Quantification of greenhouse gas emissions under different solid waste management scenarios: A case study of Kathmandu Metropolitan City, Nepal

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Abstract of a thesis submitted in partial fulfilment of the requirements for the
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Abstract

Quantification of greenhouse gas emissions under different solid waste management scenarios: A case study of Kathmandu Metropolitan City, Nepal

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Raju Khadka

Urbanization is expanding at a disturbing rate in Nepal which is squeezing municipal services, especially those dealing with the always expanding amounts of municipal solid waste (MSW). Currently, the greater part of the wastes produced in the city are not being sufficiently administered thereby threatening human wellbeing and the environment. It is an issue with financial, environmental, and social ramifications, making it both significant and complex. Notwithstanding metropolitan environmental contamination, the wrong disposal causes the production of greenhouse gases like methane, leachates from landfill sites and energy consumption.

The assessment of MSW production and greenhouse gas (GHG) emissions is important to reduce global warming. To address the issue, this study aimed to: (1) determine the MSW generation and composition in Kathmandu Metropolitan City (KMC); (2) compare different solid waste management (SWM) scenarios in terms of GHG emission in KMC; and (3) determine the feasibility of reducing methane emissions from SWM in the Sisdole landfill site, Kathmandu.

KMC was used as a model case study. A survey of 288 households in 32 wards of KMC was conducted to determine the MSW generation and its composition. Five different MSW management scenarios were developed, and greenhouse gas emissions were estimated for each scenario using the Intergovernmental Panel on Climate Change (IPCC) model and the Life Cycle Assessment (LCA) tool. The LandGEM model was used to estimate total landfill gas emission in the Sisdole landfill site.

The outcome is that per capita MSW generation in Kathmandu is 0.3 kg per day. It is estimated that households create around 76,879 tonnes of organic waste each year, most of which is uncollected: the rest is disposed of in an open dumpsite. Investigation showed that organic waste is 51% of the MSW; 49% is recyclable waste comprising 19% plastic, 13% textiles, 5% paper and paper items, 4% rubber and leather, 3% glass, 1% metal, and 4% ‘other waste.

Five MSW management scenarios were tested: S0, S1, S2, S3 and S4; where: S0 is ‘business as usual’; S1 is upgraded to landfill gas capture; S2 is composting; S3 is recycling; and S4 is the integration of gas capture, recycling, and composting. The CH$_4$ outflow is high at 15,136 m3 for scenario S0. The greatest decrease, 73%, in CH$_4$ discharges happened with the integrated gas capture, composting and recycling (S4) system. Composting S2 is the best of the other three scenarios because of the high volume of organic waste.

The quantity of CH$_4$ generation from solid waste in the Sisdole landfill site was calculated as 1.050E+06 (Mg/year) in 2006. The maximum methane generation rate occurred during 2015-2035 with the peak generation being approximately 1.100E+07 (Mg/year). Based on these volumes, it is now necessary to consider installing methane capturing facilities.

The proposed S4 solid waste management technique will make an important contribution towards improving the SWM system in Kathmandu Metropolitan City (KMC) and elsewhere. Landfill discharge results can be used to calculate power generation planning from the MSW and to establish a gas capture system at the Sisdole landfill site, eventually supporting Nepal’s contribution to global greenhouse gas emission reduction. It would also reduce environmental contamination by decreasing greenhouse gases from waste generation.

Keywords: Methane (CH$_4$) emissions, Greenhouse gas (GHG), Kathmandu Metropolitan City (KMC), Municipal Solid Waste (MSW), Landfill.

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Abbreviations and Symbols

ADB	Asian Development Bank
BSP	Biogas Support Programme
CBS	Central Bureau of Statistics
CDM	Clean Development Management
CO_2	Carbon Dioxide
CH_4	Methane
CKV	Clean Kathmandu Valley
CO_{2-} e	Carbon Dioxide Equivalent
CT	Collection Transport
DM	Default Methodology
DOC	Degradable Organic Carbon
DRMP	Dhading Resources Management Project
ENPHO	Environment and Public Health Organization
EPA	Environmental Protection Agency
EU	European Union
FOD	First Order Decay
GDP	Gross Domestic Product
GHG	Green House Gas
GTZ	German Technical Cooperation
GWP	Global Warming Potential
GIS	Geograpic information system
GPS	Global Positioning System
HHS	Households
IPCC	Intergovernmental Panel on Climate Change

IRC	International Resources Centre
JICA	Japan International Coopertaion Agency
KMC	Kathmandu Metropolitant City
LCA	Life cycle Assessment
LCI	Life Cycle Inventory
LFG	Landfill Gas
LSMC	Lalitpur Sub Metropolitan City
MCF	Methane Correction Factor (MCF)
MRF	Material Recycling Facilities
MSW	Municipal Solid Waste
MSWGR	Municipal Solid Waste Generation Rate
MSWM	Municipal Solid Waste Management
N_2O	Nitrous Oxide
NGO	Non-Governmental Organization
OECT	Organisation for Economic Cooperation and
PE	Polyethylene
PVC	Polyvinyl Chloride
SPSS	Statistical Package for the Social Science
SWM	Solid Waste Management
SWMRMC	Solid Waste Management Resources Mobilization Centre
SWMTSC	Solid Waste Management Technical Support Centre
UDLE	Urban Development Through Local Effort
UDM	Urban Development Ministry
UNDP	United Nations Development Programme
UNEP	UN Environmental Programme

WHO	World Health Organisation
WtE	Waste-to-Energy

SYMBOLS

n	Sample size
P	Probability
Z	Standrad
D^2	Maximum allowable Devitaion
R^2	Regression coefficent
ECH_4	Emitted methane (Gg/Year)
MSW_F	Fraction of urban waste landfilled
MSW_T	Total MSW generated (Gg/year)
MCF	Methane correction factor (fraction)
DOC	Degradable organic carbon (fraction) (kg C/ kg MSW)
DOC_F	Fraction DOC dissimilated
F	Fraction of CH_4 in landfill gas (IPCC default is 0.5)
16/12	Conversion of C to CH_4
R	Recovered CH_4 (Gg/year)
x	Average annual precipitation (mm)
OX	Oxidation factor
W	Waste disposed of (Tonnes)
T	Time after waste placement (year)
T1	Time between placement and start of gas generation
K(f)	First-order decay rate constant for rapidly
K(S)	First-order decay rate constant for slowly
F(f)	Fraction of rapidly decomposing waste

(S)	Fraction of slowly decomposing waste
QCH_4	Methane generation per year (mCH_4 /year)
(k)	The rate of waste decay and CH_4 production
L_0	CH_4 generation potential (m^3 CH_4/Mg waste)
CAA	Clean Air Act
TJ	Terajoule
MW	Mega watt
Tg	Teragrams
CT	Collection and Treatment
Mg	Megagram
KG	Kilograms
KM	Kilometres
CAA	Clean air Act
NMOC	Non-methane organic compounds

Chapter 1

Introduction

1.1 Population development and waste generation

Population growth coupled with rapid urbanization are significant issues around the world, leading to the expanded generation of solid waste per unit (Thenabadu et al., 2014). Urbanization and fast financial development of urban communities improves the socioeconomic status of a population leading to more food use thus more waste generation (Sankoh et al., 2012). World Bank (2012) data highlighted that the quantity of municipal solid wastes (MSW) of urban areas around the planet may reach 2.2 billion tonnes per year by 2025 and waste producing rates may double through the following 20 years in non-industrial nations (Hoornweg & Bhada-Tata, 2012a). Taking population increase into account, total solid waste generation will increase from 1.3 to 2.2 billion tonnes each year over this period (Krausz et al., 2013). This is equal to a worldwide yield of 40 tonnes each second in 2010, which is required to develop to 70 tonnes each second by 2025.

Trang et al. (2017) identified a correlation between socio-economic factors and resident waste generation. It showed that income has a huge negative impact, though family size was positively identified with the waste producing of households. Bandara et al. (2007) indicated that socio-economic components, e.g., age, income and education level, contributed to increased household waste generation. Sankoh et al. (2012) and Ogwueleka (2013) found that income expansion could alter the eating patterns of families, causing a different composition and quantity of family waste. Increased family size and improved dietary patterns have positive relationships with waste generation (Yusof et al., 2002). For example, in Dehradun, India, the composition and amount of generated waste varied among various economic and income groups. In addition, there was a huge, positive relationship between household size and waste per capita (Suthar & Singh, 2015).

Metropolitan and rural areas of emerging and least developed nations are particularly tackling huge questions in the management of solid waste (Hwa, 2007; Thenabadu et al., 2014). Emerging and least developed groups of countries are identified on three criteria: i) income; ii) access to human resources; and iii) economic vulnerability (Af, 2015). About 60% of the total population lives in Asia where the amount of waste generated has increased although the rates of waste generation are the least. The rates of waste generation in the least developed countries are lower than those of developed countries (Glawe et al., 2005; Shekdar, 2009) that directly refleted to waste generation. Visvanathan et al. (2004) stated that urban population increase, hapzard urban development, increased financial activity and increased resource use are the main causes of increasing MSW production in Asian countries. However, prevailing solid waste management (SWM) systems are not satisfactory.

Every living creature in the world during its life is involved in continuous discarding of waste in the form of solid, liquid or gas. Despite this, traders of unpacking merchandise, the remains of the kitchen stuff or undesirable materials disposed of by a maker, has a typical waste component. Whatever you call it, the produced matter is waste, refuse, rubbish or garbage (O'Brien, 2008).

Population growth, use of modern household appliances and the use of less biodegradable items and the changing lifestyle of people are some obvious reasons for the increase in the solid waste production rate in different cities of the world (Asase et al., 2009). MSW production is assessed to have been 1.2 kg/individual/day worldwide in 2010 and has been anticipated to rise to 1.4 kg/individual/day by 2025 (Krausz et al., 2013). For example, when a food thing turns out to be scant, individuals discard a greater amount of it. Frenzy buying drives people to amass an overabundance and, over the long haul, the abundance winds up in a landfill. Analysts also found that over 33% of family waste discarded in garbage containers is from fresh fruit and vegetables (Council, 2009).

In the South Asia region, around 426 million people live in urban areas and produce roughly 70 million tonnes of waste every year, with per capita quantities ranging from 0.12 to 5.1 kg each day, but more typically at 0.45 kg day per day (Hoornweg & Bhada-Tata, 2012b). The increased amount of waste asscoiated with the standard of living results from a higher consumption of products and, potentially, greater waste generation (Pariatamby & Fauziah, 2014). Figure 1-1 illustrates the population and waste generation rates of some Asian countries. As can be seen, Asian emerging countries will significantly increase waste generation rates by 2025.

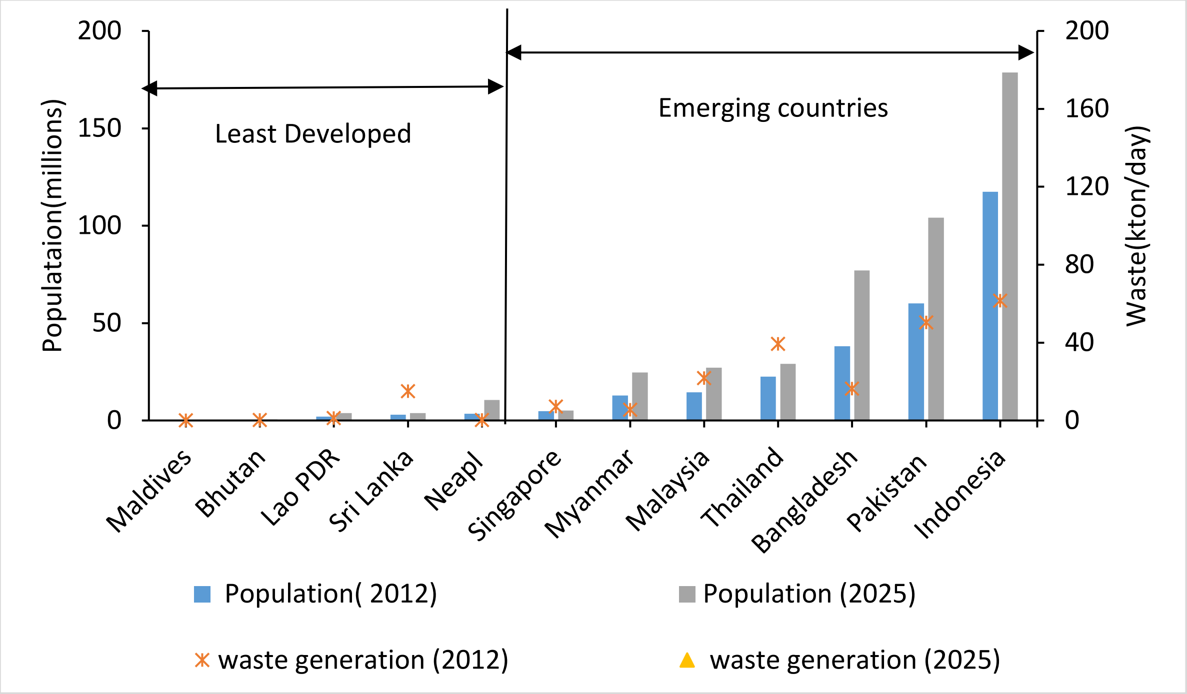

Figure 1-1. Absolute population & waste production in the chose Asian nations 2012–2025 (Hoornweg & Bhada-Tata, 2012a)

Waste generation is a demonstrated pattern of making waste by human actions that are straightforwardly identified with the people's creation and use by their financial attributes (Kneafsey et al., 2013). Waste production is adapted to a significant level by an individual's mentality towards waste, their material uses and their enthusiasm for waste reduction and minimization, including the amount they separate waste, and how much they maintain a strategic distance from capricious throwing and scattering (Schübeler et al., 1996).

The total waste created in a city and its qualities (arrangement) are huge factors in organizing a strong waste management (SWM) system. The waste producing rate and its characteristics fluctuate with population development, lifestyle, economic activity, and occasional events (Udm, 2015).

1.2 Waste composition

MSW MSW consists, to a large extent, of organic and other recyclable matter; the non-recyclable matter is dirt, ash and other household rubbish (Nabegu, 2010). Figure 1-2 compares the waste composition and per capita waste production in Asian nations (Hoornweg & Bhada-Tata, 2012a). It is stated that the MSW in most Asian nations largely comprises organic waste with an average of about 56%, followed by paper (12%),other (10%), plastic (5%), and glass and metal (1%).

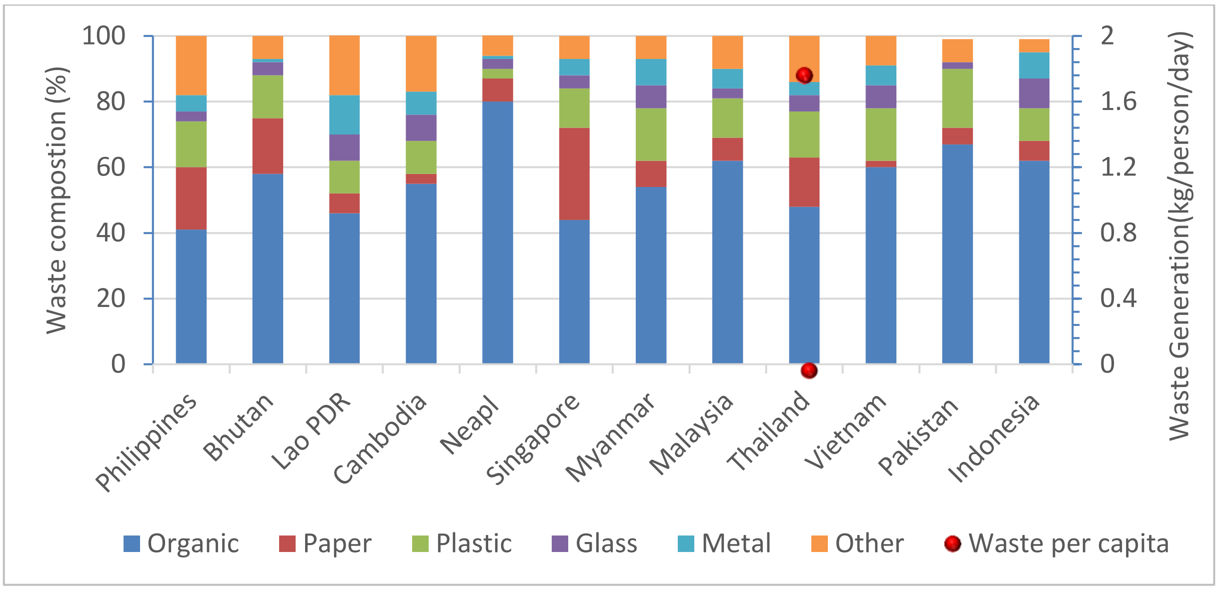

Figure 1-2. Assessment of waste composition and waste production(kg/person/day) in selected Asian nations (Hoornweg & Bhada-Tata, 2012a)

The rate of MSW generation is directly proportional to GDP. Figure 1-3 shows that Singapore, with the most notable income level (54,716 GDP per capita in 2012), has the highest rate of waste production per capita (1.49 kg/capita/day) whereas Nepal with the least income (682 GDP per capita in 2012), has the least rate of waste production per capita (0.12 kg/capita/day). Though the GDP of Singapore is many times higher than Nepal, the per capita waste waste created is multiple times higher. This might be clarified by a more grounded public economy in Singapore that offers adequate economic and expert help for enhancement in solid waste administration and innovation (Zhang, 2012).

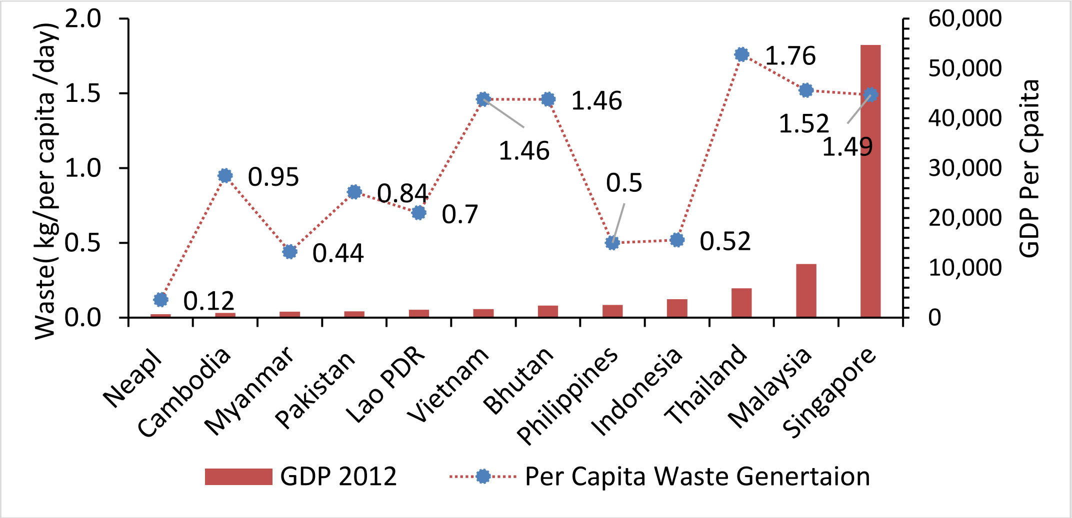

Figure 1-3: Assessment of waste generation rate and GDP per capita in selected Asia region countries(Hoornweg & Bhada-Tata, 2012b)

Organic matter by and large is 50 to 80% of MSW in Asian nations (Table 1-1). The level of organic waste in MSW in Nepal is practically identical with adjoining nations and nations of comparable financial status; it contains a higher extent of plastics. Nepal's waste composition at 80% organic is higher than upper-middle-income nations (Hoornweg & Bhada-Tata, 2012a).

Table 1-1: A comparison of waste composition(%) and GDP per capita of seclected Asian nations

Country	[1] GDP Per Capita	Organic (%)	Paper (%)	Plastic (%)	Glass (%)	Metal (%)	Other (%)
Nepal	730	80.0	7.0	2.5	3.0	0.5	7.0
Bangladesh	1,190	70.0	4.0	5.0	1.0	2.0	18.0
India	1,590	42.0	6.0	4.0	2.0	3.0	43.0
Vietnam	1,980	58.0	4.0	4.0	1.6	1.5	30.9
Indonesia	3,440	74.0	10.0	8.0	2.0	2.0	4.0
Philippines	3,540	41.6	19.5	13.8	2.5	4.8	17.8
Sri-Lanka	3,800	76.4	10.6	5.7	1.3	1.3	4.7
Thailand	5,620	48.0	15.0	14.0	5.0	4.0	14.0
China	7,820	35.8	3.7	3.8	2.0	0.3	54.4
Malaysia	10,570	40.0	15.0	15.0	4.0	3.0	23.0
Singapore	52,600	44.0	28.0	12.0	4.0	5.0	7.0

Source : (Yadav & Samadder, 2018).

1.3 Solid Waste Management (SWM)

By the continuous rise in urban populations and changes in consumption patterns, SWM[2] has become a matter of expanding worldwide concern. Developing countries are facing problems of wellbeing and environmental ramifications related to SWM with increasing pressure. SWM drivers in industrialised nations are general wellbeing, climate, asset shortage, environmental change and public mindfulness and support whereas in non-industrial nations they are urbanization, imbalances and financial development; social and financial angles; strategy, administration and institutional issues; and worldwide impacts (Marshall & Farahbakhsh, 2013) .

Ever increasing amounts of solid waste induced by growing development activities have put immense pressure on the need to take necessary steps for sustainable SWM (Asase et al., 2009; Wilson, 2007). Maintaining environmental quality via environmental friendly management of solid waste has become necessary not only for the present but also to meet future sustainability goals.

Decision makers have to consider whether the current waste management system they operate is a practical strategy to arrive at the objective of feasible waste mangement or if there are other better combinations using alternative processes for help at lower cost (Rogge & De Jaeger, 2012). Thus, it is

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[1] GDP- Gross domestic product (Gross national income per capita 2015).
Source: World Bank 2016

[2] Solid Waste: Waste material from human and animal activities and material considered as futile or undesirable.
Solid-Waste Management: The actions related to the control of waste production, storage, collection, transfer and transport, processing, and disposal of solid waste in a proper manner.

important for decision makers to recognise the different types of waste treatment technologies and their climate effect to choose a suitable innovation for economical, enviromentally friendly waste management (Allesch & Brunner, 2014). Though SWM has become a critical concern for regions and all countries, the situation with SWM is not completely perceived because of the absence of SWM baseline information, which is important for powerful planning (ADB, 2013). Therefore, where possible, it is important to compare different options, including technologies, to guide decision making. There is a number of different system analysis tools to analyze different technologies and their socio-economic and environmental performance (Zaman, 2009).

A SWM should consider the ecological, financial and social angles. It should have less impact on the environment, should be affordable and acceptable to society (Morrissey & Browne, 2004).

1.4 Waste and greenhouse gas (GHG) emissions

A further issue associated with MSW is greenhouse gas (GHG) emissions (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)) that contribute almost 5% of total human-based GHG emissions (Hoornweg & Bhada-Tata, 2012a). Increased emission of GHGs during the most recent years has prompted environmental changes around the world, causing genuine enviromental and financial risks. Unusual climate events that happen routinely today are only one sign of the inbalances in common frameworks because of an Earth-wide temperature boost (Schubert, 2014).

As per the World Bank (Hoornweg & Bhada-Tata, 2012b) “about 1.3 billion tonnes of MSW is generated annually by urban settlers globally”; this MSW is assessed as contributing 20 to 40 million tons of CH_4. This is around 5-20% of worldwide anthropogenic CH_4 and is equivalent to around 1-4% of the total anthropogenic GHG (Jensen, 2000). Carbon credits are the tradable commodity equivalent to one ton of carbon dioxide reduced or sunk from the atmosphere. There are six GHGs; if any of these gases is decreased/ sunk from the environment, carbon credits can be procured. The gases are carbon dioxide, methane, nitrous oxide, perfluoro carbons, hydro fluoro-carbon and sulfur hexafluoride. A worldwide settlement like the Clean Development Mechanism (CDM) under the Kyoto Protocol alongside Verified Carbon Standard (VCS) gives a strong stage to create GHG outflow decrease projects that will procure carbon credits (Newell et al., 2013).

With an Earth-wide temperature boost becoming a significant ecological issue, numerous examinations have studied GHG emission from waste mangement action (Kennedy et al., 2009). It is estimated that the post-consumer waste sector contributes 3 to 4% to the total global anthropogenic GHG emissions; for 2004–2005 this contribution amounted to 49 x 109 tonnes carbon dioxide equivalents (CO_2-e) per year (Bogner et al., 2008). Though this contribution is viewed as generally small, carbon decrease openings for the subject are not completely investigated (Friedrich & Trois, 2013). A progression of activities was exceptionally fruitful and showed that enormous decreases in outflows are conceivable. For instance, the commitment by the European city waste area diminished from 69 x 106 tonnes CO_2-e in 1990 to 32 x 106 tonnes CO_2-e in 2007; further decreases are anticipated (Friedrich & Trois, 2011).

Source reduction, landfilling, composting and combustion are four management and treatment choices used to manage waste. The quantity of discharges from waste relies on how waste is handled. For instance, when waste is landfilled, the organic material in the waste disintegrates and creates gas. Landfills have turned into a significant supporter of anthropogenic environmental change, representing roughly 5% of overall global GHG outflows (Stocker et al., 2013). Methane produced in a landfill is the biggest wellspring of GHGs, representing 1–2% of total GHG discharges (Bogner et al., 2011). The second-biggest sources are methane and nitrous oxide emanations created in leachate treatment (Bogner et al., 2007). A few investigations on GHG outflows from landfills have tried to use CH_4 and diminish other GHGs produced from landfills. Even though obstructions exist, a couple of accomplishments have been made with improved inventive advances and gear (Geng et al., 2017).

Methane (CH_4) comprises around half of landfill gases, the rest being carbon dioxide mixed in with little amounts of different gases. In the event that these gases are not gathered, they may escape to the air adding to unnatural weather changes. Relief/decrease alternatives are accessible to catch and use methane for energy production (Heyer et al., 2005). As per the U.S. Ecological Protection Agency (EPA), methane (CH_4) is the second most common GHG transmitted in the United States from human actions (Ken Costello, 2015). Some of the waste segment in the EPA's Inventory of US GHG Emissions is presented in Table 1-2. This gives some information about landfilling and composting and how the information has not fluctuated much in the previous decade, or in 4-5-year intervals of time (Deesing, 2016).

Distinctive GHG give more warmth holding capacity to the air. Methane can hold 25 times more warmth than carbon dioxide. Additionally, nitrous oxide is around 300 times worse than carbon dioxide (RRS, 2017) Methane is created because of anaerobic deterioration that happens in a landfill.

Table1-2:Composting versus landfill - methane emissions from MSW from EPA’s inventory

SOURCE	YEAR 2005 (MMT CO_2 Eq.)	YEAR 2010 MMT CO_2 Eq.)	YEAR 2014 MMT CO_2 Eq.)
Landfills	187.3	176.3	181.8
Composting	1.9	1.8	2.1

Source : (Deesing, 2016)

A compost heap disintegrates vigorously with oxygen, delivering basically carbon dioxide. This depends on the type and proportion of material in the compost (i.e., food, green waste, yard waste) and how frequently the heap is turned or uses another technique for oxygen presentation. If oxygen is not circling then you have a similar climate to a landfill and methane can start being created (Yazdani et al., 2012). RRS (2017) estimates that 60%-90% of the methane produced from landfills can be captured depending upon the framework and its viability. However, given that methane is a 25 times bigger problem than carbon dioxide, there is a need to gather about 95% of the landfill gas to just recover the initial investment, as demonstrated in the Global Warming Potential (GWP) in Table 1-3.

Table 1-3: Global warming potential from (IPCC, 2007)

Global Warming Potential (GWP)		GWP for 20-YEARS	GWP for 100-YEARS	GWP for 500-YEARs
Carbon dioxide	CO_2	1	1	1
Methane	CH_4	72	25	7.6
Nitrous Oxide	N_20	289	289	153

1.5 Research Aim and Objectives

Very few studies have determined solid waste generation and its compostion in a little developed country like Nepal. In addition, a comprehensive study that assess the impact of different solid waste management scenarios on GHGs emission is lacking. Further, there are limited studies focused on reducing methane emission from landfills. Therefore, the goal of this study was to verify the contribution that different waste management options make in reducing GHG emissions compared with traditional landfills. In doing so, this study analyzes the effect of different SWM scenarios on greenhouse gas (GHG) emissions taking Kathmandu Metropolitan City (KMC), Nepal, as a case study.

To accomplish this goal, the study had the following objectives:

1. To determine the municipal household solid waste generation and its composition in Kathmandu Metropolitan City.
2. To determine the the contribution of current solid waste management scenarios on methane emissions in Kathmandu Metropolitan City.
3. To determine the contribution of proposed solid waste management scenarios on methane emissions in Kathmandu Metropolitan City.
4. To determine the feasibility of reducing methane emissions from solid waste in Sisdole Landfill site.

1.6 Thesis Structure

The thesis is presented as six chapters beginning with this Introduction. Chapter 1 also includes the research objectives and chapter overview. The other five chapters are as follows.

Chapter 2 contains the literature review that provides more background relevant to the study. It covers SWM worldwide and regionally. The chapter also identifies the main characteristics of the SWM sector, highlights the necessity to enhance waste management systems and discusses possible GHG emissions from waste management.

Chapter 3 explains the study procedures used to implement this study. This chapter clarifies the investigation study area and approaches accepted for information collection and analysis. The chapter also outlines the Life Cycle Analysis (LCA) used as the primary strategy to evaluate environmental effects of discharges. Under the LCA theoretical premise, this chapter presents the waste mangement scenario improvements, and quantification of the Sisdole Landfill outflow with a landfill gas overview, selection of the model and model input parameters for the specific study area.

Chapter 4 delivers an explanation of the study result found in completing this study. This section explains the results for household waste generation and compostion. In addition, it presents the contribution of current and proposed solid waste management options to methane emissions. This also presents a quantification of CH_4 emission and energy estimation rate for Sisdole Landfill Site, Kathmandu Metropoltant City (KMC), Nepal.

Chapter 5 , the discussion chapter, reflects on the results with reference to previous literature and the contributions made.

Chapter 6, the concluding chapter, revisits the research objectives and presents the conculsions based on the results. Finally, some recommendation are made, the study's limitations are presented and suggestions for future research are preented.

Chapter 2

Literature Review

2.1 Introduction

This chapter presents the global waste generation and composition and associated influential factors. This chapter also discusses the global importance of waste generation and its contribution to GHG, and an attempt is made to give a clear picture of waste generation and management in Nepal and KMC's waste management system. Finally, the chapter is summarised.

2.2 Waste Waste Generation and Management and its Contribution to GHG Emission: the Global Context

2.2.1 Municipal solid waste generation

World Bank (2012) reported that practically 1.3 billion tonnes of MSW are produced worldwide each year, or 1.2 kg/capita/day (Hoornweg & Bhada-Tata, 2012b). More recently, in 2016, worldwide waste production was assessed as 2.01 billion tonnes. Worldwide garbage is projected to reach to 3.40 billion tonnes by 2050. There is commonly a positive connection between garbage and income level (World Bank, 2016). The rate of waste generation is commonly viewed as a marker of the level of socio-economic growth and financial success of an area or nation; expanding industrial development and rising salaries lead to more use of resources (Hoornweg & Bhada-Tata, 2012b).

The Organisation for Economic Cooperation and Development (OECD) nations account for nearly half of MSW (44%) whereas South Asia and Africa produce the least waste (5%) (World Bank, 2012). The annual per capita waste production in non-industrial countries is assessed at only 10-20% of industrial nations, but this figure is increasing because of financial development. Internationally, total waste production is expanding (Michael-Agwuoke, 2017).

As per World Bank (2016), waste generation has a general positive relationship with a country's economic level. Although they contain 16% of the world's population, elevated income nations produce 34%, or 683 million tonnes, of global waste. Low-income nations represent 9% of the total population but create only about 5% of the global waste, or 93 million tonnes annually (World Bank, 2016). Based on economic status of a country[3], waste generation varies as shown in Figure 2-1.

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[3] Nations are arranged into four pay levels as per World Bank evaluations of the 2005 gross country income per capita. High level income nations: $US10,726 or beyond; upper mid income nations: $US3,466-10,725; lower mid income nations: $US876-3,465; and low-income nations: $US875 or below

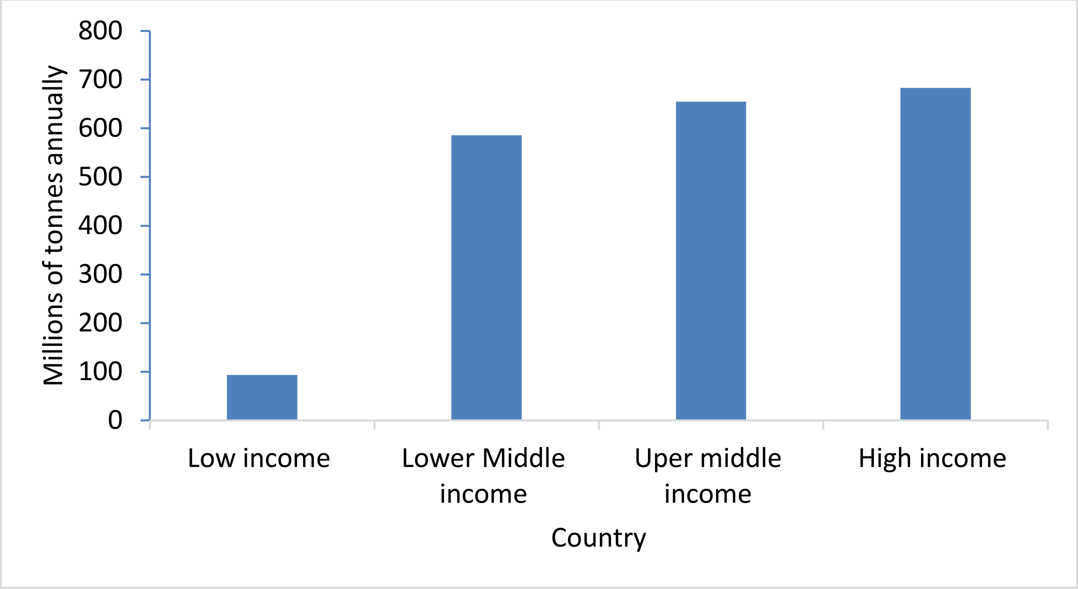

Figure 2-1: : Worldwide MSW production by income level Source: (World Bank, 2016)

The assessed worldwide average for 2016 was 0.74 kilogram of waste per capita per day, but national waste production rates varied widely from 0.11 to 4.54 kg per capita per day. Waste production amounts, by and large, correspond to income levels and urbanization (World Bank, 2016). Three nations in the North American region - Bermuda, Canada and the United States - generate the highest average quantity of waste per capita, at 2.21 kg per day (Vijayan & Parthiban, 2020). Each of those three nations is a top level income country. The explanation behind waste generation is the developments of population increase, urbanization and economic development (Barbuta et al., 2015). The three regions with the most reduced quantity of garbage per capita are: Sub-Saharan Africa, which averages 0.46 kg per day; South Asia, 0.52 kg per day; and East Asia and the Pacific, 0.56 kg every day (World Bank, 2016).

