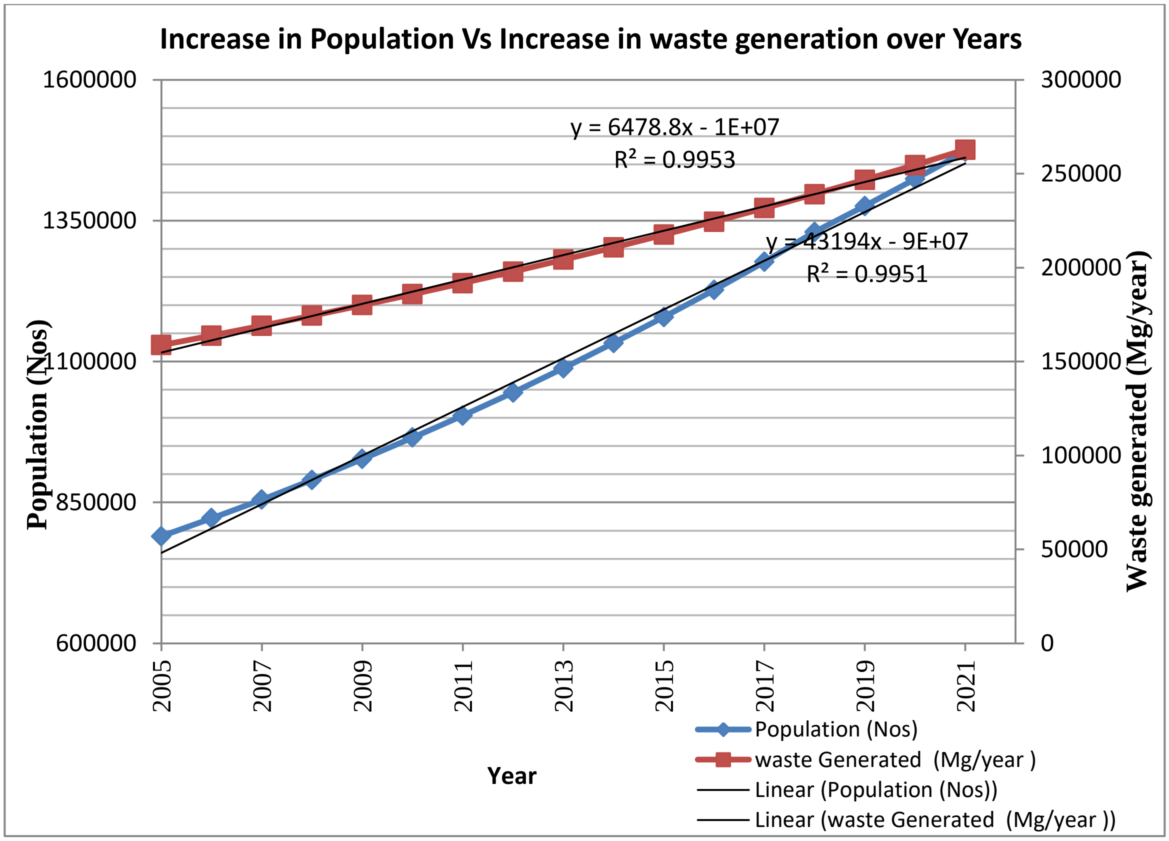


Figure 9: Yearly Population growth and waste generation trend in Kathmandu Valley

Based on this trend and regression the population waste generation by 2030 was predicted as shown in table 5. According to predicted data, 3,48,8878.90 Mg waste will be generated in 2030 with the population of 1,989,369.

Table 5: projected population and waste generation of Kathmandu valley

year	Population (Nos)	waste Generated (Mg/year)
2021	1472416	262758.90
2022	1522478	271167.18
2023	1574242	279844.53
2024	1627767	288799.56
2025	1683111	298041.14
2026	1740336	307578.46
2027	1799508	317420.97
2028	1860691	327578.44
2029	1923955	338060.95
2030	1989369	348878.90

5.3 Solid Waste Composition

According to many surveys and assessments conducted at various time intervals, the waste composition of five major donors of garbage landfilled to Sisdol, namely KMC, LMC, Bhaktapur, Kirtipur, and Mayapur Thimi, is nearly identical and has not changed significantly over decades((ADB, 2013; Dangi et al., 2017; Khadka et al., 2020; Rajbhandary, 2020). Despite the lack of appropriate waste segregation, various researchers sampled rubbish in order to determine the composition of waste created in Kathmandu as well as the weightage of each component. Table 6 displays the projected percentages of various garbage categories created in Kathmandu throughout time. It is clearly noticeable that organic waste holds maximum weightage nearly 65-75% of total municipal waste, followed by plastic waste which occupies 9-11%of total waste. Paper waste, glass and then metal waste follows consequently over years.

Table 6: Different Types of Waste Generated in Different Years in Kathmandu

S.N	Type	2003	2005	2009	2012	2015	2020
1	organic	70	69	63	73.22	63.22	75.5
2	plastic	9.5	9	10	11.43	10.8	10.35
3	Paper	8.5	9	9.5	6.89	9.02	3.85
4	Metal	NA	1	0.5	1.06	0.42	0.47
5	Glass	2.5	3	6	2.1	5.42	1.94
6	Rubber	NA	1	1	0.3	1.2	0.26
7	Textiles	3	3	2	1.61	2.3	1.61
8	Electronic Waste	NA	NA	NA	NA	NA	0.22
9	Construction and demolition	4.5	2	5	NA	4.5	NA
10	others	2	3	3	3.07	3.12	5.81

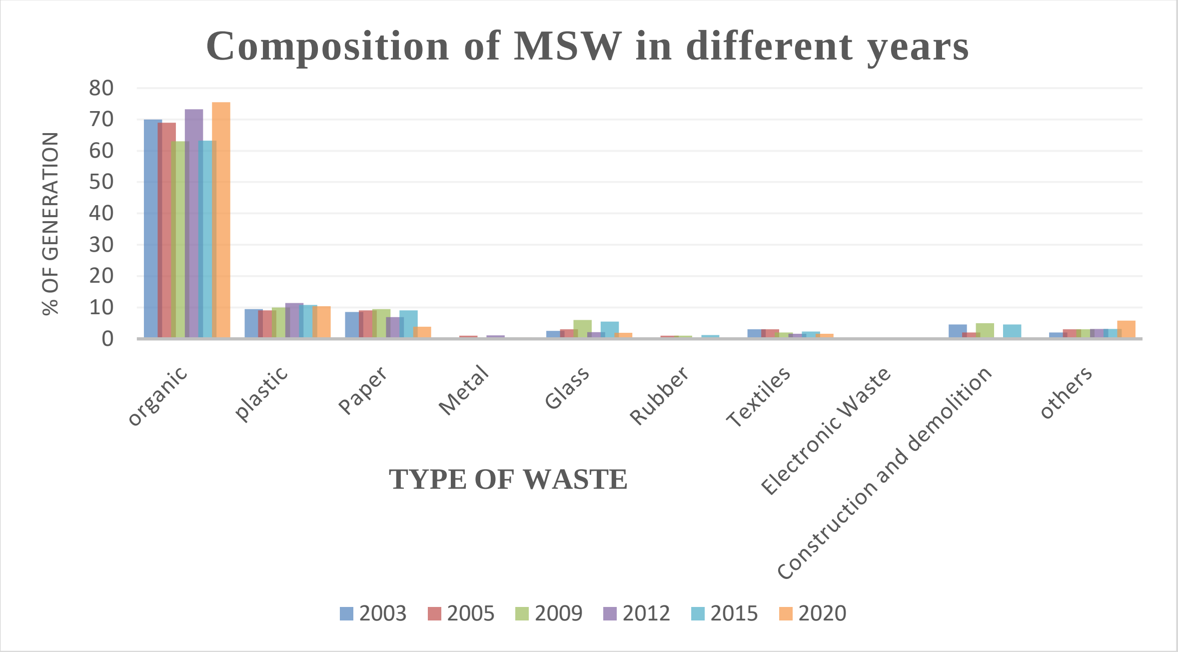


Figure 10: Composition of MSW in Different Years

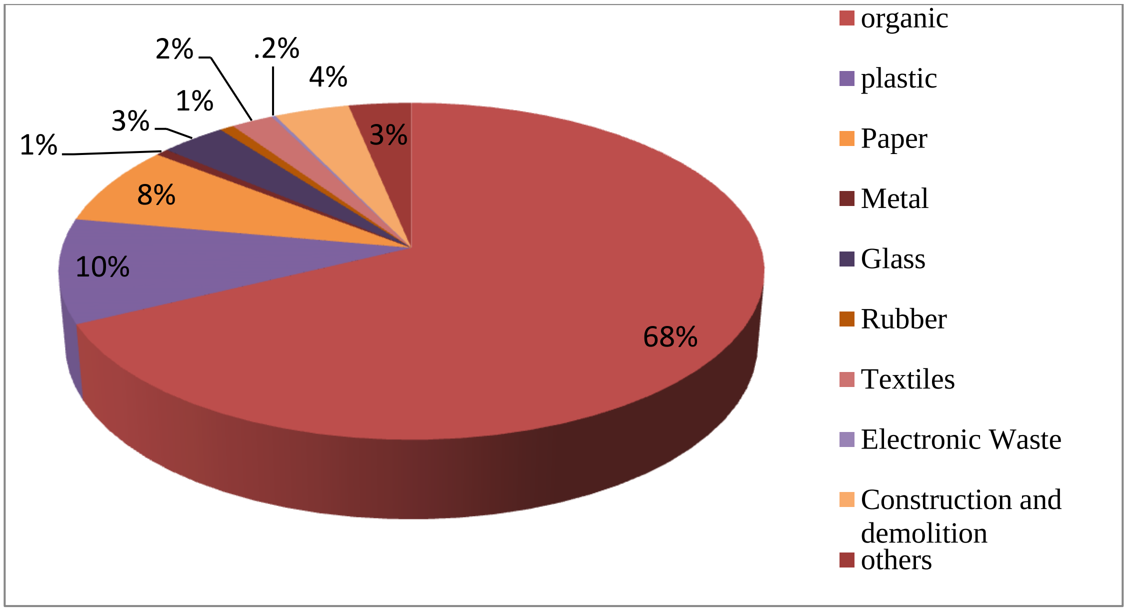


Figure 11: Percentage of Different Types of Waste in Kathmandu Valley

According to Figure 10 and 11, on an average 68% of municipal waste generated, is organic waste. 10.2% of waste is plastic waste, followed by paper waste which is 7.8%, 4% construction and demolition waste, next in row glass waste with 3.5%. 2.3% Textiles waste, 0.8% rubber waste, 0.7% Metal, 0.2% electronic waste and remaining 3% other wastes covers the entire municipal waste.

***Table* 7: Characteristics of Solid Waste in Landfill**

(Source: (Bijay & Ajay Kumar, 2011)

Parameters	**Observed Value (%)**
Moisture (%)	35.5
Organic Matters (%)	22.43
Total Nitrogen (%)	0.87
Total Phosphorous (%)	0.192
Lead (µg/g)	16.72
Cadmium (µg/g)	3.24
Nickel (µg/g)	16.47
Chromium (µg/g)	5.74
Copper (µg/g)	185.7
Potassium (µg/g)	164.72

Table 7 illustrates the laboratory results of sample of waste from sisdol landfill site performed. According to the test, the moisture content of the solid waste was found to be 35.5%.Similarly, According to baseline study of solid waste management of Kathmandu ((Rajbhandary, 2020), the waste density of landfill site was found to be 142 gm/litre.

5.4 Scenario Generation

Table 8 depicts the six scenarios with system boundaries considered in this study. The baseline scenario (S0) depicts the current MSW management system, in which 77 percent of waste is landfilled at Sisdol and the remaining 23 percent is managed through composting and recycling. All of the following scenarios include alternate choices such as composting and recycling, as well as methane capture from the current landfill. These scenarios are based on a research of people's attitudes regarding waste separation, interest in and potential for composting organic wastes, and organizations' engagement in the process.

Table 8: Different Predictive Scenarios of Municipal Waste Management

SCENARIOS	DESCRIPTION	DETAILS
S0	Business as usual	the Scenario corresponds to the current MSW management system (77% of generated MSW is landfilled)
S1	Worst Case Scenario	the scenario assumes that all the solid waste are sent to the landfill site
S2	Upgraded Landfill	Upgrade landfill gas capture (50% Methane Recovery)
S3	Composting of Organic Waste	assumes 50% of organic waste are composted
S4	Recycling Recyclable materials	assumes 50% of recyclable materials are recycled
S5	Integrated Approach	Integration of gas capture, recycling

		and composting (S2;S3;S4)

5.4.1Current ‘Business as usual’ (S0)

The current MSW collection, transportation, and landfilling scenario is included in the business as usual scenario. Only about 23% of garbage is recovered as recycled products, while the remaining 77% is dumped without further separation. MSW is not isolated at the source, according to an environmental audit assessment (Urban Development Ministry, 2015), and around 448 tons of trash per day were deposited in the Sisdol Landfill site with no further treatment until 2015.

According to Sisdol Landfill officials, 1200 tons of rubbish are disposed of everyday, with roughly 200 tons returned back to various recycling firms. As a result, just % of rubbish is disposed of at the landfill. The Sisdol site is designed as a semi-anaerobic landfill with no recovery system or LFG collection system.

5.4.2 Worst-case Scenario (S1)

The worst-case scenario is one in which no waste segregation or separation is carried out. The garbage created is simply collected and thrown into a landfill without being processed, as was the case until 2015. This is the worst practice, as it is clearly responsible for a greater amount of GHG emissions.