The waste generation rates in the least developed countries in Asia are lower than those of developed countries but Asia has an enormous population of about three-fifths of the world population so has increased the world's quantity of the waste (Glawe et al., 2005; Shekdar, 2009). The amounts and composition of solid waste generated from nation to nation are varied. The factors affecting the amount and the composition of waste are level of income, size of population, rate of urbanization, social behaviour and ways of life, degree of business activities, seasons, geographic conditions, and legislation impacts (Abd Alqader & Hamad, 2012).

For the most part, the more waste is generated with the greater economic prosperity and increased urban population. Accelerated pressure on natural and environmental resources has occurred alongside population growth and industrial activities in towns and urban communities because of urbanization. The urban communities of developing countries everywhere in the world are growing at a very fast rate because of large-scale migration to urban centres along with the natural rate of population development (Singh et al., 2011).

2.2.2 Municipal solid waste management (MSWM)

The MSWM can be credible choices to recycle and reuse programs that are very much promoted. Yet it may very well be a cause of ecological deprivation if the correct garbage management framework is not used. The 3R's (reduce, reuse, and recycle) of garbage management whenever executed properly can diminish the ecological deprivation (Compagno, 2020).

MSWM is the regulator of the creation, separation, stockpiling, assortment, transport, resource restoration, handling and clearing of the solid waste by using the most profitable strategy that is harmless to the ecosystem, socially acceptable and a moderate technique without trading off the wellbeing of individuals (Gurung, 2012). The waste management progression incorporates avoidance, reuse, recycling, recovery (3Rs) and disposal as portrayed in Figure 2-2. Mandate 2008/98/European Committee on Waste set a fivestep waste management system in the European Union (Sharholy et al., 2008).

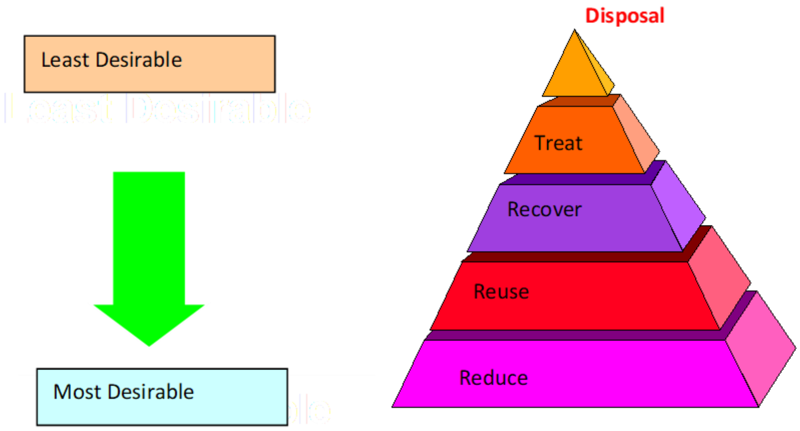

Figure 2-2: The waste management hierarchy of waste Source: (EPA, 2019)

Avoidance: This is the very preferred method of garbage management. It focuses on not making waste or reducing the amount of waste. The amount of waste is decreased by keeping out pointless use of items. Avoidance includes activity to reduce the amount of waste produced by family units, industry, and all levels of government.

Resource recovery: This includes re-use, recycling, reprocessing and energy recovery, predictably the most proficient use of the recovered resources. Compost from material recovery measures improves soil quality. The diverse methods of energy improvement include incineration, gasification, pyrolysis, anaerobic biodegradation, and landfill gas recovery.

Disposal: This is the last choice in the garbage management progression. Garbage that is not used for power recovery or the waste after power recovery is discarded in an assigned zone. The removal is done in the most ecologically sustainable way.

According to (Wilson et al., 2001), the main goal in most low-income nations ought to be to move to a new city waste management system from unloading to controlled disposal. Recycling, reuse, recovery measures and even removal, produces waste that might be alluded to as the 'waste of waste'. Hence, any maintainable MSWM should consider how to deal with the 'garbage of garbage' as a feature of the garbage to be handled (Michael-Agwuoke, 2017). The least demanding and best approach to diminish the amount of waste to be discarded is just to produce less in the first instance. This procedure appears to be basic and has guarantees; the measure of waste delivered, even in developed nations, is frequently an element of culture and opulence (Zerbock, 2003).

Waste division at the household level is a common phenomenon. However, if these should be in a low-income country, partition of the valuable goods is done with care and they are separated, which prevents the valuables and reusable materials entering the waste stream. The recovery of the important materials entering the waste flow is prevented by waste pickers and scavengers; nomad purchasers assume a crucial role in recovering materials for recycling. They buy materials like newspaper, plastic bottles, and metal scraps with some money-related worth (Zerbock, 2003).

Waste recycling can be the acceptable choice in certain countries where the nature and characteristics of the waste are like in developed countries. However, for countries that do not support waste recycling, different choices like recovery or diversion of the waste, should be considered. Recycling facilities cannot be done by local government because of a lack of funds, so private associations have been empowered as a practical choice in developing countries (Medina, 2000; Zerbock, 2003)

At the state level, there are a few strategies that can be used to decrease waste creation. This includes improved wrapping of goods, empowering the use of insignificant dispensable material important to accomplish the ideal level of wellbeing and convenience; expanding customer consciousness of waste decrease issues; and advancement of the maker’s duty regarding post-consumer waste (UNEP, 1996b). For MSWM for developing countries the following can be appropriate treatment options.

Composting

Solid waste can be broadly divided into organic waste (different degrees of biodegradability) and inorganic waste. Composting is an organic waste recycling technique where organic substances such as green garbage, manure, cooking waste, some metropolitan wastes and reasonable factory waste are organically decayed by bacteria in a controlled environment (Misra et al., 2003).

Composting has been demonstrated as the most ideal choice for dealing with organic garbage in emerging nations because it is the most practical and effective management procedure amongst other managing choices for the forms, type and composition of garbage (Taiwo et al., 2007). Waste management methods are a non-irrelevant source of GHG. In particular, methane emanates from organic waste because of the breakdown of biodegradable carbon compounds worked on in anaerobic conditions (Yang et al., 2009).

Composting is a high-impact measure that diminishes or forestalls the production of methane during organic matter breakdown (Australia, 2018). Decomposing organic material in anaerobic conditions - by organisms without oxygen - discharges methane into the environment. Anaerobic fermentation is basic in landfill and open piles, e.g., manure heaps. Worldwide outflow from waste has multiplied since 1970 and now produces 3% of anthropogenic (human cause) discharges. About 50% of these discharges come from the anaerobic maturation of solid waste dumped on land (IPCC, 2014). The high-impact interaction of treating compost does not make methane since methane-producing microorganisms are not active in the presence of oxygen. Composting is one strategy to lessen methane release from organic waste presently stored or shipped to a landfill. Composting limits anaerobic conditions and boosts oxygen consuming conditions that are best at lessening GHG outflows (Australia, 2018). Maskey (2018) indicated composting would be the best option to decrease the quantity of waste transported to landfill sites. In addition, composting provides a method to stabilize organic matter as a product, which is used as a fertilizer and reduces the odours associated with many organic materials.

Treating organic garbage at source is known to be the most ideal method of solid waste removal because it diminishes the amount of garbage to be moved to the landfill, which will lengthen a landfill's lifetime. This way favours households, the major source of waste production, making compost, which diminishes the quantity of garbage to be gathered and handled, diminishing the general expense of SWM and decreasing GHG (Pokhrel & Viraraghavan, 2005).

Composting should be possible: strongly aerobically or anaerobically. Aerobically by consuming oxygen, windrow composting is the most effective type of decay because it makes complete manure in quick time. Oxygen consuming organic entities rule the compost heap and break down the crude organic substances very effectively when a suitable quantity of food (carbon), supplements, water and oxygen are properly provided (Cooperband, 2002).

Today, the use of composting to transform organic wastes into a significant asset is growing quickly in China and other nations, as landfill space becomes scarce and costly, and as individuals become more mindful of the effects they have on climate. Treating organic materials that have been redirected from landfills avoids the creation of methane and leachate in landfills (Yang et al., 2009).

In developing nations, a normal's city waste flow is over half organic material (Hoornweg et al., 1999). Studies in Bandung, Indonesia, and Colombo, Sri Lanka, found household garbage was 78% and 81% respectively, decomposable matter and commercial waste was 89% and 90%, respectively, compostable (Cointreau, 1982). Treating compost has not been an awesomely fruitful, extensive tradition through the emerging world. Though well documented in China and different territories of eastern Asia, composting projects have had a conflicting record through Africa, Latin America and some other places , and have had the largest number of failed facilities around the world (UNEP, 1996a). There are several reasons for this, and past history should provide a guide for its implementation in the future (Epstein et al., 2008).

Composting has lower CO_2-equivalent discharges than landfill in territories where landfill sites with gas obtaining gear are inaccessible. It is generally accepted that separating recyclable waste from landfill for composting is a means to decrease GHG discharge (Hutton et al., 2013). Methane is delivered by uncontrolled anaerobic decay at landfill sites; treating compost does not create any such gas. Unsafe GHG discharges are accordingly diminished since a lot of waste goes through controlled decay at a strong waste management site. The whole local area profits from this (Saouter, 2012).

Anaerobic digestion (AD)

Anaerobic digestion is where organic substances are separated into methane by microbial action in the absence of oxygen. This procees result two product ,biogas and digetsed slurry that are used for the production of heat, electricity, biomethane, CNG fuels and as a fertilizer in farm. Biogas can be produced by processing human waste, cattle manure, green waste and other organic wastes in uniquely planned digesters (Omer, 2007). The simple method to create biogas is shown in figure 2-3.

Delivered biogas is by and large 48-65% methane, 36-41% carbon dioxide, up to 17% nitrogen, 32-169 ppm of hydrogen sulfide and a modest quantity of other unstable gases that can be combusted for the production of heat and energy. Methane is separated from the biogas to create biomethane and is provided to the gaseous petrol network as a sustainable gas or is used as truck fuel. The by-product of anaerobic digestion is rich in supplements and is used as a manure compost (Initiative, 2016). The compound responses of second and third phases of anaerobic digestion are appearing below.

Acetogenesis

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2\ CO_2$$

Methanogenesis

$$CH_3COOH \rightarrow CH_4 + CO$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

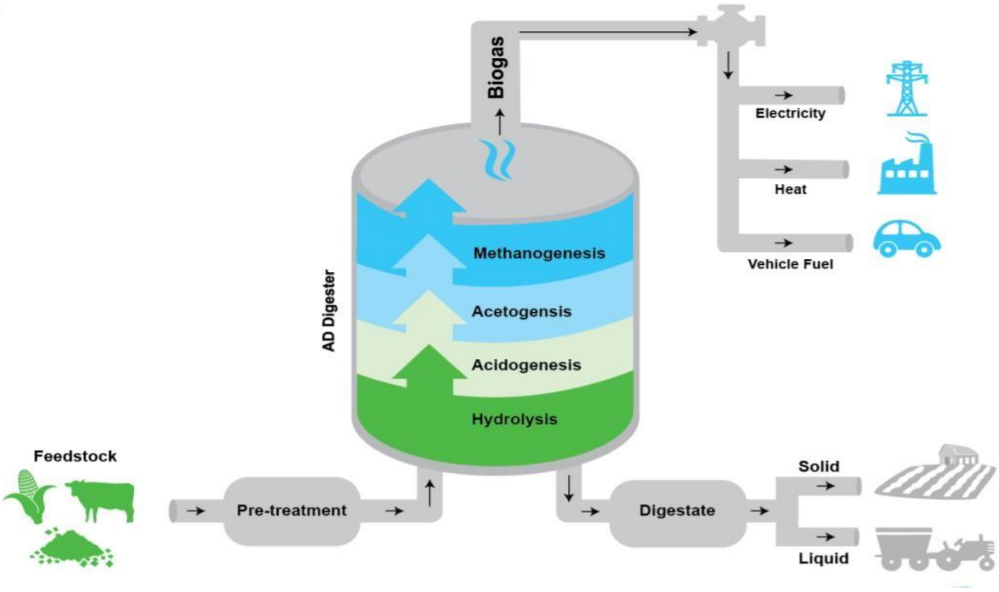

Figure 2-3: Biogas production from AD (Initiative, 2016)

Anaerobic co-handling of created compost with different organic waste assists in delivering a high measure of biogas and great natural manure. Diminishing GHG outflows from manure and organic waste is one huge benefit from this process that cannot be disregarded by any means. The anaerobic digestion cycle can be done from small scope to huge scope. There are different sorts of biogas plants in Europe organised by the process used, as shown by such a prepared substrate or according to their size (Khalid et al., 2011).

Landfilling

Landfilling is the dumping of solid waste at planned facilities in a series of compressed layers on land. Landfills are covered with impervious materials to stop leachates from contaminating groundwater, and are covered with soil (Manual, 2009). Landfilling is the most widely recognized approach for solid waste removal. Landfill space is an issue in more thickly populated nations, with landfills in some bigger metropolitan regions arriving at their limit; accessibility of new space is restricted by nearby resistance and higher environmental principles, e.g., the need to stay away from locales that could pollute groundwater or waterways (Environment, 2014) .

The dumping of solid waste is a challenge. This challenges nations to grow with the development of population and growth of activities. Dumping garbage in open ditches has become regular in many areas (Partha Das Sharma, 2009). Semisolid or solid matter that is generated by creatures that is then disposed of because it is hazardous or worthless is termed as solid waste. Most solid waste, like paper, plastic containers, bottles, cans, and even used cars and electronic items, are not recyclable, which means it does not get separated through inorganic or organic methods (Sharma, 2013).

The removal of garbage on the earth is by far the most popular method in most of the countries and most likely accounts for over 90 % of worldwide municipal refuse. Ignition accounts for most of the remainder, whereas composting of solid waste accounts for only a minor quantity. Selecting dumping depends almost wholly on cost that depends on the local context (Partha Das Sharma, 2009).

Poor disposal performance can lead to contamination of waste resources through leachate and the buildup of gases that can cause explosions; such hazards, which depend on influences such as waste composition, cover material used, rate at which deposited waste is covered, level in which waste is compressed, and dampness and weather, need to be measured on site. Checking ground waste is also essential to identify variations in waste property that may be sparked by the escape of leachate and landfill gases (IRC, 2003). A few municipalities provide only the essential elements of waste collection and disposal. Others have more complicated systems that include waste transfer to distant landfills and management of recyclable materials or organics for composting. Still others may also include recovery technologies (Alberta Environment, 2016).

Figure 2-4 shows the prospective paths of waste material flow from waste generation through to removal, recycling or recovery solutions.

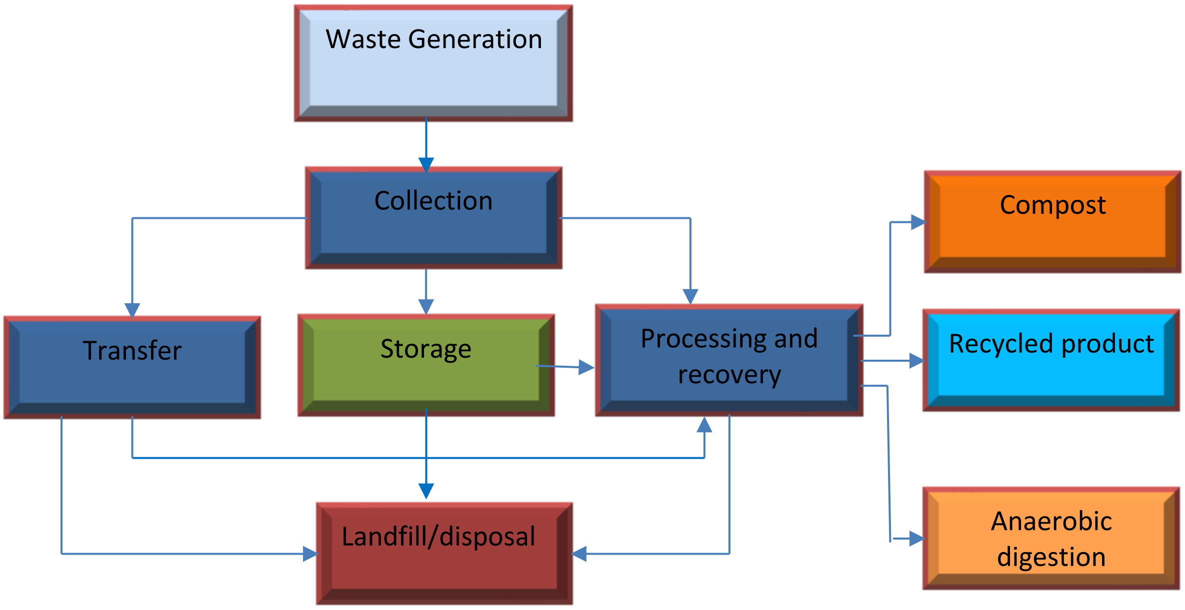

Figure 2-4: Possible paths of waste flow from producer to final disposal (Le Thi, 2012)

There are many different domestic and commercial waste collection systems. Of most interest to landfill operators is the way the waste is collected, the way it is transported to their facility, and the type of the waste in the load. Different types of domestic materials are frequently collected and transported to the waste management services individually. Three options are shown in Table 2-1.

Table 2-1:– Examples of common multi-stream collection schemes (Alberta Environment, 2016)

STREAM 1	STREAM 2	STREAM 3
All waste is put in the same bins.	Organic wastes and other wastes in different bins.	Waste materials, recyclable materials, and organics for composting are put in separate bins.
The bins are collected in one truck and disposed of at a landfill or transported to a mixed waste processing service for recovery of available recyclables.	Recyclables are collected in one truck, and waste collected in another truck. Some two-stream collection systems may use compartmentalized collection trucks for both.	The bins are collected individually

Removal practices in nations range from 'no-framework' to 'tolerably controlled removal', contingent upon the city size, the collection framework set up and financial markets. As urban communities create the rubbish, the most well-known removal frameworks are ones with slight and moderate controls. At some removal destinations, tractors are used to reduce the waste or cover it with soil, but generally this is done physically (IRC, 2003).

Conditions inside a landfill are generally anaerobic. The water expected to create the methane from the biomass waste is contained inside the MSW or is provided by precipitation and the distribution of leachate. The depth of an average landfill cell fluctuates impressively, from 20 to 80 m, contingent on the landfill location and cell size. The height of every day’s deposition in a cell fluctuates but a common one is three metres. EPA guidelines necessitate that landfill gas (LFG) collection wells be introduced inside two years after the last cover or five years after beginning to arrange waste in a cell. At numerous landfills, gas collection frameworks are introduced sooner, after half the cover has been set (van Haaren et al., 2010).

Designed landfills with choices for gathering leachate and gas outflows are fundamental for safe garbage removal. Such landfills have planned arrangements for acceptable leachate management because leachates are demonstrated sources of surface and ground water contamination. Waste is compressed and every day wrapped with a coating of soil. Through the last shutting, the landfill site is adequately covered with a thick soil layer. Every one of these variables leads to an anaerobic environment inside the landfill thus they endlessly generate methane (Ramachandra et al., 2014).

Designed landfills are made to dump waste in a logical way, by diminishing its volume and removing enviromental dangers related to garbage removal (Barros et al., 2014). These landfills are also an approach to recover energy from the common anaerobic disintegration of waste, e.g., MSW happens to make landfill gas (LFG) of primarily methane, carbon dioxide and some other gases (Vaish et al., 2019). Certain sanitary landfills accompany a landfill gas recovery framework to recover methane that can be used as a fuel source for energy or power (Diamadopoulos, 1994). Table 2-2 show waste mangement methods vary greatly among low,middle and high income countries.

Table 2-2: Solid waste management practices around world in low, middle, and high income \countries

Activity	Low Income	Middle Income	High Income
Source decrease	No organized programmes but recycle and low per capita waste production rates are common.	Some discussion of source decrease, but hardly incorporated into a scheduled programme.	Structured education system highlights the 3 'Rs'. More producer obligations & focus on product design
Collection	Intermittent and ineffective. Service is limited to high visibility areas, compostable impact collection—overall collection below 50%.	Improved service and increased collection from residential areas. Larger truck fleet and more mechanization. Collection rate varies between 50 to 80%. Transfer station slowly used in SWM.	Collection rate greater than 90%. Compactor trucks and highly mechanized vehicles and transfer stations are common. Waste volume a key consideration.
Recycling	Most recycling is through the unofficial sector and waste picking. Largely localized markets and import of materials for recycling.	Unofficial sector still involved, some high technology sorting and processing services. Materials often imported for recycling.	Recyclable material collection services and high technology sorting and managing facilities. Increasing attention towards long-term markets.
Composting	Hardly undertaken formally even though the waste stream has a high % of organics	Large composting plants usually failed; some small-scale composting projects are more sustainable.	Backyard and services. Waste stream has a smaller % of compostable than low- and middle-income countries.
Incineration	Not common or effective because of high capital and process costs, high moisture content in the waste, and high % of inert.	Some incinerators are used but suffer financial and operational problems; not as common as in high-income nations.	Common in areas with high land costs. Most incinerators have some form of environmental and energy recovery system.
Landfilling/dumping	Low-technology sites typically open unloading of wastes.	Some controlled and sanitary landfills with some environmental rules. Open dumping is still popular.	Sanitary landfills with a combination of liners, leak detection, leachate collection schemes, and gas CT systems.

Sources (World Bank, 2016)

Waste management practices vary greatly among low-, middle- and high-income countries. In the high-income countries, there are planned education systems to highlight source decrease and recycle waste materials and over 90% of the waste is collected with the aid of mechanized vehicles. In low income nations, the cost of collection is up to 80-90% of the total waste management cost but the collection is irregular and the collection rate ranges from 50-70% and the services is limited to highly noticeable areas of wealthy families (Aleluia & Ferrão, 2016). Although the proportion of biodegradable waste is extremely high in the waste stream of the low-income countries, composting facilities are rarely established in those countries. However, the high-income countries have paid remarkable attention to manage the biodegradable waste in either large scale mechanized facilities or small-scale composting. In low-income countries, sorting and recovering is performed by the unorganized sector from the mixed waste from the sources and the landfilling is in the form of open dumping (Zurbrugg, 2002).

2.2.3 Waste management and GHG emissions

At the Paris Climate Change Conference, 12 December 2015, 196 nations signed an agreement to combat environmental change, specifically to control greenhouse gas (GHG) emissions (Klein et al., 2017). Essentially, the Paris Agreement prescribes that GHG emissions should come down to a 'net zero' level by the end of the century (Falkner, 2016). The Paris Deal established a long run temperature objective of keeping the worldwide temperature increment to lower than 2°C and to pursue attempts to reduce this to 1.5°C above pre-industrial levels (Schleussner et al., 2016). It set ongoing worldwide environmental change endeavours on a totally new, committed bearing: each of the 196 countries to the UN Outline Agreement on Climate Change concurred on a shared objective and the way to deal with environmental change and accomplish worldwide greenhouse neutrality (Amelang et al., 2016). As part of this, there are nationally determined commitments, with each country deciding its own contribution, which should be ambitious and progressively positive over time.

As indicated by IPCC (2006a), the seven GHGs are: methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and nitrogen triflouride (NF_3). The three main GHGs, based on their global warming potential are methane, carbon dioxide and nitrous oxide. The essential origins of GHG discharges are energy-related creation, 65% (for the most part from power and heat), transport, 28%, fabricating, 12%, agribusiness, 14%, land-use change and forestry services, 2%, and others, 6% (Eggleston et al., 2006). Solid waste contributes 3% of total global GHG emissions (Edenhofer, 2015).

Solid waste management is of concern, because, with an ever increasing global and urbanized population, the generation of waste is rising. This waste has historically been disposed of in open dumps and landfill sites. These destinations produce gas because of the anaerobic disintegration of organic matter. Landfill gas contains roughly 45 to 60% methane, and 40-60% carbon dioxide (Williams, 2001). However, the global warming ability of methane is 21 times higher than that of carbon dioxide (Eggleston et al., 2006). Therefore, effective management of methane is important.

The US Environmental Protection Agency (USEPA, 2006) stated that landfill sites were the biggest cause of methane discharges in the US, representing around 90% of all methane discharges from the waste sector. Landfill sites are expanding GHG discharges in developing countries. For example, in 2000, developing nations accounted for around 29% of total GHG discharges; this is anticipated to rise to 64% by 2030 and 76% by 2050, with landfills being the main reason behind this expansion (Monni et al., 2006). In contrast, for developed nations the corresponding GHG outflow is reducing. For instance, the EU municipal waste area diminished from 69x106 tonnes CO_2-e in 1990 to 32x106 tonnes CO_2-e by 2007; additional decreases have been anticipated (ISWA, 2010). This shows that decreases in GHG discharge are conceivable.

(Sandra et al., 2010) suggested that developing countries can possibly relieve national emissions by around 5% and, in the long term, by10% when coordinated strong waste administration is executed. However, developing countries face numerous challenges. First, there is an lack of national data on solid waste activity producing trouble in calculating, and enormous vulnerability in assessing, GHG discharges from such exercises (Kumar et al., 2004). Second, there is trouble in getting suitable methodologies. This has produced challenges in setting up GHG accounting and the ensuing focus on a decrease in solid waste.

Landfilling is the most well-known garbage removal technique all over the world. Landfill advances have grown in recent years, yet these improvements have not yet arrived everywhere in the world (Manfredi et al., 2009). For instance, a large portion of undeveloped nations in Asia are yet to practise open unloading and landfilling without gas recovery. Universally, waste delivered almost 800 million metric tonnes of carbon dioxide comparable in 2010 which is around 11% of all CH_4 created by people. The US had the most noteworthy absolute amount of methane discharges from landfills in 2010; around 130 million metric tonnes of carbon dioxide. China was second with 47 million tonnes, then Mexico, Russia, Turkey, Indonesia, Canada, the United Kingdom, Brazil and India, as indicated by the Worldwide Methane Initiative (Gies, 2016).

Metropolitan solid waste organic material represents about 55% of waste presently arriving at landfills, essentially comprising food scraps, yard waste, wood, and paper/paperboard. Because of their part as the origin of methane in landfills, redirection of these materials before landfilling might be used as a GHG decrease procedure. Redirection techniques include compost and biogas (EPA, 2011).

Engineered landfills with opportunities for gathering leachate and gas emanations are fundamental to safe garbage removal. Garbage is packed and consistently covered with a layer of soil. During the last fixing, the landfill site is adequately covered with a thick soil layer. Each of these components leads to anaerobic conditions inside the landfill site that consequently ceaselessly produces methane gas (Ramachandra et al., 2014).

When food waste is landfilled, anaerobic microbes cause waste degradation. As demonstrated by the Global Methane Initiative, the absolute assessed anthropogenic release of methane was 7Tg of carbon dioxide in 2010, of which landfills represented 11% of total discharge. The concentration of methane in the air has been growing for a very long time at the scale of 1-2%; it has been projected that overall anthropogenic methane release will be augmented by 15% by 2020. Non-industrial nations have been estimated at around 29% of worldwide GHG outflows and this is expected to move up to 64% by 2030 because of developments in population and urbanization, increased numbers of landfills without a gas collection framework, and increased waste collection facilities (Friedrich & Trois, 2011; Initiative, 2016; Kumar et al., 2004).

Decomposing organic material in a landfill produces gas, predominantly methane. To prevent methane, a greenhouse gas, getting away into the atmosphere it can be collected by a network of pipes and used as fuel to drive generators to produce electricity for the national power grid. This is the case for the Kate Valley Landfill, Canterbury, New Zealand. In 2011/12, 207,000 tonnes of waste were placed in the Kate Valley Landfill (Zealand, 2013) with only 19 % of organic waste. The methane capturing system generating 4 MW of electricity in 2019 (Zealand, 2013).

When MSW is first placed in a landfill, it goes through a high-impact (with oxygen) biodegradation stage when little methane is delivered. At that point, normally inside a year, anaerobic conditions are set up and methane-creating microbes start to disintegrate the waste and produce methane (Kjeldsen et al., 2002). Landfill gas (LFG) is a characteristic result of the decomposition of organic material in landfills. LFG is about half methane (CH_4) (the essential part of natural gas), half carbon dioxide (CO_2) and a restricted amount of non-methane organic compounds (Nair et al., 2017).

GHG outflows from landfill are dictated by the IPCC. In the First Order Decay (FOD) model, the steady decay of degradable organic carbon of MSW in a landfill for quite a long while was considered (Xin et al., 2020). A few researchers have announced modelling methods that pay attention to the biological and/or chemical degradation of garbage that produces gases. Among the integrated models, LandGEM is a generally used program for the environmental evaluation of solid waste landfills. LandGEM assesses the quantity and composition of the created gas through time because the biodegradation of organic material takes time in the landfill (Bogner et al., 2008) .

2.2.4 The global situation regarding waste generation and management

Presently, the amount of waste produced is steadily expanding everywhere in the world because of fast population increase, economic development, urbanization, and improved living conditions in urban areas. Solid-waste management is a key issue in city areas throughout the world (Reddy, 2011).

The dumping of solid waste has become a significant worry. Factors, e.g., the expanding economy of a nation, elevated population development, urbanization and increased neighbourhood living requirements, have promoted a higher production rate of metropolitan solid wastes. MSWM has been greatly overlooked especially in the metropolitan regions of developing nations because of a lack of organization, economic resources, and system complexity (Al-Khatib et al., 2010).

The composition of waste fluctuates with various factors including people's lifestyle, climatic conditions, financial status (Joshi & Ahmed, 2016). Waste composition is a critical factor in choosing how waste is overseen. For low-income nations there is a raised degree of organic waste whereas paper, plastics and inorganic materials make up the most of MSW in high-income nations (World Bank, 2012). An examination undertaken in Sri Lanka city showed there is a reasonable expansion in organic waste amount as the property valuation tax value increased. The moderately higher food use trends of income groups expands the purchase of packaged items and reading material and, accordingly, in the waste produced (Bandara et al., 2007).

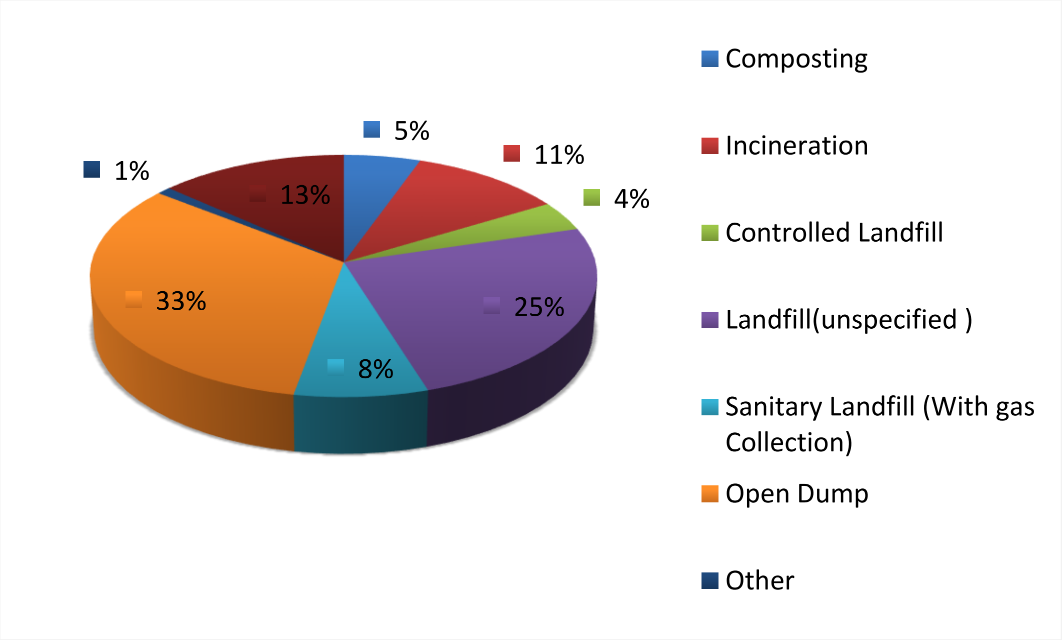

Figure 2-5: Global patterns of Municipal solid Waste disposal technology (World Bank, 2016)

Overall, practically 40% of waste is discarded in landfills around the world. Around 19% goes through material recovery like recycling and composting, and 11 % is handled through incineration. Universally, 33% of waste is still transparently unloaded in open areas. These world waste treatment innovations shown in Figure 2-5 is a huge pointer to the non-sustainability of waste management. Additionally, current management approaches are still amazingly low on the waste management hierarchy scale (see Fig. 2.4). A landfill, which is at the lower end of the waste management hierarchy, sticks out, followed by recycling with not large portion of the estimated waste to landfill (World Bank, 2016).

In the urban communities of non-industrial nations, the principal disposal practice for MSW is open dumping. Very often landfill sites are river side or low-lying areas, with the waste being used for reclamation. Hence, these landfill sites are basically not controlled, creating significant health, safety, and ecological problems (Guerrero et al., 2013). More financially advanced nations have choices through designed (sanitary) landfills and incinerators (Al-Khatib et al., 2010).

The garbage generated by a developed nation may not be comparable to that generated by a non-developed nation considering that non-developed nations have more organic waste. These organic wastes are damp and have low heating value, causing them to be hard to burn without adding extra fossil fuel. Composting and anaerobic digestion can be suitable decisions after a biowaste split for organic waste management in non-developed nations (APO, 2007). It has been said that drawn out disposal options are restricted and will also hinder sustainable solutions. It is been important to discover methods to reduce the waste or transforming it into useful resources (Verma et al., 2016).

Waste that is taken to dumps, landfills and incinerators has most possibility for recycling, reuse, or processing. In developed countries, wastes such as paper, metals, and plastics are exceptionally reused because pressure is growing. An ever-rising number of nations are choosing a materials recovery service to transform these wastes into valuable items (Guerrero et al., 2013). The most significant step that ought to be completed at the underlying stage for composting methods is waste separation. People should split their waste at origin so that composting can be completed successful (APO, 2007).

2.3 Measuring waste generation, composition and GHG emissions

2.3.1 Measuring waste generation and composition

World Bank (2016) characterized MSW into seven source classes: family (HH), modern, business, factory, building and demolition, municipal facilities, and processes.

Table 2-3 shows the order of the waste regarding sources, type of waste generator and the type of solid waste.

Local governments in undeveloped nations often do not have resident information on the multitude of households inside the town (Alberini & Cooper, 2000). Waste production is the base information for assessing other functioning markers and improving targets. The amount and the composition of metropolitan solid waste are necessities for the assurance of the proper taking care of and management of these wastes. Such data are key and important in setting up a solid waste management service inside the region (Abdel-Shafy & Mansour, 2018).

Table 2-3: The global causes and types of solid waste

Source	Classic Waste Producers	Nature of Garbage
Residential	Single and multifamily residences	Food waste, paper, cardboard, plastics, textiles, leathers, yard waste, wood, glass, metals, ashes, different wastes (e.g., consumer electronics, goods, batteries, oils, tires) and household hazardous waste
Industrial	Factories, industries, construction sites, energy, and chemical plants	Cleaning wastes, packaging, food waste, construction materials, hazardous waste, ashes, special wastes
Municipal Services	Road cleaning, landscaping, parks, beaches, other recreational areas, water, and treatment plants	Street sweeping, landscaping and tree trimmings, general waste from parks, beaches and other recreational areas, sludge
Commercial	Shops, hotels, restaurants, markets, office buildings etc.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes
Institutional	Schools, hospitals, prisons, colleges, government offices	Same as commercial
Construction and Demolition	Construction sites, road repairs, renovation sites, demolition of buildings	Wood, steel, concrete, dirt, etc.
Process	Manufacturing, processing and refineries, chemical plants, power plants, mineral removal, and processing	Industrial process wastes, scrap materials, off specification products, slag, tailings
Agricultural	Crop waste, green waste, trim waste, dairies, feed lots	Farm wastes, hazardous wastes (e.g., pesticides)

Source: (World Bank, 2016)

Resident or metropolitan wastes are ordinarily created from varying sources where distinct human activities occur. Usually, the solid waste from such sources as municipalities, families and businesses are significant and diverse in type. As such, they have variable physical and chemical attributes depending on their unique sources. The composition is backyard waste, food waste, plastics, wood, metal, paper, rubber, leather, batteries, debris materials, paint cans, textiles and as various others that are hard to classify (Nabegu, 2010).

It is accepted that weekly data (Dahlén & Lagerkvist, 2008; Gu et al., 2015) to determine waste quantity and composition by visiting generating site and collecting waste separated manually and weighing each type of waste directly there, is the most simple and precise data collection (Gu et al., 2015). During waste composition assessment of Asian countries in 2016, each household was provided two garbage bags, which had the sample number and was asked to separate organic and other garbage sorts for a week, after being given appropriate training on waste separation. With the help of municipal waste workers, the separated waste was collected and transported to the disposal site by truck for re-separating and weighing the components of all the garbage for easy analysis. Waste categorization using a defined method makes analysis unmatched, which is genuine for nationwide aggregated statistics that may ignore major variations between urban areas in a similar country (Aleluia & Ferrão, 2016).

Studies were based on a single day of waste production and did not include all municipal wards. Also, because of an absence of consistent logical techniques and the various suppositions made in measuring the waste produced from various origins, the results are variable. One item is that there is no steady incremental pattern in per capita waste production. This leads us to suspect the reliability of the data and whether the stakeholders ought to depend on them for judgements. Many developing countries have the same problem where statistics are either missing or are not consistent because the data sources were not reliable or are based on assumptions instead of logical estimates (Miezah et al., 2015). Despite the estimation of household solid waste, it is essential to show waste production to recognize the components that impact the waste production rate of the households and planned approaches to reduce it. The correlation analysis was utilized to understand the individual factors that predict the amount of waste produced. Then, multiple linear regression assessment was utilized to discover the connection with waste production and socioeconomic factor (Bosire et al., 2017; Wegedie, 2018).

2.3.2 Measuring GHG emissions

Various investigations have estimated and caught the amount of gas delivered from MSW removal site, since the various programmes have been made to process landfill gas production (LFG), oxidation, and discharges. Unfortunately, however, the use of simulation programming as a device for the plan, activity and observing is not as developed in the field of MSW landfills as in other areas of environmental design (Mohareb et al., 2008). Though there are various instruments that recreate the gas production measure, a conclusive and trade-acknowledged technique is yet to be found. Normally, the quantity of discarded decay garbage is used as a reason in each current approach and applying an empirical formula for the degradation of garbage is one normal way that various experts calculate methane production rates from landfills (Oonk, 1994; Peer et al., 1992). Model adjustment relies on information noticed in a specific landfill or comparative offices, which does not give rise to actual projection programs. Regardless, these programs are still used for inexact assessments when more refined tools are not available. A few researchers have demonstrated methods that depend on the biological or chemical deprivation of garbage that produces toxic gases (EPA, 2005b).

To assess LFG, different models, e.g., programming models, stoichiometric models, biochemical models, have been created. Each of these models contrasts in dynamic expression and considerations (NEERI, 2002). Over time, various mathematical and numerical models have been created to calculate LFG dependent on zero, first, and second- order methods. Second-order models are not usually used because the necessary boundaries in each model are frequently questionable to such an extent that they adversely influence the exactness of the results (Tintner et al., 2012). Zero order models do not mirror the biological LFG production processes (Amini et al., 2012). As per IPCC (2006a), on a national level, two methods, viz. the default method and first order method are recommended to assess LFG.

A landfill methane program is a numerical method to estimate methane production over the long haul from a quantity of waste. In its least difficult structure, the program calculates the discharge production or recuperation from a selected bunch of waste, landfilled for a given length of time. Landfill discharge models are shifting as better landfill information accessible for modelling is developing (Michael-Agwuoke, 2017). Among other various integrated models, some are widely used software for the environmental evaluation of MSW landfills as detailed below:

- Stoichiometric model by Boyle
- IPCC default method (DM)
- IPCC first order decay model (FOD)
- NV Afalzorg (FOD modified)
- US EPA LandGEM

Stoichiometric model by Boyle: basic ideas, like stoichiometry, chemical equilibrium, transition modes, motion balance investigation, and motion arrangement spaces, are clarified (Maarleveld et al., 2013).

IPCC Methods: The basic difference between the two IPCC models is that DM does not mirror the time difference in solid waste removal and the deprivation cycle because it expects that all probable methane is delivered the year the waste is discarded. The timing of the genuine emanations is mirrored in the FOD strategy. If the yearly quantities and composition of waste discarded have been almost consistent for a significant period, the DM technique delivers great assessments of yearly emanations (IPCC, 1995). Expanding measures of waste discarded prompt an overrating and diminishing sums equally to underestimation of yearly discharges. The FOD technique gives a more precise estimate of yearly emanations. Numerous nations may, regardless, have issues getting the vital information and data (authentic information on garbage removal, the rate steady for the decay) to set up the appropriate model for emanation inventory with satisfactory accuracy. Among the accessible techniques, the most straightforward one for the assessment of methane emanations from landfills depends on the mass equilibrium approach, i.e., the IPCC default strategy (Jigar et al., 2014a; Kumar et al., 2004).

IPCC first order decay model (FOD): The FOD technique requires information on present and historic waste amounts, composition and waste disposal practices over quite a long time (IPCC, 1996). The first order decay model is relevant for a specific landfill or a choice of particular landfill where LFG is not extracted (Change, 2006).

NV Afalzorg (FOD modified): This is a first order decay (FOD) model that relies on IPCC equations and the resulting default boundaries (IPCC, 2006a; Luning & Oonk, 2011). The model consolidates distinctive decay rates for various sorts of degradable carbon and regards municipal waste as a mass amount without arrangement or waste composition. The amount of garbage being dealt with is seen exclusively as family waste with % portions classified as having quick, moderate, slow degradability, independently or non-degradable organic carbon matter (Mou et al., 2015). Multi-stage first order decay models rely on similar principles but differ between different types of organic waste. This yields a more modern method that achieves more consistent production forecasts (IPCC, 1995; Oonk & Boom, 1995). Multi-stage first order decay models rely on similar principles but vary between various types of organic waste. This produces a more modern approach that produces more consistent forecasts (Scharff & Jacobs, 2006).

LandGEM Model: LandGEM depends on a first-order deterioration rate condition to evaluate emanations from the disintegration of landfills in MSW. LandGEM is a fairly simple way to deal with assessing landfill gas discharges (Kim, 2003). LandGEM is a mechanized estimation system with a Microsoft Excel line that can be applied to appraise the outflow rates for all landfill gases including methane. LandGEM can use either site-specific information or default boundaries to assess outflows if no site-specific information is accessible (Alexander et al., 2005; Kumar et al., 2004). LandGEM is maybe the most used and most adaptable model (Sadeghi et al., 2015). The model was introduced to measure yearly discharges over a period depending on user specification (Kalantarifard & Yang, 2012; Rodrigue et al., 2018). The model includes two procedures of default boundaries, the Clean Air Act (CAA) defaults and inventory defaults. The CAA defaults depend on the US federal guidelines for MSW landfills spread out by the CAA. The inventory defaults rely on discharge considerations in the Environmental Protection Agency (EPA's) Compilation of Air Pollutant Emission Factors (AP-42) (Dimishkovska et al., 2019a).The LandGEM computer programs was produced by US EPA's experts to bring most of the huge US landfills into an air quality surveillance program (under Clean Air Act amendments) and to expand them for neighbourhood outflow stocks. To compute the quantity of methane discharges via LandGEM, the heaviness of the waste created during the arrangement time frame ought to be sensibly surveyed. LandGEM decides the methane mass created by using the mass of garbage accumulated and the methane production limit (Fallahizadeh et al., 2019).Summarised models widely used for the GHG emissions from MSW landfill are DM, FOD, LandGEM and NV Afvalzorg. Key advantages and challenge associated with the models are summarised in Table 2-4.

Table 2-4. Comparison of GHG emission estimation methods

Model	Emission trend	Accuracy	Output	Challenges
Stoichiometric model by Boyle	Considering waste formula and elevated emission amount	Approximate idea	Methane discharge (Gg/year	Mass balance easy
Default Method (Zero order)	Considering suspicion that all possible CH_4 is delivered in the same year at waste disposed of.	Yearly measures if the quantity and compostion of kept waste has been consistent or gradually changing over a time of a few years. In any case, when the quantity and compostion changes with time, the IPCC method will not give a precise pattern.	Methane discharge (Gg/year)	Easy method based on mass equilibrium equation
FOD (First order)	Method is a time-dependent discharge profile and is a genuine example of a base measure over the long run.	Generates the best outcomes of all techniques as it incorporates waste compostion,amount, and removal practices of the previous year.	Methane discharge (Gg/year)	Necessitates information on existing waste amounts, compostion and removal systems for quite a few years.
NV Afvalzorg (First order)	A multi-stage first order decay model depends on similar standards. However varies between various sorts of organic waste.	Regards the city waste as a mass amount without arrangement for waste compostion data.	Methane emission (Gg/year)	The benefit of a multi-phase model is that without composition data can calculate use default data.
LandGEM (First order)	Follows a similar pattern to FOD.	Absence of adaptability on the impact of shifting waste composition on methane production.	Methane discharge (Mg/year)	Comparatively easy method to compute GHG emission movement.

There are two types of heat of combustion, viz. high heat, and low heat. High heating values (HHV) of solid waste are computed using Dulong’s equation and calculate energy value of waste (Tchobanoglous et al., 1993)

2.4 A case study of Kathmandu Metropolitan City, Nepal

2.4.1 Waste generation and management in Nepal

Nepal is a landlocked nation formally called the Federal Democratic Republic of Nepal. It borders China to the north and India in the east, west and south. The number of inhabitants in Nepal in the 2011 statistics was roughly 26.6 million of which, 4.5 million individuals (17%) lived in the 58 regions of Nepal. The number of inhabitants in the municipal areas has now reached 40% of the population when municipalities expanded from 58 to 217 (Pathak, 2017). Nepal is known as the nation of the Himalayas. The eight mountains of the ten highest worldwide are found in Nepal, including the highest, Mount Everest. Nepal is geologically isolated into three locales. They are the Mountain, Hilly, and Terai (Plane) areas. The nation's altitude goes from 60m in the Terai to 8,848m in the mountain over a short distance of 90-120 km (Pokhrel & Viraraghavan, 2005). The essential business in Nepal is the travel industry. Nepal had a per capita GDP for the financial year 2016/2017 of $US853 (Pant, 2019).

In Nepal, SWM is one of the important facilities that should be provided by municipalities to keep metropolitan areas clean under the Local Government Action Act 2017, the SWM Act 2011 and Regulation 2013. The solid waste management technical support centre (SWMTSC) is a critical partner offering help to municipalities in SWM and the Ministry of Local Development (MOLD) encourages municipalities to discover specialized and financial help from global associations and upholds MSWM exercises in general (Udm, 2015). A few governments, nongovernmental and international agencies are directly or, by implication, engaged with the development of SWM services in Nepal. Because of the inter-disciplinary nature of SWM, different associations are assigned to be engaged with SWM issues as demonstrated in figure 2-6.

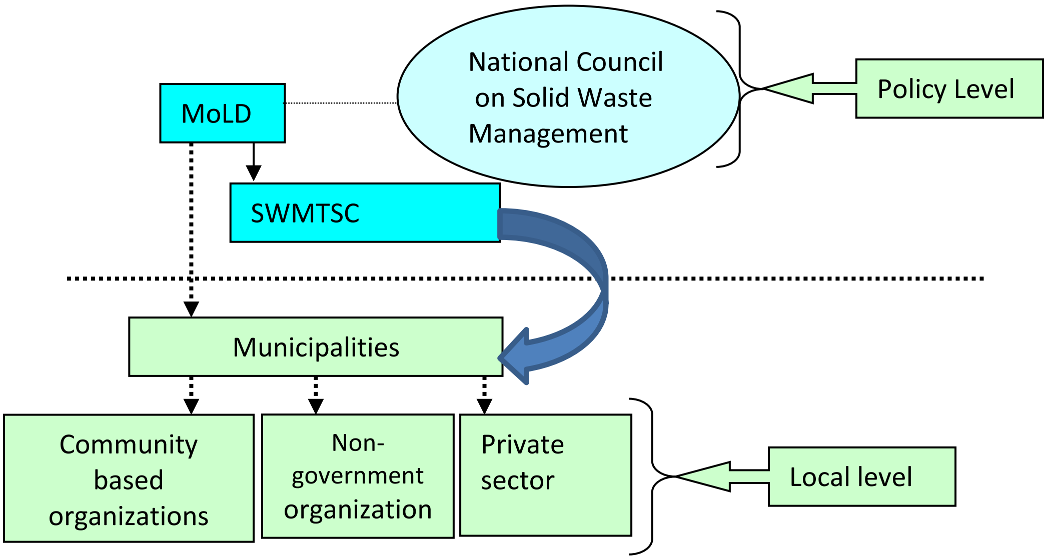

Figure 2-6: Institutional structure for the MSWM in Nepal

Fast, unrestrained city growth, lack of community concern, and weak management by municipalities have increased ecological issues in urban communities in Nepal, such as unsanitary waste management and removal. Though SWM has become a major concern for municipalities and the nation in general, the situation with SWM is not entirely understood because of the absence of SWM information, which is important for good organizing (ADB, 2013; Khajuria et al., 2010).

The least developed countries in Asia, such as Nepal, face environmental challenges because of fast and haphazard urbanization and an absence of public understanding regarding weak SWM by municipalities (ADB, 2013). The volume of waste and its composition depends on different variables including urbanization, community living standards, population growth, and financial status. These need to be tackled during the creation of a scheme and approach for MSWM in Nepal (Raj GC, 2018).

Expanding urbanization and financial advances quicken use rates as well as increasing waste generation. The fast increase in municipalities with spontaneous urbanization and movement of individuals promotes a huge amount of MSW in all regions of Nepal, including the new regions. Hence, SWM has become a significant worry for the districts of Nepal (Pathak, 2017).

An increasing population coupled with increased industrial and commercial activities, poor urban planning and haphazard human settlements, weak management of MSW and the absence of technical support have deepened the crisis related to dumping (ADB, 2013). Among the various environmental problems in the city, a study by Sigdel and Koo (2012) highlighted that a large portion of individuals believe that MSW is a serious concern in the metropolitan Nepal (see Table 2-5).

Table 2-5: A public survey on environmental pollution in the urban areas of Nepal

Major environmental problem	Percent responses (N=3980 urban residents)
Solid waste	59
Sewage	25
Water pollution	5
Air pollution	7
Other	4

Source:(Sigdel & Koo, 2012)

A lack of civic understanding and weak management by municipalities have intensified environmental challenges in cities in Nepal, with dirty garbage management and removal systems. This attitude is coupled with the habit of dumping waste in areas where no one complains. As a result, piles of dirt can be seen easily in all parts of the city. Cases of open fires were elevated in areas where rubbish collection trucks were unusual or missing because of bad street situations. Burning of waste was also observed as elevated in the areas where rubbish collection was poorer (Post, 2018).

As per West Bank (2015), the Nepal's municipal capacity is under immense pressure because of rapid urbanization and the struggle to address SWM. Of the 700,000 tonnes of waste generated each year in Nepal's municipalities, less than 50 percent is collected. The remaining waste is informally dumped, including on riversides and roadsides (Bank, 2015) .The MSW production and composition of Nepal varies according to the topography and climate. According to the Asian Development Bank (ADB) report for 2011-2012 (ADB, 2013), the normal family every day garbage production was 0.88 kg/HH in the Terai, 0.72 kg/HH for the Hilly area, and 0.49 kg/HH for the Mountain area. Overall, Nepal's average waste generation was 24.74 tonnes/day an increase from 19.89 tonne/day in 2008; per capita waste generation is 0.32kg/day (ADB, 2013).

Municipal or household wastes are commonly generated from a few sources where variable human activity are faced. In Nepal, households generated 75% of complete municipal waste generation (Maskey & Singh, 2017). Household waste generation rates additionally fluctuate depending on financial status. Figure 2-7 show that family units with a higher average spending likewise create a greater quantity of garbage each day. Normal garbage production for families with monthly spending of NRs 40,000 or more produce 0.88 kg/family/day, which is more than twice that of 0.4 kg/family /day waste generation for families with monthly spending of less than NRs 5,000 (SWMTSC, 2017).

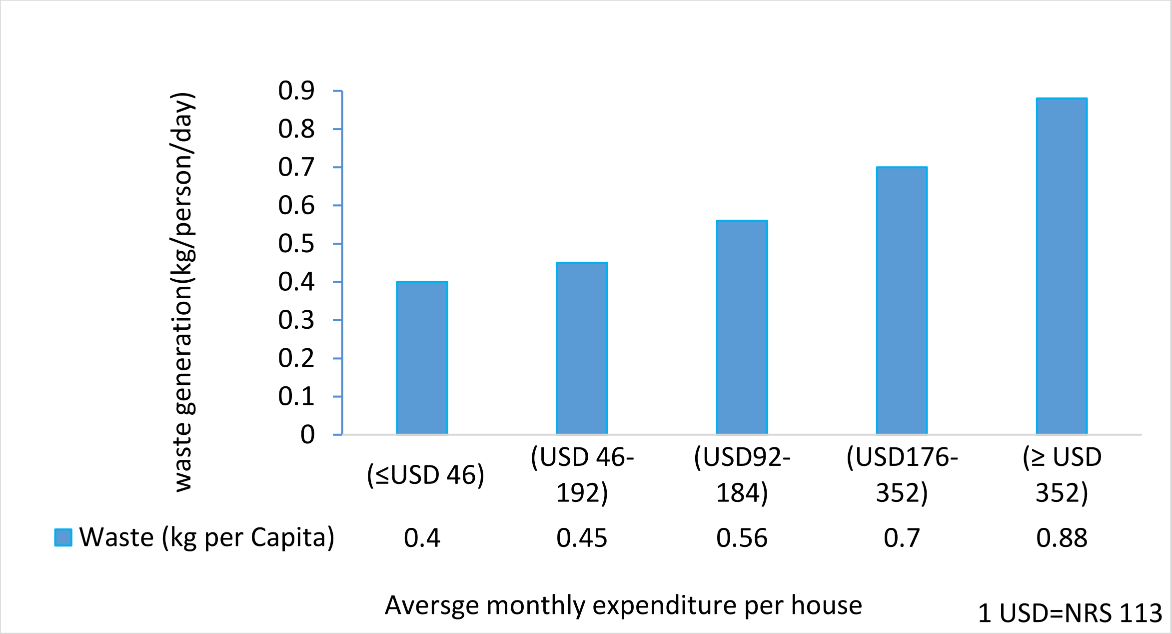

Figure 2-7: Normal family waste generation by monthly spending level (SWMTSC, 2017)

According to UNEP (2001), the main origin of MSW in Nepal is family garbage that differs according to the lifestyle of the household. The projected normal per capita MSW production of a municipality based on the size of the population differs from 0.25 kg per capita to 0.50 per capita (Figure 2-8).

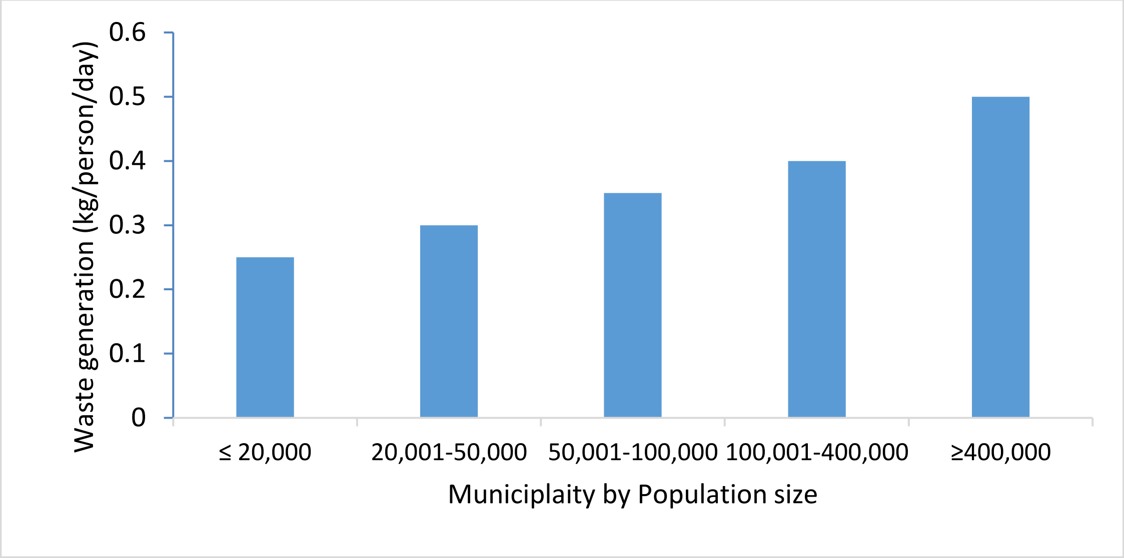

Figure 2-8: Per capita waste production of municipalities in Nepal by population size (UNEP, 2001)

In 1997, the absolute garbage production by 58 regions of Nepal was 835.2 tonnes/day. It contained 83% MSW, 11% agricultural waste and 6% factory waste. The absolute amount per dwelling in the 58 regions was around 3,172,000 tonnes which is about 15% of the total population (UNEP, 2001). As per the overview by the Japan international Cooperation Agency (JICA) in 2004, the complete MSW amount was 1370 tonnes/day by Nepal's municipalities. The review directed by ADB in 2011-2012 detailed the MSW amount at 1435 tonnes/day from 58 municipalities as shown in figure 2-9.

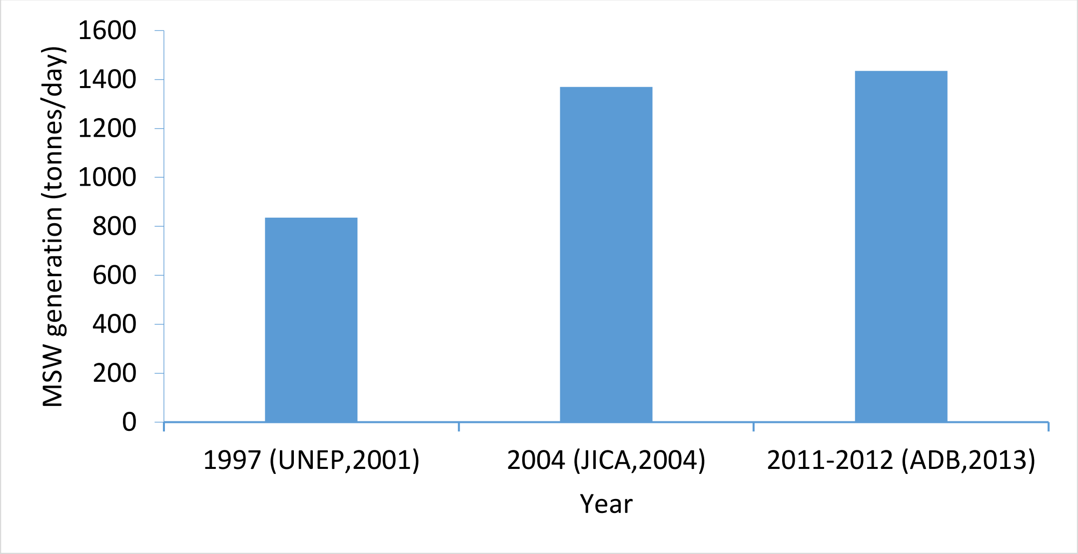

Figure 2-9: A comparison of municipal waste generation in Nepal by year (ADB, 2013)

The waste composition study completed in 2016 by the SWMTSC showed the normal composition of MSW (60 New Municipalities) was determined by combining household, commercial and institutional wastes. When all three significant sources of waste are combined, the general MSW composition is 61% organic waste, 12% plastics, 11% paper, 6% glass, 2% metals, 1% materials, 1% elastic and leather and 6% others. The composition of commercial, household, and institutional waste from 60 new municipalities of Nepal is shown in Figure 2-10.

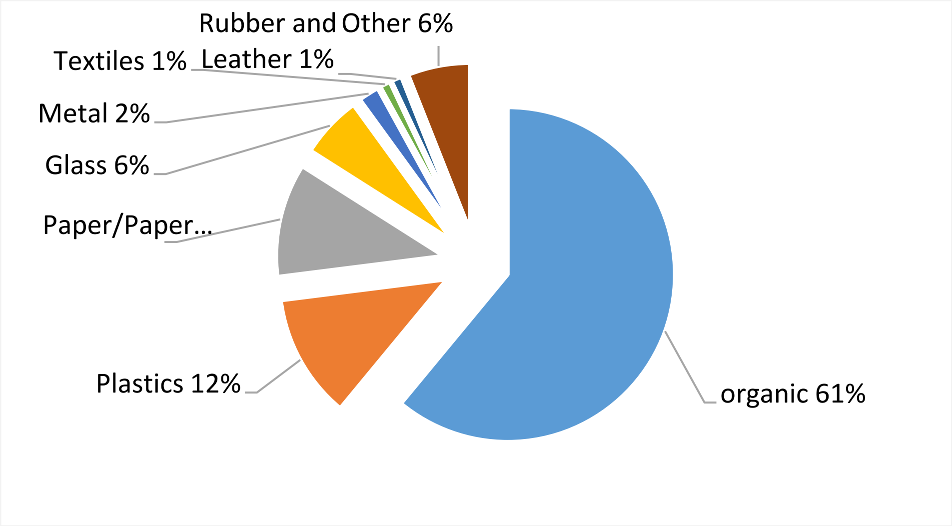

Figure 2-10 : The composition of waste of the new municipalities of Nepal (SWMTSC, 2017)

Solid waste is not the major issue because people have consistently delivered or managed rubbish in some way. The current worry is the changes in quantity and kinds of waste created, and methods of handling (CBS., 2015). The genteral phases of the waste management framework in Nepal are: generation at source; collection; transport/processing and disposal (Gautam, 2011). The main functional elements of MSW are shown in figure 2-11.

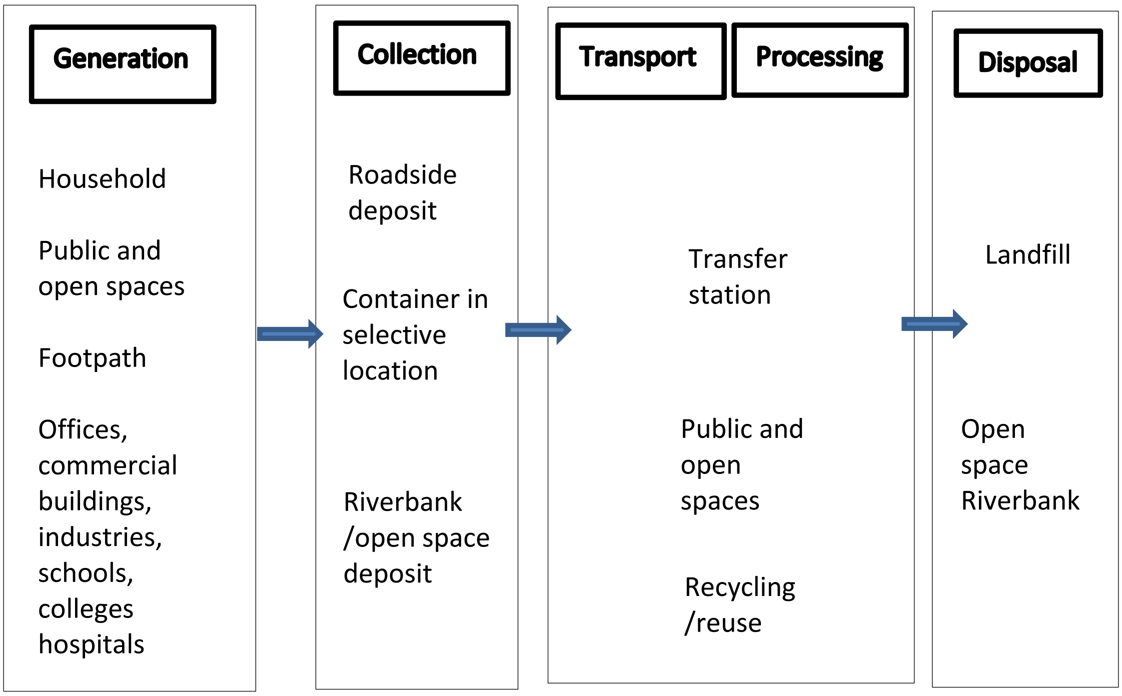

Figure 2-11: Schematic representation of municipal solid waste flow diagram in Nepal (Gautam, 2011)

The waste produced from different sources in the municipalities is gathered and moved to a removal site (either customary open destinations, e.g., riverside, forests, or on a not appropriately arranged and created temporary removal site). This happens consistently in practically 95% of Nepal's municipalities (SWMRC, 2004).

Most municipalities do not have a sanitary landfill disposal site; only 6 out of Nepal's over 58 official municipalities have designed sanitary landfill sites. Most municipalities do not earn any revenue from SWM services, yet SWM is a major contributor to municipal expenditure (Bank, 2015). The random disposal of waste in improvised unloading sites is the most well-known practice for the removal of gathered waste in Nepal. Most municipalities just 'discover' nearby locales that will not be questioned by anyone. Generally, these destinations do not take any careful steps, e.g., cover the material, a leachate collection component, drainage, and are not surrounded by any fencing. All the waste gathered by municipalities is directly unloaded at the riverside with no recovery. The different sorts of removal practices of the 58 districts are presented in Figure 2-12.

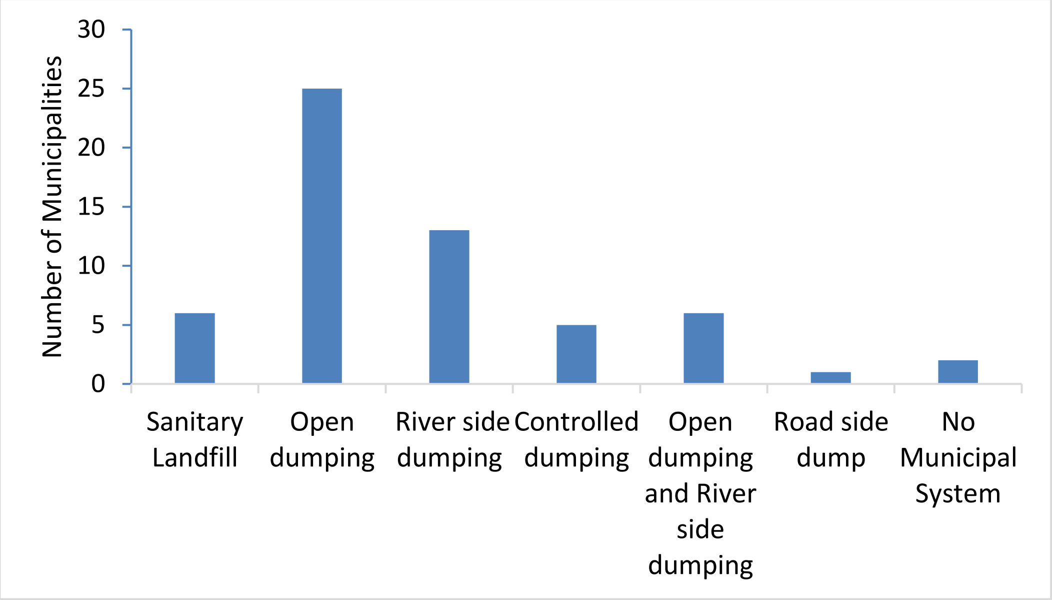

Figure 2-12 :Methods of waste disposal in the municipalities of Nepal (ADB, 2013)

In Nepal, the organic portion of solid waste is commonly greater than the types of inorganic waste. Therefore composting could be the the best SWM option to reduce the landfill waste volume . Between 15% and 100% of rural households compost their organic waste. In metropolitan areas, where less land is available, fewer than 10% of households undertake composting (Sigdel & Koo, 2012).

Composting is the most workable innovation for recycling organic waste in Nepal on the grounds that the innovation is straightforward, reasonable and simple, and the compost item is valuable for agricultural uses. Various composting methods can be used dependent on the amount of waste and space available. Basic oxygen consuming treating composting should be possible in heaps, windrows, pits, or vessels and Vermi Composting. Numerous individuals, especially in the countryside, are associated with treating their waste, i.e. composting, by putting it in heaps or pits and allowing it to decompose. Since over 70% of the soild waste created in Nepal is organic, composting is the best way to manage solid waste. There are no huge fertilizer plants in Nepal, but a couple of municipalities have small compost plants with a capacity to manage around six tonnes of waste per day (Lohani, 2017).

A wide range of paper, e.g., office paper, newsprint, old magazines and cardboard boxes, can be reused in Nepal. The greater part of paper pieces are changed to mash and paper in huge paper factories, e.g., the Bhrikuti Paper Factory. Some small handcraft paper-reusing units are likewise active. These plants take small quantities of scrap paper and produce 'claim to fame' paper (Thapa & Devkota, 1999). Most metal waste, e.g., scrap iron and aluminum, is gathered and reused as the cost of metal piece is typically very high. Thus next to no metal waste winds up in the solid waste stream (Tuladhar, 2004). Nepal has industrial facilities for reusing some regular sorts of plastic like polyethylene (PE) and polyvinyl chloride (PVC). Some different sorts of plastics, e.g., PET containers, can be shipped to India for reusing. Nonetheless, a large part of plastic waste is, as yet, not being reused in the absence of an appropriate system for gathering it separately and the generally low estimated amount of plastic waste (Tuladhar, 2004). Alcohol and soft drink bottles are, by and large, gathered and reused but reusing other glass waste is low resulting in the low value of glass waste in the scrap market. Nepal had a glass reusing plant at Simara, but it is presently shut and all glass waste must be shipped to India for reusing (Thapa & Devkota, 1999).

2.4.2 Waste generation and management in Kathmandu Metropolitan City

Kathmandu, the capital of Nepal, is a highly developed city. Expanding urbanization has heightened ecological pressure including disorderly garbage removal. There are limited data on the amount and generation rates of all MSW in KMC (Dangi et al., 2011). For instance, KMC simply checks the waste that is municipally collected for disposal. Family unit waste collected by the municipal service is usually confused as all MSW created. Piles of waste are seen every where in open spaces, walkways and internal streets. Despite this, the waste amount has been expanding as population development continues expanding in KMC. Currently, roughly 600 to 700 tonnes of waste is created each day in KMC. The per capita waste produced in KMC is 0.23 kg/individual (ADB, 2013).