5.4.3 Upgrading Landfill Gas Capture Scenario (S2)

The landfill gas capture scenario is the same as S0, except that % of the CH4 gas is collected by the landfill gas capture vent pipe and only % is released into the atmosphere. Based on the climatic conditions and the waste composition, moisture content of the waste, and direct observation of existing vent pipe positions in the site to allow methane gas to escape, as well as discussions with staffs at the Sisdol landfill site and officials of the KMC's environmental department, and literature reviews associated with the collection of gas using vent pipes, it is assumed in this scenario the inventory of a gas capture system will be effective at gathering 50% of the gas produced (R=0.5). Other parameters in the scenario are the same as S0.

5.4.4 Composting Scenario (S3)

According to (Amatya, n.d.; Dangi et al., 2011; Khadka et al., 2020; Rajbhandary, 2020), organic waste, particularly food waste, accounts for nearly 70% of waste generated in Kathmandu valley. According to Nepalese food scientists and technologists, approximately 60% of organic waste is food waste, primarily vegetable waste. After discussions and interviews with various companies involved in organic waste composting, such as Praramva Biotech (https://praramvabiotech.com) and Bio Comp Nepal (http://www.biocompnepal.com), it was discovered that nearly 100% of organic waste can be composted at the generation level itself using proper composting techniques, and that it has proven to be one of the best fertilizers and need not send to the landfill site. Unfortunately, organic waste is landfilled due to a lack of waste segregation and people's indifference to waste management. According to (Rajbhandary, 2020), 50% of people are unconcerned about waste management and are hence willing to accept garbage segregation. In the S3 scenario, it is estimated that 50% of the organic waste created trash will be composted, while the remaining 50% will be landfilled.

5.4.5 Recovery and Recyclable Scenario (S4)

The plausibility and practicality of segregating and recycling recyclable garbage was analyzed after questioning the personnel and concerned authorities of Doko recyclers, Khalisisi.com, and the people involved in harvesting recyclable waste from the sisdol landfill site. They estimate that 25% of residential garbage and a substantially higher proportion of institutional and commercial waste, excluding organic waste, might be reused or recycled. This scenario assumes that 50% of recyclable trash, such as paper, metals, glass, plastic, building and demolition waste, and textiles, is separated and recycled at the source, with the remainder going to landfill.

5.4.6 Integrated Approach Scenario (S5)

S5 assumes the integrated approach of scenario S2, S3 and S4. That means, firstly, 50% of organic waste out of total MSW will be gathered and treated for composting. Also, 50 % of recyclable materials, for example, paper, metals, glass, plastic, wood and material will be recycled at in the material recycling facility. The remaining waste shall be sent to the landfill. Lastly, out of all generated methane, 50% of CH4 emissions will be collected and recovered.

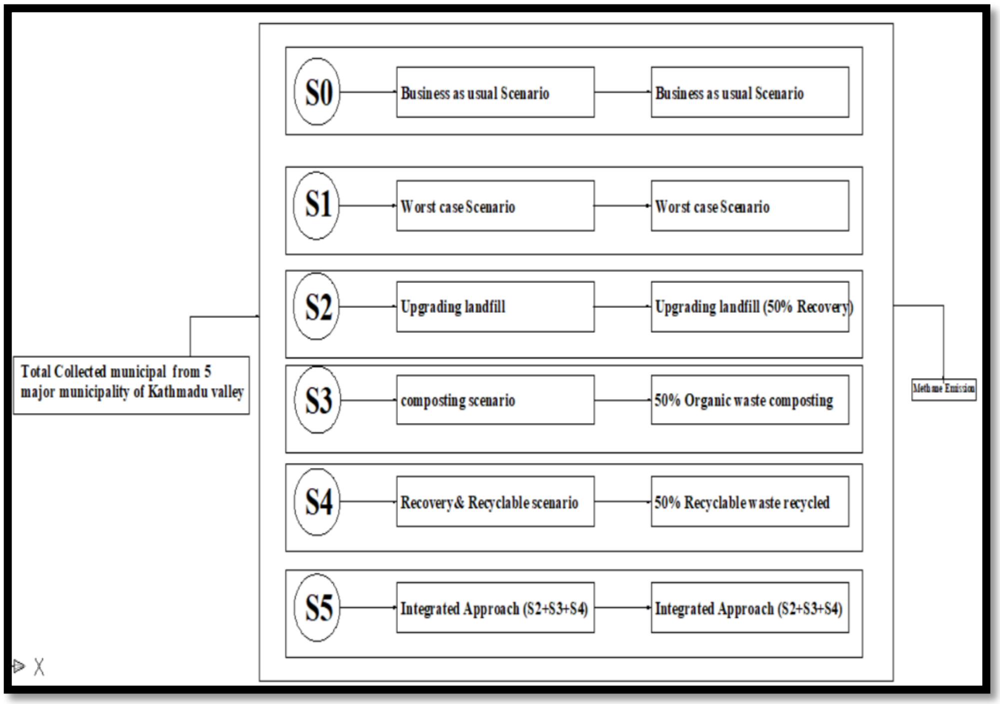


Figure 12: Different Scenarios generated based on feasibility and possibility of waste management

Figure 12 above represents different predicative scenario and their description.

5.5 Model Parameters Calculation

The basic condition to obtain modeling results that are as suited as possible to the actual production of gas is the right choice of assumption, with regard to the constants of the CH_4 generation potential (L_0) and CH_4 generation rate (k) (Park et al., 2018). These parameters are strongly dependent on the chemical composition, properties of waste, and the condition of the process(Atabi et al., 2014).

In order to calculate potential methane production capacity, IPCC methodology (IPCC, 2006) was used and it was calculated using equation 2 as mentioned in the literature section:

$$\mathbf{L_0 = DOC \times DOC_f \times MCF \times F \times \frac{16}{12}} \qquad (2)$$

To calculate DOC equation 3 is used:

Equation 4: Calculation of DOC

$$\mathbf{DOC_i = OC_i \times Fb_i \times (1 - U_i) \times P_i}$$

Where,

Table 9: Characteristics of Municipal Waste

Materials	*OCi (kgC/Kg)*	*Ui (Kg H2O/Kg)*	*(Fb)i (kg biodeg.C/Kg)*
organic	0.48	0.60	0.8
Paper	0.44	0.08	0.5
Textiles	0.55	0.10	0.2

Based on potential for each scenario for Sisdol landfill was the characteristics of municipal waste, the organic carbon in the waste that can convert to LFG was calculated using data in table 9 and on the basis of composition of municipal waste under different scenarios. DOC_f is temperature dependent (0.014T+0.28) and it is expected that temperature stays steady at 35°C in the anaerobic zone in the landfill and about 80% of the DOC would convert to LFG under this temperature, so DOC_f is taken as 0.77.

Similarly, MCF reflects the status of the landfill management of the site. Table 10 shows the MCF values for various landfill sites. Since, Sisdol Landfill is semi aerobic type with depth greater than 5 m, MCF value used is 0.5.

Table 10: MCF value for Different landfill condition

Landfill Site	*Depth < 5m*	*Depth ≥ 5m*
Without Management	0.4	0.8
With Management	0.8	1
Semi Aerobic	0.4	0.5
Condition Unknown	0.4	0.8

F gives fraction of methane in LFG and the value was assumed to be 0.6.

Based on these values, the methane generation calculated as shown in Table 11. According to (Balogun-Adeleye et al., 2019),the L_0 value depends almost exclusively on the waste composition and it is a function of the organic content of the waste. The higher the organic content of the waste, the higher the L_0.

The value of L_0 varies across different landfills and is site specific and ranges from 6-270 m3/Mg as specified by US EPA.

Table 11: Methane generation potential under different Scenarios

Scenarios	*L_0 (m^3/Mg)*	*DOC*	*DOC_f*	*MCF*	*F*
S0	42.68	138.57	0.77	0.5	0.6
S1	42.68	138.57	0.77	0.5	0.6
S2	42.68	138.57	0.77	0.5	0.6
S3	21.35	69.33	0.77	0.5	0.6
S4	42.67	138.53	0.77	0.5	0.6
S5	21.33	69.28	0.77	0.5	0.6

Similarly, methane generation rate is calculated using following equation:

$$\mathbf{k = \left(3.2 \times 10^{-5} \times annual\ precp\ in\ mm\right) + 0.01}$$

Since, the annual precipitation at the sisdol landfill site as per DHM is 1111.11 mm, K is calculated to be 0.043 $year^{-1}$.

CHAPTER SIX: RESULTS AND DISCUSSIONS

6.1 Emission Calculation under Each Scenario

6.1.1 Emission till 2021 under business as usual condition

Firstly, the methane emission till 2021 was calculated based on the present condition and status of the landfill site and average waste composition of the disposed waste to the landfill site. At present 77% of the generated waste is landfilled with about 69% of organic waste in it(Rajbhandary, 2020). Based, on this data, the analysis was done in LandGEM software to obtain the emission by the end of 2021. Table 12 shows the result of the disposed solid waste quantity in Sisdol landfill during last 16 years since the opening of the site. The amount of disposed municipal waste was approximately estimated 122,228.645 Mg in 2005 which increased to 196,050.727 Mg in 2020. According to Table 5, total quantity of disposed waste is estimated to be 2,502,990.783 Mg by the end of 2021.It shows the rapid growth in municipal waste generation in the area. Methane emission by the end of 2021 in the site closes till then is estimated based on LandGEM using the modified parameters according to the site condition and waste composition.

Table 12: Waste disposed to Sisdol landfill over years

YEAR	WASTEACCEPTED (Mg/year)	WASTE-IN PLACE (Mg)
2005	122,228.645	-
2006	126,139.962	122,228.645
2007	130,176.440	248,368.607
2008	134,342.087	378,545.047
2009	138,641.033	512,887.134
2010	143,077.546	651,528.167
2011	147,656.028	794,605.713
2012	152,381.021	942,261.741
2013	157,257.213	1,094,642.762
2014	162,289.444	1,251,899.975
2015	167,482.706	1,414,189.419
2016	172,842.153	1,581,672.126
2017	178,373.102	1,754,514.279
2018	184,081.041	1,932,887.381
2019	189,971.634	2,116,968.422
2020	196,050.727	2,306,940.056

2021	202,324.350	2,502,990.783

According to plan of Government, once the sanitary landfill site which shall be used to landfill the waste for 25 years at Banchare danda which is under construction comes into use, Sisdol landfill site shall close as sisdol landfill site was actually planned as temporary landfill site for only 2 years but due to lack of alternative, it is still being used. According to the workers of Banchare danda landfill site, shall construction shall complete by 2022 A.D. So, Assuming, Sisdol landfill shall close in 2021, total landfill gas and methane generated till 2021, shall be as shown in Table 6. As seen in table 13, the total production of methane in 2006 was 146.80 Mg which increased to 2,138.48 in 2020 and total 2283.93 Mg methane shall be produced in year 2021.

Table 13: Landfill Gas and Methane Production for Sisdol Landfill over Year

Year	Landfill Gas (Mg/Year)	Methane (Mg/Year)
2005	-	-
2006	482.44	146.80
2007	960.01	292.11
2008	1,433.42	436.16
2009	1,903.34	579.14
2010	2,370.45	721.28
2011	2,835.41	862.75
2012	3,298.88	1,003.77
2013	3,761.48	1,144.54
2014	4,223.87	1,285.23
2015	4,686.65	1,426.04
2016	5,150.45	1,567.17
2017	5,615.89	1,708.79
2018	6,083.57	1,851.09
2019	6,554.09	1,994.26
2020	7,028.07	2,138.48
2021	7,506.08	2,283.93

Figure 13 shows the emission of different LFG till 2021. It indicates the increasing trend of different LFGs and shows the production of methane by the end of 2021 shall be 2283.93 Mg.