KMC waste mangement has shown up as a significant difficulty in many years since the Sisdole Landfill has been unable to accept the expanding waste volume from KMC, in particular organic waste which is a significant component of that waste. Further, KMC has inadequately overseen MSW, which causes ecological and public concern. Hence, there is a pressing need to deal with this MSW challenge (ADB, 2013; Bhattarai & Conway, 2021; Pathak, 2017; Raj GC, 2018).

The issue of solid waste management in KMC on the edge of the Kathmandu Valley is not as serious as in the regions in the valley. Kathmandu Valley has about 0.5% of Nepal's land area yet it has 10% of the population. Because of this, the management of solid waste and the difficulties experienced by the regions in Kathmandu Valley are more remarkable than elsewhere (Pokhrel & Viraraghavan, 2005). The Sisdole Landfill, which has been the main site for the three significant cities in the Kathmandu Valley to dispose of their waste through the previous 12 years, has nearly arrived at its most extreme limit. The Nepal government is launching the new Banchare Danda landfill site, but it is still months from being ready. No progress has yet been made on the building at the landfill site that is expected to be used to manage the waste of Kathmandu Valley for the next 100 years (Khabarhub, 2020).

In 1990, with financial support from the German Technical Cooperation Agency, the municipalities started to work with SWMRMC, a government body under the Ministry of Local Development, collecting and transporting to landfill and partly recycling the waste. In 1995, the municipalities took full responsibility when SWMRMC closed all it activities in waste management (Anderzen & Blees, 2003). City waste management in Kathmandu, especially the establishment of a landfill site, has been a problem for a long time. The present method of unlawful dumping of solid waste on riverbanks has generated a major environmental and public health problem. The data show that 70% of the solid wastes produced in Kathmandu Valley are organic (Pokhrel & Viraraghavan, 2005).

Because of rapid urbanization, KMC is facing an increasing rate of MSW generation. From 2001 to 2011, the population of KMC increased by 4.76% per year (CBS., 2011a). During the same period, waste generation increased by 5.36% per year (Dangi et al., 2011). This has placed exceptional pressure on the city's limited resources and public services creating MSW management problems (Dangi et al., 2011). Different reports have indicated that solid waste production in city areas differs from one municipality to another, ranging from 0.25 kg to 0.5 kg per capita with an average of 0.37 kg per capita (Ministry of Science Technology and Environment, 2014). Dangi et al. (2011) reported the normal family waste production in KMC was around 0.5 kg per capita for a population of 750,597 during late 2010. In the 2011 Census, the number of inhabitants in KMC was over 1 million and the normal solid waste generation was 0.3 kg per capita. A more recent MSW production and composition study in KMC suggested that the MSW produced by households was about 0.38 kg per capita (Dahal, 2015).

Studies by SWMRM (2004), ADB (2013) and Dahal (2015) compared the quantity of waste generated and its composition KMC with the national average (see Table 2-6 and Table 2-7).

Table 2-6: A comparison of KMC's MSW generation with the national municipal average

	2003		2008		2013	
Sources	Nepal	KMC	Nepal	KMC	Nepal	KMC
HH waste production (kg/person/day)	0.25	0.39	0.27	0.38	0.17	0.23
Total waste production (Tonnes/day)	23.60	300.00	19.89	336.00	24.74	466.14
Total waste collection (Tonnes/day)	11.79	250.00	13.05	306.00	18.27	405.00
Collection Efficiency (%)	49.95	83.00	65.61	91.00	73.85	86.90

Sources: SWMRM (2004), ADB (2013) and Dahal (2015)

Table 2-7: A composition comparison of KMC's MSW with the national municipal average

	2003		2008		2013	
Waste Composition (%)	Nepal Average (%)	KMC (%)	Nepal Average (%)	KMC (%)	Nepal Average (%)	KMC (%)
Organic	62.00	67.00	61.30	68.00	66.20	64.24
Plastic	7.30	16.00	8.40	13.00	12.00	15.96
Paper and paper products	8.20	10.00	8.60	10.00	9.00	8.66
Glass	2.40	1.00	4.10	4.00	3.10	3.75
Metal	1.20	1.00	1.30	1.00	1.90	1.72
Textile	1.90	4.00	1.70	1.00	2.20	3.40
Rubber and Leather	0.90	0.24	1.10	1.00	1.10	1.12
Others	16.10	0.24	13.50	1.00	4.50	1.15

Sources: SWMRM (2004), ADB (2013) and Dahal (2015)

The daily waste generation from various sources was 516 tonnes/day in 2015 (Udm, 2015) with waste collection effectiveness at 86.9% (ADB, 2013). In 2015, the basic origin of KMC solid waste was household waste (50%) followed by commercial (44%) and institutional (6%). The largest component of the waste was organic followed by plastics and paper (Dangi et al., 2011).

MSW in KMC is usually put in storage at households in polythene-sacks or disposed of into plastic buckets. Wastes, independent of type, are by and large kept in local area containers, road corners, riversides, and open spaces, either by the inhabitants or by waste labourers from non-government organizations (NGOs), community-based organizations (CBOs), or private collectors from households. As a rule, the city authority gathers waste from the bulk storage (roadside deposits, containers and open space deposits) and stores it at assigned removal landfill locales (Gautam, 2011). SWM is weak in KMC Nepal. The waste is gathered as mixed material, not separated, and is brought to a transfer station (Teku) and directly transported to the Sisdole Landfill. Material recovery is on an exceptionally limited scale after being inspected by waste pickers. The waste picker sells the paper, plastic, metals, glass bottles to a scrap vendor (Malla et al., 2019).

Following the implementation of the Local Self Governance Act 1999, all regions, municipalities, and community developments are liable for the management of MSW at the neighbourhood level. KMC, since its foundation in 1919, has the fundamental obligation to deal with the waste of the entire city from collection to last removal (Ranabhat, 2015). KMC is the focal organization accountable for handling the waste generated in KMC by collecting and disposing of it. A total of 1,320 staff are engaged to manage the solid waste (Udm, 2015). These staff are spread across 32 ward offices, each has a tractor or tipper and 20-30 sweepers, amounting to 927 street sweepers. Some private sector organisations and NGOs also have sweepers to clean the streets (Udm, 2015).

The KMC office now has 13 divisions and 33 sections. The Environment Department is liable for overseeing the solid waste that is created in the city. Three sections in the Environment Department are: The Solid Waste Management (SWM) Section, the Mechanical Section; and the Urban Environmental Section. KMC is the one municipality in Nepal that has a group with the responsibility to thoroughly address various sections of SWM. Figure 2-13 presents KMC's institutional structure for MSWM. MSWM is the environment security program, consequently, the Environment Department is responsible for the MSWM work. The MSW area is answerable for managing MSWM in KMC. The MSWM section is especially focussed on normal activities under a different part of MSWM and is additionally split into the MSWM portion, Landfill site Management Section, and the Activities Mobilization Section (Bhattarai & Conway, 2021).

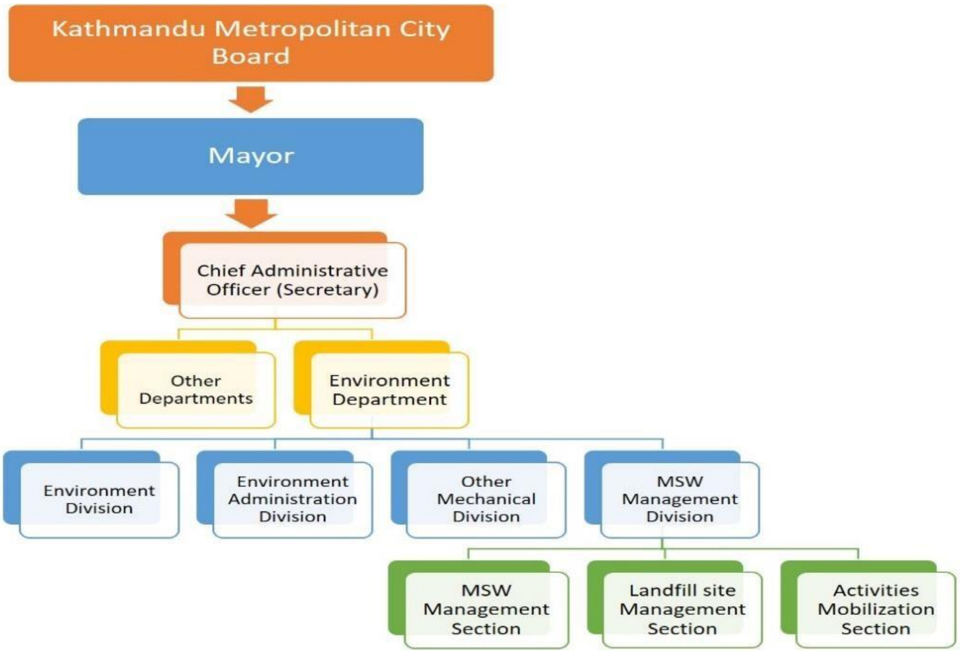

Figure 2-13:Organizational structure of the Kathmandu Environment Department (Silwal, 2019)

The waste collection techniques used in the greater part of the Nepal municipalities containing KMC are house to house collection, truck collection, and pavement collection from a waste deposit area or open waste piles. KMC is answerable for the MSW collection and transport to landfill from 32 wards of KMC (Silwal, 2019). The waste from families is sent away in family containers unsegregated. Some waste is thrown away locally at collection points on the side of the road, empty spaces or on riverbanks. The greater part of the waste produced goes directly to the landfill site called 'Sisdole Landfill Site', situated in Sisdole, which is around 28 km from Kathmandu City. The landfill site was set up with the help of JICA in 2005 with a life of three years. There is no other option for rubbish removal; waste from the whole Kathmandu Valley is being unloaded there (Singh et al., 2015). The progression of waste and recyclable materials in KMC appears in Figure 2-14. In KMC, a lot of waste is delivered first to a transfer station (Teku) and then shipped to the Sisdole Landfill.

The SWM facilities have regularly neglected to keep up with the huge quantity of solid waste generated in the city. Recently, private companies have started sweeping streets and organizing house-to-house collection of waste in some areas under a public-private partnership programme. They collect the waste from the production point and transfer it to allocated waste collection stations, temporary storage or the last removal site (Alam et al., 2008). Teku is used to store waste; no recycling is done here. The current system for waste collection and transport in KMC is shown in figure 2-14.

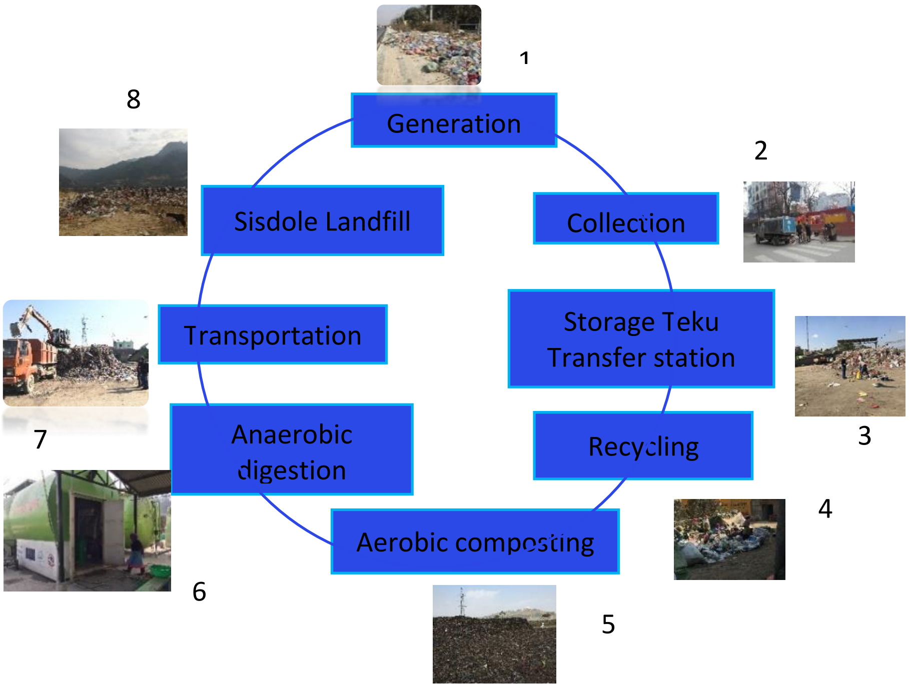

Figure 2-14: The flow of waste and recyclable materials in Kathmandu City.

Over time, conventional strategies for taking care of waste have become insufficient, improper, and incompetent to adapt to the developing, expanded issues of SWM that came about because of fast metropolitan population development in KMC (Bhattarai & Conway, 2021). For example, in KMC the generated waste transfer operation occurs at roadsides or empty yards. The waste collected is intermingled; it is rarely source separated by private collectors for composting. Recyclable materials like plastics, paper, metal, and glass are sold by the generators or are taken by the waste pickers from the roadside waste stack, Teku storage station or a landfill site. The progression of waste and recyclable materials in KMC appears in Figure 2-15 (Gautam, 2011). Figure 2-15 details a schematic picture of the solid waste stream in KMC.

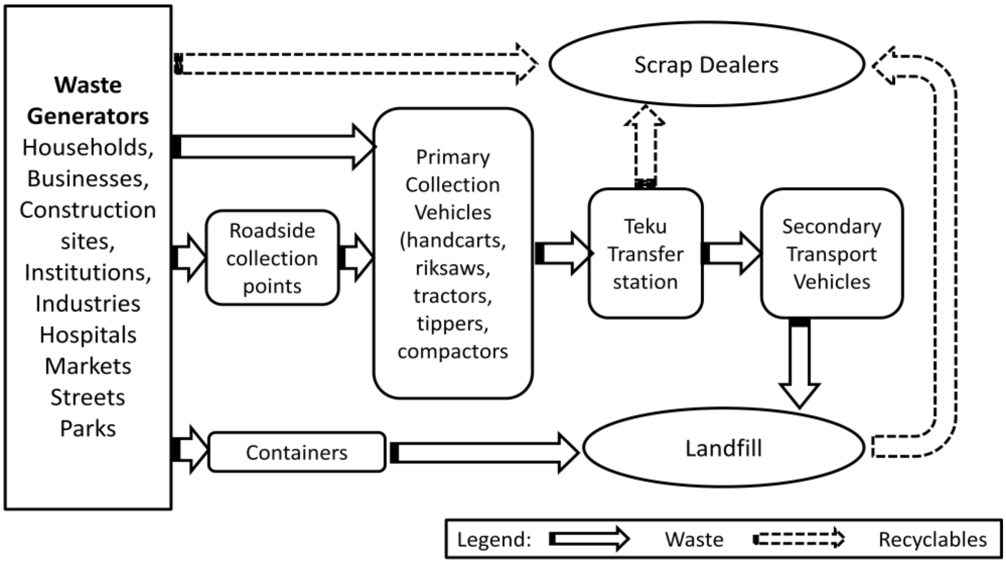

Figure 2-15: Waste generation and recyclable material flow in Kathmandu City (Poudel, 2012)

Primary and secondary collection services are accessible for gathering waste from houses in KMC. In primary collection, families place their generated solid waste into a garbage bucket that is then transferred to the storage point or landfill location by KMC. In secondary collection, solid waste is accumulated from roadsides or community points and transported to the transfer point or final disposal site (Alam et al., 2006) as shown in Figure 2-16 and Figure 2-17.

Figure 2-16: Door-to-door collection using a rickshaw (Source: Field visit (2018))

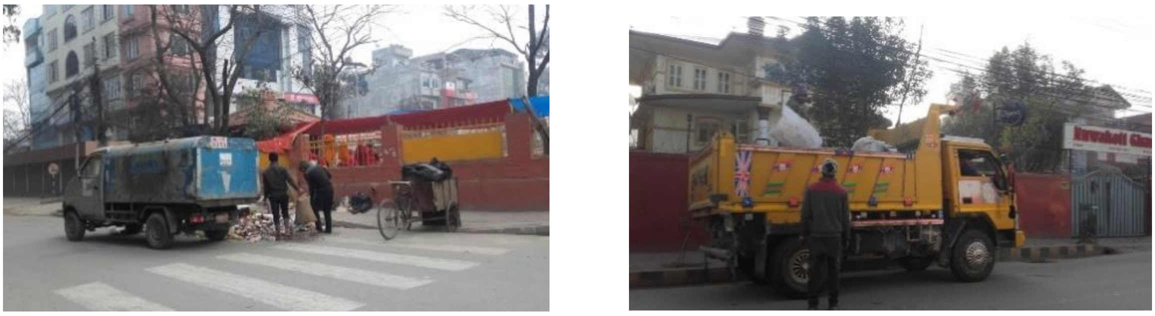

Figure 2-17: The transfer station (left) and collecting waste in the block using a tipper (right).

The organic element of waste has been noted as high as 61.6% at Sisdole Landfill. Because of this high organic content, there is potential for biogas generation (Adhikari, 2019). Biogas generation depends on the moisture content and volatile solids present in the total organic waste. According to the existing Sisdole Landfill organic compostion the theortical methane yield was calculated as 0.35 cum/kg VS (AEPC, 2014). This is 50% to 75% methane (Igoni et al., 2008). At an average of 65% methane at Sisdole, the energy generated from total biogas is 6 Kwh/m^3 (AEPC, 2014). This generation of electricity (resource recovery) reduces the emissions of GHG.

Figure 2-18: KMC’s bio plant at Teku has started producing fuel.

In June, 2017 KMC formally began producing energy from bio-degradable waste as shown in Figure 2-18. Under the Integrated Sustainable SWM Project that started about four years ago, KMC aims to produce 14 KW of electricity, 300 kg of organic fertilizer and 13,500 litres of water on a daily basis from three metric tonnes of organic material. The project has a joint investment of Rs18.2 million from KMC and the European Union (EU) (Post, 2017). There are no formal compost plants working in any region and there are not many privately owned businesses getting compost from organic waste. BioComp Nepal is one model that gathers around 20-50 tonnes organic discard per in KMC vegetable markets and makes compost manure (Raj GC, 2018). This project was started by the author in 2012 with the help of the Swiss My climate organization until now.

2.5 Summary

Populations are increasing in many countries around the world, including Nepal, resulting in increasing amounts of waste amount, putting more pressure on solid waste management. The need for efficient sloid waste management is more pressing in least developed countries like Nepal. The most common option for SWM is landfilling; other options are composting, anaerobic digestion and incineration. The capacity of landfill waste volume in Nepal and KMC is in danger of being exceeded. In addition, landfill leads to GHG emissions. Good estimates of solid waste production and GHG emissions are vital for efficient solid waste management. There are different models to estimate GHG emissions such as DM, FOD and LandGEM. In Nepal one third of the waste is generated by households; commercial and institutions produces less. There is a high percentage of organic waste in KMC Waste but there is no formal composting plant on a big scale.

Chapter 3
Material and Methods

3.1 Introduction

This chapter presents the research approach and exploration strategies used in this investigation. It starts with the study area and an outline of the Sisdole Landfill followed by details of the research methods including the waste generation and composition estimation methods applied in the household survey, the KMC waste management scenarios, and quantification of emissions using the Boyle's Stoichiometric model, IPCC default, IPCC FOD, NV Afalzorg (FOD modified), LandGEM, and input parameters for this study area to be used in the estimation of GHG emissions. It also discusses the waste to energy estimate by Dulong's equation method as mentioned in chapter 2. Finally, the chapter is summarised.

3.2 Conceptual framework

The main concept behind this study is environmentally friendly SWM by assessing MSW generation and composition based on increasing waste production and identifying the optimal recycle and reuse scenarios for Municipal Waste Management to minimise greenhouse gases.

The idea of sustainable solid waste is focused on process and is in three phases to answer the study objectives in Section 1.5. In the principal phase, the three research objectives were created to focus on the effects of changes in assessment of MSW generation and composition and the factors that impact on the Kathmandu waste management system. This phase also brought out issues about the impact of household waste and other kinds of waste. The final question developed in this phase concerns the high 75% amount of household waste rather than the 25% of other types of waste.

The second phase identified the different SWM scenarios in terms of GHG emissions approaches (quantitative analysis) in Kathmandu City that were used to collect the data from the municipal authority to reach the study objectives, respond to study queries and estimate the GHG emissions (CH_4 and CO_2) using a life cycle assessment tool and the IPCC mathematical model that is main contributor to global warming study.

Phase three of the study involved quantification of the GHG emissions of the existing Sisdole Landfill area where Kathmandu disposes more waste than other municipalities in the Kathmandu valley based on data from the Sisdole Landfill Authority.

The conceptual framework created for the examination is presented in Figure 3-1. The study used various strategies and procedures. The specific approaches are discussed in each independent chapter.

The examination was conducted on field data from a visit to KMC, a household survey and landfill data from the Sisdole Landfill site. Comprehensive explanations, sources and information sets are referenced in each separate chapter.

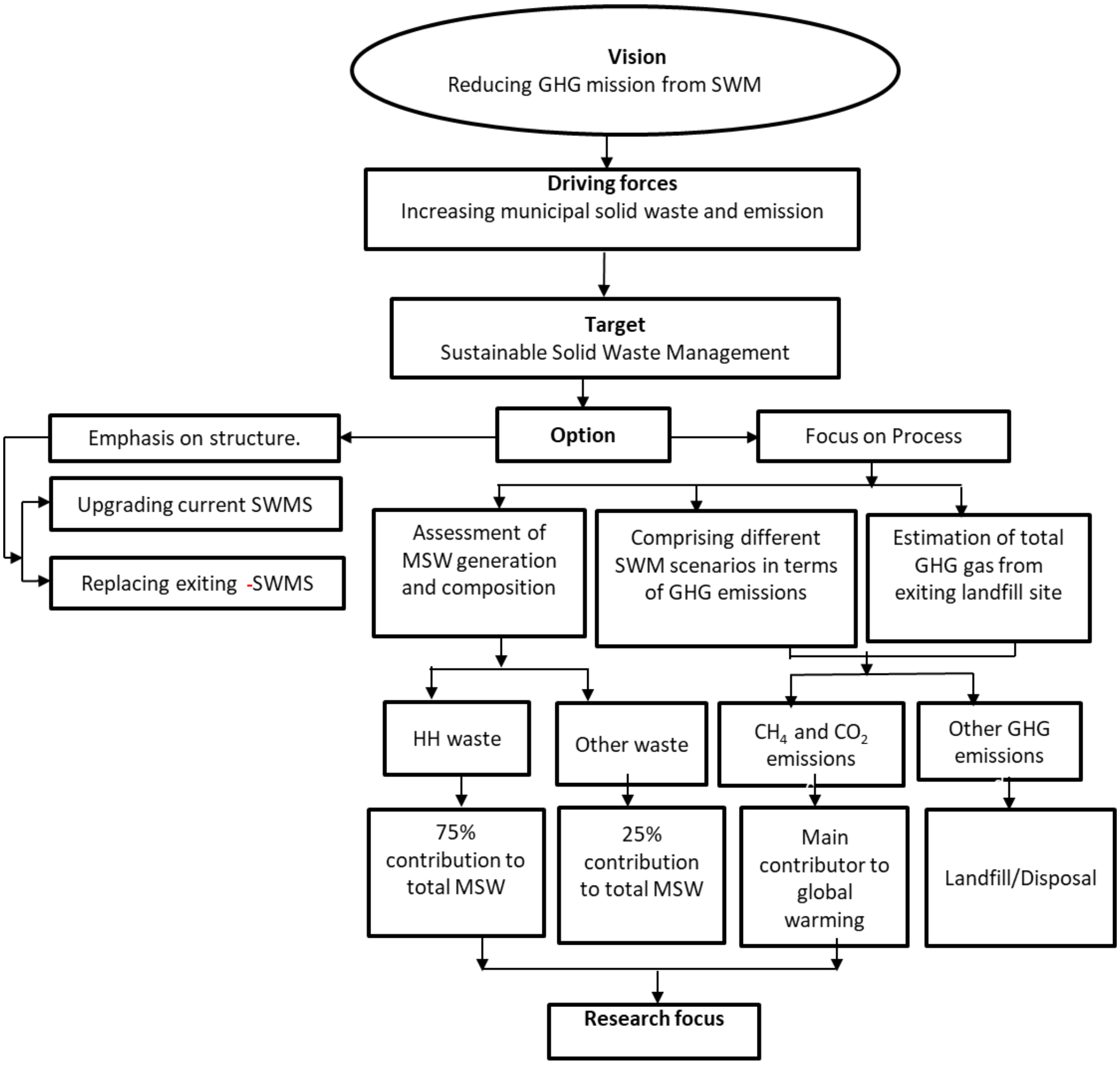

Figure 3-1: The conceptual structure of this study.

3.3 Study area

The field study was done at two placess: 1) Kathmandu Metropolitant City (KMC) and 2) the Sisdole Landfill. In KMC, solid waste generation and composition was estimated by a household survey. Methane emissions in proposed different solid waste management scenarios were compared with the existing scenario by using the IPCC default and first order modified method. In Sisdole landfill site, methane gas emissions from solid waste were estimated using the IPCC default, first order decay, LandGEM and Boyle methods.

3.3.1 Kathmandu Metropolitant City (KMC)

The study area area, Kathmandu Metropolitan City (85° 20’ East and 27° 42' north), lies in the Kathmandu Valley, Nepal. It covers an area of 50.67 km^2. The elevation of Kathmandu is 1,350 metres above mean sea level (DRMP, 2005). The Kathmandu Basin has a gentle climate most of the time with summer temperatures ranging from 19-27°C and winter temperatures ranging from 2-20°C. Total annual rainfall in the area is 1,505 mm (Pant & Dangol, 2009).

In the last 20 years, the population of the KMC has grown at a yearly growth rate of 4.82% from 671,846 in 2001 to 1,006,656 in 2011 (CBS., 2011b). The total number of households in KMC is 154,302. There are 32 wards in KMC and, of them, the largest population is in ward 16 with 84,441 people and 22,715 households as shown in Figure 3-2. The lowest population is in ward 26 with 4,133 people and 947 households. The population intensity of KMC is 20,289 people per km^2 (CBS., 2011b) and the normal family size is 3.94, which is below the national average of 4.21 (CBS., 2014). Because of rapid population growth and growth of the city’s quantity of garbage generated is so rapidly increasing, there is a demand for proper SWM.

Figure 3-3 shows a strong linear correlation between garbage production and population with regression coefficient $R^2 = 0.99$. Based on this regression the waste quantity by 2025 is predicted to be 271,965 tonnes.

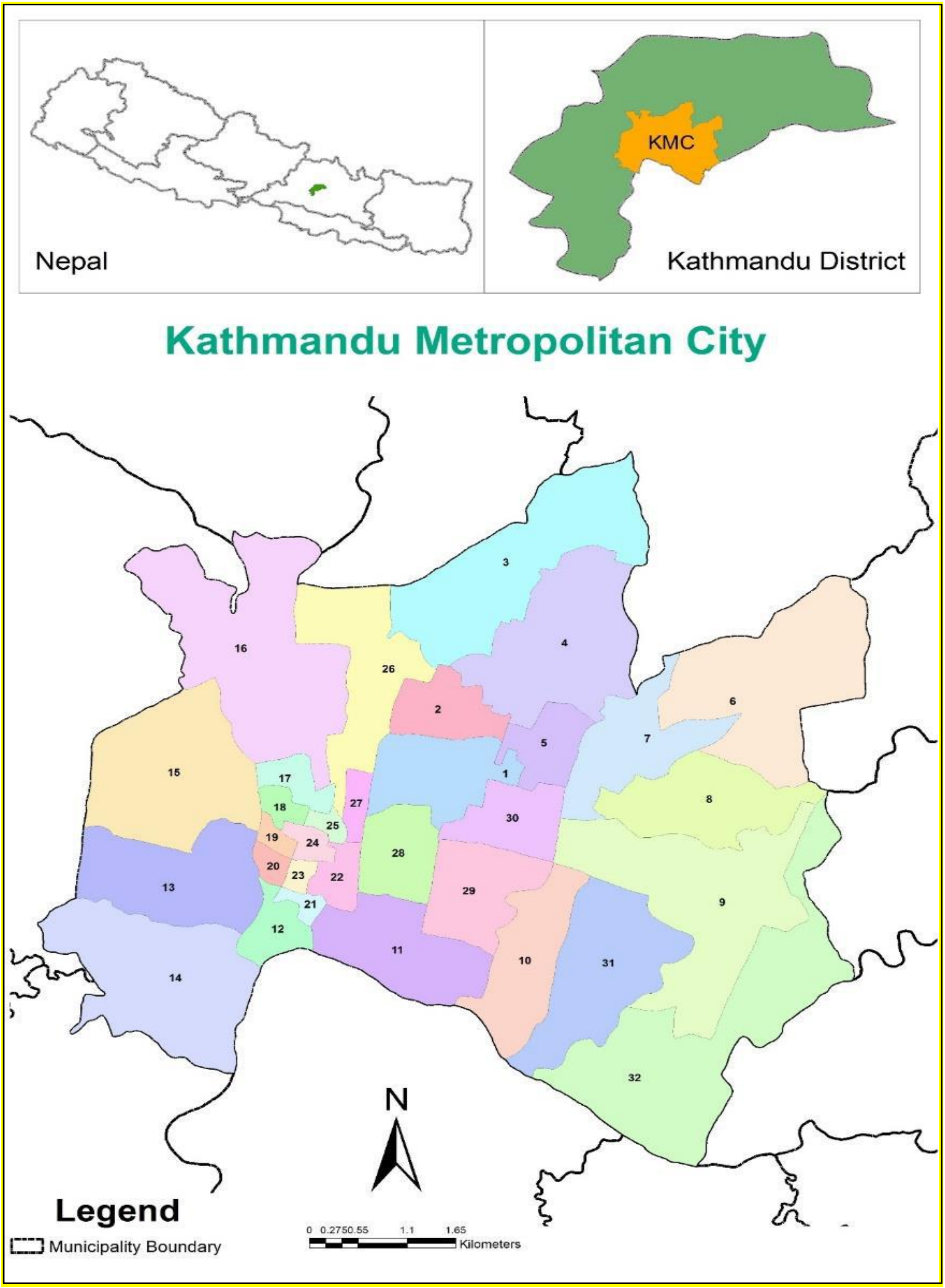

Figure 3-2: The study area, Kathmandu, Nepal (KMC, 2016)

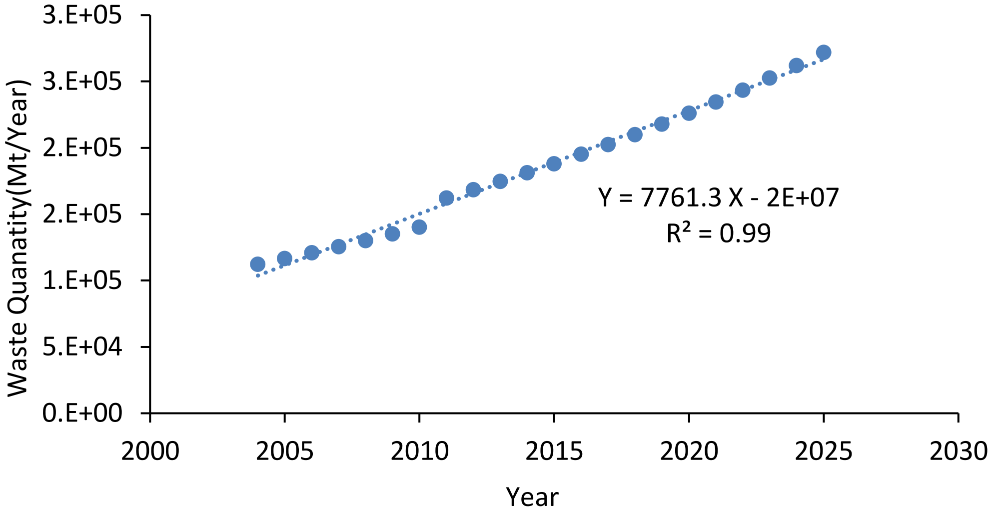

Figure 3-3: Yearly waste generation trend in Kathmandu city, Nepal

3.3.2 Sisdole Landfill site

The law gives the duty supervising and working the landfill site to KMC. Waste produced in KMC is discarded at the Sisdole Landfill site of the Okharpauwa Village Development Committee (VDC) in the region of Nuwakot. The site is around 28 km away from the Teku Transfer Center and has been active since 2005. At the outset, the site was proposed to last for 3 years. Presently, it has re-examined the assessment time to 10 years by accomplishing some development work, but at the same time it proceeds to shutting of the site in 2025. On a normal day, 111 trucks/trips (21 from the KMC, 85 from private area waste gatherers and 5 from Lalitpur Sub-Metropolitan City) of waste are shipped to Sisdole. The main features of the Sisdole Landfill are given in Table 3-1.

Table 3-1: The main features of the Sisdole Landfill site, Kathmandu, Nepal

Location	Okharpauwa
Latitude	27 46°33.69’’ N
Longitude	85°14’39.58’’ E
Year Opened	2005
Year of Closing	Continues but expected to shut in 2025
Total area	15 hectares
Landfill area	2 hectares
Landfill capacity	27500 m^3
Soil cover	5-10 cm
Waste height	7-10 m
Elevation	1329 m see level

Sisdole landfill is in the Nuwakot region near Kathmandu Valley. It has a continental climate with 1505 mm/year of precipitation and an average air temperature of 18.1°C. Figure 3-4 presents the climate situation in the Kathmandu Valley.

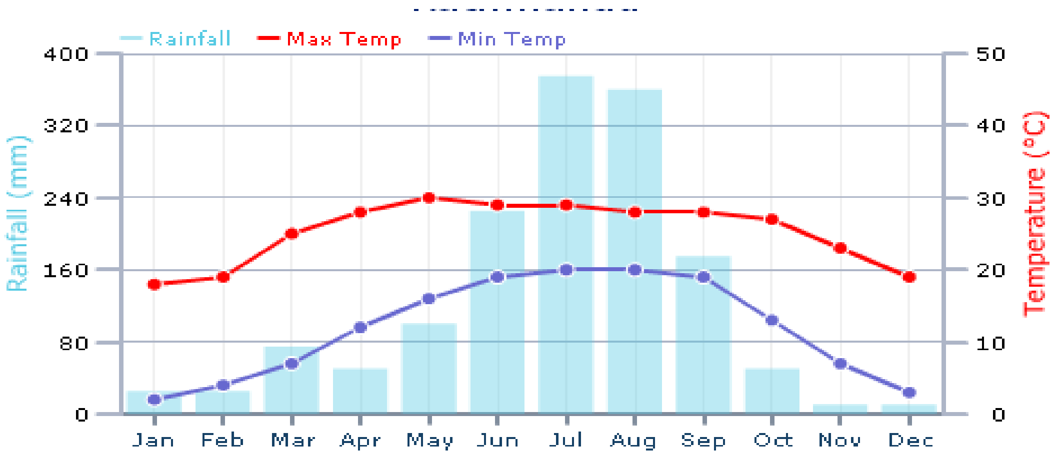

Figure 3-4: Mean monthly air temperature and rainfall in Kathmandu Valley.

Source: Temperature Climate and Weather.htm (2017)

Information on waste generation for the two municipalities of Kathmandu and Lalitpur was gathered from 2005 to 2018 from the landfill site and forecasts of garbage production were estimated data using the geometric mean method to calculate the population trailed and increasing per capita waste production. The annual quantity of disposal garbage in the semi anaerobic landfill at Sisdole was around 235,263 tonnes in 2018. In total, about 2,492,847 tonnes of waste were unloaded at Sisdole landfill from 2005–2018. More data are presented in Table 3-2.