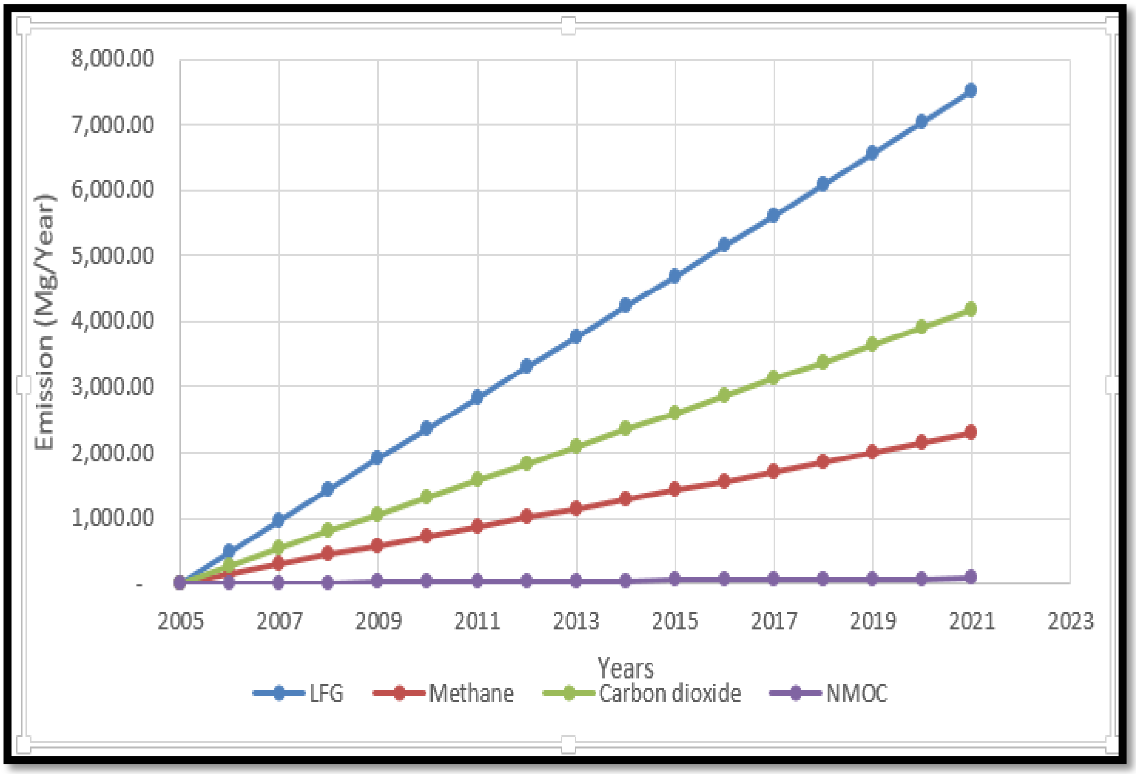


Figure 13: Emission of different LFGs under BAU till 2021

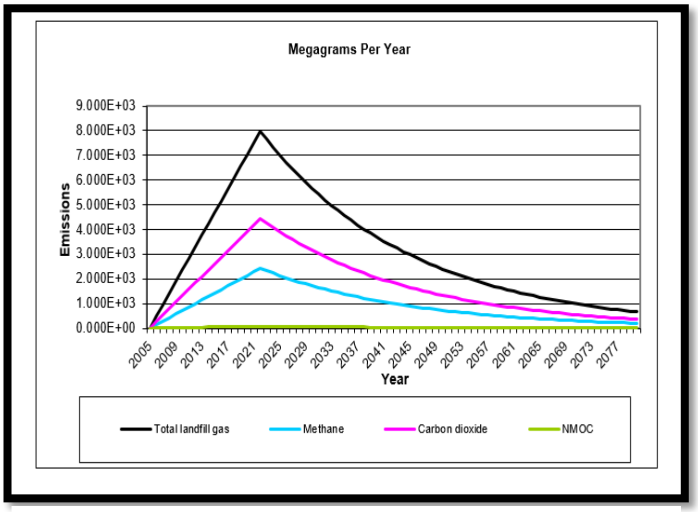


Figure 14: Emission of LFGs for Sisdol landfill under BAU over years

Figure 14 indicates the production of LFG occurs from 2006 at an increasing rate, peaking in 2022 with the emission of methane 2,431 Mg/year followed by a decrease rate throughout in the landfill closes in 2021. The most reasonable time to capture methane is from 2006 to 2037.

Also, Considering if the Sisdol landfill doesn't close in 2021 and landfilling still continues till 2030 but under different scenarios, emission of landfill gas and methane gas emission estimation was done under 6 different scenarios.

6.1.2 Emission till date under S1 scenario

As we know S1 scenario is the worst case scenario where there is no segregation of the waste and all the waste collected is directly dumped to the landfill. So, without any doubt the emission of landfill gas and methane is highest in this scenario.

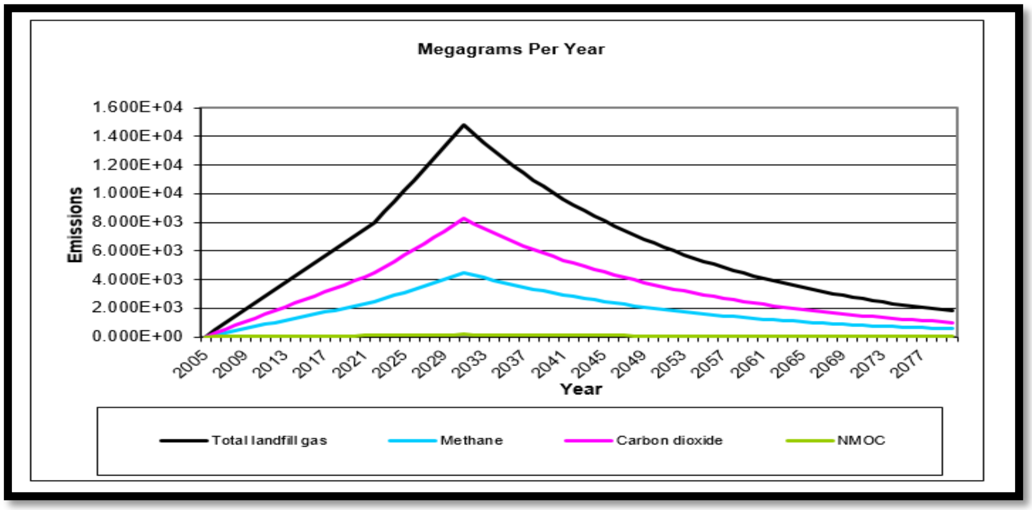


Figure 15: Emission of LFGs for Sisdol landfill under S1 over years

Figure 15 indicates the production of LFG occurs from 2006 at an increasing rate, peaking in 2031 with the emission of methane 4502.4 Mg/year which is highest among all the scenarios followed by a decrease rate throughout. The most reasonable time to capture methane is from 2022 to 2045.

6.1.3 Emission till date under S2 scenario

Under S2 Scenario, trapping of methane gas is given much priority than segregation of waste. 50% of the generated gas is assumed to be utilized by trapping.

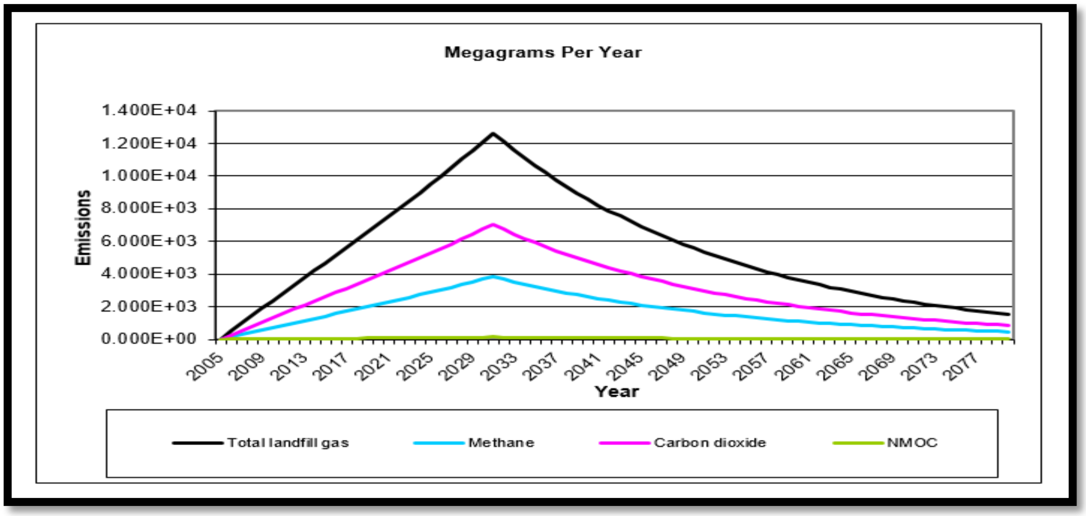


Figure 16: Emission of LFGs for Sisdol landfill under S2 over years

Figure 16 indicates the production of LFG occurs from 2006 at an increasing rate, peaking in 2031 with the emission of methane 1923.12 Mg/year followed by a decrease rate throughout. The most reasonable time to capture methane is from 2025 to 2045.

6.1.4 Emission till date under S3 scenario

S3 scenario focuses on the segregation of waste and utilizing organic waste for making compost rather than landfilling it.

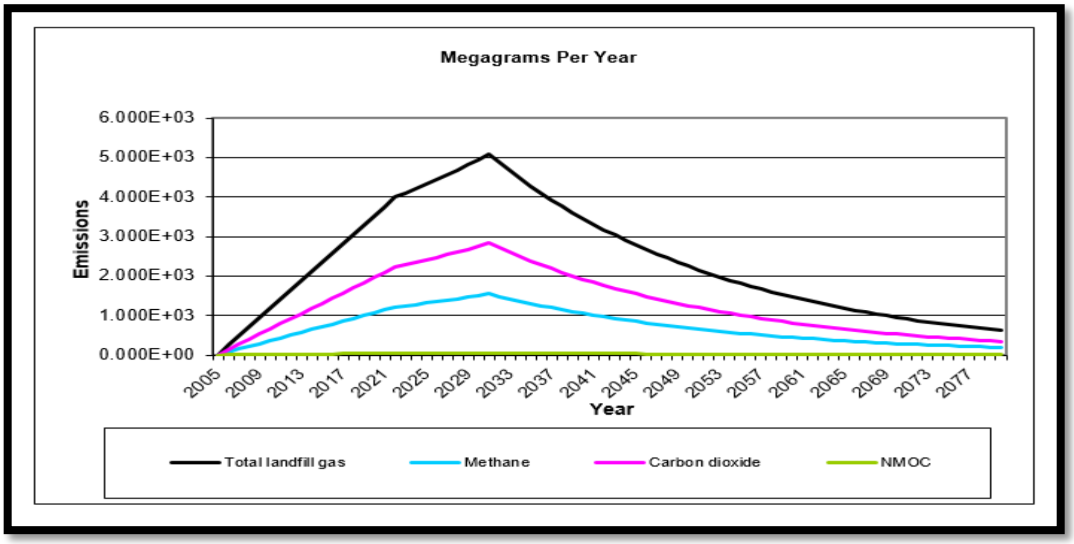


Figure 17: Emission of LFGs for Sisdol landfill under S3 over years

Figure 17 indicates the production of LFG occurs from 2006 at an increasing rate, peaking in 2031 with the emission of methane 1547.10 Mg/year followed by a decrease rate throughout. The most reasonable time to capture methane is from 2022 to 2045.

6.1.5 Emission till date under S4 scenario

Considering that almost 18%-20% waste generated are recyclable waste and can be recycled and reused, this scenario considers 50% of the recyclable waste are recycled and remaining are sent to the landfill.

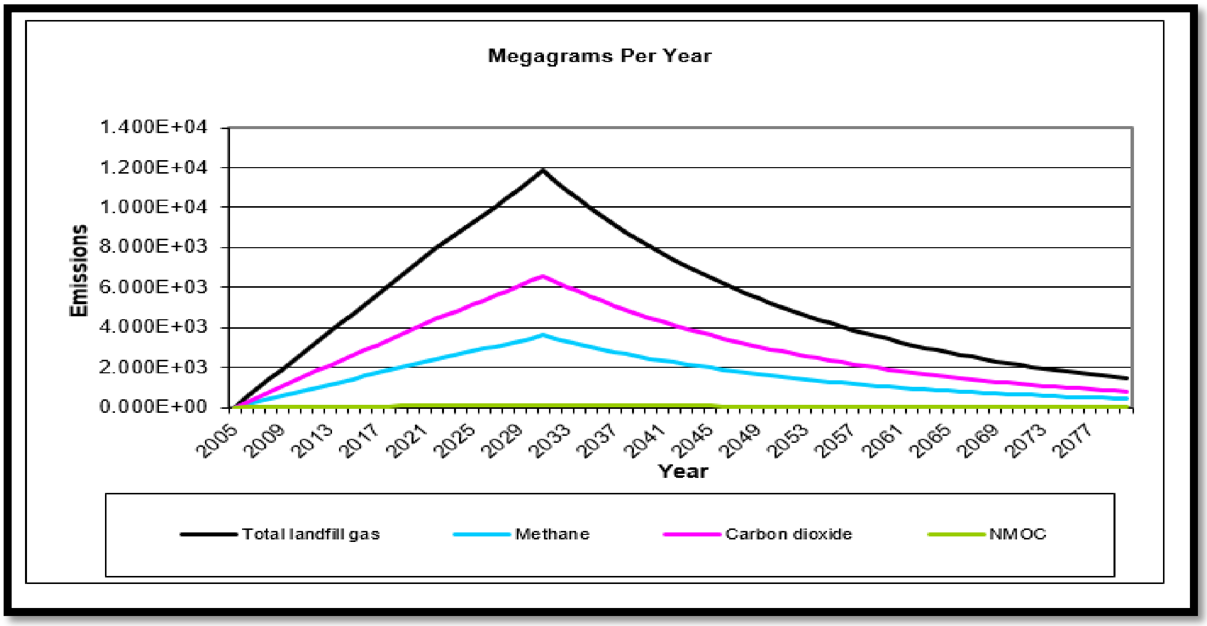


Figure 18: Emission of LFGs for Sisdol landfill under S4 over years

Figure 18 indicates the production of LFG occurs from 2006 at an increasing rate, peaking in 2031 with the emission of methane 3602.5 Mg/year followed by a decrease rate throughout. The most reasonable time to capture methane is from 2022 to 2045.

6.1.6 Emission till date under S5 scenario

S5 scenario is predicated based on very optimistic approach that every possible way is adopted to maintain the principle of waste management i.e. reduction in waste, reuse and recycle of waste and recovery. It assumes S2, S3 and S4 all three scenario is maintained at same time.

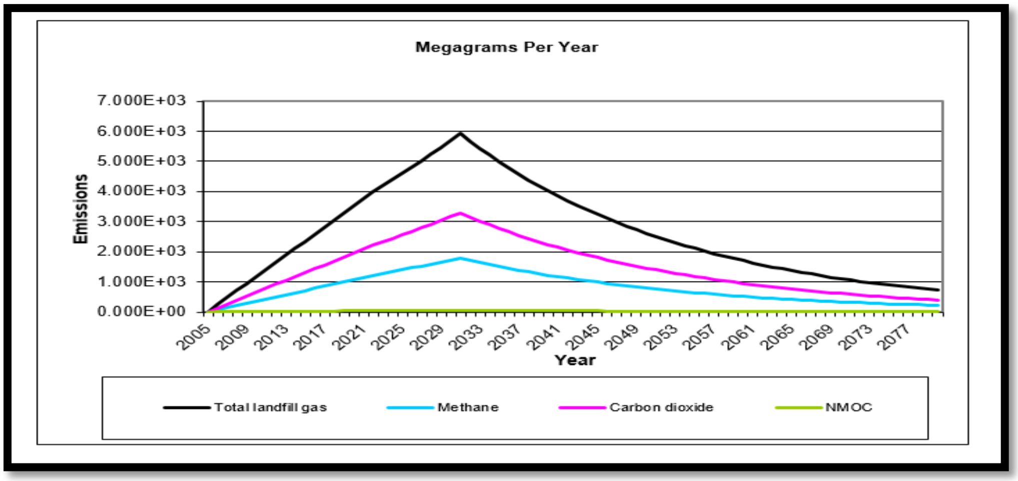


Figure 19: Emission of LFGs for Sisdol landfill under S5 over years

Figure 19 indicates the production of LFG occurs from 2006 at an increasing rate, peaking in 2031 with the emission of methane 900.36 Mg/year followed by a decrease rate throughout. The most reasonable time to capture methane is from 2022 to 2045.

6.2 Comparison of Emission from each scenarios

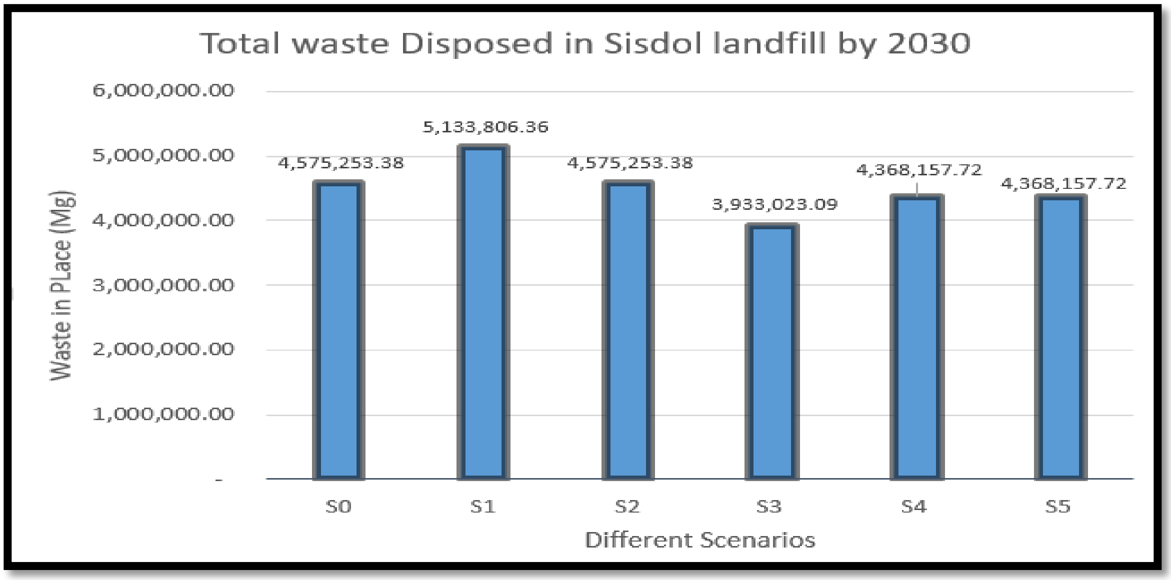


Figure 20: Total waste accumulated at Sisdol landfill by 2030 under different Scenarios

As seen in figure 20, Largest amount of waste shall be accumulated under worst case i.e. S1 scenario with total 51, 33,806.36 Mg waste in place in 2030 and it would be least under S3 i.e. composting scenario with total 39, 33,023.09 Mg waste in place in 2030.

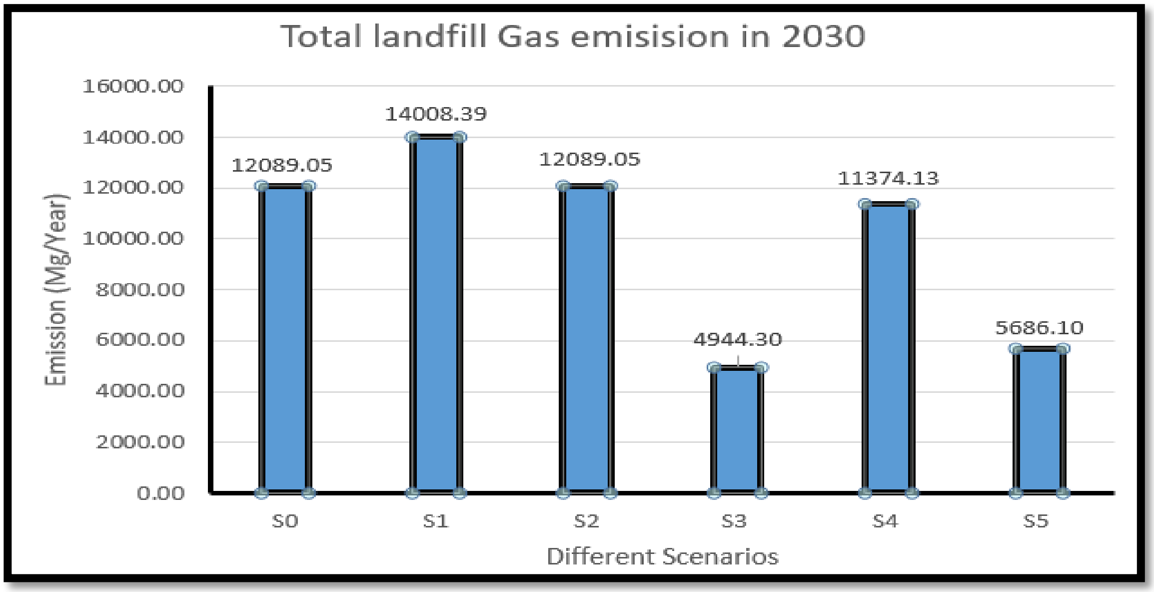


Figure 21: Total landfill gas emission in Sisdol landfill in 2030 under different scenarios

The total landfill gas emission under S1 scenario is predicted to be 14,008.39 Mg/year and 4,944.30 Mg/year in S3 Scenario in the year 2030 as seen in figure 21. According to this, it can be which supports composting of organic waste as better approach for landfill gas emission reduction from landfills.

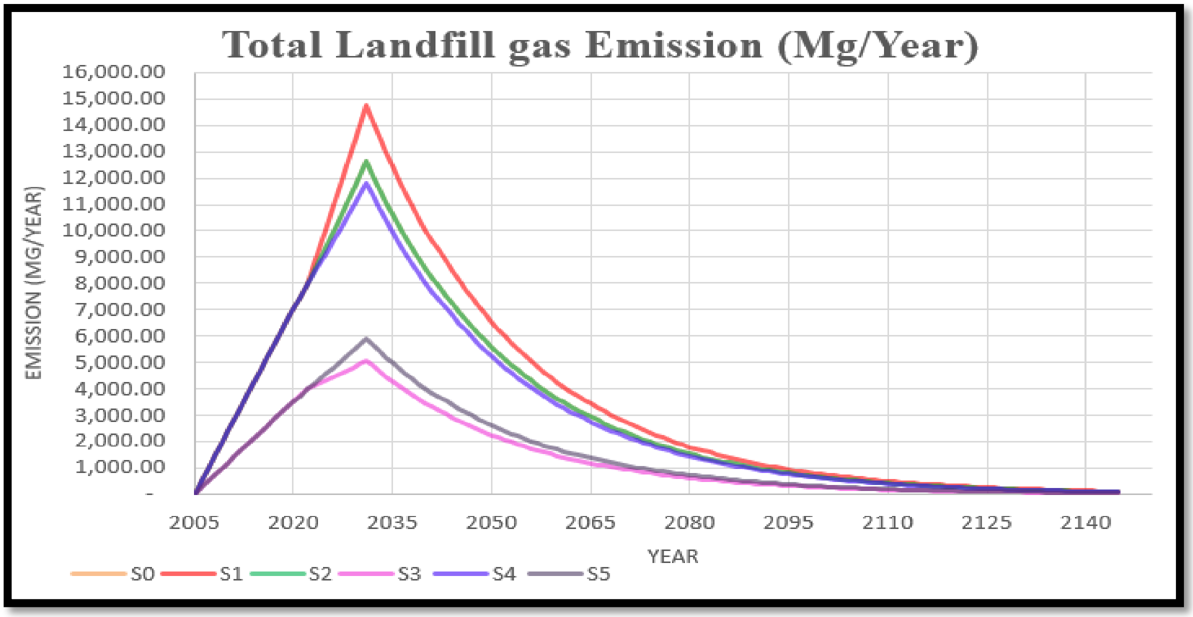


Figure 22: Total Landfill gas emission for sisdol landfill under different scenario

As illustrated by figure 22, the total emission of landfill gases are maximum for S1 scenario and minimum for S3 scenario. S4 scenario doesn't not show significant variation from BAU S0 scenario. This shows a great dependency of the landfill gas generation upon the proportion of organic waste present in the total amount of disposed waste to the landfill.

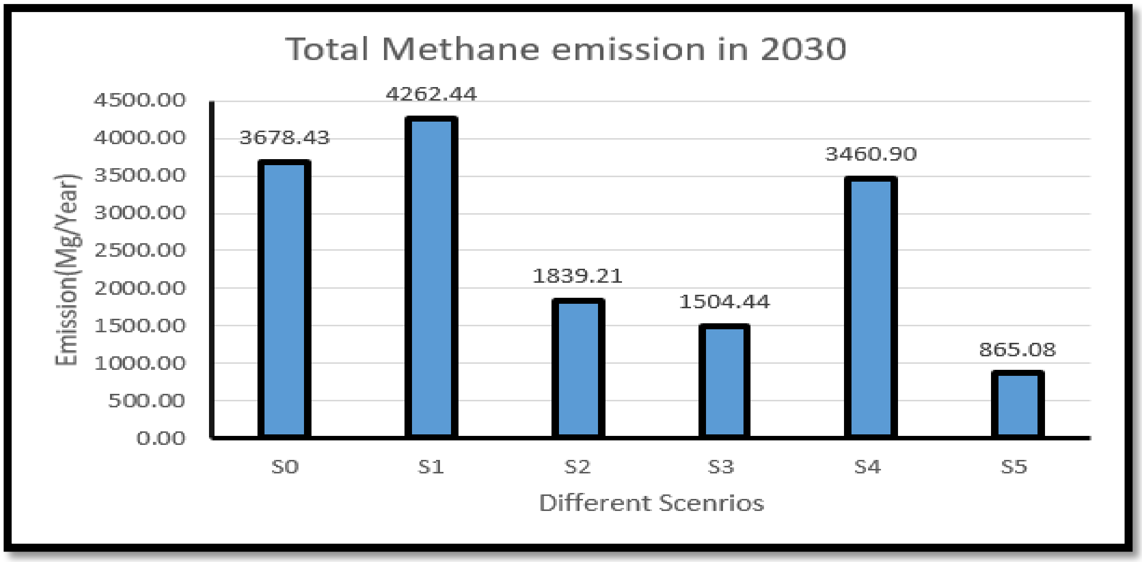


Figure 23: Total emission of methane in year 2030 under different Scenarios

The amount of methane generated for BAU scenario in 2030 is 3,678.43Mg. Methane emission varied according to different scenario. In year 2030, maximum emission is predicted for S1 scenario with total emission of. 4,262.44 Mg/year whereas in S5 scenario the emission of methane in same year is least which is predicted to be 865.08 M as shown in figure 23.

Similarly, Figure 24 shows the trend of methane gas emission in different years of the project at the waste disposal Sisdol site under different predictive scenarios. The results showed that the amount of annual production of methane is maximum for S1 scenario. Significant reduction in atmospheric methane emission was seen under landfill gas capture S2 scenario as 50% of the generated gas was supposed to be captured by the gas capture inventories.

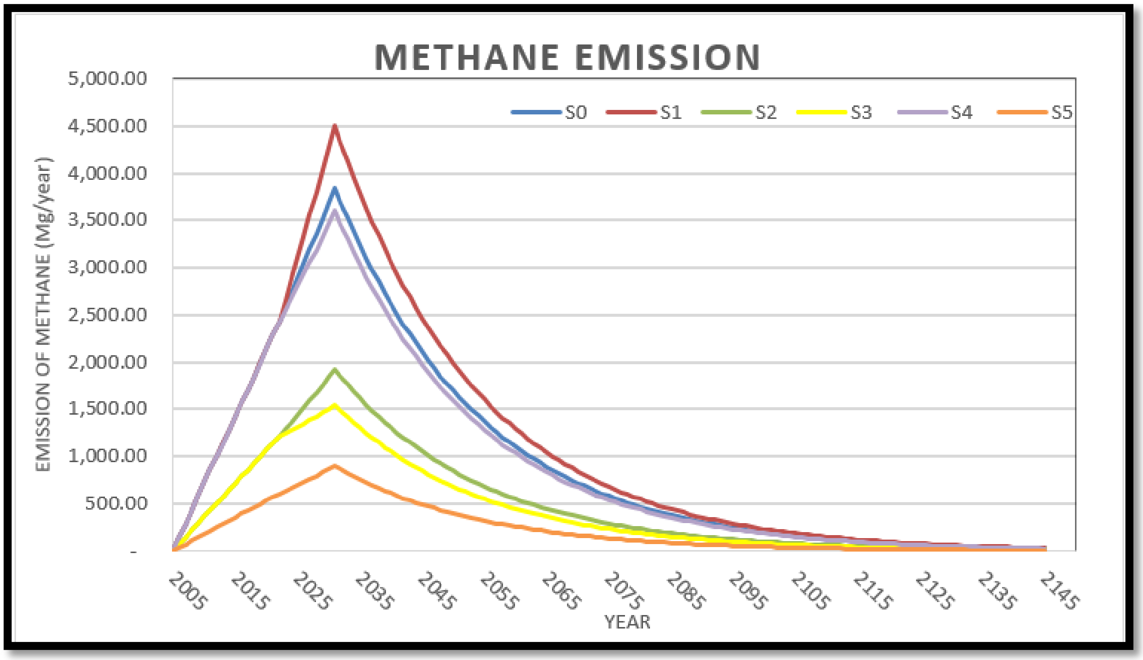


Figure 24: Methane emission under different scenario for Sisdol landfill

Also, least emission was seen under integrated S5 scenario. Best yield period for capture of methane could be 2025 to 2055. S4 scenario didn't not show must effectiveness in reduction of emission.