Table 3-2: Waste disposal at the Sisdole Landfill 2005–2018

No.	Year	Waste Dumping (year/tonnes)	Accumulated Disposed Waste (tonnes)
1	2005	126,283	126,283
2	2006	131,018	257,301
3	2007	135,932	393,233
4	2008	141,029	534,262
5	2009	146,318	680,579
6	2010	151,804	832,384
7	2011	181,818	1,014,202
8	2012	188,636	1,202,838
9	2013	195,710	1,398,548
10	2014	203,049	1,601,597
11	2015	210,663	1,812,261
12	2016	218,563	2,030,824
13	2017	226,760	2,257,584
14	2018	235,263	2,492,847

As indicated by the environment audit report from the Ministry of Urban Planning and Administration (Udm, 2015), the daily average waste is 0.3 kg/day/individual for Kathmandu and 0.37 kg/day/individual for Lalitpur.

The composition of the solid waste is an important factor affecting the GHG discharge from the landfill (Babel & Vilaysouk, 2016). As indicated by the investigation of the waste composition by a landfill expert in 2019 for Sisdole, it has a high oragnic waste proportion. The principal parts of the waste are food waste representing 61.6% and plastic at 10% (Adhikari, 2019). The solid waste composition at the Sisdole landfill site is presented in Figure 3-5.

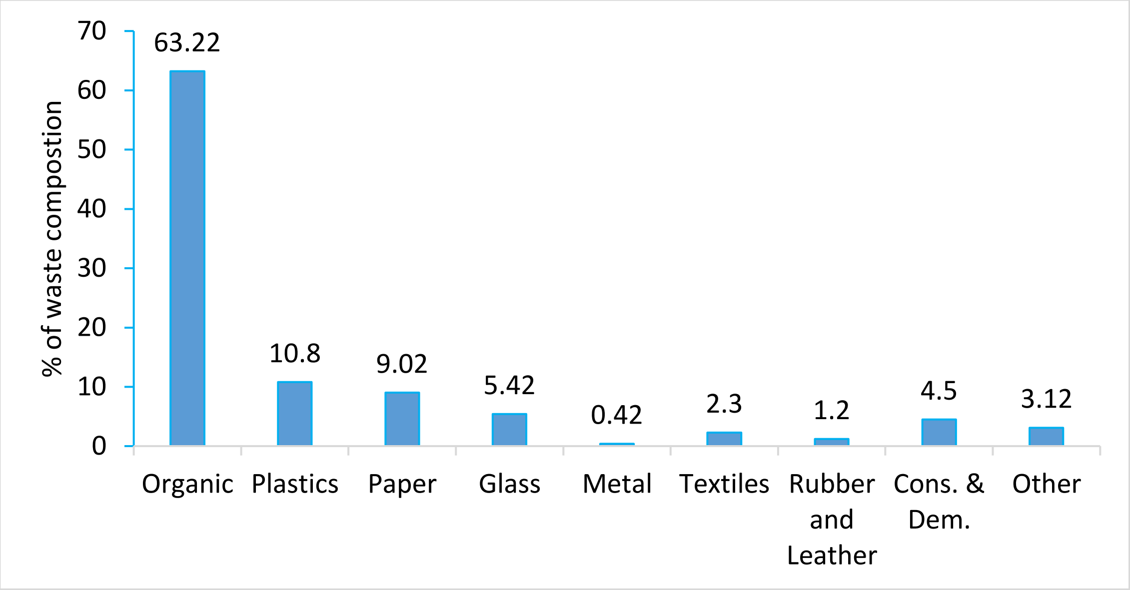

Figure 3-5: The waste composition of the Sisdole Landfill (mass %)

The above waste disposal quantity and waste compostion data are used to estimate GHG discharge from MSW landfill site in Kathmandu.

3.4 Estimating waste generation and composition

Increasing metropolitan solid waste and an absence of concrete information sources is a developing worry in city regions of developing nations like Kathmandu. The goal of this study is to estimate family solid waste production and its composition, and assess the socioeconomic factors affecting family garbage production. Using stratified sampling, 288 families were chosen from the 32 metropolitan wards of KMC for a household survey. Quantification of total waste and its composition was undertaken for each household using digital scales. Socioeconomic variables affecting household waste generation were analyzed by using regression analysis.

3.4.1 Household survey

The study highlight is a focus on the assessment of waste’s composition, various scenarios, and emissions from landfill. To better understand waste management scenarios, we need-to-know the city’s waste generation and its composition. Municipalities’ records show inconsistency and limited availability of recent data and verification of previous years' data, so this study was undertaken by a household survey of all wards with selected households.

This study depends on the primary data from the household survey. The survey focuses only on households rather commercial and institutional areas because, in Nepal, household waste is about 75% of total municipal waste (Maskey et al., 2016) . A study method that consolidates at least two tactics to collect information, a mixed mode survey strategy, was used in this investigation (Baum et al., 2012). The mixed mode survey technique used in this study comprises first dispersing copies of the questionnaire, so families knew about the inquiry and afterwards finishing the survey interview by posing the inquiries directly in their individual home. The questionnaire was set up to target waste management practices including the amount of waste generated and its composition and household head information, looking for specific answers. Consequently, a one-to-one interview was the proper method for the household survey.

The questionnaire was distributed to 300 households in 32 different wards (each ward had a minimum of 4 to a maximum 25 questionnaires distributed randomly depending on the number of households in each ward) whose physical addresses were obtained from KMC. The questionnaire requested that householders participate in the survey. A total of 288 households agreed to be surveyed and were interviewed between November 2019 and July 2020.

The survey questionnaire was developed stage by stage by checking with numerous researchers, appropriate specialists at Lincoln University, and other agencies including Christchurch Waste Management, Aqualinc Research Limited New Zealand and the Solid Waste Resources Mobilization Centre, Nepal, before the survey. The questionnaire was pre-tested on some chosen family units. The pre-test survey information (pilot study) was excluded from the final information. To administer the survey, endorsement was obtained from the Human Ethics Committee, Lincoln University, Christchurch, New Zealand. Before conducting survey, consent was obtained from the person responsible for household management (household head). In this study children less than 10 years old were not considered.

This household survey was a semi-structured questionnaire (see Appendix A1, A2, A3, A4 and A5) including single responses. The questionnaire (see Appendix A4) included personal information (e.g., age, education level and income) along with other questions to obtain information on total daily waste generation, its composition and collection method. Since waste storage and separation determine the feasibility of recycling and composting in a financially and environmentally sustainable manner, this part is crucial in the MSWM framework. Therefore, the respondents were posed an important question concerning their understanding of and habits in segregating solid waste and questions about waste collection frequency, collection tariff and the municipality's management system. All surveys were done after formal oral consent from respondents was obtained after clarifying the study's objective and method. Meetings went from 30 – 60 minutes depending on family size and waste sorting by the family unit, and the profundity of data given. One-to-one interviews were completed at the respondent's home.

The questionnaire was designed to find any relationship between waste generation and various variables such as income, family size, education level and age, because various studies, e.g., Maskey et al. (2016), have suggested that waste generation activities vary with those variables. The quantification of total waste and its composition was undertaken for each household using digital scales.

For reliability and to find the overall situation for the population, Equation 3-1 was used to compute the sample size. The formula is applicable for populations of 10,000 or more (Grande, 2016):

$$n \geq \frac{p(1-p)Z^2}{d^2} \qquad \text{Eq [3-1]}$$

where: n is the minimum test size; z is the value from the standard normal distribution (1.645 with a 90% level of confidence); p is the expected probability, it affects in a community larger than 10,000; and d is the maximum allowable deviation or estimate error, i.e., ±5% precision. Based on the formula, the minimum sample size required for this study was 227. Each household had an equal opportunity to be chosen in the study to ascertain representative views.

3.4.2 Data analysis

All completed questionnaires were coded before the results were entered into a spreadsheet database. Data processing and analysis were done with Excel software. Simple statistical tools like number, percentage, mean, standard deviation, regression model, average and ratios, were used to interpret the findings. The variables used in this study are discussed below.

Household size

Household size (HH) is associated with waste production because of its effect on eating and consumption behaviours (Liu et al., 2019). Afroz et al. (2011) showed that family waste production is highly significantly affected by household size. Changes in household living patterns and demographic attributes impact waste generation. Household size is directly linked to waste generation with larger households naturally producing more waste (Bandara et al., 2007; Mazzanti et al., 2008; Thanh et al., 2010). Bureecam and Chaisomphob (2015) found that population intensity, the family size and the size of the city were the major influences determining the MSW production rate in Thailand. For the Philippines, Jenkins (1993) suggested that smaller families generated more waste per capita whereas Cailas et al. (1993); (Rhyner et al., 1976) found no effect in Illinois, USA. This study intends to discover the impact of family size on waste production.

Age

Kayode and Omole (2011) found a negative effect of age in Nigeria; older people produced less waste, whereas Maskey et al. (2016) found the age of household's oldest person had a significant positive relationship with waste generation in the Philippines. In emerging countries, Jenkins (1993) highlighted a positive correlation between waste production and age. Richardson and Havlicek Jr (1978) indicated that those who were middle aged rather than young or old created more waste. This variable is to see if there is a correlation between age and waste production.

Education level

Education level potentially plays a key role in a household's decision on how to manage its waste. Higher education has been associated with lower waste generation (Monavari et al., 2012) and with an increase in separation and recycling (Duggal et al., 1991); (Reschovsky & Stone, 1994);(Jenkins et al., 2003) ; (Ferrara & Missios, 2005); (Callan & Thomas, 2006). Kayode and Omole (2011) found a positive effect of educational level on waste generation. Sujauddin et al. (2008) showed a positive effect of education level on garbage production in Bangladesh. This study considers household education level as the education level of the oldest person in the family to investigate any relationship between education level and waste generation.

Income

Various studies have shown how socio-economic parameters affect household waste generation. There is evidence that higher income households generate more waste (Afroz et al., 2011; Bandara et al., 2007; Johnstone & Labonne, 2004). Medina (1997) found that waste generation is directly associated with the income level of families, higher-income individuals use more items, and their waste incorporates more recyclable things. Growth in the income level prompts a reasonable distinction in the quantity and compostion of waste created as a result of changes in families' usage (Ogwueleka, 2013). Trang et al. (2017) showed that higher-income families like to eat outside food more rather than cooking at home, thus creating less waste. This investigation considers family unit income as the income of the household head of the family. This variable is to test any connection between income and waste production.

The flow research uses ordinary least squares as a multiple linear regression model that is the most used method for boundary assessment because of its easiness. Multiple linear regression was used to examine the relationship a between's family waste and relevant factors. It is a set of techniques to study straight-line relationships among two or more variables (Allison, 1999). A basic model with a notable R^2 can be planned through a mix of forward, backward, and stepwise regression changes. The terms are constantly kept in the model if they were significant at $p=0.05$. The initial step, the connection between waste production and each input variable, was tried with simple linear regression using the R^2 as the choice rule. A multiple linear regression model as in Equation 2 was then produced to forecast waste production:

$$Y=x_0+x_1M_1+x_2M_2+\ldots+x_nM_n+\epsilon \qquad \text{Eq [3-2]}$$

where: Y is the total quantity of household waste produced; x_0 is the intercept coefficient; M_1-M_n are the independent variables (household socioeconomic factors); and ϵ is the error (Safa et al., 2015). The model is in a linear form to correspond with the linear links between the dependent and the independent variables and the interactions among the individual variables. The explanations and measurement units are shown in Table 3-3.

Table 3-3: A description and units of the continuous variables of waste production and household head

Variable	Description	Measurement unit
Household waste	Solid waste generation by the household	kg/day
Age	Oldest person of household	annual
Education	Educational level of oldest person	annual
Household size	Family persons	number
Income	Total monthly income of oldest person	USD

3.4.3 Model validation

A model is considered valid if it reproduces the outcomes. To measure model legitimacy from a stochastic viewpoint, specialists have proposed different statistical induction methods, e.g., the $\chi 2$ test on residuals among model and test results (Gregoire & Reynolds, 1988). Similarly, prototype approvals are regularly founded on a correlation between the product of deterministic simulations and production from a single or repeated tests (Chen et al., 2004). (Chen et al., 2004) sorted model approval tactics as either abstract examinations of x-y plots, showing the pattern in information after some time and space or quantitative correlations of model output and exploratory perceptions. In Fakruddin et al. (2011), the confirmation of coefficient R^2 can be used to evaluate the model's integrity of fit. The higher the worth ($0 < R^2 < 1$), the better is the consequence of the pattern.

3.5 Waste management scenarios

In this section different waste management scenarios are defined. It first introduces the two parts, i.e., Life Cycle Assesment(LCA) and the emission accounting two phases (Figure 3-6). It then explains the different waste mangement scenarios used. The waste management scenarios are based on the existing waste management system data base for only KMC yearly waste generation and composition not included in the Sisdole Landfill. For this analysis the IPCC Default method and FOD method (assuming gas recovery) were used, comparing the different scenarios with existing scenarios. This analysis also uses different input parameters based on city waste generation and composition in general conditions like the annual average temperature.

3.5.1 Life Cycle Assessment (LCA)

There are various techniques available for solid waste emision estiamte like, Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Environmental Risk Assessment (ERA), Environmental Impact Assessment (EIA), and Cost-Benefit Analysis (CBA) (Finnveden & Moberg, 2005). Among these approaches, "Life Cycle Assesment" is considered as a more suitable assessment tool and has been commonly accepted in different waste mangement system to evaluate and implement opportunities to minimise environmental impacts (Del Borghi et al., 2009).

Diffrent waste mangement scenarios were comapred using LCA to identify the most suitable SWM with less GHG emission. This study examines the level of solid waste generation and related GHG emissions and then develops alternative scenarios of ways to reduce the emissions for KMC lying in the Kathmandu Valley, Nepal, as a developing country case study.

LCA is a significant instrument that manages SWM from production to removal. It assesses the environmental load related to an item, cycle or action, by distinguishing and surveying the effect of the used energy, materials and waste delivered to the environment (Curran, 2004). LCA has been used in numerous research as a environmental tool for relative evaluations of solid waste removal alternatives or the management scenarios (Banar et al., 2009). The after effects of the evaluation can be used for policy choices, as essential choices on a waste management framework, with a waste chain of importance for environmental preference for either single waste treatment choices or combinations of options. LCA will be used in an environmental effect appraisal by investigating the mix of various options. The Municipal Waste Management options included: collection and transfer (CT), material recovery facility (MRF), landfill without energy recovery (L), landfill with energy recovery (LER), incineration (I), and composting (C) with the production of various situations to assess the environmental problems of KMC regarding a SWM system.

3.5.2 Emissions accounting

Emission accounting for the framework is shown in Figure 3-6. In Phase 1, LCA is proposed as the key emission accounting method. LCA is an diagnostic means for the logical, quantitative assessment of the environmental effects of a waste generation or disposal method across all phases of its life (Silvestre et al., 2020). The standards and context for LCA involve outlining the objectives and extent: Life Cycle Inventory (LCI) analysis; Life Cycle Effect Analysis (LCIA); and Life Cycle Explanation (ISO, 2006). In view of LCA’s structure, the objectives and extent of the investigation will be re-imagined.

Similarly, predictive scenarios will be structured, and discharge stock techniques will be chosen. Most computations will centre on Inventory Analysis, as the study’s objective is to analyse probable environmental benefits through optional scenarios. The focus of the scenarios is on the current situation in Kathmandu and potential future waste treatment facilities that fit the waste characteristics of Kathmandu targeting less energy consumption, low emissions while being cost effective with maximum social benefits acceptable to society.

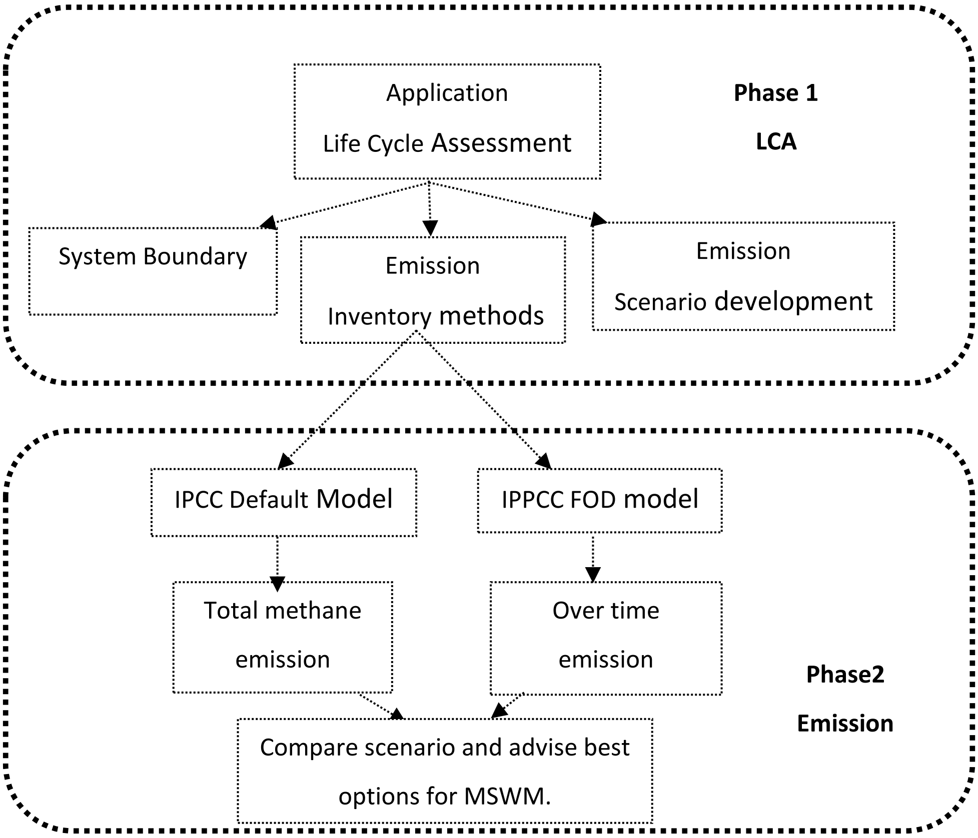

Figure 3-6: The emission accounting framework for KMC Waste management

Phase 2 involves emission accounting and evaluates methane discharges using two numerical models: IPCC default; and the first order decay (FOD) model (IPCC, 2006c). The results for every situation are then evaluated and compared to determine the best MSW management for Kathmandu for reducing GHG emissions. In this study, available data from KMC using IPCC default are one-off, they just tell the amount of methane in one annual amount; IPCC FOD tell us the overtime emissions since the landfill started.

3.5.3 Development scenario in LCA

In this section, scenarios are characterized and made for investigation in LCA. The scenario design in this study investigates the potential decrease in the environmental impacts associated with a potential decrease in methane emissions because of the optional scenarios identified.

MSW in KMC is collected waste without segregation at source mixed with other waste and conveyed to Sisdole Landfill. The existing Sisdole Landfill, however, is overloaded. Accepted government policy is focused on improving MSW management systems, especially with the rate of increase in food waste and recyclable components in MSW. This has led to some segregation of food waste and other waste at source to be handled by composting and reprocessing, rather than landfill. The five scenarios proposed in this study with system boundaries are shown in

Table 3-4. The baseline scenario (S0) represents the existing MSW management system, the status of MSW undertaken by KMC, and subsequent scenarios reflect options that include composting, recycling, and gas capture from the existing landfill site.

Table 3-4: The scenarios proposed in this study.

Scenario	Explanation of Scenario
S0	Existing 'business as usual' (landfilling of 87% of collected MSW)
S1	improved to landfill gas catch (70% methane recovery)
S2	Composting 50% of organic waste
S3	Recycling 25% recovery items
S4	Combination of gas capture, reprocessing, and composting

'Business as usual' (S0)

The business-as-usual scenario includes the collection, transport and landfilling of MSW. This is the existing practice of MSW carried out by KMC. An extremely small fraction of the waste is recovered as reprocessed materials, but this is not considered here. Corresponding to the environmental review information (Udm, 2015), MSW is not isolated at the source and roughly 448 tonnes of waste each day are discarded at Sisdole landfill with no further treatment.

Table 3-5: The physical composition of the solid waste of Kathmandu City (%)

Year	Organic waste	Plastic	Paper	Glass	Metal	Textiles	Rubbers	Construction & demolition	Others
2003	70.00	9.50	8.50	2.50	-	3.00	-	4.50	2.00
2005	69.00	9.00	9.00	3.00	1.00	3.00	1.00	2.00	3.00
2009	63.00	10.00	9.50	6.00	0.50	2.00	1.00	5.00	3.00
2013	73.22	11.43	6.89	2.10	1.06	1.61	0.62	-	3.07
2015	63.22	10.80	9.02	5.42	0.42	2.30	1.20	4.50	3.12

Sisdole is structured as a semi anaerobic landfill site, without a recuperation framework or a landfill gas (LFG) catching system. Data on the solid waste composition of KMC during for the years 2003, 2005, 2009, 2013 and 2015 are shown in table 3-5 (ADB, 2013) (Dangi et al., 2011); (Udm, 2015). The waste composition flow of the year 2015 is considered for assessment in this study's analysis.

Improved landfill gas capture (S1)

The landfill gas capture scenario is the same as S0 but assumes 70% of methane is gathered. Landfill gas (LFG) is normally created by the biodegradation of organic materials (otherwise called biomass) and expanding moisture can quicken the waste decay rate. At Sisdole landfill site, the average estimated moisture content by the solid waste was 69% and the percentage of the volatile solid was 44.41% (Adhikari et al., 2015). After waste positioning, precipitation, surface water and groundwater penetration, along with the containing waste breakdown, can contribute extra moisture. Based on the existing conditions and observations of existing vent pipe placements to allow methane to escape and discussions with Alternative energy projection centre (AEPC) Nepal there is 0,35 m3/kg of volatile solid which contains 75% methane gas in Sisdole landfill site (GC, 2018) .This scenario assumes that the introduction of a gas capture system will gather 70% of the gas produced (R=70%). Other input parameters in this scenario are the same as for S0. Assessment of the model parameters for scenario S1 appear in Table 3-6.

Composting of organic waste (S2)

In this scenario, 50% of organic waste from 86.9% of the landfilled waste is isolated, gathered and composted with the remaining waste sent to the landfill. The figure is based on discussions with KMC staff on the feasibility of the process. In this scenario using input data of 50% of organic waste is identical to 51,743 tonnes of the 103,486 tons of organic waste which can be treated as compost. The adjustments in the waste amounts and levels of the waste composition for the input scenario S2 are shown in Table 3-6.

Recycling before landfill (S3)

Considering the investigation of Kathmandu SWM (ADB, 2013) , 25 % of family unit waste and a lot more institutional and commercial waste could be either recycled or reused. This is excluding organic waste. This scenario believes that 25% of the MSW from the quantity of interred MSW, including paper, metal, glass, plastic, demolition and construction waste, and textiles is isolated at source and recycled with the leftover waste shipped to landfill. A similar quantity of MSW, with a composition as in S0 is covered. The difference in the waste amount and level of the waste composition to the input scenario S3 are in Table 3 6.

Combined gas capture, recycling, and composting (S4)

In this scenario, 50% of organic waste from landfilled MSW will be separated and handled as compost as in S2. Recyclable materials, e.g., paper, metal, glass, plastic, wood, and material will be reused at a 25 % rate in the material reprocessing plant. The leftover waste is shipped to the landfill. Ultimately, as in S0, 70% of methane emissions will be gathered and used. A similar measure of MSW, with a similar composition as in S0 is delivered to and treated at the landfill site.

3.5.4 System boundaries

The practical unit in this investigation is the aggregate sum of waste produced in KMC in a year, i.e., household, commercial and institutional. This amounts to 163,666 tonnes in terms of solid waste collected. The functional system boundaries selected for this LCA include only the direct emissions from the waste after landfill, where waste was characterized the minute, the material stops having value.

In this investigation, Figure 3-7 presents the key points for each scenario for the MSW management approach for Kathmandu. The upper limit begins with MSW being discarded in the dumping area. The procedure of assorting and haulage is excluded in the framework flow for all scenarios. This is on the grounds that it is hard to recognize and isolate the GHG outflows produced from the assortment that might be conveyed to either the dumping site or other processing destinations.

Division procedures incorporated into the discharge scenarios are: (1) foundation of landfill, e.g., establishment of an LFG catching framework; (2) combined composting to landfill; and (3) coordinated reprocessing to landfill. Deciding the division forms and isolating each procedure from the principal framework assists assessing their environmental effects inside the framework. Any difference will prompt adjustments in the first framework. The planned analysis assesses the environmental problems of four different waste management situations as demonstrated in Figure 3-7.

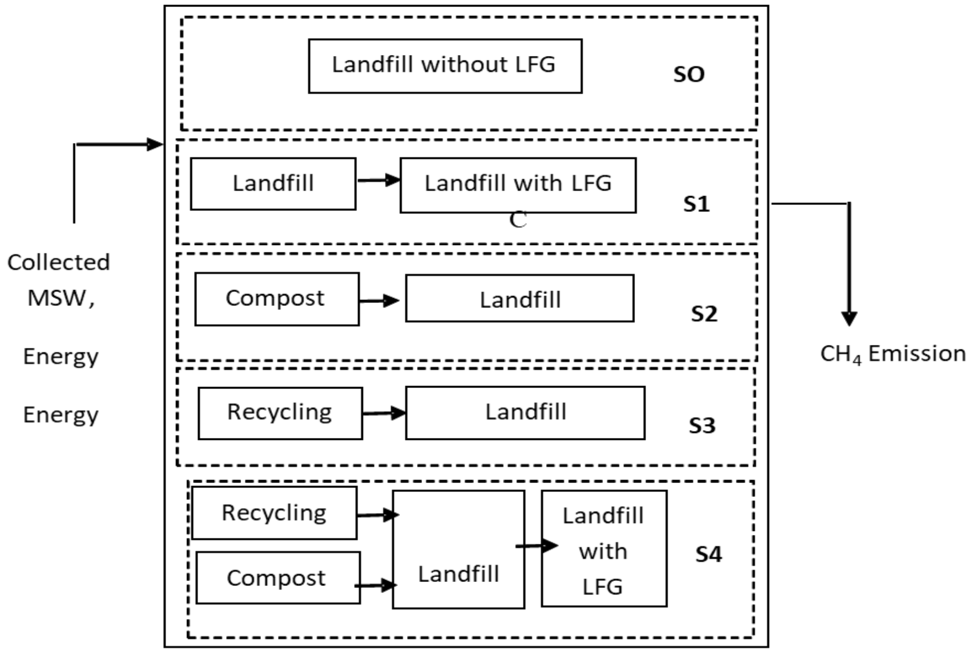

Figure 3-7: System boundaries for Kathmandu's solid waste management options

3.6 Quantification of emissions

This study was to estimate gas emissions from the MSW landfill site near Kathmandu, Nepal, applying the LandGEM model and compare the results with other mathematical models. In addition, methane and carbon dioxide generation have also been estimated according to input data. The study also provides background information on total annual volume of collected MSW delivered to be discarded at the landfill site.

In Kathmandu, a large portion of the solid wastes is discarded via landfilling in low territories situated in and around the metropolitan communities. At the current Sisdole landfill, there is no arrangement for the collection and use of gases created in the site. It can be said that the destiny of collected or uncollected waste is anaerobic degradation that produces an outflow of GHGs. The present study, therefore, estimates the GHGs emission from a municipal solid waste (MSW) landfill, according to data from the Sisdole Landfill authority and measure the methane gas making to estimate power equivalent and electricity generation value for the Solid Waste Disposal Site (SWDS), Sisdole, which would be an inspiration for moving from the existing open landfill scheme to a designed landfill with arrangements of gas capture and use.

Quantification of landfill gas emission is based on the existing Sisdole landfill's data that also includes waste from other municipalities. This means waste generation and composition may vary from KMC. This analysis also used different input parameters based on the Sisdole landfill waste generation and composition under specific conditions including seasonal temperature and rainfall. With varying temperature and rainfall, we assume the landfill waste decomposition rate (k) will change. In this study, five methodologies have been checked to evaluate the methane emissions, corresponding energy and compare the power generated from methane delivered in 1-years' time:

1. Stoichiometric Method (Boyle)
2. IPCC default
3. IPCC FOD
4. NV Afalzorg (FOD Modified)
5. LandGEM Model

For this analysis using a specific landfill, the IPCC FOD method and LandGEM model there is no gas extraction and recovery. Using the stoichiometric method (Boyle) we understand theoretical emission is based on the landfill's waste chemical composition and computed emissions per tonne of waste.

Finally, the heat ignition of MSW is determined using Dulong's equation. This method is suitable for waste mainly to estimate energy instead of directly measuring gas emissions from waste and verifying gas estimates that help decision makers decide to instal a landfill gas recovery system. All methods are described in self-contained sections.

3.6.1 Landfill gas overview

Landfill gas (LFG) is gas that is delivered under an anaerobic environment in a landfill. LFG like methane and carbon dioxide are an after effect of anaerobic deterioration of organic wastes in a landfill (Rettenberger, 2018). LFG contains numerous organic and inorganic other pollutant gases, some of which are amazingly harmful. The significant trace gases are those containing chlorine, fluorine, sulfur, and silicon (Cossu & Stegmann, 2018). LFG has a changing composition depending on time and location; the level of every segment of LFG varies (Tchobanoglous et al., 1993) because of the different degradation phases in a landfill and more or less air infiltration. The composition of gas generated varies in each of the four phases of degradation as shown in Figure 3-8 (Abedini, 2014; Berger et al., 2001).

Aerobic phase (Phase I) During the initial time of decay, aerobic microbes—microbes that stay just within the reach of oxygen — use oxygen while separating long atomic strings of dense carbohydrates, proteins and lipids that comprise organic waste (Mor et al., 2006).

Anoxic, nonmethanogenic phase (Phase II) Decay begins after the oxygen in the landfill has been spent. Using anaerobic interaction (a cycle that does not need oxygen), complex organic material is degraded to less difficult organic acids (acetic acid (CH_3COOH), carboxylic acids) and hydrogen (H_2) (Nguyen, 2017).

Anaerobic, unsteady methanogenic phase (Phase III) Methane formation starts in Phase III underneath anaerobic circumstances, with methanogens using carbon dioxide and hydrogen particles that were made during the corrosive (acid) stage. It requires 3-4 months to be set up (Berger et al., 2001).

Anaerobic, steady methanogenic phase (Phase IV) Decay starts when both the composition and creation rates of landfill gas are generally steady. Stage IV landfill gas generally comprises 50% to 55% methane by volume, 45% to 50% carbon dioxide and 2% to 9% different gases, e.g., nitrogen (Abedini, 2014).

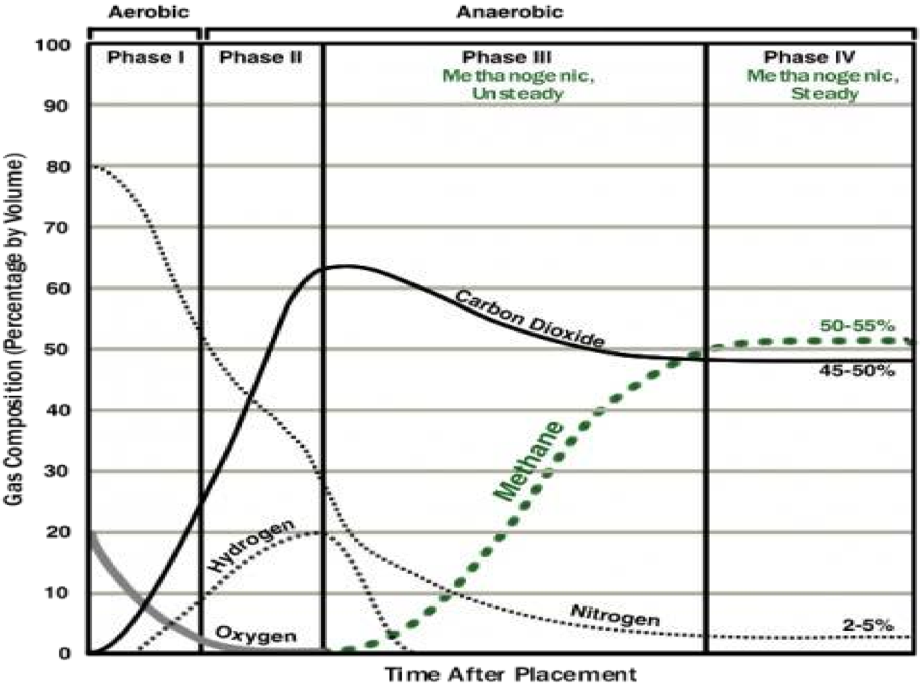

Figure 3-8: Landfill gas four phase production (Berger et al., 2001)

3.6.2 Stoichiometric method by Boyle

The method of Boyle is a stoichiometric estimate for gas creation from garbage at the Sisdole landfill. For these estimates, the MSW composition is from (Adhikari, 2019) through Kathmandu University environmental research. Other data needed for this investigation include the moisture content of the different waste components (See Appendix A7). O'Leary et al. (2002) say the following equation 3-3 explains the overall change of organic substances in the presence of appropriate bacteria in an anaerobic situation.

$$\text{Organic matter} + H_2O + \text{nutrients} \rightarrow \text{new cells} + \text{resistant organic matter}$$

$$+CO_2 + CH_4 + NH_3 + H_2S + \text{Heat} \qquad \text{Eq [3-3]}$$

The model is time independent according to information for basic components for organic substances that form methane and carbon dioxide as principal outputs. Boyle's equation 3-4 (Bryant et al., 1977) to calculate the total amount of gas produced in landfills is:

$$C_aH_bO_cN_d + \frac{(4a-b-2c+3d)}{4} H_2O \rightarrow \frac{(4a-b+2c+3d)}{8} CO_2 + \frac{(4a+b-2c-3d)}{8} CH_4 + dNH_3 \qquad \text{Eq [3-4]}$$

This method has determined gas yields in various studies that run from 170– 453 m^3 for every tonne of moist waste, of which 85 – 244 m^3 is accounted for as the amount of methane (Schumacher, 1983).

3.6.3 IPCC model / IPCC default method

The IPCC proposes two strategies for ascertaining methane outflows from landfills, the default strategy and the first order decay technique. The least complex one for the assessment of methane outflow from landfills relies upon a mass equilibrium method. This is the default strategy (DM). DM, on a very basic level, is an exact model. Different factors have been thought of in using the DM. The experimental factors differ such as the composition of the garbage, the landfill site's system, and the depth of the landfill. The strategy accepts that all emissions of methane happen in the same year as the waste is stored in the landfill (IPCC, 1996). Even though this is not the situation, IPCC expresses that the DM gives a reasonable yearly measure of genuine discharges. It has been extensively used in conditions where point by point data are not accessible (Kumar et al., 2004). DM requires the MSW quantity and composition that is shipped to the landfill site and information on the current movement at the site. According to IPCC guidelines, the conditions for deciding GHG outflow from solid waste landfills are as follows (IPCC, 1995):

$$ECH_4 \text{ (Gg/yr)} = (MSW_F * MSW_T \times MCF * DOC * DOC_F * F * *(\frac{16}{12} - R) * (1\text{- }OX) \qquad \text{Eq [3-5]}$$

where: 1 Gg/yr: 1000 Mg/yr; E CH_4 = Emitted methane from landfills; MSW_T = total MSW produced (Gg/year); MSW_F = percentage of urban waste land filled; MCF = methane correction factor (fraction); DOC = degradable organic carbon (fraction) (kg C/ kg MSW); DOC_F: fraction DOC dissimilated; F = fraction of methane in landfill gas (IPCC default is 0.5); 16/12 = conversion of carbon to methane; R = recovered methane (Gg/year); and OX = oxidation factor.