Table 14: Reduction of Emission in various Scenarios in year 2030

Scenario	Total waste disposed(Mg)	CH4 emission (Mg)	Reduction
S0	4,575,253.38	3,678.43	
S1	5,133,806.36	4,262.44	15.88
S2	4,575,253.38	1,839.21	- 50.00
S3	3,933,023.09	1,504.44	- 59.10
S4	4,368,157.72	3,460.90	- 5.91
S5	4,368,157.72	865.08	- 76.48

Table 14 shows the reduction in emission under different scenarios. The pessimistic S1 scenario predicted an increased emission of 4,262.44 Mg with an increase of 15.88 %. for the same event, the gas capture scenario i.e. S2 gave the emission as 1,839.21 Mg and S3 scenario predicted it to be 1,504.44 Mg with decrease of reduction about 50% and 59.10% respectively. The least effective option i.e. recycling, S4 predicted emission of 3,460.90 Mg with reduction of only 5.91% whereas the best option i.e. integrated approach assumed it to be 865.08 Mg/year with reduction in emission of methane by 76.48% in 2030.

6.3 Validation of Results

United Nations Development Program (UNDP) suggested the waste generation per capita for the citizens of developing countries are between 500 and 900 grams daily(USEPA-United States Environmental Protection Agency, 2005). In current study, the amounts of waste generation per capita for the Kathmandu was found around 360 gram, which is lower than the UNPD range.

(Popli et al., 2020) Found that population and total MSW are directly correlated. S.Fallahizah et al. (Fallahizadeh et al., 2019) in Yasuj landfill showed emission of 29.02 Mg methane in 1992 and 1610 Mg methane in 2010 with total disposal of waste being 5756 Mg and 42,973 Mg respectively. According to(Njoku et al., 2020) The methane (CH_4) and carbon dioxide (CO2) emitted from the Thohoyandou Landfill estimated from LandGEM will peak in the year 2026 at 3517 Mg/year and 9649 Mg/year, respectively. The LandGEM model showed that total LFG, CH4 and CO2 emitted from the landfill between 2005 and 2040 (Mg/year) are 293,239, 78,325 and 214,908, respectively.

Similarly, according to (Kaushal & Sharma, 2016) annual average CH_4 emission rates from Panki open dump site was found as 25,140 Mg by LandGEM for the period 2010-2030 with 1500 Mg/day disposal of waste to the site. The generation under BAU scenario for Sisdol landfill in 2030 is 3,678.53 Mg with average disposal of 1200 Mg/day to the landfill site.

Comparing the results of other research with the result of this study, the amount of generation of methane was found to be higher may be because of higher the amount of waste generated per capita in Kathmandu, amount of moisture in the waste sample, higher proportion of organic waste present in the waste disposed to the landfill site and climatic condition of the site.

Validation of Model

For validation of the model, the trend for the modelled CH_4 for the waste disposed at the site from 2005 to 2011 was analysis. Based on the trend, the methane emission was projected upto 2021. The modelled CH_4 emission was compared to the projected methane emission.

Table 15: Modelled Methane emission from 2005 to 2011

Year	Waste Accepted (Mg/Year)	Modelled Methane emission (Mg/Year)
2005	122228.65	0.00
2006	126139.96	146.80
2007	130176.44	292.11
2008	134342.09	436.16
2009	138641.03	579.14
2010	143077.55	721.28
2011	147656.03	862.75

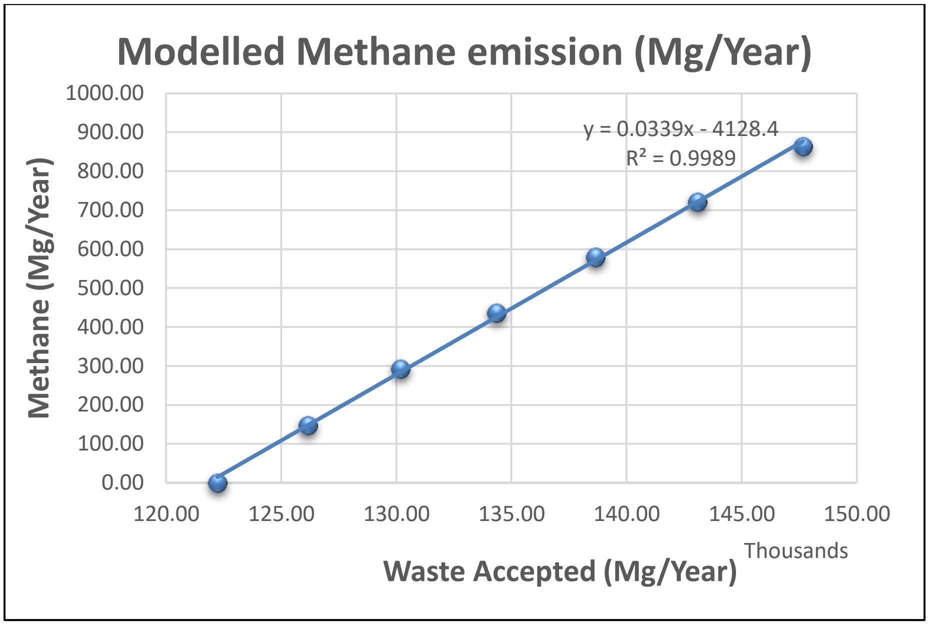


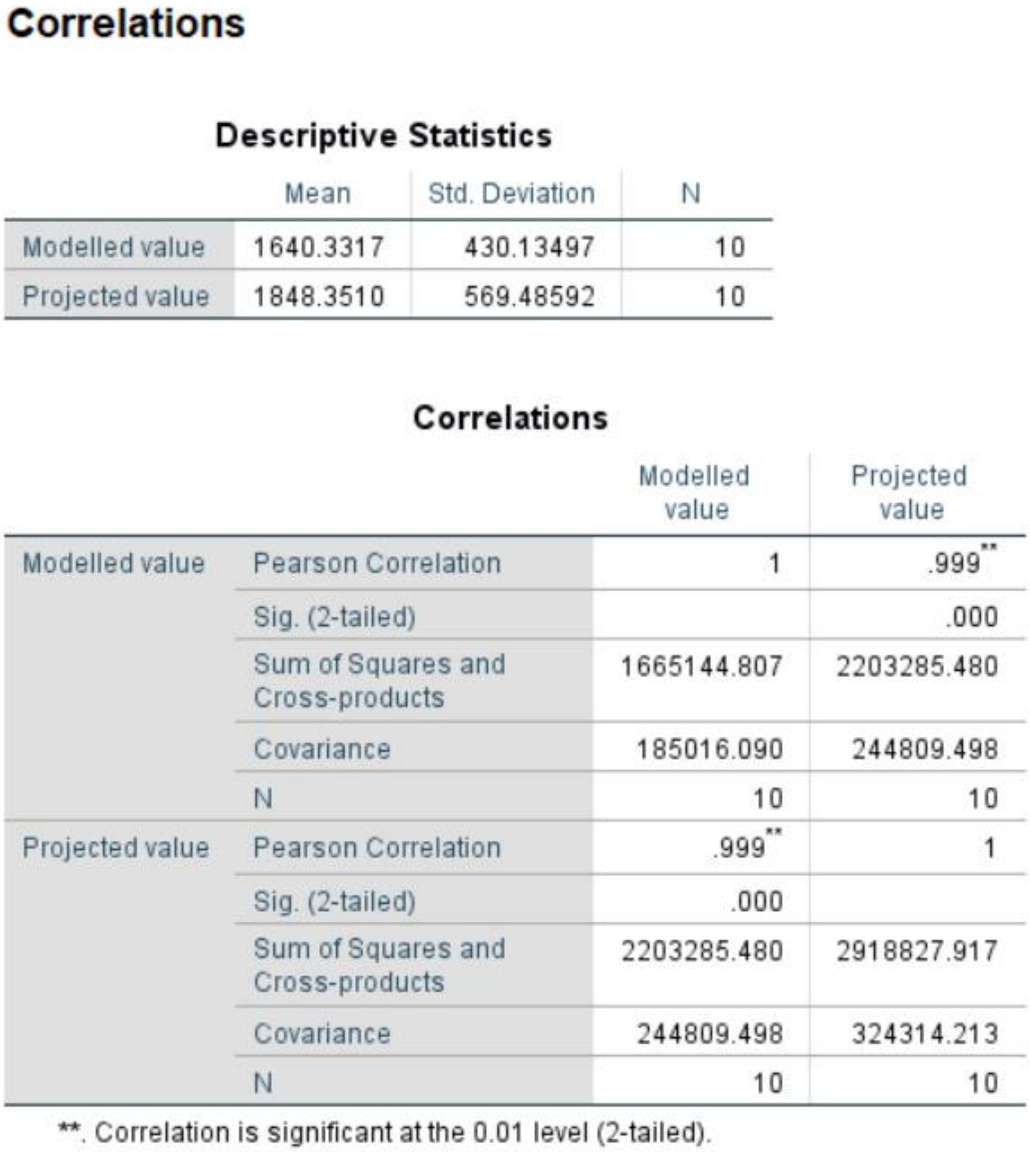
Figure 25: Trend of Methane emission

Figure 25, illustrates the trend of Methane emission as given by the LandGEM software. Based on the linear regression R2=0.9989, and equation Y= 0.0339x-4128.4, the methane emission for year 2012 to 2021 was projected and compared to modelled methane emission as shown in Table 16.

Table 16: Modelled and Projected Methane Emission

Year	Waste Accepted (Mg/Year)	Modelled Methane Emission (Mg/Year)	Projected Methane Emission (Mg/Year)
			y = 0.0339x - 4128.4
2012	152381.02	1003.77	1037.32
2013	157257.21	1144.54	1202.62
2014	162289.44	1285.23	1373.21
2015	167482.71	1426.04	1549.26
2016	172842.15	1567.17	1730.95
2017	178373.10	1708.79	1918.45
2018	184081.04	1851.09	2111.95
2019	189971.63	1994.26	2311.64
2020	196050.73	2138.48	2517.72
2021	202324.35	2283.93	2730.40

Correlation between the Modelled result and the projected result were highly significant at significance level 0.01 with coefficient of correlation being 0.999.



Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
Modelled value	1640.3317	430.13497	10
Projected value	1848.3510	569.48592	10

Correlations

		Modelled value	Projected value
Modelled value	Pearson Correlation	1	.999**
	Sig. (2-tailed)		.000
	Sum of Squares and Cross-products	1665144.807	2203285.480
	Covariance	185016.090	244809.498
	N	10	10
Projected value	Pearson Correlation	.999**	1
	Sig. (2-tailed)	.000	
	Sum of Squares and Cross-products	2203285.480	2918827.917
	Covariance	244809.498	324314.213
	N	10	10

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 26: Correlation between modelled data and projected data

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

The study was conducted to estimate methane emissions from the Sisdol landfill which is the biggest landfill site in Nepal. The study also aimed to establish alternative solid waste management system scenarios that have the greatest potential to reduce methane emissions. After modifying its default parameters such as methane production potential (L_0) and methane generation rate (K) according to the type of trash disposed to the site and the meteorological condition of the site, the LandGEM model was used to estimate methane over years.

The LandGEM model simulations showed the generation of LFGs and methane starting in 2006, i.e. after one year of waste disposal to the landfill site, and increasing at a steady rate until 2021 in a business-as-usual scenario. From 2022 through 2030, various scenarios have been offered. S1, S2, S3, S4, and S5 alternative scenarios were compared to the Business as Usual S0 scenario for reducing CH_4 emissions. S2 scenario gave an effective reduction in methane emission to the atmosphere as 50% of the generated gas would be trapped and utilize for energy generation. Reduction in methane production with segregation of organic waste and composting it in scenario S3 concluded the significant contribution of organic waste in total waste generated in Kathmandu. The amount of garbage that was recycled was minimal.so, it had no significant change in methane generation in case of Sisdol landfill.

The results showed that the S1 scenario produced the greatest trash, with a 15.88 % increase in emissions, while the S5 scenario produced the least methane, with a 76.48 % reduction in emissions, which shows that the majority of the wastes are perishable organic materials.

Based on the findings, it can be inferred that reducing organic waste generation can help to reduce methane emissions from landfills. Also, residential trash segregation is a must importation step to take in order to limit the amount of waste disposed to the landfill, which is currently overburdened beyond its carrying capacity. Although GHG emissions are not a current concern in Nepal because they contribute so insignificantly, alternatives to disposal should be given top consideration for long-term waste management.

7.2 Recommendation

Based on the study's findings and conclusions, it is recommended that:

- The results of the study can be utilized by the environmentalist to evaluate the contribution of the landfill site to GHG emission.

- It would be helpful to the policy maker to formulate and implement the best scenario for MSW management.

- Considering seasonal variation in generation of waste, Seasonal Variation in the emission can be further analysed.

- Also, if the GHG emission by the transportation sector during transport of the waste from collection to the landfill site is considered, the emission scenario may change.

- Different other scenarios could be considered for further analysis of sustainable waste management plan.

References

ADB. (2013). Solid Waste Management in Nepal: Current Status and Policy Recommendations. In *Asian Development Bank (ADB)*. http://cpfd.cnki.com.cn/Article/CPFDTOTAL-ZGKL200509001593.htm%0Ahttps://www.adb.org/sites/default/files/publication/30366/solid-waste-management-nepal.pdf

Adeyemi, A. T. (2013). *ESTIMATING METHANE GAS GENERATION FROM DEVIL ' S SWAMP LANDFILL USING GREENHOUSE GAS EMISSION MODELS Thesis Submitted to The College of Engineering Southern University and A & M College In Partial Fulfillment of the Requirements for The Degree of Master o*.

Adhikari, B., Manandhar, D. R., & Khanal, S. N. (2013). Study of Leachate and Waste Composition at Different Landfill Sites of Nepal. *Kathmandu University Journal of Science, Engineering and Technology*, *9(2)*(Ii), 15–21.

Amini, E., Nematollahi, H., & Moradi Banestani, N. (2017). Estimation and Modeling of Biogas Production in Rural Small Landfills (Case Study: Chaharmahaal and Bakhtiari and Yazd Rural Areas). *Environmental Energy and Economic Research*, *1*(4), 383–392. https://doi.org/10.22097/eeer.2018.122498.1023

Amini, H. R., Reinhart, D. R., & Niskanen, A. (2013). Comparison of first-order-decay modeled and actual field measured municipal solid waste landfill methane data. *Waste Management*, *33*(12), 2720–2728. https://doi.org/10.1016/j.wasman.2013.07.025

Atabi, F., Ehyaei, M. A., & Ahmadi, M. H. (2014). *Calculation of CH 4 and CO 2 Emission Rate in Kahrizak Landfill Site with Land GEM Mathematical Model*.

Balogun-Adeleye, R. M., Longe, E. O., & Aiyesimoju, K. O. (2019). A model for the accurate estimation of methane emissions in landfills. *Nigerian Journal of Technology*, *38*(3), 784. https://doi.org/10.4314/njt.v38i3.34

Bijay, T., & Ajay Kumar, K. C. (2011). Solid waste management at landfill sites of Nepal. *Indian Journal of Science and Technology*, *4*(3), 164–166. https://doi.org/10.17485/ijst/2011/v4i3/29956

CBS. (2020). Waste Management Baseline Survey of Nepal 2020. In *Central Bureau of Statistics*. https://cbs.gov.np/wp-content/upLoads/2021/04/Waste-Management-Baseline-Survey-of-Nepal-2020.pdf

Chalvatzaki, E., Glytsos, T., & Lazaridis, M. (2015). *A methodology for the determination of fugitive dust emissions from landfill sites*. *3123*(November). https://doi.org/10.1080/09603123.2014.989491

Dangi, M. B., Pretz, C. R., Urynowicz, M. A., Gerow, K. G., & Reddy, J. M. (2011). Municipal solid waste generation in Kathmandu, Nepal. *Journal of Environmental Management*, *92*(1), 240–249. https://doi.org/10.1016/j.jenvman.2010.09.005

Fallahizadeh, S., Rahmatinia, M., Mohammadi, Z., Vaezzadeh, M., Tajamiri, A., & Soleimani, H. (2019). Estimation of methane gas by LandGEM model from Yasuj municipal solid waste landfill, Iran. *MethodsX*, *6*(February), 391–398. https://doi.org/10.1016/j.mex.2019.02.013

Fourie, A. B., & Morris, J. W. F. (2004). Measured gas emissions from four landfills in South Africa and some implications for landfill design and methane recovery in semi-arid climates. *Waste Management and Research*, *22*(6), 440–453. https://doi.org/10.1177/0734242X04048332

Hardy, M. (2018). *An Assessment of the Global Warming Potential of Municipal Solid Waste Treatment Scenarios in the Netherlands Colophon*. 1–56.

Hosseini, S.S. & Yaghmaeian, K. & Yousefi, Nader & Mahvi, A. (2018). Estimation of landfill gas generation in a municipal solid waste disposal site by LandGEM mathematical model. *Global Journal of Environmental Science and Management.*, *4*(4), 493–506. https://doi.org/10.22034/gjesm.2018.04.009

IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Vol 5 Chapter 3 Solid Waste Disposal. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, *4*, 6.1-6.49. http://www.ncbi.nlm.nih.gov/pubmed/20604432

Kaushal, A., & Sharma, M. P. (2016). Methane Emission from Panki Open Dump Site of Kanpur , India. *Procedia Environmental Sciences*, *35*, 337–347. https://doi.org/10.1016/j.proenv.2016.07.014

Korenaga, T. (2007). Environmental Monitoring. *Comprehensive Microsystems*, *3*, 391–420. https://doi.org/10.1016/B978-044452190-3.00069-0

Mann, John & Wilder, Lynn & Zarus, Gregory & Nickel, R. (2001). Landfill Gas Basics. *Landfill Gas Primer*, 3–14. https://www.atsdr.cdc.gov/hac/landfill/html/intro.html

Njoku, P. O., Edokpayi, J. N., & Odiyo, J. O. (2020). Modeling landfill gas potential and potential energy recovery from Thohoyandou landfill site, South Africa. *Journal of the Air and Waste Management Association*, *70*(8), 820–833. https://doi.org/10.1080/10962247.2020.1778137

Park, J. K., Chong, Y. G., Tameda, K., & Lee, N. H. (2018). Methods for determining the methane generation potential and methane generation rate constant for the FOD model: a review. *Waste Management and Research*, *36*(3), 200–220. https://doi.org/10.1177/0734242X17753532

Popli, K., Lim, J., Kim, H. K., Kim, Y. M., Tuu, N. T., & Kim, S. (2020). Prediction of greenhouse gas emission from municipal solid waste for South Korea. *Environmental Engineering Research*, *25*(4), 462–469. https://doi.org/10.4491/eer.2019.019

Rajbhandary, J. (2020). KMC SWM Baseline Study 2020 _Final_August132020_SB_v5_KK. In *KMC SWM Baseline Study 2020*.

Ranabhat, R. (2015). Journal of Advanced College of Engineering and Management, Vol. 1, 2015. *Journal of Advanced College of Engineering and Management*, *1*.

sisdol report. (n.d.).

Srivastava, C. M. (2014). *International Journal of Research in Advent Technology RECENT DEVELOPMENTS IN REGENERATED International Journal of Research in Advent Technology*. *2*(1), 267–277.

Thapa, G. B. (1998). Lessons learned from solid waste management in Kathmandu, Nepal. *Habitat International*, *22*(2), 97–114. https://doi.org/10.1016/S0197-3975(97)00030-1

UNFCCC. (2011). Climate change science - the status of climate change science today. *United Nations Framework Convention on Climate Change*, *February 2011*, 1–7. https://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf

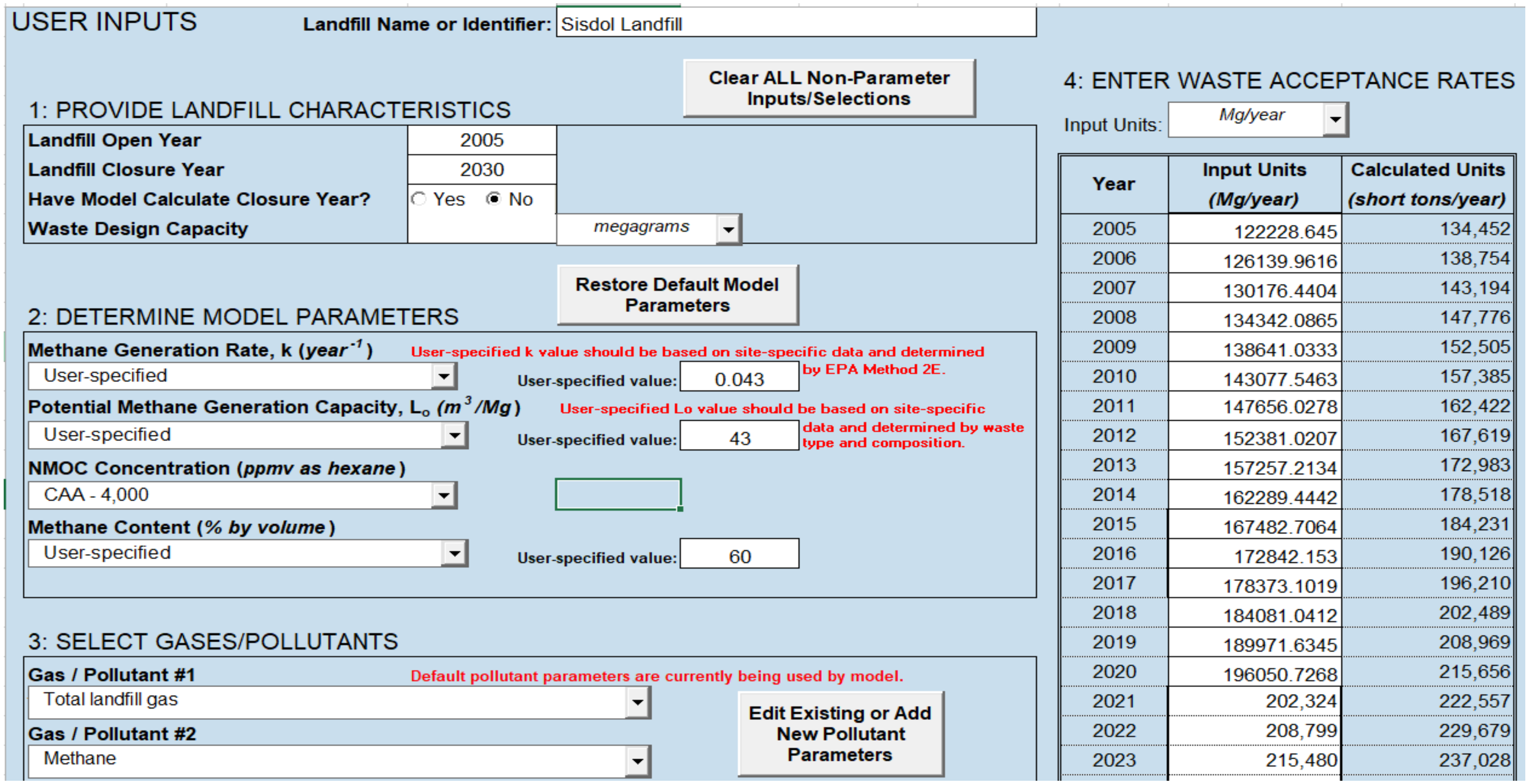
Urban Development Ministry. (2015). *Solid Waste Management of Kathmandu Metropolitan City, Environment Audit Report*. 321–342.

Uri, D., & Saleem, S. A. (2014). *SUSTAINABILITY MODELING AND ASSESSMENT OF PRODUCT RECOVERY SYSTEMS - AN ENGINEERING APPROACH TO A SUSTAINABLE FUTURE*.

USEPA- United States Environmental Protection Agency. (2005). *Landfill gas emissions model. United States Environmental Protection Agency, Version 3.02 user's guide. May*, 48. http://www3.epa.gov/ttncatc1/dir1/landgem-v302-guide.pdf

ANNEXES

Annex I: LandGEM Results



USER INPUTS

Landfill Name or Identifier: Sisdol Landfill

1: PROVIDE LANDFILL CHARACTERISTICS

Landfill Open Year	2005
Landfill Closure Year	2030
Have Model Calculate Closure Year?	○ Yes ● No
Waste Design Capacity	*megagrams*

2: DETERMINE MODEL PARAMETERS

Methane Generation Rate, k (*year*$^{-1}$): User-specified; **User-specified value:** 0.043

User-specified k value should be based on site-specific data and determined by EPA Method 2E.

Potential Methane Generation Capacity, L_o (*m*^{3}*/Mg*): User-specified; **User-specified value:** 43

User-specified Lo value should be based on site-specific data and determined by waste type and composition.

NMOC Concentration (*ppmv as hexane*): CAA - 4,000

Methane Content (*% by volume*): User-specified; **User-specified value:** 60

3: SELECT GASES/POLLUTANTS

Default pollutant parameters are currently being used by model.