3.6.4 IPCC FOD

The FOD model estimates the temporal changes in methane outflows. The fundamental presumption in this technique is that the DOC decays steadily with methane formation. The FOD technique requires information on present and historic waste amounts, composition and waste disposal practices over quite a long time (IPCC, 1996). The first order decay model is relevant for a specific landfill or a choice of particular landfill where LFG is not extracted (Change, 2006). Methane outflows can be determined as follows:

$$\mathrm{Q} = L_O \,.\, w . (e^{-kc} - \ e^{-kt}) \qquad \text{Eq [3-6]}$$

Where: Q, is the methane produced in present year (m^3/year); L_0 is CH_4 generation potential (m^3/Mg of deny); w, is the normal yearly waste acknowledged rate during dynamic life (Mg/year); k, is the methane production rate (year-^{1}); and c, is the time since removal end (year); and t, is the time since removal began (year).

3.6.5 NV Afalzorg (FOD Modified)

In the FOD model, methane generation from landfill is a function of time mirroring the actual time that it takes material to decay. The FOD model requires information on current waste amounts, composition and disposal practices extending over periods (IPCC, 1996). At present, because of the absence of information, this technique cannot be used to assess methane emanation. Therefore, a modified model has been used. The modified model is the NV Afvalzorg multiphase landfill gas emission and recapture method, which is a first order decay model grounded on IPCC mathematics and default data and the model estimates methane production, recapture and discharge of individual landfills for which incomplete data on waste composition are obtainable (NVAfvalzorg, 2014). Various sorts of waste have distinct elements of organic substances that decompose at various rates. The benefit of the NV Afvalzorg Multiphase model is that the standard garbage composition can be taken into account (Scharff & Jacobs, 2006). The estimation approach IPCC 2006 rules for solid waste disposal site were followed. Furthermore, the IPCC default values were adopted as much as possible (IPCC, 2006c). The formula used in this model to calculate methane generation (G) is equation 3-7. For this model the time horizon is 100 years. This IPCC FOD method uses the general case assuming gas extraction and recovery. At present because of an absence of information, this technique cannot be used for assessment of methane emission.

$$G = WLo\ [F(f)\ (K(f)e{-}K(f)(t{-}t(1))) + F(s)(K(s)e{-}K(s)(t{-}t(1)))] \qquad \text{Eq [3-7]}$$

Where: G = methane production (million cubic metres per year); W = waste disposed of (tonnes); L_o = methane yield potential (cubic metre per tonne of waste); T = time after waste placement (years); T1

= lag time (between placement and start of gas generation); K (f) = first-order decay rate constant for rapidly decomposing waste; K(S) = first-order decay rate constant for slowly decomposing waste; F(f) = fraction of rapidly decomposing waste, and (S) = fraction of rapidly decomposing waste.

3.6.6 Description of the LandGEM model

The LandGEM modelling programming offered by US Environmental Protection Agency (EPA, 2005b) is intended to calculate the emission from solid waste dependent on US EPA standards.

LandGEM is a robotized assessment apparatus with a Microsoft Excel interface that can be used to measure discharge rates for landfill gases, methane, and carbon dioxide. It can use either site-explicit information to appraise outflows or default data if no site-explicit information is accessible (Alexander et al., 2005). The model contains two arrangements of default data, Clean Air Act (CAA) defaults and inventory defaults. The CAA defaults depend on criteria for MSW landfills set out by the Clean Air Act (CAA), including the inventory defaults that depend on the emanation factors in the Environmental Protection Agency's (EPA) Edition of Air Pollutant Emission Factors (AP-42) (Dimishkovska et al., 2019b). LandGEM depends on a first order decay rate equation for evaluating discharges from the disintegration of landfilled waste in MSW landfills and to measure yearly outflows through a time span dependent on the user. The equation is in equation 3-8 for measuring outflows from the disintegration of landfilled garbage for user over a time interval (consider 80 years) (EPA, 2005a).

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_o \left(\frac{M_i}{10} \right) e^{-k t_{ij}}$$

Eq [3-8]

where: QCH_4 is the amount of annual methane production in the year (CH_4/year); i is the one-year time increase; n characterizes as (year of the figuring) - (starting year of waste acknowledgment); j is 0.1-year time increase; k is the methane creation rate (year^{-1}); L_O is the possible methane creation limit (m^3/Mg); Mi. is the quantity of garbage acknowledged in the ith year (Mg); tij is the age of the jth area of waste mass; and Mi. acknowledged in the ith year (decimal years, e.g., 3.2 years). This model depends on climatic conditions and waste composition. In this study we look at three climatic levels wet, dry, and moderate.

3.6.7 Input parameters used in model

The main input parameters for methane gas estimation are:

- Municipal solid waste tonnage (MSW_T)
- Methane correction factor (MCF)
- Degradable organic carbon (DOC)
- Fraction DOC dissimilated (DOC_F)
- Fraction of methane (F)

- Recovered methane (R)
- Oxidation factor (OX)
- The decay rate (k)
- Methane generation potential (L_0)

The above parameters depend on solid waste volume and composition. Therefore, they have been estimated separately for KMC and the Sisdole Landfill because solid waste generation in the two areas varies greatly.

Municipal solid waste tonnage (MSW_T): Total municipal solid waste (MSW) generated Ga/year (MSWT) was calculated from the population (in thousand persons) multiplied by the annual MSW generation rate. According to an environmental audit report (Udm, 2015), total MSW equals 163,666 tonnes of solid waste for KMC. Therefore, this is the amount applied to the IPCC Default and FOD modified model adopted to estimate methane in the KMC waste management scenario. However, for the Sisdole Landfill a single stage model was used. MSW was estimated for 2005-2018. The yearly amount of deposited waste in the semi anaerobic landfill at Sisdole amounted to about 235,263 tonnes in 2018 as shown Table 3-2.

Methane correction factor (MCF): The value of the methane correction factor (MCF) reflects the status of landfill management of the site. To accommodate different types of landfill site, the IPCC recommends default MCF values, ranging from 0.4 to 1 (see Appendix B6). This corresponds to a range of unmanaged to well-managed landfill sites. In an ideal Sisdole Landfill of KMC, the burial areas of MSW are well managed with a top cover of soil, so the assumed value of MCF is 1, which is applied to all scenarios as shown in Table 3-6.

This accepts that unmanaged SWDS yields less methane than a managed one. In the former, a large part of waste in the top layer goes through vigorous decay and, hence, the MCF of SWDS fluctuates with the site management techniques (Kumar & Sharma, 2014a). The MCF for various classes of SWDS is given in Appendix B6. Since the Sisdole Landfill open dump site is a profoundly deep unmanaged site, the MCF is accepted as 0.8 (Appendix B6). Table 3-7 gives the model parameters that are assumed for the Sisdole Landfill. The default value for methane recovery(R) is considered as zero because methane recovery is not considered at the existing Sisdole site.

Degradable organic carbon (DOC): DOC is fundamental in methane generation. It depends on the composition of waste and changes from scenario to scenario. The organic fraction of each type of organic waste is considered as having different decay rates (Thompson et al., 2009) shown in equation 3-9:

$$DOC = (0.15 * A) + (0.4 * B) + (0.43 \bullet C) + (0.24 * D) + (0.39 * E) \qquad \text{Eq [3-9]}$$

where: DOC is degradable organic carbon; A is the fraction of organic waste; B is the fraction of paper waste; C: is the fraction of wood waste; D: is the fraction of textile waste and E: is the fraction of rubber and leather waste.

Applying measurable information on waste composition in the KMC MSW, the level of DOC in MSW is 14.1%. This figure is for scenarios S0 and S1. In contrast to S0 and S1, the estimates of DOC for the remaining scenarios are 13.7%, 14.1% and 13.69% for S2, S3 and S4, respectively, computed using equation 3-9 and the waste composition from Table 3-5. The computed DOC values are shown in table 3-6.

The LandGEM 3.02 model calculates methane yield based on four key inputs. The first necessary input is waste amount deposited in landfill over all the years that the landfill has been operational. The second input is the DOC, which is the waste portion available for microbial degradation into landfill gas (Kim, 2003). The organic fraction of each type of organic waste is considered as having different decay rates. The Sisdole site waste composition from Figure 3-5 was classified into five categories of waste stream (see Appendix B4) after applying certain approximations and a computed DOC value of 0.151.

Fraction DOC dissimilated (DOC_F): This is the fraction of carbon that is ultimately degraded and released from SWDS. It represents the amount of organic carbon in SWDS that either does not degrade or degrades very slowly. It can be calculated by the following formula from the EPA landfill guidelines (Alexander et al., 2005):

$$DOC_F = 0.014*T+0.28 \qquad \text{Eq [3-10]}$$

where: T is the atmospheric temperature of area. By the IPPC Default and Amini and Reinhart (2011) we use 35^0 C landfill temperature and a value of DOC_F of 0.77 was computed for the study site.

Fraction of methane (F): The fraction of methane (F) is usually taken as 0.5, but it can vary between 0.4 and 0.6, depending on the waste's composition and site conditions. It is assumed as 0.5 for methane for the Sisdole Landfill and KMC.

Recovered methane(R): Recovery of LFG **(**Gg/year) does not yet take place in Nepal. For scenarios S1 and S4 it is assumed that if a gas capture system is introduced it would effectively collect 70% of the gas produced (R0.7).

Oxidation Factor (OX): This accounts for the methane that oxidises in the upper layer of waste mass where oxygen is present. Using a landfill top cover of soil, the default parameter for the oxidation factor is 0.1 (Kumar et al., 2004). An oxidation rate of 10% is applied to managed and unmanaged SWDS (Santos et al., 2015). Both study areas take a 10% OX factor.

Decay rate (k): This is the rate of waste decay and methane production, also known as the refuse decay rate constant or methane generation constant (per year). Decay rates range from 1 to 50 years and even longer in landfills located in dry, cold climates. It can be calculated by:

$$k=3.2*10^{-5}(x)+0.01 \qquad \text{Eq [3-11]}$$

where: x is the average annual precipitation in mm for the interested period for the area where the landfill is located. In this study, the considered value of the decomposition rate (k) depends on the climate conditions at Sisdole, the waste components and reference to the IPCC default k values. Sisdole Landfill is located near the Kathmandu Valley in a warm humid tropical climate with precipitation around 1505 mm per year and an annual average temperature range of 19-27°C. Therefore, the default values of k and the corresponding half-lives have been taken from the 2006 IPCC Guidelines for a tropical climate zone with a mean annual temperature over 20°C and a mean annual precipitation over 1,000 mm. According to the equation, K=3.2*10-5 (X) +0.01 of US (USEPA, 2006), the calculated value of k is 0.06 and corresponding t1/2 is 10 years. This value is applied to the first order modified method for the KMC Waste management scenarios.

Methane generation potential (L_0): This is the amount of methane (m^3) generated per Mg of MSW decomposed and is a function of moisture content and organic content of the refuse and depends on waste composition (% wet basis). The LandGEM model uses the methane generation potential, L_0, rather than DOC as the input parameter. The higher the cellulose content of the refuse, the higher is the value of L_0. The value of L_0 ranges from 6.2 to 270 m^3/ Mg refuse (see Appendix B5 for the organic matter in MSW). The EPA default value of L_0 is 170 m^3/Mg refuse. L_0 can be calculated from DOC using the following equation (the calculation assumes that the default values for MCF, DOC_F and F apply):

$$L_0 = 493\times DOC \qquad \text{Eq[3-12]}$$

where: L_0 is the methane generation potential (m^3 CH_4/Mg waste); and DOC is the degradable organic carbon. The potential methane generation capacity relies just on the type and composition of waste placed in the landfill as shown in Appendix B5. The higher the cellulose content of the waste, the higher the estimate of L_0. Ideally, L_0 should be found out experimentally. In this study, in the absence of test data, L_0 = 170m^3/Mg was taken because of similar conditions to an Indian landfill site studied by Kumar et al. (2014)

Based on the existing MSW management practices in Kathmandu, along with its topographic features, climatic conditions, a wet tropical climate, the default parameters for all factors used in the models is presented in Table 3-6.

Table 3-6: The factors considered in the calculations for Kathmandu City's scenarios of MSWM

Input Parameters	MCF*	D0C	DOCF*	F*	R	OX*
S0	1	14.11%	0.77	0.5	-	0.1
S1		14.11%			0.7	
S2		13.70%			-	
S3		14.10%			-	
S4		13.69%			0.7	

*All scenarios average value

The assessment of the methane production from the landfill has been consistently studied by applying specific input parameters related to Sisdole landfill such as the yearly amount of unloaded waste and the quantity of observed constants like the methane correction factor, methane production rate, and methane production limit in the LandGEM model as shown in Table 3-7. Most GHG outflows from waste management exercises are from waste disposed at and the anaerobic decomposition of organic garbage in landfills. Not long after solid waste is landfilled, the organic material begins to go through biochemical reactions.

MSW is characterized into three stages in terms of decay: rapidly, moderately, and slowly biodegradable organics. Quickly degradable organics (food) begins disintegrating a couple of days after the garbage is put in the landfill and requires five years to finish decay. Moderately decomposing organics (nursery and green waste, leaves, grass trimming, tree branches) begin interaction after a couple of months and end after seven to ten years of internment. Paper, textiles, leather, rubber and wood are delayed and start decaying around five years after they are covered in a landfill and may require 50 years to finish the interaction (Doorn et al., 2006). In our calculations, data from 2005 to 2018 on annual deposited waste at Sisdole from KMC were used.

Table 3-7 Input parameters used in calculation with three models for the Sisdole Landfill

Parameter	IPCC Default Method	FOD Method	LandGEM Model
Methane correction factor (MCF)	0.8	-	-
Fraction of CH_4 in landfill gas (F)	0.5	-	-
Oxidation factor (OX)	-	-	0.1
The CH_4 generation rate constant (k) (year $^{-1}$)	-	0.05, 0.1 ,0.2,0.3, 0.4	0.05, 0.1 ,0.2,0.3, 0.4
CH_4 generation potential (L_O)(m^3/mg)	-		170.0

Table 3-8 shows the provided supplementary data. The methane emissions were determined by running the LandGEM model. The CAA default values have a high methane generation potential (L_0) of 170 m^3 methaneCH_4 Mg waste-^{1}. Methane generation rates (k) of 0.05, 0.1, 0.2, 0.3 and 0.4 were used as in the IPCC method and methane content was 50% by volume. Concentration of total non-methane organic compounds (NMOCs) of 4000 ppmv were taken as hexane.

Table 3-8: Description of the recommended input data to run LandGEM

Parameter	Reference	Unit	Symbol	Rate
Methane generation rate	CAA	Year -1	k	0.4
Potential methane generation capacity, Lo	CAA	m^3/Mg	Lo	170
NMOC concentration	CAA	ppmv	-	4000
Methane content	CAA	by volume	-	50

3.6.8 Sensitivity analysis

The amount of methane and carbon dioxide emissions to the atmosphere very much depend on the decay rate, k. Depending upon the type of collection system and various cover materials, the LFG collection efficiency varies greatly (EPA, 2011). Numerous factors affect the production of methane gas in landfill. The total amount of organic waste fraction taken for decomposition is a leadng factor which affects the quantity of methane generated. Considering that fact, this study analyses different values of k for methane emissions estimates.

The k determines the methane generation rate for the waste mass in the Sisdole Landfill which depends on the environment of the location of SWDS. The IPCC guidelines cite a range of 0.005–0.4 year^{-1} for k with a greater value to be adopted for higher moisture content. The higher the value of k, the higher the rate of methane production but it then drops over time. In this study, based on previous studies on an Indian city landfill site, the default values of k used are 0.05, 0.1, 0.2, 0.3 and 0.4 year^{-1} for dry, moderate, and wet Sisdole landfill. Despite the high organic matter content (food waste) weight percentage of 61.6%, the value of k could have been higher in Sisdole MSW but was considered the same as the default value. The characteristics of the model parameters to run LandGEM were adopted from (Alexander et al., 2005).

3.7 Dulong's equation energy calculation

This technique aims to value the energy value of garbage as opposed to the gas delivered. The energy value of solid waste is the heat out when the garbage is combusted (Kumar et al., 2014). There are two types of heat of ignition, viz. high heat and low heat. High heating values (HHV) of solid waste are computed using Dulong’s equation as presented in Tchobanoglous et al. (1993). The formula considers the fractions of elements of the components, essentially carbon, hydrogen, oxygen, nitrogen sulfur, and ash. This can be applied to all types of waste and HHV can be calculated by the following formula:

$$H = 32{,}851*C + 141{,}989*(H) + 9263*S \qquad \text{Eq [3-13]}$$

where: HHV is the high heat value (kJ/kg); C is the carbon %; H is the hydrogen %; O is the oxygen %; and S is the sulfur %. The weight rates of carbon, hydrogen, oxygen, nitrogen and sulfur on a dry or wet basis are shown in Table 3-9 .These values were determined through analysis of the typical amounts of these elements in the organic components of waste presented by (Sincero & Sincero, 1996; Tchobanoglous et al., 1993).

Table 3-9: Typical analysis data for organic components of municipal solid waste

Component	% By mass (dry basis)					
	C	H	O	N	S	Ash
Food waste	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	-	-	10.0
Textiles	55.0	6.6	31.2	4.6	0.2	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Yard waste	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5

Source: (Sincero & Sincero, 1996)

3.8 Summary

This study depends on the examination of three principal stages. To appropriately assess the research questions, numerous strategies and insightful procedures are used. In the first stage, a household survey was conducted to collect information about waste generation and composition to verify earlier data. Field data were gathered mostly using KMC staff interviews and their records. To enhance the authenticity and reliability of the information, other data sources like the field visits and report analysis and household survey were used for triangulation. Household survey data were analysed using a multiple regression computer model and study areas were worked out from secondary information.

At the second stage, we described KMC's five different waste mangement scanarios in terms of GHG emissions. We presented an outline of Life Cycle Analysis (LCA) applied as the leading process to evaluate the ecological effects of discharges. KMC waste generation and compostion data are computed, and methane discharge using DM and multistage FOD model assuming gas recovery scenarios and a selection of model input parameters for the specific study area are derived (KMC).

In the third stage the method for quantification of methane emissions and energy estimation rates by the IPCC single stage without gas recovery FOD model and LandGEM model for the Sisdole Landfill Site were described. The Sisdole landfill has yearly waste generation and compostion data that were useds for this computation. Additionaly, we use mass balance emission estimate simple method in an underdeveloped country where there are limited data sources and compare each method. We use an energy estimation method that is beyond the reseach objectives but helps descison-makers understand the energy content of landfill waste. Finally ,using a selection of model input parameters for the specific study areas, KMC and Sisdole lanfill site were provided.

Chapter 4

Results

4.1 Introduction

This chapter describes the results created from subjective and quantitative information gathered in the two territories using the techniques described in Chapter 3. Data assembled during the field visits are examined to meet the study's goal. The chapter starts with a short account of the socio-economic and demographic qualities of the respondents to the household survey and moves into the subtleties of the results. By and large, the findings are according to research goal: a) household waste generation and its composition by establishing the amount of per capita waste generation; b) assessing the results of the methane emission decrease amounts from existing MSW management and the proposed scenarios for KMC; and c) the quantification of methane emissions and energy estimates with the mathematical model for the Sisdole landfill site. Each section explains the results analysed for KMC Sisdole landfill waste management data with selected model input parameters and the household survey conducted with KMC citizens. Where appropriate, findings regarding household waste generation and composition, waste management scenarios and quantification of landfill emissions, are also made. An outline of the findings is introduced toward the end of the chapter.

4.2 Socio-Economic and Demographic Characteristics

In this study, it was trying to investigate a diverse sample of households with different socio-economic characteristics. The characteristic features of the respondents include age, sex, education level, work status, income, and family size. Table 4-1 presents the family and population results of the sampled households. At the 90% confidence level and ±5% accuracy, the minimum necessary number was 227 households (HHs). Therefore 227 households plus an additional 20% as a precaution against any deficiencies of non-responses and/or partially covered questionnaires gave a total 288 households that were selected from 32 different wards.

As shown in Table 4-1, the percentages of male and female household heads (respondents) were 74.7% and 25.3%, respectively. Of the respondents, 49.3% of respondents were in the age group 20-50 years. Of the respondents, 42.0% had higher education. This fact contributed to the accuracy of information gathered from the respondents. The household size and proportions were 22.9% had 1-3 family members; 21.5% had 7-9 family members and most, 52.8%, had 4-6 family members. The employment status of the respondents was 25.7% were in the government sector. The remaining 74.3% were engaged in range of other employment. For monthly income, the dominant household average of 34.4 was for $US1000-$2US000 per month.

Table 4-1: The demographic characteristics of the survey respondents

Characteristic	Category	Frequency	Percent
Sex	Female	73	25.3
	Male	215	74.7
	Total	288	100.0
Age	29-40	36	12.5
	40-50	106	36.8
	50-60	103	35.8
	70-80	40	13.9
	above 80	3	1.0
	Total	288	100.0
Educational status	No Formal education	1	0.3
	1-8 Primary education	94	32.6
	9-12 secondary education	71	24.7
	16-17 Higher education	121	42.0
	Above Higher education	1	0.3
	Total	288	100.0
Family size	1-3 member	66	22.9
	4-6 member	152	52.8
	7-9 member	62	21.5
	10 and above	8	2.8
	total	288	100
Employment Status	Agriculture	10	3.5
	Business	77	26.7
	Government sector	74	25.7
	Foreign employment	13	4.5
	Private employee	27	9.4
	Unskilled (daily wage basis)	14	4.9
	Unemployed	29	10.1
	Other	44	15.3
	Total	288	100.0
Average Monthly Income USD	Below $100	10	3.5
	$100-$600	84	29.2
	$600-$1000	70	24.3
	$1000-$2000	99	34.4
	Over $2000	25	8.7
	Total	288	100.0

Of the 288 households, 97.9%, disclosed their rubbish habits; only 6 households (2.1%) of the respondents did not respond to the question. Of those who responded to this question, 92.0% (264 households) said they were willing to separate organic waste from non-decomposable, only 5.9% (17 households) stated that they were not willing to make the separation (Table 4-2).

Table 4-2: Household willingness to segregate their waste at source.

Are you willing to segregate the waste at the source?	Number	Percentage	Cumulative Percent
Yes	265	92.0	92.0
No	17	5.9	97.9
Do not know	6	2.1	100.0
Total	288	100.0	

In Kathmandu, the private sector has a different interest for solid waste management and has set up a reasonable action plan for waste that has a critical part in the progression of the cycle by implementing rules, guidelines, and standards; private sector has profited by this. Based on this, the sampled households were asked about paying a fee for a SWM service by a service provider. Table 4-3 shows that 92.4% of the respondents said they would pay a service fee for the SWM service; 3.8% reported that they would not pay, and 3.8% did not respond to question.

Table 4-3: The number of households willing to pay a fee for a waste management service.

Would you pay a fee for waste management in your locality?	Number	Percentage	Cumulative Percent
Yes	266	92.4	92.4
No	11	3.8	96.2
Do not know	11	3.8	100.0
Total	288	100.0	

4.3 Waste Generation and Composition

4.3.1 Waste generation

The per capita waste production of every family unit was determined by separating all waste created by the individuals living in that family on the sample collection day. The relationships between waste amount and various influential factors are summarized in Table 4-4. Household size varied from 1 to 13 with an average of 5.4. Household waste ranged between 0.2 and 3.8 kg per day, with an average of 1.6 kg. This average household waste generation of 0.3 kg/capita /day is higher than that of the other 58 municipalities in Nepal. However, it was close to the cities in other south Asian countries (Kaza et al., 2018). For the 2019 population (1,376,000), it has been estimated that 413 tonnes of household waste per day were generated in Kathmandu Municipality. The waste amount has increased by 77.77% since 2013 (ADB, 2013).

The correlation results show that all demographic influences are positively connected to MSW generation as shown in Table 4-5. The factors are also inter-connected. However, household size is the strongest factor; it can be used to predict waste generation in the absence of other information.

Table 4-4: Waste generation factor correlation coefficients

Variable	HH Size	Income	Education level	Age	Waste
Household size	1				
Income	0.009	1			
Education level	-0.046	-0.019	1		
Age	0.204^{**}	0.105	-0.052	1	
Waste	0.921^{**}	-0.034	-0.123^{*}	0.183^{**}	1

Table 4-4 shows that the family garbage production rate is related to families, whereas the per capita waste production rate reduced with a rise in family size.

Table 4-5: A description of continuous variable results summary

Variable	Sample Size	Mean	Standard Deviation	Min	Max
HH waste (per capita per day)	288	0.30	0.06	0.07	0.62
HH waste (kg per day)	288	1.58	0.76	0.20	3.80
Age (Year)	288	49.53	10.10	29	85
Education level (Year)	288	10.93	5.40	1	19
HH size (No)	288	5.13	2.15	1	13
Income*(USD)	288	9,32	6,29	57	2,201

Note. * Income is in USD. 1 U.S. Dollar = 114.05 Nepalese rupees (Nepal Rastra Bank, 2020)

Figure 4-1 show the results from the multiple regression model. An R^2 value at 0.86 confirms the good fit of the model. It indicates that 85.67% of total variation in per day household waste generation is accounted for by four of the independent variables in the model.

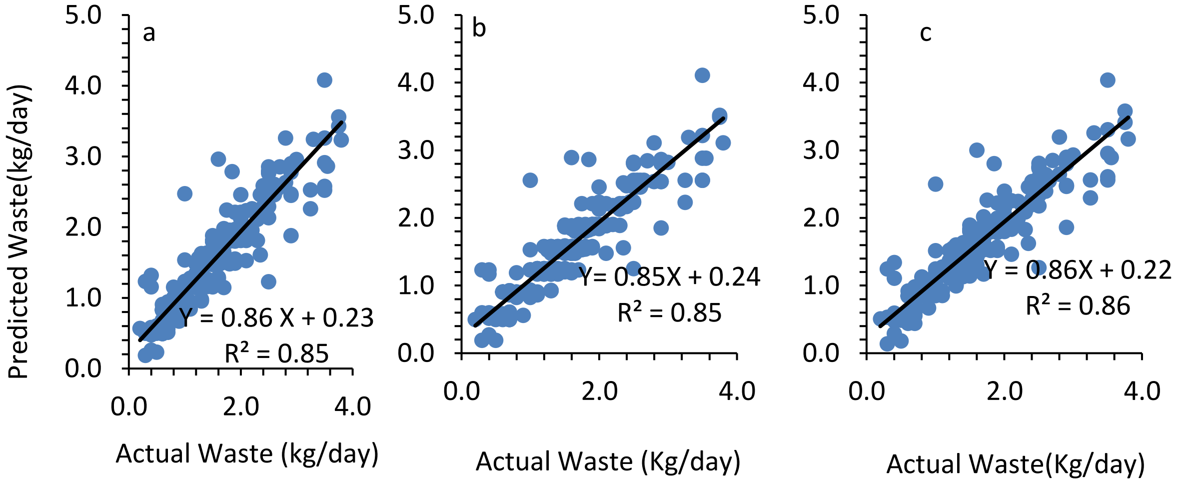

Figure 4-1: The correlations between actual household waste and predicated waste based on (a)household size, (b)income (c) age, income, and education.

Among the tested variables only family size significantly affected waste generation. The other variables had a minimal effect on waste generation. This is similar to a previous study by Maskey and Singh (2017). Afroz et al. (2013) also indicated that the more people in a household, the extra will be bought and used that will eventually lead to greater garbage production.

Although educated people should be progressive and mindful of waste's effect on conditions, the results do not show any significant effect. Therefore, education level does not explicitly teach or make individuals mindful enough about waste's effect on the environment. In contrast, a study by Oribe-Garcia et al. (2015) suggested that educated people were more aware of the influence of garbage on the environment. The difference can be described by the gentler waste generation rate at which such awareness rises compared with the rate for an uneducated person. Today, high income people in Kathmandu have changed their eating habits. They usually eat out in restaurants rather than cook at home. It was expected that high salary people would spend more time outside their home thus creating less household waste than homemakers and retirees. The latter have more opportunity to make their own dinner instead of purchasing packaged food like high salary people.

A study by Maskey and Singh (2017) indicated that waste generation is high in a house with diverse occupations; the stay-at-home members compensate for waste generation by those whose work requires more time outside the home. Waste generation in the study area was the result of the merged behaviours of all family members.

Of the 288 households, 10% were used for model validation. Input variables included household size, age, income, and education level. As can be seen in Figure 4-2, the waste generation per day estimated by the MLR model accounted for 82% of the actual data. This shows a strong relationship between actual and predicted waste which confirms the model's validity.

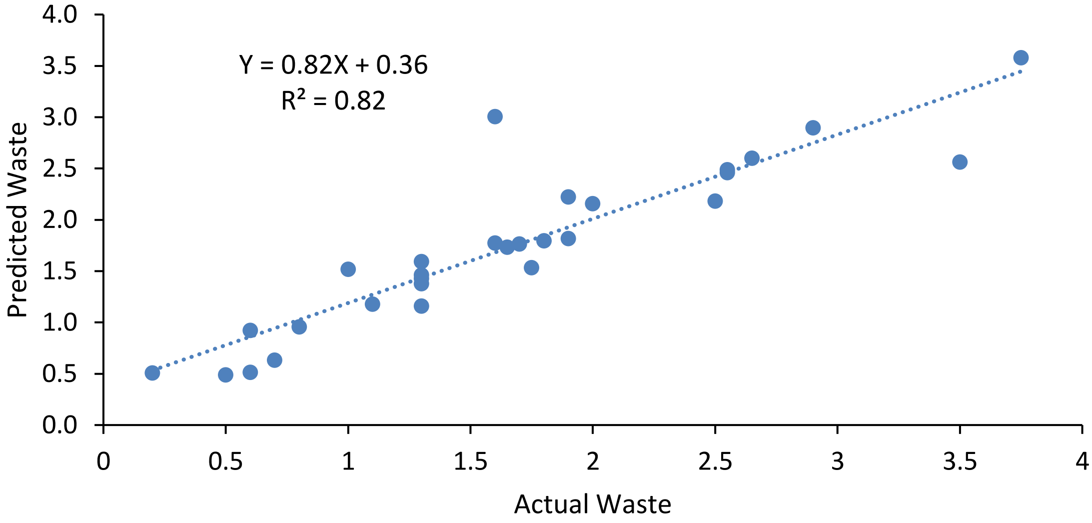

Figure 4-2: The predicted and actual waste generation (kg/capita/day) for model validation

4.3.2 Waste Composition

Household waste composition in KMC is shown in Figure 4-3. Organic waste is the largest fraction (51%), followed by plastic (19%) and textiles (13%). Paper, rubber and leather, glass, metal, and other inert wastes range between 1% and 5% of the total waste. The results agree with previous studies conducted in Nepal (ADB, 2013) and reflect the general organic waste proportion in developing countries (Hoornweg & Bhada-Tata, 2012a).

The high organic waste component means that the waste requires frequent collection and removal from its source (ADB, 2013) because of its fast decomposition. Inorganic waste, comprising 49% of total MSW, can be reused and recycled in some circumstances by a waste recovery process. The rest of the waste has to go landfill in the case of Kathmandu.

The use of plastic and paper has been expanding; they have currently become essential materials in everyday life especially for packaging. The use of plastic has increased from 5.4% in 2005 to 12% in 2007 (Dangi et al., 2011) and to 22% in 2013 (ADB, 2013). The rapid increase in use of plastic might be because of its versatility and functionality including light weight, durability, and cost effectiveness. The proportion of paper has also increased but in a steady, gradual way (Udm, 2015). With the increasing development work and the construction of new infrastructure, a different kind of waste has emerged in Kathmandu, construction debris. However, construction and demolition waste are not collected by the waste management service and are usually used again as construction material.

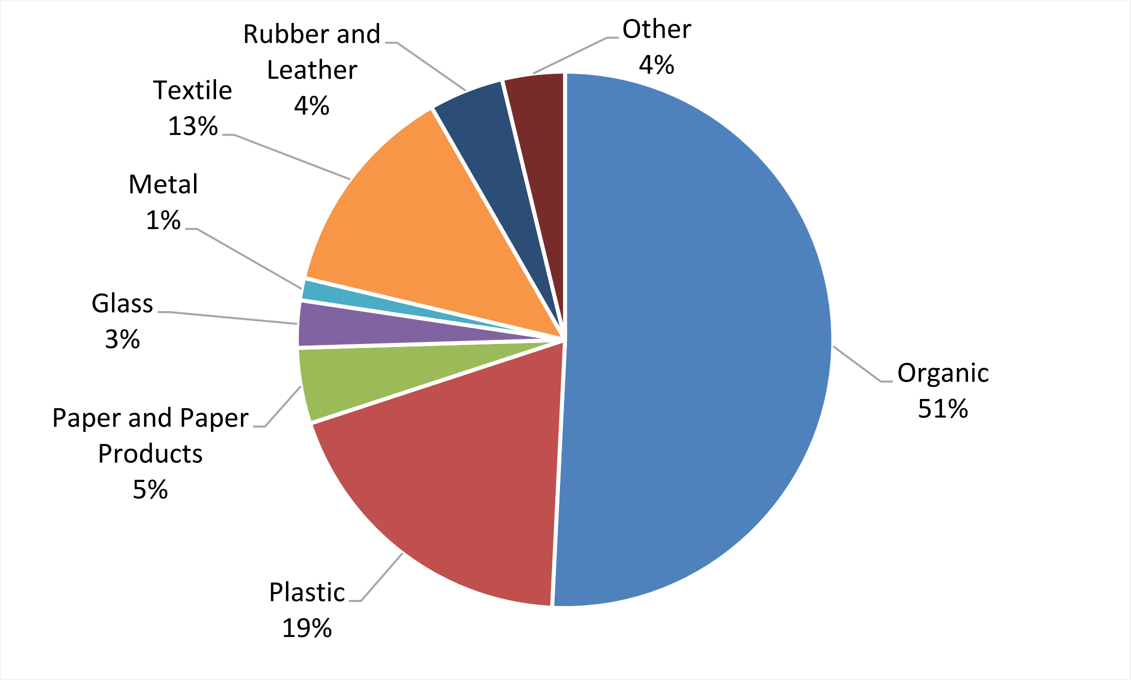

Figure 4-3: The composition of solid waste of Kathmandu City (%)

Currently, mixed waste generated within KMC is directly disposed of to the Sisdole landfill 28 km from the Teku Transfer Station. If all the garbage produced is collected and controlled by the municipality, the total garbage produced by each household would be about 150,745 tonnes/year. Presuming 51% of this is organic waste, about 76,879 tonnes/year of organic waste would be produced. This organic waste, when decayed in the Sisdole landfill, generates methane that, on a weight basis, has 21 times the global warming potential (GWP) of carbon dioxide (EPA, 2011). Landfill sites are identified as the largest source of methane emissions from the solid waste sector (UNEP, 2010). At the Sisdole site, waste workers take up paper and plastic bottle recyclable items to sell to scrap dealers. There is no information on the reprocessing rate.