Gas / Pollutant #1: Total landfill gas

Gas / Pollutant #2: Methane

4: ENTER WASTE ACCEPTANCE RATES

Input Units: *Mg/year*

Year	Input Units (*Mg/year*)	Calculated Units (*short tons/year*)
2005	122228.645	134,452
2006	126139.9616	138,754
2007	130176.4404	143,194
2008	134342.0865	147,776
2009	138641.0333	152,505
2010	143077.5463	157,385
2011	147656.0278	162,422
2012	152381.0207	167,619
2013	157257.2134	172,983
2014	162289.4442	178,518
2015	167482.7064	184,231
2016	172842.153	190,126
2017	178373.1019	196,210
2018	184081.0412	202,489
2019	189971.6345	208,969
2020	196050.7268	215,656
2021	202,324	222,557
2022	208,799	229,679
2023	215,480	237,028

Figure 27: LandGEM input Data Interface

Table 17: Total LFGs Emission under BAU till 2021

Year	**Waste Accepted**	**Waste-In-Place**	**Total landfill gas**		**Methane**		**Carbon dioxide**		**NMOC**	
	(Mg/year)	**(Mg)**	**(Mg/year)**	**(m3/year)**	**(Mg/year)**	**(m3/year)**	**(Mg/year)**	**(m3/year)**	**(Mg/year)**	**(m3/year)**
2005	122,228.65	-	-	-	-	-	-	-	-	-
2006	126,139.96	122,228.65	482.44	366,724.28	146.80	220,034.57	268.515	146,689.711	5.258	1,466.897
2007	130,176.44	248,368.61	960.01	729,748.82	292.11	437,849.29	534.322	291,899.527	10.463	2,918.995
2008	134,342.09	378,545.05	1,433.42	1,089,604.86	436.16	653,762.92	797.808	435,841.944	15.623	4,358.419
2009	138,641.03	512,887.13	1,903.34	1,446,813.31	579.14	868,087.98	1,059.356	578,725.323	20.744	5,787.253
2010	143,077.55	651,528.17	2,370.45	1,801,885.54	721.28	1,081,131.32	1,319.340	720,754.215	25.835	7,207.542
2011	147,656.03	794,605.71	2,835.41	2,155,324.20	862.75	1,293,194.52	1,578.127	862,129.681	30.903	8,621.297
2012	152,381.02	942,261.74	3,298.88	2,507,624.00	1,003.77	1,504,574.40	1,836.081	1,003,049.602	35.954	10,030.496
2013	157,257.21	1,094,642.76	3,761.48	2,859,272.46	1,144.54	1,715,563.48	2,093.558	1,143,708.983	40.996	11,437.090
2014	162,289.44	1,251,899.98	4,223.87	3,210,750.63	1,285.23	1,926,450.38	2,350.910	1,284,300.250	46.035	12,843.003
2015	167,482.71	1,414,189.42	4,686.65	3,562,533.84	1,426.04	2,137,520.30	2,608.486	1,425,013.535	51.079	14,250.135
2016	172,842.15	1,581,672.13	5,150.45	3,915,092.40	1,567.17	2,349,055.44	2,866.629	1,566,036.959	56.134	15,660.370
2017	178,373.10	1,754,514.28	5,615.89	4,268,892.28	1,708.79	2,561,335.37	3,125.681	1,707,556.912	61.207	17,075.569
2018	184,081.04	1,932,887.38	6,083.57	4,624,395.80	1,851.09	2,774,637.48	3,385.980	1,849,758.319	66.304	18,497.583
2019	189,971.63	2,116,968.42	6,554.09	4,982,062.27	1,994.26	2,989,237.36	3,647.864	1,992,824.910	71.432	19,928.249
2020	196,050.73	2,306,940.06	7,028.07	5,342,348.70	2,138.48	3,205,409.22	3,911.665	2,136,939.478	76.598	21,369.395

2021	202,324.35	2,502,990.78	7,506.08	5,705,710.35	2,283.93	3,423,426.21	4,177.718	2,282,284.138	81.808	22,822.841

Table 18: Total LFGs Emission under BAU till 2030

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane		Carbon dioxide		NMOC	
	(Mg/year)	(Mg)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)
2005	122228.645	0	0	0	0	0	0	0	0	0
2006	126139.9616	122228.645	482.4399	366724.28	146.7957	220034.6	268.5153	146689.71	5.2580441	1466.89711
2007	130176.4404	248368.6066	960.0126	729748.82	292.1104	437849.3	534.3217	291899.53	10.463042	2918.99527
2008	134342.0865	378545.0471	1433.417	1089604.9	436.1569	653762.9	797.8082	435841.94	15.62261	4358.41944
2009	138641.0333	512887.1336	1903.339	1446813.3	579.1435	868088	1059.356	578725.32	20.744217	5787.25323
2010	143077.5463	651528.1668	2370.45	1801885.5	721.275	1081131	1319.34	720754.21	25.835196	7207.54215
2011	147656.0278	794605.7132	2835.412	2155324.2	862.7526	1293195	1578.127	862129.68	30.902753	8621.29681
2012	152381.0207	942261.741	3298.876	2507624	1003.774	1504574	1836.081	1003049.6	35.95398	10030.496
2013	157257.2134	1094642.762	3761.483	2859272.5	1144.535	1715563	2093.558	1143709	40.995869	11437.0898
2014	162289.4442	1251899.975	4223.866	3210750.6	1285.228	1926450	2350.91	1284300.3	46.035317	12843.0025
2015	167482.7064	1414189.419	4686.65	3562533.8	1426.043	2137520	2608.486	1425013.5	51.079138	14250.1353
2016	172842.153	1581672.126	5150.455	3915092.4	1567.169	2349055	2866.629	1566037	56.134076	15660.3696
2017	178373.1019	1754514.279	5615.892	4268892.3	1708.791	2561335	3125.681	1707556.9	61.206811	17075.5691
2018	184081.0412	1932887.381	6083.57	4624395.8	1851.095	2774637	3385.98	1849758.3	66.303974	18497.5832
2019	189971.6345	2116968.422	6554.094	4982062.3	1994.265	2989237	3647.864	1992824.9	71.432148	19928.2491
2020	196050.7268	2306940.056	7028.065	5342348.7	2138.484	3205409	3911.665	2136939.5	76.597887	21369.3948
2021	202324.3501	2502990.783	7506.081	5705710.3	2283.933	3423426	4177.718	2282284.1	81.807718	22822.8414
2022	208798.7293	2705315.133	7988.741	6072601.4	2430.796	3643561	4446.356	2429040.6	87.068154	24290.4058
2023	215480.2886	2914113.862	8476.64	6443475.8	2579.253	3866085	4717.91	2577390.3	92.385701	25773.9031
2024	222375.6578	3129594.151	8970.377	6818787.3	2729.486	4091272	4992.713	2727514.9	97.766868	27275.1492

2025	229491.6789	3351969.809	9470.549	7198990.8	2881.677	4319394	5271.098	2879596.3	103.21817	28795.963
2026	236835.4126	3581461.488	9977.757	7584542.3	3036.009	4550725	5553.398	3033816.9	108.74616	30338.1691
2027	244414.1458	3818296.9	10492.6	7975900	3192.665	4785540	5839.95	3190360	114.3574	31903.5998
2028	252235.3985	4062711.046	11015.69	8373524.5	3351.83	5024115	6131.091	3349409.8	120.05848	33494.0981
2029	260306.9312	4314946.445	11547.64	8777879.8	3513.689	5266728	6427.159	3511151.9	125.85608	35111.5193
2030	268636.753	4575253.376	12089.05	9189433.5	3678.429	5513660	6728.499	3675773.4	131.75688	36757.7341

Table 19: Total LFGs Emission under S1 till 2030

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane		Carbon dioxide		NMOC	
	(Mg/year)	(Mg)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)
2005	122228.645	0	0	0	0	0	0	0	0	0
2006	126139.9616	122228.645	482.4399	366724.3	146.7957	220034.6	268.5153	146689.7	5.258044	1466.897
2007	130176.4404	248368.6066	960.0126	729748.8	292.1104	437849.3	534.3217	291899.5	10.46304	2918.995
2008	134342.0865	378545.0471	1433.417	1089605	436.1569	653762.9	797.8082	435841.9	15.62261	4358.419
2009	138641.0333	512887.1336	1903.339	1446813	579.1435	868088	1059.356	578725.3	20.74422	5787.253
2010	143077.5463	651528.1668	2370.45	1801886	721.275	1081131	1319.34	720754.2	25.8352	7207.542
2011	147656.0278	794605.7132	2835.412	2155324	862.7526	1293195	1578.127	862129.7	30.90275	8621.297
2012	152381.0207	942261.741	3298.876	2507624	1003.774	1504574	1836.081	1003050	35.95398	10030.5
2013	157257.2134	1094642.762	3761.483	2859272	1144.535	1715563	2093.558	1143709	40.99587	11437.09
2014	162289.4442	1251899.975	4223.866	3210751	1285.228	1926450	2350.91	1284300	46.03532	12843
2015	167482.7064	1414189.419	4686.65	3562534	1426.043	2137520	2608.486	1425014	51.07914	14250.14
2016	172842.153	1581672.126	5150.455	3915092	1567.169	2349055	2866.629	1566037	56.13408	15660.37
2017	178373.1019	1754514.279	5615.892	4268892	1708.791	2561335	3125.681	1707557	61.20681	17075.57
2018	184081.0412	1932887.381	6083.57	4624396	1851.095	2774637	3385.98	1849758	66.30397	18497.58
2019	189971.6345	2116968.422	6554.094	4982062	1994.265	2989237	3647.864	1992825	71.43215	19928.25

2020	196050.7268	2306940.056	7028.065	5342349	2138.484	3205409	3911.665	2136939	76.59789	21369.39
2021	202324.3501	2502990.783	7506.081	5705710	2283.933	3423426	4177.718	2282284	81.80772	22822.84
2022	271167.1809	2705315.133	7988.741	6072601	2430.796	3643561	4446.356	2429041	87.06815	24290.41
2023	279844.5306	2976482.314	8722.81	6630601	2654.157	3978360	4854.923	2652240	95.06867	26522.4
2024	288799.5556	3256326.845	9460.233	7191149	2878.538	4314690	5265.356	2876460	103.1057	28764.6
2025	298041.1414	3545126.4	10201.97	7754973	3104.231	4652984	5678.188	3101989	111.1898	31019.89
2026	307578.4579	3843167.542	10948.96	8322794	3331.523	4993676	6093.946	3329118	119.3311	33291.18
2027	317420.9686	4150746	11702.15	8895331	3560.703	5337199	6513.157	3558132	127.5401	35581.32
2028	327578.4396	4468166.968	12462.49	9473301	3792.059	5683981	6936.347	3789321	135.8269	37893.21
2029	338060.9496	4795745.408	13230.92	10057421	4025.875	6034453	7364.039	4022969	144.202	40229.69
2030	348878.9	5133806.357	14008.39	10648407	4262.441	6389044	7796.759	4259363	152.6755	42593.63

Table 20: Total LFGs Emission under S2 till 2030

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane		Carbon dioxide		NMOC	
	(Mg/year)	(Mg)	(m3/year)	(Mg/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)
2005	122228.645	0	0	0	0	0	0	0	0	0
2006	126139.9616	122228.645	366724.3	146.7957	73.39785	220034.6	268.5153	146689.7	5.258044	1466.897
2007	130176.4404	248368.6066	729748.8	292.1104	146.0552	437849.3	534.3217	291899.5	10.46304	2918.995
2008	134342.0865	378545.0471	1089605	436.1569	218.0784	653762.9	797.8082	435841.9	15.62261	4358.419
2009	138641.0333	512887.1336	1446813	579.1435	289.5718	868088	1059.356	578725.3	20.74422	5787.253
2010	143077.5463	651528.1668	1801886	721.275	360.6375	1081131	1319.34	720754.2	25.8352	7207.542
2011	147656.0278	794605.7132	2155324	862.7526	431.3763	1293195	1578.127	862129.7	30.90275	8621.297
2012	152381.0207	942261.741	2507624	1003.774	501.8872	1504574	1836.081	1003050	35.95398	10030.5
2013	157257.2134	1094642.762	2859272	1144.535	572.2677	1715563	2093.558	1143709	40.99587	11437.09
2014	162289.4442	1251899.975	3210751	1285.228	642.6141	1926450	2350.91	1284300	46.03532	12843

2015	167482.7064	1414189.419	3562534	1426.043	713.0216	2137520	2608.486	1425014	51.07914	14250.14
2016	172842.153	1581672.126	3915092	1567.169	783.5843	2349055	2866.629	1566037	56.13408	15660.37
2017	178373.1019	1754514.279	4268892	1708.791	854.3954	2561335	3125.681	1707557	61.20681	17075.57
2018	184081.0412	1932887.381	4624396	1851.095	925.5475	2774637	3385.98	1849758	66.30397	18497.58
2019	189971.6345	2116968.422	4982062	1994.265	997.1324	2989237	3647.864	1992825	71.43215	19928.25
2020	196050.7268	2306940.056	5342349	2138.484	1069.242	3205409	3911.665	2136939	76.59789	21369.39
2021	202324.3501	2502990.783	5705710	2283.933	1141.967	3423426	4177.718	2282284	81.80772	22822.84
2022	208798.7293	2705315.133	6072601	2430.796	1215.398	3643561	4446.356	2429041	87.06815	24290.41
2023	215480.2886	2914113.862	6443476	2579.253	1289.626	3866085	4717.91	2577390	92.3857	25773.9
2024	222375.6578	3129594.151	6818787	2729.486	1364.743	4091272	4992.713	2727515	97.76687	27275.15
2025	229491.6789	3351969.809	7198991	2881.677	1440.839	4319394	5271.098	2879596	103.2182	28795.96
2026	236835.4126	3581461.488	7584542	3036.009	1518.005	4550725	5553.398	3033817	108.7462	30338.17
2027	244414.1458	3818296.9	7975900	3192.665	1596.333	4785540	5839.95	3190360	114.3574	31903.6
2028	252235.3985	4062711.046	8373525	3351.83	1675.915	5024115	6131.091	3349410	120.0585	33494.1
2029	260306.9312	4314946.445	8777880	3513.689	1756.845	5266728	6427.159	3511152	125.8561	35111.52
2030	268636.753	4575253.376	9189434	3678.429	1839.215	5513660	6728.499	3675773	131.7569	36757.73

Table 21: Total LFGs Emission under S3 till 2030

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane		Carbon dioxide		NMOC	
	(Mg/year)	(Mg)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)
2005	122228.645	0	0	0	0	0	0	0	0	0
2006	126139.9616	122228.645	241.37661	183481.2308	73.44552452	110088.74	134.3449	73392.49	2.63073	733.9249
2007	130176.4404	248368.6066	480.318066	365111.3909	146.1500858	219066.83	267.3344	146044.6	5.234919	1460.446