4.4 Life Cycle Assessment Results

4.4.1 Waste composition under different scenario in KMC

One critical part of MSW in KMC from a management perspective is the huge organic portion in the MSW flow. The rest of the waste contains glass, metal, elastic, and other materials. Organic waste records 60–70% of all solid waste and the level of this waste that is recyclable is strikingly high. The authority records of KMC for 2015 show that essentially 63.22% (by weight) of the waste delivered in KMC is organic followed by plastic and paper. A similar amount of waste with an unchanged composition is used in the computations for this study. Thus, the waste creation information for 2015 is used in the scenario 'Business as usual' (SO). It remains the same for the gas recovery scenario (S1). For Scenarios S2, S3, and S4, the expansion of reprocessing and composting of MSW decreases the aggregate sum of solid waste delivered to the landfill site. This produces new percentages for the waste composition (Table 4-6).

Table 4-6: Solid waste material composition for the stream of scenarios

Scenario	Waste (tonnes)	Solid Waste composition (%) in different scenarios								
		Organic	Plastic	Paper	Glass	Metal	Textiles	Rubber	Dem.	Others
S0 &S1	163,666	63.23	10.80	9.02	5.42	0.42	2.30	1.20	4.50	3.11
S2	111,923	46.23	15.79	13.19	7.93	0.61	3.36	1.75	6.58	4.55
S3	149,894	69.04	8.84	7.39	4.44	0.34	1.88	0.98	3.69	3.40
S4	98,151	52.72	13.51	11.28	6.78	0.53	2.88	1.50	5.63	5.19

For the S0 and S1 scenarios, the MSW in Kathmandu comprises a great extent of organic waste, representing over half (63.23%) of the landfilled waste. Comparable levels are seen in scenario S3 with 69.04% of organic waste. On the other hand, scenarios S2 and S4 have a lesser amount of organic waste (46.23% and 52.72%, respectively); they additionally have the greatest percentage level of gradually decomposing garbage (paper, material, plastic, glass, and metal). This determines the varying levels of methane outflow and the age of the landfill in every scenario.

For Scenarios S2, S3 and S4 there is a change in the aggregate sum of waste sent to landfill with the expansion of composting in S2, in recycling for S3 and both composting and recycling in S4. Figure 4-4 illustrates the tonnage composition for each scenario.

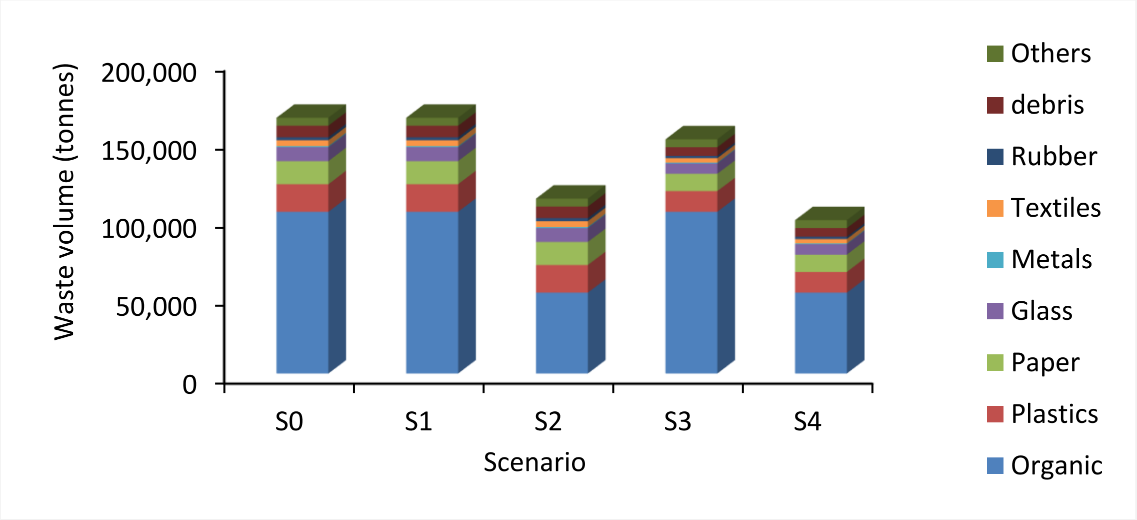

Figure 4-4: Estimated waste under different scenarios (tonnes)

4.4.2 Potential CH_4 emissions

The possible outflows of CH_4 from the Sisdole Landfill site using the IPCC default model varies between the five scenarios as shown in Table 4-7. Scenario S0 (Business as usual) demonstrates that the aggregate sum of CH_4 discharged is 15,136 m^3 while the scenario S4 (Landfill, recycle and compost) reduces CH_4 emissions by 11,049 m^3 to 4,114 m^3. In the event that a gas recuperation framework is introduced (S1), it would by itself lessen CH_4 outflows by 8,022 m^3 down to 7,069 m^3.

Table 4-7: The potential emissions of various scenario using the IPCC default model.

Scenarios	Amount of waste (tonnes)	CH_4 emissions (m^3)	Emissions reduction m^3
S0 (Business as Usual)	163,666	15,136	-
S1 (Gas Capture)	163,666	7,069	8,022
S2 (Landfill/Compost)	111,923	9,882	5,298
S3 (Landfill/Recycle)	149,894	13,663	1,514
S4 (Landfill/Recycle & Compost)	98,151	4,114	11,049

The next best alternative is S2 (Composting) which reduces the CH_4 outflows by 5,298 m^3 to 9,882 m^3. S3 (Recycling) is the least effective option reducing CH_4 emissions by only 1,514 m^3 to 13,663 m^3.

Figure 4-5 shows the emission reduction for each scenario in percentage terms. All scenarios reduce CH_4 emissions, with minimal advantage from recycling reflecting the relatively limited amount of recyclable material that is landfilled. Composting leads to a much larger decrease in emissions, related to the greater amount of organic material that is currently collected and landfilled. This also has implications for gas capture. The greatest reduction understandably is with the integration of all three scenarios.

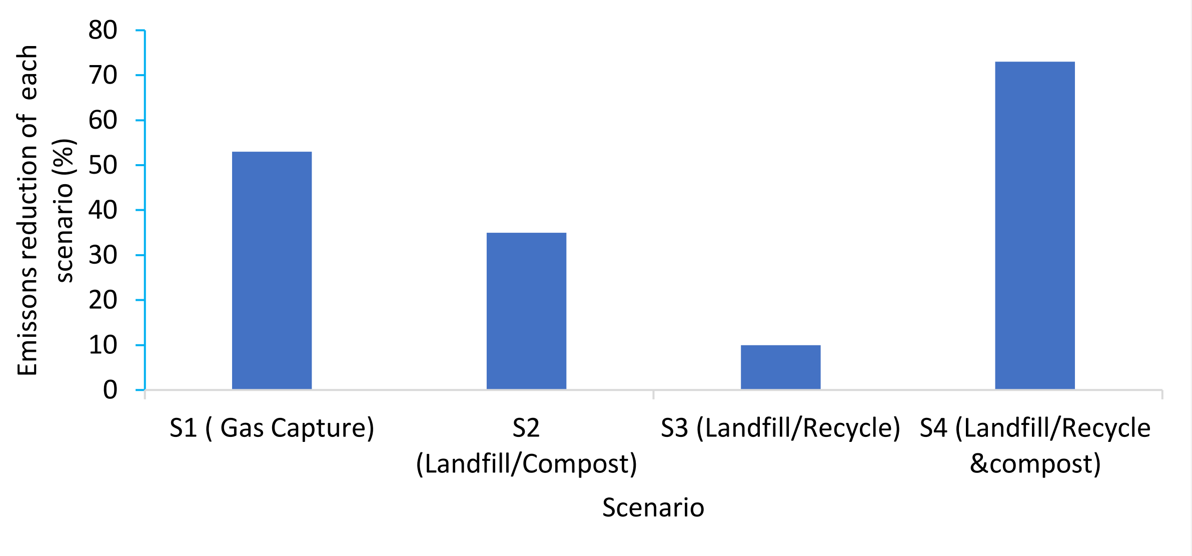

Figure 4-5: The total emissions (%) reduction of each scenario

4.4.3 Volume disposal of landfill waste

In the S0 scenario (Business as usual), the volume of waste going to the landfill site is 163,666 tonnes each year, which occupies a huge volume in the landfill when contrasted with the S2 and S4 scenarios. Waste coming to landfill will reduce faster because of the massive volume of the waste. The volume of the waste in scenarios S0 and S1 is the equivalent of 163,666 tonnes annually. The only difference is that in scenario S1 the waste is used to generate gas through a 70% gas capture system. In scenario S0, there is no gas capture and mixed waste is directly disposed of as usual. In scenario S2, the volume of the waste decreases to 111,923 tonnes per year because of more recycling of recyclable materials and recovery of organic materials. In scenario S4, the volume of landfill waste decreases to 98,151 tonnes. This is because of 50% of composting, 70% of methane recovery at the landfill and 25% inorganic waste recycling as an integrated scenario (compost/recycle and landfill gas recovery assuming individual %) as shown in figure 4-6.

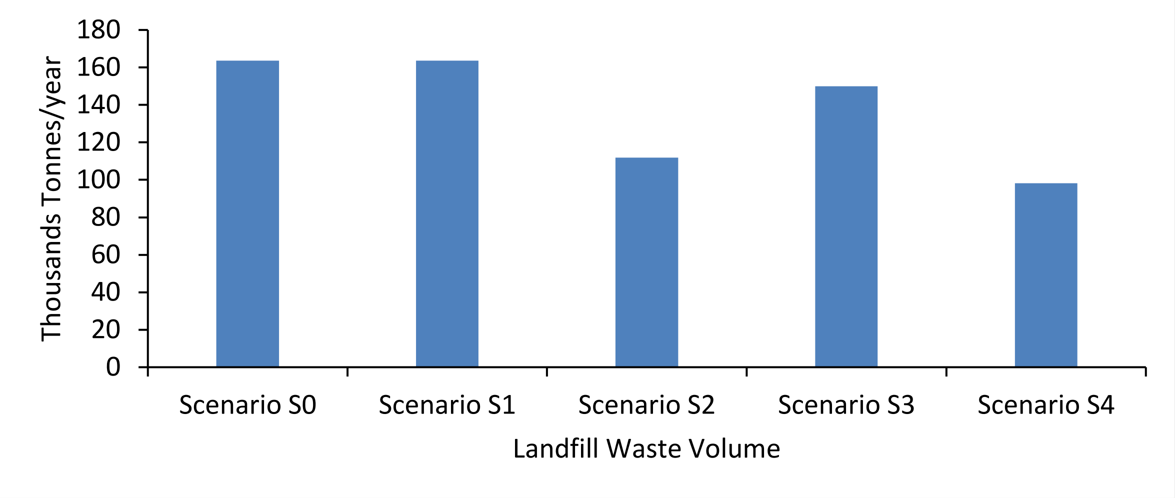

Figure 4-6: The final disposed waste volume in different scenarios

4.4.4 The difference in methane production over time

The methane emission values from solid waste landfill estimated for 2005 to 2018 using the default method and NV Afvalzorg model are shown in Figure 4-7. Default method (DM) does not reflect the time variation in solid waste disposal and the degradation process, as it assumes that all potential methane is released in the year the solid waste is disposed. However, the FOD method provides a time-dependent emission profile that reflects the true pattern of the degradation process over time. Therefore, the DM produced higher estimate of the yearly emission than FOD method. The values used in the FOD model assume that the gas generation takes up to 13 years. Although it appears that the FOD model shows lower emissions than the DM model, which is not considered in this analysis is that the emissions that will occur because of previous waste deposition has not been calculated here. This should be considered in the following analyses.

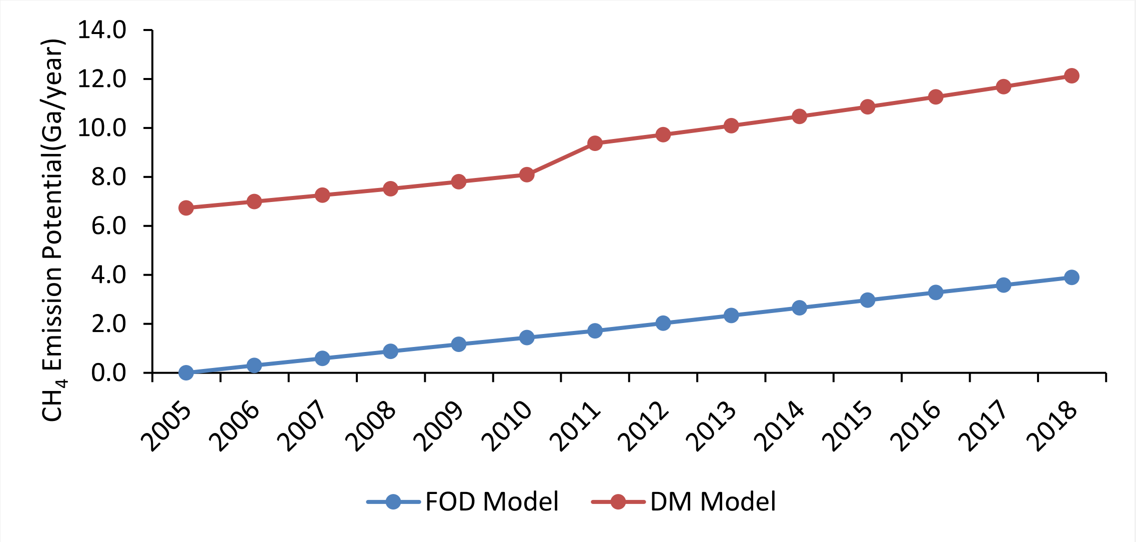

Figure 4-7: Methane emissions in Sisdole landfill site using various models.

Using the FOD base, the NV Afvalzorg model alongside the DM model for historic and projected methane emissions and the annual 2005-2018 waste disposal quantity (tonnes/year) current and future methane emissions were estimated for each scenario. These are shown in Figure 4-8, where scenarios S0 and S1 overlap since same volume of waste is disposed in the landfill under these scenarios. Degradation starts one year after MSW deposition and increases, gradually reaching a peak after 10 years. Therefore, in 2005, when landfill was started, there were zero emissions, and they reached a peak in 2017.

The NV Afvalzorg model simulations demonstrate that ‘quickly and moderately biodegradable’ organic wastes start decaying a year after being placed in the landfill. The production of methane occurs from 2006 at an increasing rate for each scenario, peaking in 2018 after 13 years. Emissions peak at 3,897 (mg/year) for S0; 2,672 mg/year for S2; 3,565(mg/year) for S3; and 2,346(mg/year) for S4, followed by a decrease through the following 20 years (see Appendix C1). The ‘gradually biodegradable’ portions start disintegrating around 5 years after burial peaking by 2018, 10 years after landfilling. Over the initial 30 years, roughly 80% of all methane will be released; emission continues until 2100. Accordingly, the life expectancy of the landfill site is around 100 years; the most reasonable time to capture methane is from 2006 to 2035.

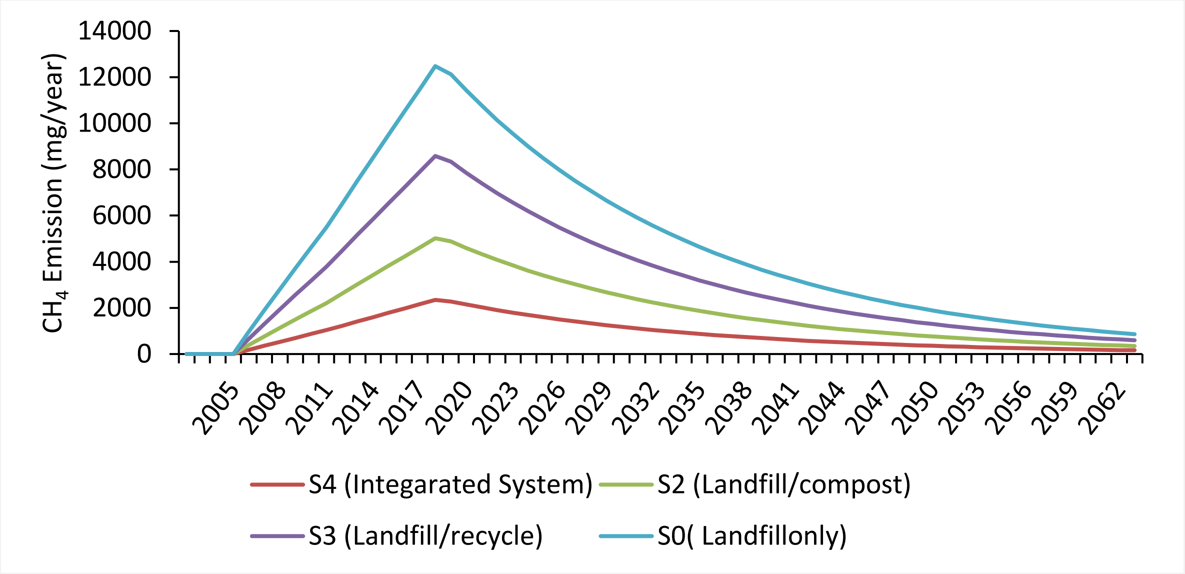

Figure 4-8: Methane emissions in Sisdole landfill site over time for scenarios

4.5 Emission Quantification Results

4.5.1 Gas stoichiometric estimate of gas production

The dry percentage of the chemical parts (i.e., C, H, O, N, and S) included in organic waste were adapted from Appendix Tables B.1 and B.2 using waste composition data from Sisdole Landfill site (as shown in Figure 3-5). The preliminary calculation showed that 39.54% of the garbage disposed of at the Sisdole

Landfill in 2018 was dry organics and the proportions of chemical components were 19.55%, 2.60%, 14.29%, 0.85%, and 0.12% for C, H, O, N, and S, respectively as shown in table 4-8.

Table 4-8: Assessed Chemical elements and formula of waste deposited in the Sisdole in 2018.

Organic waste composition	Weight in 100 kg		Chemical elements (dry weight in 100 kg)					
	Wet	Dry	C	H	O	N	S	Ash
Paper	10.00	9.50	4.13	0.57	4.18	0.03	0.02	0.57
Food waste	61.60	24.64	11.83	1.58	9.26	0.64	0.10	1.23
Textile	3.00	2.70	1.49	0.18	0.85	0.12	0.00	0.07
Rubber	3.00	2.70	2.11	0.27		0.05		0.27
Total	77.60	39.54	19.55	2.60	14.29	0.85	0.12	2.14
Normalised (%)			49.45	6.56	36.14	2.14	0.31	5.41
Atomic Weight			12.00	1.00	16.00	14.00	32.10	0.00
Mole Ratio			4.12	6.56	2.26	0.15	0.01	0.00
Chemical formula of Waste(N=1)					$C_{27}H_{43}O_{15}N$			

These outcomes decide the chemical nature of solid waste without sulfur, uses the lowest represented element nitrogen (which is 0.15) as the base dividing each value by the number of moles of nitrogen, along with the decided chemical formula of the waste. They are shown in Table 4-8 for the organic elements of the garbage formula found as $C_{27}H_{43}O_{15}N$.

Accordingly, the stoichiometric equation 3-4 for this specific waste composition is:

$$C_{27}H_{43}O_{15}N + 9.5 \cdot H_2O \longrightarrow 12.25 \cdot CO_2 + 14.75 \cdot CH_4 + 1 \cdot NH_3$$

Using the atomic weights of the elements, the equation is:

$$(910) \quad + \quad (171) \longrightarrow (539) \; + (236) \quad + \; (17)$$

Therefore, the methane generation potential for the waste deposited at Sisdole in 2018 was:

Methane (M_g)= (236 / 910) · (39.5 / 100) = 0.10244 kg CH_4/ kg wet waste

where: (M_g) is the methane yield (kg CH_4/ kg wet waste); (236 / 910) is the molecular weight ratio of methane to the deposited organics; and (39.5 / 100) is the amount of dry organics (kg in 100 kg of wet waste).

Based on methane density under the principal conditions (15°C and 1 atm) equals 0.678 kg/m3, then the methane generated per tonne of waste is:

$$M_g = 0.10244 / 0.678 \cdot 1000 = 151 \text{ m}^3 \text{ } CH_4 \text{ /tonne of wet waste}$$

By expecting gas assortment effectiveness of 70%, 3981 TJ of energy and 127 MW of power can be delivered, whose worth is much greater than acquired by the IPCC technique.

This mass equilibrium method is the least complex discharge assessment. Its use is, for the most part, is debated on the grounds that it gives a high assessment of discharge. This strategy excludes any variables and does not recognize different sorts of removal site (Tchobanoglous et al., 1993).

4.5.2 IPCC default method estimate of gas production

This approach is also a mass equilibrium method that does not indicate a time difference in solid waste (SW) dumping and is a deprivation method because it assumes that all possible methane is emitted in the first year after the placement of the waste in Landfill. Table 4-9 gives the percentage landfill waste disposal volume (MSW_T) for 2018; the other estimation parameters, MCF, R, OX MSW_F, are from IPCC 2006 and compute the DOC value based on landfill waste composition using equation 3-9.

Table 4-9: The IPCC default method estimation parameters adopted for Equation 3-5

Parameter	Value	Sources
MSW_T 9(Ga/year)	235.26	Year 2018
MCF	0.80	(IPCC, 2006a)
DOC_F	0.77	(IPCC, 2006a)
R	0.00	(IPCC, 2006a)
OX	0.00	(IPCC, 2006a)
MSW_F	1.00	(IPCC, 2006a)
DOC	0.15	Equation 3-9

The methane emissions for the Sisdole landfill waste were calculated from equation 3-5. The emission of methane (CH4) = 235.3 * 0.80 * 0.77 *0.15 *16/12= 28.95 Ga/Year.

This model gives emissions to the extent the mass of methane is delivered in one year. Energy and power production from the calculated methane in 1 year is decided using the density and calorific value of methane. The density of methane under principal conditions was taken as 0.678 kg/m^3 (Abedini, 2014) and the calorific value as 9,000 kcal/m^3 (Yedla, 2005). Energy created in one year, assuming a gas collection efficiency of 70% is 1125 TJ; the comparable power created is 36.2 MW.

4.5.3 FOD method to estimate gas production

FOD gives a more exact estimate of annual discharges. There are issues obtaining the required information and data (past data on SW removal, decay constant rate) to build the correct version of discharge records with reliable precision (Jigar et al., 2014b). The circumstance of the real emissions is reflected in the FOD technique. If the yearly waste quantity and composition of waste are arranged with in disposal methods practically steady for significant phases. This investigation centres around the amount of methane created inside one year's placement of garbage in a solid waste landfill site (SWDS). In this, c = 0 year, and t = 1 year and, respectively, five values close to upper bound of suggested extent, 0.05, 0.1, 0.2, 0.3 and 0.4, were picked and methane discharges Q (x10^6m^3) for these values were calculated using Equation 3-6. This gave 1.95, 3.81, 7.25, 10.37 and 13.19 (x10^6m^3) respectively and the energy generated (Tj) in one year corresponding to the values of decomposition rate (k), respectively, of 73.48, 143.38, 273.12, 390.51 and 496.73. The corresponding power (MW) generated is, respectively, 2.36, 4.61, 8.78, 12.55 and 15.97 as shown in Table 4-10.

Table 4-10: The results from the FOD method for different estimates of methane constant

CH_4 production constant k(year^-1)	CH_4 produced in one year, Q (x10^6m^3)	Energy produced (TJ)	Power, MW
0.05	1.95	73.48	2.36
0.10	3.81	143.38	4.61
0.20	7.25	273.12	8.78
0.30	10.37	390.51	12.55
0.40	13.19	496.73	15.97

4.5.4 LandGEM method estimate of gas production

The LandGEM model adaptation 3.02 was used to calculate the outflow rates for methane and carbon dioxide from the Sisdole Landfill site. LandGEM decides the mass of methane produced by using the methane production limit and the quantity of garbage saved. LandGEM suggests deducting inert materials, e.g., the methane production factor and possibly for both CAA (Clean Air Act) and AP42 (EPA, 1998) requirements.

The first order decay methane discharge pattern for different estimates of k, specifically 0.05, 0.1, 0.2, 0.3 and 0.4 (in year 1), as acquired from LandGEM. Table 4-11 presents the estimates of methane radiated in one year after waste positioning, alongside the energy and the related power created (MW) 2.37, 4.63, 8.87, 12.74 and 16.29, respectively, for different k values as shown in table 4-11.

Table 4-11: Results of the LandGEM method for several values of methane constant (k)

CH_4 production constant k (year^-1)	CH_4 produced in one year, Q (x10^6m^3)	Energy generated (TJ)	Power, MW
0.05	1.96	73.67	2.37
0.10	3.83	144.10	4.63
0.20	7.32	275.86	8.87
0.30	10.52	396.39	12.74
0.40	13.45	506.73	16.29

4.5.5 Methane (CH_4) production over time in the Sisdole Landfill

The impact of the half life span of organic substances, e.g., food, paper, wood, and textiles, to general methane creation is identified by the decay rate (k=0.05) of the model through equation 3-8. Using average annual rainfall of Kathmandu Valley of about 1505mm and according to the waste's composition, food waste is approximately 61.6% of the garbage flow to this landfill and the disposal volume from 2005 to 2018 from Table 3-2, we obtained the results for methane, carbon dioxide and NMOC gas emission at Sisdole Landfill as presented in Table 4-12 and

Figure 4-9. The results are based on the LandGEM model and input factors.

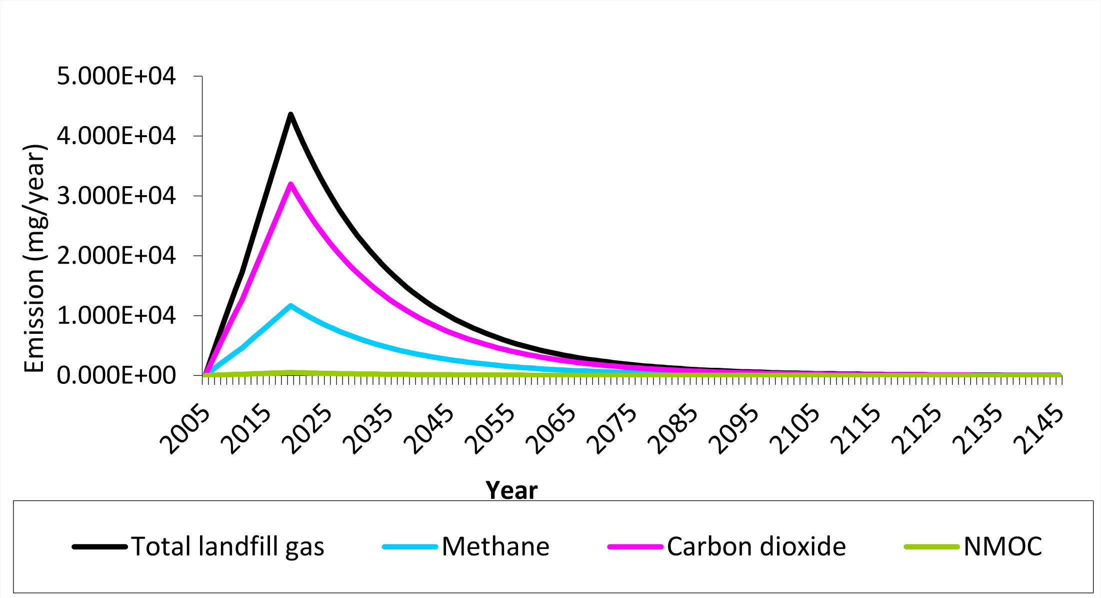

Figure 4-9: The quantity of gas production from Sisdole landfill site from 2005 to 2085(Mg / year)

Methane production has been assessed using the LandGEM model for the Sisdole landfill This landfill has operated from 2005 with the resolve to receive the solid waste from the enclosed area till 2015. The quantity of methane production from solid waste was intended to be 1.050E+06 (Mg/year) in 2006 with the extreme methane production rate happening during 2015-2035 with a peak of production of approximately 1.100E+07 (Mg/year).

The aggregate sum of methane has been assessed at 1.050E+06 (Mg) for 2006 which will reduce to 1.345E+07 by 2035. Table 4-12 shows the yearly expanding pattern of methane creation from waste at the landfill. The model's conditions are set up to assess the methane outflow from solid waste. However, the different components have a positive or negative impact on gas discharge. High-impact degradation of MSW in a non-tropical country, e.g., Nepal, might be lower because of lower temperatures and dampness that positively affect methane creation. Climate conditions, e.g., the rate of precipitation, are distinguished as other significant factors that affect methane creation. A lot of organic carbon is cleaned out during rain and may get disposed of, which decreases methane creation. Uncertainties in the amount of waste arriving at a landfill site, expanding the organic carbon mixture, e.g., paper and textiles, because of industrialization, the oxidation rate of methane in the top coating of the landfill and net outflow to the air have a wide range of various factors adding to variation in GHG emission assessment from landfills.

It is supposed that 10% of the CH_4 produced will oxidize close the landfill surrounding, so the CH_4 discharges would be 1.050E+06 × (1 – 0.1) = 9.447E+05 Mg CH_4/yr for 2006. Converting the CH_4 emissions (GWP = 21) to CO_2e: CH_4 emissions are 9.447E+05 × 21 = 1.984E+07Mg CO2e/yr. Adapting to short tonnes: CH_4 emissions are 1.984E+07Mg CO_2e/yr × 1.1 t/Mg = 2.182E+07tpy CO_2e generation at landfill.

Carbon dioxide emissions from landfill without gas collection are calculated using equation of (EPA, 2010):

$$GHG= CH_4 \text{ Emission x } (1-F/F+0.1) \text{ x } 44/16)$$

and the computed total GHG emissions from the landfill are:

$$3.18E+06+ 2.182E+07= 2.50E+07 \text{Mg CO2e/yr}$$

Then converting to short tonnes and rounding to their significant value, the total GHG emissions from the landfill are:

(2.50E+07Mg CO_2e/yr × 1.1 t/Mg = 2.75E+07tpy CO_2e)

at year 2006 as shown in Table 4-12 for the corresponding year.

Table 4-12: Estimated total GHG emissions from disposed waste at the Sisdole landfill.

Year	Methane (x10^9 kg/year)	Methane generation CO_2e(x10^9) kg/year	Total GHG Emission CO_2e(x10^9) kg/year
2005	0.00	0.00	0.00
2006	1.05	21.82	27.50
2007	2.09	43.40	54.68
2008	3.12	64.77	81.61
2009	4.14	85.98	108.34
2010	5.15	107.07	134.92
2011	6.16	128.08	161.39
2012	7.37	153.25	193.11
2013	8.58	178.38	224.76
2014	9.79	203.50	256.41
2015	11.00	228.66	288.12
2016	12.21	253.91	319.94
2017	13.43	279.29	351.92
2018	14.66	304.86	384.14

4.5.6 Sensitivity analysis

The sensitivity analysis for different values of k (methane creation rate) show that any increase in k brings about a methane discharge increment from the landfill. In addition, during the first long periods of unloading waste, a lot of methane will be released which, if there should be a brief recovery strategy, will control a lot of climatic and ecological contamination. The first order decay methane emission pattern for different estimates of k (in year^{-1}) as from LandGEM appear in Figure 4-10.

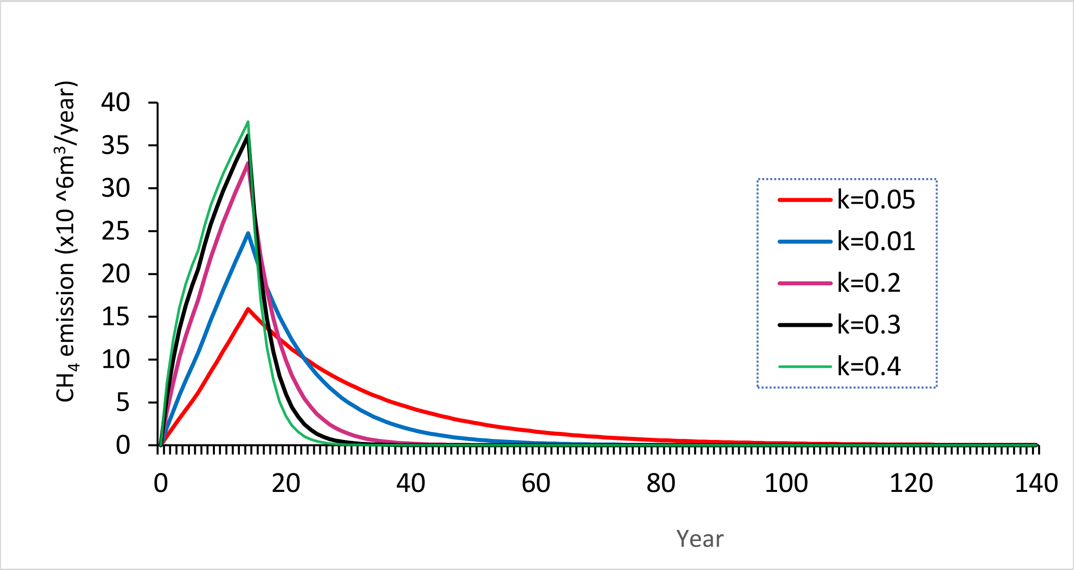

Figure 4-10: Methane production estimate for several values of k (in yr^{-1}) by LandGEM

Kathmandu waste materials are unloaded directly up to 87%. In such conditions, GHG generation rate is about 384.14 of CO_2e(x10^6) t/year in 2018.

4.6 Estimate of energy value using Dulong's method

Elemental ratios for different waste types were obtained from (Tchobanoglous et al., 1993) and applied directly to obtain the calorific values. This technique aims to assess the energy value of waste instead of gas generation from waste. The waste composition of Sisdole Landfill, as presented in Figure 3-5, were related with the categories in Table 3-9 and the fractions of carbon, hydrogen, oxygen and sulfur for each classification was observed. Equation 3-13 was used to obtain the high heating values (HHV) of solid waste. The result of this HHV value with portion of total waste related to every composition was calculated and each such value was summarized to get the heat measure of MSW as 17545.46 kJ/kg. Having the waste disposal amount at Sisdole Landfill as 235,263 tonnes of waste for a year, energy produced from this measure of waste was determined as 4128 TJ and 132 MW of power as shown in Table 4-13.

Table 4-13: The energy content computation for the Sisdole Landfill waste

Composition	C	H	O	S	HHV combustion, (kj/kg)	Fraction of Landfill waste	Net heat of combustion (kj/kg)
Food waste	0.48	0.06	0.38	0.00	18219.35	0.62	11223.12
Plastic	0.60	0.07	0.23		25887.12	0.10	2588.71
Paper and cardboard	0.44	0.06	0.44	0.00	15018.66	0.10	1501.87
Glass	0.00	0.00	0.00	0.00	150.00[4]	0.05	7.50
Metal	0.00	0.00	0.00	0.00	700.00[5]	0.00	2.80
Textiles	0.05	0.07	0.31	0.00	5494.78	0.03	164.84
Rubber and Leather	0.78	0.10			39822.68	0.03	1194.68
Cons. dust and other	0.25	0.03	0.01	0.00	12313.46	0.07	861.94
						Total	17545.46

4.7 Summary of Estimated Energy

The DM and FOD methods measure energy and power for methane and LandGEM for garbage over time. The outcomes from FOD and LandGEM were close on the grounds that both methods depend on the first order decay principle. Boyle's and Dulong's methods give the highest values in contrast with other IPCC methods. Dulong's method is predicated on the heat of ignition value for waste that is most elevated. The findings of energy and power assessment are presented in Table 4-14.