2008	134342.0865	378545.0471	717.174029	545156.2743	218.2200781	327093.76	399.1632	218062.5	7.816378	2180.625
2009	138641.0333	512887.1336	952.287354	723876.5001	289.7598246	434325.9	530.022	289550.6	10.37885	2895.506
2010	143077.5463	651528.1668	1185.99463	901527.9231	360.871741	540916.75	660.0983	360611.2	12.92599	3606.112
2011	147656.0278	794605.7132	1418.62669	1078362.033	431.6564958	647017.22	789.5762	431344.8	15.46141	4313.448
2012	152381.0207	942261.741	1650.50917	1254626.342	502.2131657	752775.81	918.6368	501850.5	17.98867	5018.505
2013	157257.2134	1094642.762	1881.96292	1430564.765	572.6393873	858338.86	1047.459	572225.9	20.51125	5722.259
2014	162289.4442	1251899.975	2113.3046	1606417.99	643.0315046	963850.79	1176.218	642567.2	23.03261	6425.672
2015	167482.7064	1414189.419	2344.84705	1782423.836	713.4847144	1069454.3	1305.09	712969.5	25.55616	7129.695
2016	172842.153	1581672.126	2576.89984	1958817.608	784.093207	1175290.6	1434.245	783527	28.08527	7835.27
2017	178373.1019	1754514.279	2809.76966	2135832.444	854.9503045	1281499.5	1563.855	854333	30.62328	8543.33
2018	184081.0412	1932887.381	3043.7608	2313699.651	926.148597	1388219.8	1694.09	925479.9	33.17352	9254.799
2019	189971.6345	2116968.422	3279.1756	2492649.04	997.7800751	1495589.4	1825.116	997059.6	35.73927	9970.596
2020	196050.7268	2306940.056	3516.31484	2672909.252	1069.936261	1603745.6	1957.103	1069164	38.32382	10691.64
2021	202324.3501	2502990.783	3755.47818	2854708.077	1142.708337	1712824.8	2090.216	1141883	40.93043	11418.83
2022	137086.8057	2705315.133	3996.96459	3038272.774	1216.187272	1822963.7	2224.622	1215309	43.56235	12153.09
2023	141473.5835	2842401.939	4099.45635	3116181.375	1247.373231	1869708.8	2281.666	1246473	44.6794	12464.73

2024	146000.7382	2983875.522	4206.29736	3197396.041	1279.882571	1918437.6	2341.132	1278958	45.84384	12789.58
2025	150672.7618	3129876.261	4317.58179	3281988.347	1313.743943	1969193	2403.07	1312795	47.05671	13127.95
2026	155494.2901	3280549.022	4433.40871	3370033.601	1348.987493	2022020.2	2467.537	1348013	48.31909	13480.13
2027	160470.1074	3436043.312	4553.88216	3461610.9	1385.644881	2076966.5	2534.59	1384644	49.63212	13846.44
2028	165605.1509	3596513.42	4679.11128	3556803.192	1423.749312	2134081.9	2604.29	1422721	50.99697	14227.21
2029	170904.5157	3762118.571	4809.21034	3655697.346	1463.335557	2193418.4	2676.7	1462279	52.4149	14622.79
2030	176373.4602	3933023.086	4944.29888	3758384.224	1504.439989	2255030.5	2751.887	1503354	53.88721	15033.54

Table 22: Total LFGs Emission under S4 till 2030

Year	**Waste Accepted**	**Waste-In-Place**	**Total landfill gas**		**Methane**		**Carbon dioxide**		**NMOC**	
	(Mg/year)	**(Mg)**	**(Mg/year)**	**(m3/year)**	**(Mg/year)**	**(m3/year)**	**(Mg/year)**	**(m3/year)**	**(Mg/year)**	**(m3/year)**
2005	122228.645	0	0	0	0	0	0	0	0	0
2006	126139.9616	122228.645	482.3006	366618.4	146.7533	219971.1	268.4378	146647.4	5.256526	1466.47367
2007	130176.4404	248368.6066	959.7355	729538.2	292.0261	437722.9	534.1675	291815.3	10.46002	2918.15266
2008	134342.0865	378545.0471	1433.003	1089290	436.031	653574.2	797.5779	435716.1	15.6181	4357.16133
2009	138641.0333	512887.1336	1902.789	1446396	578.9763	867837.4	1059.05	578558.3	20.73823	5785.58267
2010	143077.5463	651528.1668	2369.765	1801365	721.0668	1080819	1318.959	720546.2	25.82774	7205.4616
2011	147656.0278	794605.7132	2834.593	2154702	862.5036	1292821	1577.672	861880.8	30.89383	8618.80816
2012	152381.0207	942261.741	3297.923	2506900	1003.485	1504140	1835.551	1002760	35.9436	10027.6006
2013	157257.2134	1094642.762	3760.397	2858447	1144.205	1715068	2092.954	1143379	40.98404	11433.7884

2014	162289.4442	1251899.975	4222.647	3209824	1284.857	1925894	2350.231	1283930	46.02203	12839.2952
2015	167482.7064	1414189.419	4685.297	3561505	1425.632	2136903	2607.733	1424602	51.06439	14246.0219
2016	172842.153	1581672.126	5148.968	3913962	1566.716	2348377	2865.801	1565585	56.11787	15655.849
2017	178373.1019	1754514.279	5614.271	4267660	1708.298	2560596	3124.779	1707064	61.18914	17070.64
2018	184081.0412	1932887.381	6081.814	4623061	1850.561	2773837	3385.003	1849224	66.28483	18492.2436
2019	189971.6345	2116968.422	6552.202	4980624	1993.689	2988374	3646.811	1992250	71.41153	19922.4966
2020	196050.7268	2306940.056	7026.036	5340807	2137.866	3204484	3910.536	2136323	76.57578	21363.2262
2021	202324.3501	2502990.783	7503.914	5704063	2283.274	3422438	4176.512	2281625	81.7841	22816.2533
2022	185674.27	2705315.133	7986.435	6070849	2430.094	3642509	4445.072	2428339	87.04302	24283.394
2023	191615.8466	2890989.403	8382.947	6372255	2550.744	3823353	4665.762	2548902	91.36455	25489.0207
2024	197747.5537	3082605.25	8786.215	6678798	2673.449	4007279	4890.212	2671519	95.75971	26715.1901
2025	204075.4754	3280352.804	9196.705	6990830	2798.352	4194498	5118.682	2796332	100.2336	27963.3186
2026	210605.8907	3484428.279	9614.888	7308709	2925.596	4385225	5351.433	2923484	104.7913	29234.8361
2027	217345.2792	3695034.17	10041.24	7632797	3055.325	4579678	5588.73	3053119	109.438	30531.1879
2028	224300.3281	3912379.449	10476.24	7963459	3187.685	4778075	5830.841	3185384	114.179	31853.8357
2029	231477.9386	4136679.777	10920.37	8301065	3322.825	4980639	6078.036	3320426	119.0196	33204.2604
2030	238885.2326	4368157.716	11374.13	8645991	3460.895	5187594	6330.59	3458396	123.9651	34583.963

Table 23: Total LFGs Emission under S5 till 2030

Year	Waste Accepted	Waste-In-Place	Total landfill gas		Methane		Carbon dioxide		NMOC	
	(Mg/year)	(Mg)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)	(Mg/year)	(m3/year)
2005	122228.645	0	0	0	0	0	0	0	0	0
2006	126139.9616	122228.645	241.10939	183278.1	36.68210755	54983.4312	134.19614	73311.242	2.6278171	733.11242
2007	130176.4404	248368.6066	479.78632	364707.19	72.99414362	109412.156	267.03843	145882.87	5.2291233	1458.8287
2008	134342.0865	378545.0471	716.38007	544552.75	108.9892465	163365.824	398.72126	217821.1	7.8077251	2178.211
2009	138641.0333	512887.1336	951.2331	723075.12	144.7195199	216922.535	529.43525	289230.05	10.367355	2892.3005

2010	143077.5463	651528.1668	1184.6816	900529.87	180.2361151	270158.96	659.36753	360211.95	12.911678	3602.1195
2011	147656.0278	794605.7132	1417.0562	1077168.2	215.5893107	323150.463	788.70204	430867.28	15.444295	4308.6728
2012	152381.0207	942261.741	1648.6819	1253237.4	250.82859	375971.214	917.6198	501294.95	17.968751	5012.9495
2013	157257.2134	1094642.762	1879.8795	1428981	286.0027173	428694.308	1046.2992	571592.41	20.48854	5715.9241
2014	162289.4442	1251899.975	2110.965	1604639.6	321.1598115	481391.871	1174.9163	641855.83	23.007109	6418.5583
2015	167482.7064	1414189.419	2342.2511	1780450.6	356.347418	534135.17	1303.645	712180.23	25.527864	7121.8023
2016	172842.153	1581672.126	2574.047	1956649.1	391.61258	586994.717	1432.6575	782659.62	28.054175	7826.5962
2017	178373.1019	1754514.279	2806.659	2133467.9	427.0019068	640040.377	1562.1242	853387.17	30.58938	8533.8717
2018	184081.0412	1932887.381	3040.3911	2311138.2	462.5616423	693341.466	1692.2143	924455.29	33.136793	9244.5529
2019	189971.6345	2116968.422	3275.5453	2489889.5	498.3377308	746966.85	1823.0959	995955.8	35.699705	9959.558
2020	196050.7268	2306940.056	3512.422	2669950.2	534.3758827	800985.045	1954.9362	1067980.1	38.281391	10679.801
2021	202324.3501	2502990.783	3751.3206	2851547.7	570.7216388	855464.314	2087.9019	1140619.1	40.885113	11406.191
2022	185674.27	2705315.133	3992.5397	3034909.2	607.4204331	910472.757	2222.159	1213963.7	43.514125	12139.637
2023	191615.8466	2890989.403	4190.7621	3185587	637.5777612	955676.086	2332.4852	1274234.8	45.674523	12742.348
2024	197747.5537	3082605.25	4392.3619	3338832.1	668.2489393	1001649.63	2444.6913	1335532.8	47.871732	13355.328
2025	204075.4754	3280352.804	4597.5722	3494821.7	699.4694001	1048446.51	2558.9068	1397928.7	50.10829	13979.287
2026	210605.8907	3484428.279	4806.628	3653734.4	731.2749114	1096120.33	2675.2626	1461493.8	52.38676	14614.938
2027	217345.2792	3695034.17	5019.7669	3815750.9	763.7016194	1144725.27	2793.891	1526300.4	54.70973	15263.004
2028	224300.3281	3912379.449	5237.2293	3981053.8	796.7860941	1194316.15	2914.9257	1592421.5	57.079822	15924.215
2029	231477.9386	4136679.777	5459.2586	4149828.3	830.5653729	1244948.48	3038.5022	1659931.3	59.499687	16599.313
2030	238885.2326	4368157.716	5686.1015	4322261.8	865.0770055	1296678.55	3164.758	1728904.7	61.972017	17289.047

Table 24: Comparison of waste in place under different scenarios till 2030

year	Waste in Place (Mg)					
	S0	**S1**	**S2**	**S3**	**S4**	**S5**
2005	-	-	-	-	-	-
2006	122,228.65	122,228.65	122,228.65	122,228.65	122,228.65	122,228.65
2007	248,368.61	248,368.61	248,368.61	248,368.61	248,368.61	248,368.61
2008	378,545.05	378,545.05	378,545.05	378,545.05	378,545.05	378,545.05
2009	512,887.13	512,887.13	512,887.13	512,887.13	512,887.13	512,887.13
2010	651,528.17	651,528.17	651,528.17	651,528.17	651,528.17	651,528.17
2011	794,605.71	794,605.71	794,605.71	794,605.71	794,605.71	794,605.71
2012	942,261.74	942,261.74	942,261.74	942,261.74	942,261.74	942,261.74
2013	1,094,642.76	1,094,642.76	1,094,642.76	1,094,642.76	1,094,642.76	1,094,642.76
2014	1,251,899.98	1,251,899.98	1,251,899.98	1,251,899.98	1,251,899.98	1,251,899.98
2015	1,414,189.42	1,414,189.42	1,414,189.42	1,414,189.42	1,414,189.42	1,414,189.42
2016	1,581,672.13	1,581,672.13	1,581,672.13	1,581,672.13	1,581,672.13	1,581,672.13
2017	1,754,514.28	1,754,514.28	1,754,514.28	1,754,514.28	1,754,514.28	1,754,514.28
2018	1,932,887.38	1,932,887.38	1,932,887.38	1,932,887.38	1,932,887.38	1,932,887.38
2019	2,116,968.42	2,116,968.42	2,116,968.42	2,116,968.42	2,116,968.42	2,116,968.42
2020	2,306,940.06	2,306,940.06	2,306,940.06	2,306,940.06	2,306,940.06	2,306,940.06
2021	2,502,990.78	2,502,990.78	2,502,990.78	2,502,990.78	2,502,990.78	2,502,990.78
2022	2,705,315.13	2,705,315.13	2,705,315.13	2,705,315.13	2,705,315.13	2,705,315.13
2023	2,914,113.86	2,976,482.31	2,914,113.86	2,842,401.94	2,890,989.40	2,890,989.40
2024						

	3,129,594.15	3,256,326.84	3,129,594.15	2,983,875.52	3,082,605.25	3,082,605.25
2025	3,351,969.81	3,545,126.40	3,351,969.81	3,129,876.26	3,280,352.80	3,280,352.80
2026	3,581,461.49	3,843,167.54	3,581,461.49	3,280,549.02	3,484,428.28	3,484,428.28
2027	3,818,296.90	4,150,746.00	3,818,296.90	3,436,043.31	3,695,034.17	3,695,034.17
2028	4,062,711.05	4,468,166.97	4,062,711.05	3,596,513.42	3,912,379.45	3,912,379.45
2029	4,314,946.44	4,795,745.41	4,314,946.44	3,762,118.57	4,136,679.78	4,136,679.78
2030	4,575,253.38	5,133,806.36	4,575,253.38	3,933,023.09	4,368,157.72	4,368,157.72

Annex II: Photographs

Figure 28: Household waste thrown in the streets of Jorpati, Kathmandu

Figure 30: Trucks ready for dispatching waste to Sisdol landfill

Figure 29: Plastic waste segregated for recycling at the collection site

Figure 31: Workers collecting waste thrown in streets without segregation

Figure 32: Vegetable (organic) waste from vegetable market of Jorpati

Figure 35: Waste dumped at Sisdol Landfill

Figure 33: Solid waste collected from the bank of Bagmati near Bijulibazar

Figure 36: Leachate flow from the landfill to the river

Figure 34: Segregation of collected waste

Figure 37: piled up waste at sisdol landfill