Table 4-14: The energy and power values of waste at a landfill by four different estimation methods

Method	Energy Generated (TJ)	Power (MW)
Stoichiometric Boyle	3981.00	127.00
IPCC Default (DM)	1125.00	36.20
FOD (k=0.4)	496.73	15.97
LandGEM (k=0.4)	506.73	16.29
Dulong's	4128.00	132.00

4.8 Summary

Overall, the results reported correspond to the research objectives. Two goals of this study were: (1) to estimate household solid waste generation and its composition; and (2) to assess the demographic considerations affecting on family waste production. The rate of family garbage production in KMC was found to be 0.3 kg per capita and total family garbage production was 413 tonnes/day. Household waste comprised 51% organic and 49% recyclable, comprising 19% plastic, 13% textiles, 5% paper and paper products, 4% rubber and leather, 3% glass, 1% metal and 4% other waste. Family size and income had a positive effect on garbage production; both were statistically significant and thus are key

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[4] Glass value taken 150 kj/kg and metal value [5] 700 kg/kj directly from sources (Kumar et al., 2014)

indicators in forecasting solid waste generation trends. Additionally, over 92% of households would segregate waste and pay a waste collection fee.

Secondly, this examination analysed methane outflows from SWM in Kathmandu for five waste management alternative scenarios: S0, S1, S2, S3 and S4. The outcomes indicated that methane discharges are amazingly high at 15,136 m^3 for scenario S0 - "Business as usual “, which is currently practised in KMC. A critical decrease of 53% in methane outflows was accomplished with a gas catch scenario (S1) if the Sisdole landfill installs a gas capture system. Likewise, the treating compost scenario (S2) accomplished a decrease of 35% mirroring the high organic portion of waste that is at present just landfilled buried under the soil. The recycling scenario (S3) accomplished a decrease of just 10%. Obviously, the best decrease in methane emissions happened with a combination of gas capturing, treating compost, and reusing scenario (S4) with a 73% decrease.

Finally, the amounts of landfilled waste, landfill features, and composition of landfilled garbage as well as seasonal variations in emissions have been evaluated. The total quantity of methane has been projected to be 1.050E+06 Mg for 2006, which would reduce to 1.345E+07 by 2035. The Sisdole landfill materials are dumped directly up to 87%. In such conditions, the GHG creation-rate would have been about 384.14 of CO_2e(x10^6) t/year in 2018. In this study, the four independent methodologies, have been presented for emission quantification and energy for the Sisdole Landfill. The results show that methane released in one year after garbage positioning along with energy and the resultant power produced a maximum of 132 MW using Dulong’s method and a minimum of 15.97 MW using the FOD method for 0.4 k values. LandGEM is close to FOD followed by the IPCC Default Method and the Stoichiometric Boyle method are 16.29, 36.320 and 127 MW, respectively, are the computed equivalent power.

Chapter 5

Discussion

5.1 Introduction

This chapter discusses the critical findings of the observational assessment from sections corresponding to speculation and information created from the literature study. Section one revisits the factors influencing municipal solid waste generation and composition from a household survey used to collect and analyse data for this study. Section two evaluates the scenarios and management systems of KMC Waste management in terms of methane emission reduction under different scenarios. Section three described the methodology applied for quantification of methane emission and energy estimation rate in the Sisdole landfill. Section four highlights the significance of this study for the evaluation of the physical state and management systems of the MSW position of KMC. Finally, the chapter is summarised.

5.2 Factors Influencing Municipal Solid Waste Generation and Composition

Increasing metropolitan solid waste and an absence of concrete information sources is a developing worry in city areas of emerging nations like Nepal. The study's goal was to measure family unit solid waste production and its composition, and evaluate the socioeconomic reasons affecting family garbage production. This study was based on a household survey of 288 families chosen using a graded sample method from the 32 metropolitan wards of Kathmandu Metropolitan City (KMC). The quantity of the waste produced in KMC was 0.3 kg/person/day and the total household waste generation was 413 tonnes/day. Different studies have comparatively similar outcomes: (ADB, 2013; Dangi et al., 2011; Khan et al., 2016; Masebinu et al., 2017; Maskey, 2018; Pathak, 2017; Pokhrel & Viraraghavan, 2005; Pudasaini, 2014; Sigdel & Koo, 2012; Trang et al., 2017). The higher the number of household members, the more will be purchased and consumed, which produces more waste.

The remainder of the factors did not show any huge effect on garbage production. For the gender variable, there is no huge impact on garbage production since it is the aggregated consequence of all household members (Dalen & Halvorsen, 2011). Additionally, age of household head likewise has no critical effect. In this study, the education level was positive but not substantial. The positive signal for worry about the environment was reinforced by the Oribe-Garcia et al. (2015) study. This means that households allowed to split the waste at their home are eager to reprocess further and produce less waste. Households in the city lack of enough space is insignificant (Afroz et al., 2011). In the study, most households do not have extra space for recycling and the city authority does not provide such facilities, but the result does not make any difference in the analysis. Small amounts of segregated inorganic waste were sent to scrap dealers for some money. The study found the higher the family member's income promoted increased household consumption and an increasing waste generation similar to the Xu et al. (2016) study.

Household waste comprised 51% organic and 49% recyclable comprising 19% plastic, 13% textiles, 5% paper and paper products, 4% rubber and leather, 3% glass, 1% metal, and 4% other waste. Waste production changes with the seasons but, in this study, we considered waste produced only on one day because of time constraints.

This study found that organic waste composition was over (51%), which is very similar to earlier findings in Nepal (ADB, 2013; Manandhar, 2017; Pathak, 2017; Silwal, 2019; Singh et al., 2014; Udm, 2015). The organic waste of emerging nations commonly comprises over 50% of overall garbage (Nguyen, 2017; Raj GC, 2018; World Bank, 2012). However, a normal municipal organic garbage composition in Nepal was 62% (Sodari & Nakarmi, 2018) but the organic garbage composition in KMC is near the worldwide municipal organic garbage composition of 44% (World Bank, 2016).

Socio-economic variables affecting household waste generation were analysed using a regression model. The results show that a family's size and income impact positively on waste generation. Therefore, these parameters can be used to forecast household waste generation. Education level and age did not have major impact on waste generation.

In developing countries, disposal of non-organic and organic waste without segregation is common practice (Wilson et al., 2015). However, this study found 92% of respondents reported that they are willing to pay a waste management tariff and are willing to segregate organic waste though currently total waste is disposed to landfill site without segregation because of a lack of composting facilities. A similar study has found that 83% would segregate waste at their place and 93 % of family units would pay a waste collection fee to have a house-to-house collection system in Bharatpur Metropolitan City, Nepal (Rai et al., 2019). Therefore, the concerned agency should take immediate steps to establish organic waste management facilities such as a composting plant or anaerobic digestion plant, which will help to reduce the landfill waste volume and thus increase the landfill's life span. This finding is an important piece of information. Organic waste is the most attractive option but if not overseen appropriately, it can create significant health and environmental threats. It can be used productively by composting at the household and neighbourhood government level.

5.3 Methane Emission Reduction from MSW Under Different Scenarios

This study has determined that the KMC solid waste management system has the potential to achieve a great reduction in methane (CH_4) emissions based on the five scenarios in the study: S0, S1, S2, S3, and S4, where S0 is "Business as usual", and the others are optional scenarios to reduce methane emissions. The scenarios were tested using the Life Cycle Assessment (LCA) tool alongside the default and first order decay methods suggested by IPCC. The methane discharges under the different scenarios were compared.

The outcomes showed that the methane emissions were very high at 15,136 m^3 for scenario S0 - "Business as usual ". A critical decrease of 53% of methane discharges can be accomplished with gas recovery (S1). Treating the compost (S2) accomplishes a decrease of 35% mirroring the high organic content of the waste that is dumped to a landfill. Reusing (S3) accomplishes a decrease of 10%. The biggest decrease in methane outflows happens with a mix of gas recovery, making compost, and recycling (S4) - a 73% decrease. On account of the great volume of organic waste in the examined region, making compost situation is the best option. Making compost from organic waste at the source is known to be the most ideal method of waste removal, because it diminishes the waste volume moved to landfill and lengthens the landfill's life (Pokhrel & Viraraghavan, 2005). This is an approach favored by households, the principal origin of waste production, to compost and so lessens the amount of waste gathered and overseen, reducing the general expense of SWM, and decreasing GHG.

Scenario S4 is highly flexible to implement in KMC, as based on the household survey more than 90% household were willing to segregate organic waste which can be easily compost. In addition, currently vegetable market, and fruit market separate green waste. Thus, 50% solid waste can be easily compost. Municipality already segregate inorganic recycling waste like plastic, cardboard and metal that can reduce another 25% of disposal volume. In Sisdole landfill, from the disposed 70% MSW it is possible to capture methane by installing Land fill gas capture system.

Making compost is a cycle that emits gases some of which are GHG that promote a global temperature boost. Specifically, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) coming from compost affect global warming. Some of these gases can be reduced by processes such as biofiltration (Sánchez et al., 2015).

The NV Afvalzorg model’s simulations demonstrate that production of methane started in 2006, i.e., one year after the landfill started in 2005 continued an increasing rate for each scenario, peaking in 2018 after 13 years. The measure of methane outflows determined by the NV Afvalzorg FOD model is far lower than the IPCC default model on the grounds that solitary decomposable materials that produce methane (organic waste, paper, material, elastic, and leather) are considered in the last model.

The normal complete volume of MSW produced in KMC from 2005 to 2018 was around 516 tonnes/day. This has been projected to increment by 9.6% each year raising numerous problems in managing solid waste in KMC. The unit rate of waste production in KMC is 0.3 kg per capita, with organic waste being the most notable portion (63%) in all KMC waste. Given the current composition of waste deposited at the Sisdole landfill, it is proposed that the practicality of gas recovery and treating the compost be examined. Recycling material likewise ought to be reviewed since over time plastics and comparable matter may later take up a more prominent portion of the waste.

5.4 Methane Emissions and Energy Estimation

In the Sisdole landfill, organic materials represent about 61.6% of waste presently arriving. lt principally comprises food scraps, yard refuse, wood, and paper/paperboard. They have been the origin of methane in the landfill since 2005. EPA guidelines rule that LFG collection wells be introduced inside two years after positioning the top cover of soil but this is not currently making a difference at the Sisdole site. At numerous landfills, gas collection frameworks are introduced soon after a moderate cover has been laid (van Haaren et al., 2010). At Sisdole, waste is compressed and day by day covered with a soil coating. After the last shutting, the landfill site is covered with a thick soil layer. Every one of these factors lead to an anaerobic environment inside the landfill and consequently it generates methane (Ramachandra et al., 2014).

In this study, an evaluation of the energy and electricity from methane produced from the Sisdole Landfill in one year was completed using four mathematical models: DM, FOD, LandGEM and Boyle's stoichiometric model. They forecast high values of methane creation by Boyle method in Sisdole Landfill. Similarly, applying Dulong's method predicted highest energy generation estimate of Landfill waste. The 'LandGEM' model result seen clearly visible in a graph (Figure 4-9) and, over time, the emission rate compared with the other methods. The Land GEM model produced a similar result to the laboratory experiment result for methane emission in Kumar et al. (2014) study. However, several factors like decomposition decay rate(k), methane generation potential (L_o), placement, temperature, annual rainfall and waste composition affect methane generation in a landfill.

The outcomes from the different models appear in Table 4-14. The results show the presumptions and likenesses in the input parameters of the models. LandGEM, IPCC DM and FOD models have comparable presumptions as is shown in the closeness of their outcomes. However, the plotting ends with 100 years of emissions because LandGEM's conditions resemble the other models. Two other mathematical models with chemical equilibrium analysis using the mass balance methods are only an approximate result.

In Table 4-14, the energy estimate that LandGEM and FOD give low estimates showing that that IPCC default technique yields overestimates of methane discharges and assessed energy produced. The distinction in the evaluations among LandGEM and the IPCC techniques could be because of their input parameters as given in Table (3-6, 3-7 and 3-8). The key point is that the results for methane discharges and energy produced are high for the IPCC default and an overestimate, and much lower for the IPPC FOD and LandGEM models.

The LandGEM evaluation depends on different factors like the measure of decomposable organic matter, methane production potential, the conditions and leachate treatment system that impact the gas creation in landfills. There are vulnerabilities identified in the inferences from the results. The vulnerabilities depend very much on the country's explicit information about the different input parameters required in the calculation.

LandGEM relies upon the primary first order rate equation to assess the reduction in the substrate and thus the decline in outflow over time; the IPCC Default technique does not do this. That causes LandGEM to achieve the most reliable -yearly methane outflows from landfills compared with the IPCC default strategy. The FOD technique yields practically the same outcomes as LandGEM where the waste composition information is available. However, it is difficult to collect consistent data in Nepal for open landfill sites. From this investigation, LandGEM can be regarded as the most sensible strategy for an open dumpsite, since it can use two conditions, either site-explicit information or default values (Alexander et al., 2005)

As indicated by Themelis and Ulloa (2007), universally MSW in landfills is 1.5 billion tonnes and the landfill waste production of methane is assessed at around 50 million tonnes, of which just 5 million tonnes is caught. Comparative investigations have found worldwide that numerous nations are use methane gas as an energy source. In the metropolitan urban communities of India, the removal of waste from landfills would permit the recovery of 60% to 90% of biogas suitable for energy production or use as fuel (Kumar & Sharma, 2014b). In São Paulo and Rio de Janeiro (Brazil), Souza and partners show that with the production of gas, roughly 7% of power could be provided (de Souza et al., 2014). According to Raj GC (2018), Nepal does not have a waste to energy plant in operation. In June 2017, KMC started a pilot undertaking to create biogas and power from it. The 14-kW power production pilot venture has been under review for a year. It will be duplicated in different regions if it is discovered to be fruitful (Post, 2018).

The consequences of this study and flow examination can be used to compute the energy creation arrangements and different uses of LFG as Nepal's commitment to the reduction of worldwide emissions of GHG. Because of the high amount of methane gas production, it is conceivable to plan and a complete methane collection system for the Sisdole landfill to use the gas collected in the burial areas and so prevent remarks.

5.5 Significance of the Study

Dumping solid waste in the city and open spaces of the valley has become a typical practice. The decay of such wastes promotes the creation of methane, a hurtful GHG which is 21 times more heat holding than carbon dioxide. For a place like Kathmandu, where waste heaps can be seen in pretty much every other corner, such an impact can be critical (UN-Habitat, 2015).

IPCC (2006b) gives rules to countries to calculate their country's emissions. These rules were used to analyse outflows from a landfill, treating the soil or biogas plant with one tonne of organic waste, and installing an effective landfill gas catching framework. The IPCC 2006 report covers genuine country discharges from decay, including direct carbon dioxide, methane and nitrous oxide emissions from transport, mechanical equipment uses and so on. As indicated by Hutton et al. (2013), emissions from transport, machine use, industrial equipment and so on, have been determined, yet they are probably going to be higher from treating compost than from landfill. Compost might be source isolated, requiring a different vehicle to gather it from families, or isolated mechanically. Both techniques are energy severe. Besides composting (Hutton et al., 2013) has lower carbon dioxide emissions in landfill in zones where landfill destinations with a gas recovery system are inaccessible. Compost is useful for natural agribusiness; it might be the most helpful treatment in certain circumstances.

Previous studies on MSW in KMC included only daily activity of waste management; problems associated with waste management; technical, social and institutional gaps; challenges and recommendations (Dangi et al., 2011; Pokhrel & Viraraghavan, 2005). This study looked at potential methodologies for Kathmandu Valley to manage the disparity between waste emission interests and practical solid waste management. Waste generation rates (measurements), interpretation of waste and several scenarios have been created and assessed, both quantitatively and subjectively. The comprehensive scenario, acquired from the created scenarios, appears to be better than the others and helps decrease GHG outflow. The scenario suggests Kathmandu city authority will support an organic waste recycling plant, the use of a biogas plant and composting, and convert solid waste into energy by reducing GHG emissions. The study focussed on the following:

- An evaluation of Kathmandu City's Municipal Solid Waste Mangement (MSWM)
- Determination of the connection between the MSWM scenario in Kathmandu's waste mangement and the responsibility of Nepal to global settlements around the IPCC Kyoto Protocol
- Recommendations for developments in MSWM and the quantificationn of emission model methodology towards accomplishing a positive outcome of lessening GHG emissions

To guarantee sustainable improvement with respect to solid waste management, three zones must be guaranteed (McDougall et al., 2008): environmental supportability; social acknowledgment; and reduced carbon dioxide emission approaches applied in a municipal solid waste management plan.

This implies that an ecological appraisal is not adequate to put together choices with respect to why models for assessing environmental results of a solid waste management framework are choice help instruments instead of choice devices. The outcomes from an ecological assessment should be considered alongside financial expense and sociability in the public arena (Kirkeby & Christensen, 2005).

Regularly, it seems hard to limit two factors, cost and ecological effect, at the same time. Subsequently, an equilibrium that should be struck to decrease the general environmental effect of the waste management system beyond what many would consider possible inside a satisfactory expense limit. Because of time limitation, this study predominantly centred around diminishing GHG discharges.

Estimation scenarios are valuable for perusing the direct effect of the exercises and distinguishing areas for more itemized investigation and expected action. It additionally shows how changes in conduct or strategy will modify situations and can lead directly to huge decreases of outflows at a state level.

5.6 Summary

This chapter examined the outcomes identified with the study objectives in the more extensive setting of the literature review. The examination explored the generation to disposal chain of municipal solid waste in the city of Kathmandu. We surveyed the socio-economic issues affecting the waste production and composition in KMC, and the association between solid waste production and ultimate removal of solid waste in KMC. MSW is creating stress in KMC, and household size are the key factor. Organic waste is the biggest problem and, if not handled fittingly, gives rise to genuine human wellbeing and ecological risks. This examination analysed the methane discharges from MSW in Kathmandu for five situations. The outcomes recommend that a gas recovery and treating compost are workable choices. Recycling material ought to likewise be considered since plastics may later make up a more prominent portion of waste. In this study, four independent methods were used for GHG measurement and energy for MSW from a landfill near Kathmandu. In view of the outcomes, it very well may be expected that the amount of created methane from the solid waste inside one year in a landfill is adequate for consideration of introducing a methane catching service. The use of methane as a fuel source expands the extraction of helpful assets from landfills, limits a worldwide temperature alteration and balances a lot of petroleum products.

Chapter 6

Conclusions

6.1 The Study's Contributions

Municipal solid waste (MSW) generation is an environmental issue in Kathmandu Metropolitan City (KMC), Nepal. Therefore, the aim of this study was to determine the contribution that different waste management options can make to reduce GHG emissions compared with traditional landfill. To achieve this aim, the study had the following objectives.

- To determine municipal household solid waste generation and its composition in Kathmandu Metropolitan City .
- To determine the contribution that current solid waste management options in Kathmandu Metropolitan City make to methane emissions
- To determine the contribution that proposed solid waste management scenarios in Kathmandu Metropolitan City make to methane emissions
- To determine the feasibility of energy generation system establishment at Sisdol landfill site.

MSW generation is the strongest environmental issue in KMC though not much research has evaluated what further investigations MSW requires to measure household waste generation and composition in KMC. The theoretical system Created for this study reports on an assessment of household solid waste generation and assessed various solid waste management scenarios for GHG outflow with complete landfill gas emissions are significant for supportable waste management system. Based on the study's outcomes, the following conclusions can be drawn for each research objective.

1. **Determine what factors, influence waste generation and composition.**

This study found the normal household waste production was 0.3 kg/capita/day. Given a population of 1,307,500 residents, it is projected that 392.25 tonnes of household waste per day are being produced in Kathmandu. Of the studied socioeconomic factors, age, education level, income, family size, only the family size impacted solid waste generation, the larger the family the more the waste production.

Organic waste is the largest fraction (51%), followed by plastic (19%) and textiles (13%). Paper, rubber and leather, glass, metal, and other inert wastes range between 1% and 5% of total waste. Based on this result organic waste is over half of all waste and, therefore, composting is the best option rather than landfill disposal. Landfilling organic waste produces high levels of methane, which, if not manage properly, can cause environmental pollution. Based on the survey result that over 92% of households would segregate organic waste from inorganic waste and/or pay a waste collection fee indicates a high possibility of promoting community composting and household composting that would help reduce the volume of landfill waste and reduce landfill waste emissions.

In KMC, households produce around 76,879 tonnes of organic waste each year that is directly disposed of in an open landfill site at Sisdole. The mixed waste disposal creates issues of smell for the surrounding area, leachate polluting nearby river, and landfill methane emissions that will influence GHG emissions. Given the amount and the force of its effects, organic waste ought to be managed separately. Making compost has been shown to be the most conservative and efficient strategy among management choices in emerging nations given the waste type and composition.

The recyclable ability of waste is also extremely high (45% of all waste or around 67,835 tonnes/year). There is no recycling and reusing foundation in the region; present waste workers who gather plastic, paper, and beer bottle waste from the Sisdole landfill ought to be organized into a network for such recyclable material to scrap merchants who are responsible for moving these materials to urban communities where reuse exists. Other waste is 4% of all waste (around 6,029 tonnes/year) which is also a noteworthy sum and should be handled appropriately. This includes hazardous waste that ought to be handled in the best ecologically and publicly friendly way since it comprises destructive or poisonous materials that contaminate the atmosphere and cause danger to humans. If waste from other origin, e.g., businesses, factories and institutions were to be incorporated, the total waste produced in KMC would be a lot greater.

2. Determine the contribution that current and proposed SWM options in KMC make to methane emissions.

This study used two models to calculate methane emissions from a disposal site over its life in a Life Cycle Inventory (LCI); the DM and FOD models mirror production of methane after some time. Considering the norm of mass adjustment, the DM model was used because of its basic suppositions of all possible methane produced from disposed waste. The FOD model, a changed model of the first order decomposition, was formed and used the available information. It portrayed the genuine production of methane in the long run.

The study created five scenarios: Scenario S0 is "Business as usual " and four other scenarios illustrate MSW management in KMC. The suggested scenarios help investigate the probable methane production reduction by gas recovery (S1 – 70% of methane recovery), composting (S2 – 50% composting), reusing (S3 – 25% recycling) and scenario S4, the integration of composting, recycling and gas recovery.

The results show that methane discharge is elevated at 15,136 m^3 for scenario S0. A huge decrease of 53% of methane discharge with a corresponding recovery of landfill gas is accomplished in scenario S1. The best decrease in methane discharge happens in scenario S4, an integration of gas recovery, composting and recycling and with a 73% decrease in methane discharge. The composting scenario (S2) achieved a decrease of 35% indicating the elevated organic matter in waste currently present at the disposal site. The recycling scenario (S3) gave a decrease of only 10%, which shows that the current solid waste management is risky in terms of global warming. The proposed scenario S4 is the best option among the five studied scenarios.

All scenarios gave peak methane emissions in 2018 that might be because of the greater level of organic waste in the solid waste segment at the Sisdole disposal site. The year that ends the process of methane discharge is consistent for all scenarios. For scenarios S0 and S3, the production of methane in the Sisdole site keeps going for about 30 years from 2006 to 2035. Likewise, scenarios S2 and S4, methane productions last till 2035, 30 years after covering.

It can be concluded that scenario S4 is the best choice for the advancement of MSW management in KMC and to decrease the ecological effects of GHG discharges. This alternative may be a useful solution to help the policy and plan making of SWM at a regional agency level, as well as policymakers at the state level to enhance MSW management and decrease GHGs discharges to reduce climate change.

3. Determine the feasibility of reducing methane emissions from solid waste management.

Methane discharge has been assessed by using the LandGEM model for the Sisdole Landfill, the solid waste removal destination for Kathmandu. This landfill has been active since 2005 with the outlook of receiving solid waste from the neighbouring zone until 2015. The amount of methane production from solid waste was determined as 1.050E+06 (Mg/year) in 2006 and the most extreme methane generation rate happens from 2015 to 2035 with peak of generation being around 1.100E+07 (Mg/year). In view of these volumes, introducing a methane catching system should now be considered.

Studies indicate that KMC waste is a source of energy because it has high percentage of organic material that can be harnessed as energy. There are many possibilities for using methane as source from the Sisdole landfill. This study clearly demonstrates a motivation to create planned removal at the site by fitting it out with gas mining and utilization systems. It is highly recommended that the available methane be used as an energy source which will increase useful supplies from the disposal site. The findings indicate that waste is an origin of energy, and a critical measure of energy can be used from it. There is tremendous need to use methane as a source of power. KMC focuses the motivations to build a sanitary landfill with gas capturing system. The use of methane as a fuel source will amplify the extraction of useful assets from landfills. An investigation of methane outflows with various values of k has been estimated. The higher the estimate of k, the faster the methane generation rate increments and then decays over the long run. The Sisdole Landfill has a favourable climate that does not affect methane generation from the existing landfill.

6.2 The Study's Limitations

This study faced two main limitations, a one point in time collection of waste generation and composition. Needs to be done at different times of the year, to reflect waste generation in the different seasons. Only considers household waste. The survey did not consider commercial and institutional waste nor seasonal waste generation because of time resource constraint.

The current MSWM system of KMC is totally disorganized and conventionally practised. The data recording and management system is very poor therefore some data have been taken directly from the model's default parameters to estimate methane and carbon dioxide emissions at the Sisdole Landfill. The estimation of methane and carbon dioxide emissions only consider Landfill microbial process emissions and did not consider non biogenic emissions like from waste collection and transportation fuel emissions.

6.3 Recommendations and Potential SWM Options

A recommendation of this study is that households be requested to segregate waste and that households help pay for a system to separate waste at collection. The feasibility first needs to be determined. What would it cost? How would it be funded? Would households be willing to pay the money needed? If households segregate their waste; there is a need to develop facilities to help them do so. Compostable material – given the 51% organic fraction – is suggested as the first type of waste that should be segregated the other options of gas recovery from landfill gas need to be investigated for their financial feasibility and sustainability in a developing country like Nepal with minimal resources.

Further, for a decrease in GHG and the sustainability of waste management systems in KMC, there are the following recommendations:

- Private companies are successful in waste recycling and raising public awareness. So, they should be encouraged by KMC to expand their activities to a bigger scale.
- Efficient recycling of plastic, paper and metal should be promoted in Kathmandu long term with arrangements for a subsidy to conserve the resources. When more and more waste is

redirected from landfill disposal to recycling process that will help reduce the volume of landfill waste and decease GHG emissions.

- As organic fraction contains most of the waste, organic waste compost or biogas production ought to be advantageous. Household composting, community composting and biogas production will be beneficial especially in distant settlements where waste collection and transportation can be problematic.

- Kathmandu Valley is using Sisdole landfill site for MSW disposal. Currently LFG is being disposed to the atmosphere through PVC pipes without any treatment which is deteriorating the environment and wasting energy. Therefore, municipality should create an integrated gas capturing system to generate electricity.

6.4 Future Research

The findings of this study highlighted the following further research opportunities to enhance the experimental outcomes:

- There is an opportunity to improve the study's findings by extending the household survey to consider seasonal and annual variations in solid waste production.
- Customary qualities, strict convictions and the various religious cultures are the principal factors in behaviour towards effective city solid waste management in metropolitan territories of undeveloped nations. These perspectives ought to be considered in future studies.
- Research studies performing an energy audit comparing the energy consumption and carbon dioxide emissions in waste collection and transportation system would be highly recommended to explore the energy savings and discourage the use of fossil fuel.

- Further study needs to compare all possible solid waste management systems in terms of GHG emission and energy recovery to determine the most feasible solid waste management system with least environmental impact and less energy consumption. This was beyond the scope of this study.
- Research on a digital tool to monitor and forecast landfill disposal volume, energy surges, waste transportation costs and related GHG emissions would be an exciting area for future studies that could help KMC to monitor and control SWM.
- Further research examining the investment required and financial feasibility of the various options suggested should be conducted. This was beyond the scope of this study.

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Appendix A

A.1 Approval letter to conduct survey.

Research Management Office

T 64 3 423 0817
PO Box 85084, Lincoln University
Lincoln 7647, Christchurch
New Zealand
www.lincoln.ac.nz

22 June 2020

Application No: 2020-25

Title: Greenhouse Gas (GHG) Emissions of Solid Waste Management System: A case study of different Solid Waste Management Scenario in Kathmandu, Nepal

Applicant: R Khadka

The Lincoln University Human Ethics Committee has reviewed the above noted application. Thank you for your response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed. I am pleased to give final approval to your project.

Please note that this approval is valid for three years from today's date at which time you will need to reapply for renewal.

Once your field work has finished can you please advise the Human Ethics Secretary, Alison Hind, and confirm that you have complied with the terms of the ethical approval.

May I, on behalf of the Committee, wish you success in your research.

Yours sincerely

Grant Tavinor
Chair, Human Ethics Committee

PLEASE NOTE: The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

A.2 Research Information Sheet

Invitation to participate as a subject in a project: You are invited to participate as a subject in a project entitled "Greenhouse Gas (GHG) Emissions of Solid Waste Management (SWM) System: A case study of different SWM Scenario in Kathmandu, Nepal".

This project has a focus on, researching methods for the better management of municipal solid waste. As part of my research, I would like to understand current waste management practice in Kathmandu Municipality, particularly in relation to waste volume and composition. This will inform my PhD how it can best contribute towards improved sustainable solid waste management.

Your participation in this project involves providing information about your solid waste management practices. This survey is voluntary and will take around 45 minutes to complete.

There will not be follow-up to this activity and there are no risks involved in participating in this project. In addition, there are no risk in the performance of the tasks and application of the procedures.

The results of the project may be published, but you may be assured of your anonymity in this investigation. Your identity will not be made public or made known to any person other than the researcher and his supervisors.

All information will be used for the research purpose only. To ensure anonymity only the code given to each survey document will be used to summarise the outcome of the survey. All the hard copies of the survey will be locked in my locker on campus. After my course completion all the survey documents will be locked in my main supervisor's locker for 6 years and then destroyed.

The project is being carried out by Raju Khadka, a PhD student in the Faculty of Agribusiness and Commerce at Lincoln University. This project has been subject to ethical review, according to the procedures specified by the Lincoln University Research Ethics Committee and has been allowed to proceed.

If you have any queries or would like to discuss anything about this surveying, we would be please to provide you any information.

Main supervisor of the research and his address is:

Majed Safa
Senior Lecturer
Department of Land Management and Systems
Faculty of Agribusiness and Commerce
Lincoln University, Lincoln 7647
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P +64 3 4230263 | m +64 2108222339 | f +64 3 3253615
e- Majeed.safa@lincoln.ac.nz

A.3 Consent Form

Project Title: **Solid Waste Management Scenario in Kathmandu, Nepal**

Project Supervisory Team: Dr. Majeed Safa and Prof. Alison Bailey

Researcher: Raju Khadka

1. I have read the Information Sheet and have had details of the study explained to me.
2. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.
3. I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that confidentiality will be preserved.
4. I understand that I may withdraw from the project, including withdrawal of any information I have provided at any time of survey interview and information thereof, will be destroyed.
5. I am providing my consent for taking part in this research and understand results generated from the data may be reported into any publication/reports both nationally and internationally, without disclosing my identity.
6. I wish to receive a copy of the report from this research (Please tick one): YES, No

Participant Full Name:	Code:
Participant Signature:	Date:

Researcher Contact Details:
Raju Khadka (Email: raj. Khadka @lincolnuni.ac.nz, Mobile: + 64-2102467906)

A.4 Survey Questionnaire Used for Data Collection

रधुरी सर्वेक्षण प्रश्नावली (House-Hold Questioners)

जिल्ला (District) ....
न.पा./गा.वि.स (Municipality/VDC) ....
वडा नं (Ward No)...... टोल (Street) ....
अन्तरवार्ता मिति (Interview Date) ....

सामाजिक-आर्थिक विवरण(Social-Economical Details)

(उपर्युक्त कोठामा (√) यो चिन्ह लगाउनु होस्) (Please tick in the appropriate box)

१ अन्तरवार्ता दिनेको नाम/थर(Full name of the interviewer) : ....

२ घरमुलिको नाम(House-Hold owner name) ....

३ घरमुलिको पेशा (House-Hold owner occupation) ....

४ घरमुलिको उमेर (House-Hold owner Age) ....

५ घरमुलिको लिङ्ग(House-Hold owner Sex) : १) पुरुष (Male) ☐ २) महिला (Female) ☐ ३)तेश्रो लिङ्गी(Third gender) ☐

६ घरमूलिको शिक्षा र स्तर ?(House-Hold owner Education level)(१)अशिक्षित(Illitrate) ☐ (२)निम्न शिक्षा हासिल(Basic education) ☐ (३) माध्यमिक शिक्षा(Secondary ☐ education) ४)उच्च शिक्षा (Higher education)

७ परिवारको स्वरुप ?(Family structure) १) संयुक्त (Joint) ☐ (२) एकल ☐ (Nuclear)

८ परिवार सदस्य संख्या (Number of family members)? १) पुरुष (Male) ☐ (२) महिला ☐ (Female) ☐ जम्मा: संख्या (Total)

९ परिवार सदस्यहरुको उमेर संख्या (Number of family members of various age group) ?

(Male) (0-15 yrs. Old) (15-30 yrs. Old) (30-60 yrs. Old) (60+ yrs. Old)

पुरुष १) ०–१५ ☐ २) १५–३० ☐ ३) ३०–६० ☐ ४) ६०+ ☐

(Female) (0-15 yrs. Old) (15-30 yrs. Old) (30-60 yrs. Old) (60+ yrs. Old)

महिला १)१०–१५ ☐ २) १५–३० ☐ ३) ३०–६० ☐ ४) ६०+ ☐

(How long have you been living in this town)? (Permanent member) (Migration)
१० यस नगर/शहरमा कहिले देखि बस्दै आउनु भएको छ ? १) स्ववासी ☐ २)बसाइ सराई ☐

Do you possess this house by yourself? (Yes) (No)
११ यो घर आफ्नै हो ? १) हो ☐ २) होइन ☐

Mention the type after inspections? Concrete Semi-concrete (Brick, Stone+CGI) Mud-Mortar (Mud, Bamboo and locally available materials)

घरको अवलोकन गरी घरको किसिम लेख्ने । १)पक्की ☐ २)अर्ध पक्की ☐ ३) कच्ची ☐

(पक्की : छत ढलान, अर्ध पक्की : ढुङ्गा/इट्टाको गाह्रो, टीनको छाना/ढुङ्गा/स्लेट,झिगटी/टायल आदि, कच्ची : माटो गाह्रो र खर/टायलले छाएको)

१२ घरमा उठेको फोहरको व्यवस्थापन कत्तिको गर्नुहुन्छ How often do you manage Solid waste generated from your house?

१)दैनिक (Daily) ☐ २)दुई दिनमा एकचोटी (Once in two days) ☐ ३)हप्तामा एकचोटी (Weekly) ☐ ४) महिनामा एकचोटी(Monthly) ☐

(During what time of days do you dispose the waste?
१३ फोहरको व्यवस्थापन दिनमा कुन समयमा गर्नुहुन्छ ?
Morning Daytime Evening Night
१) बिहान ☐ २) दिउँसो ☐ ३) साँझ ☐ ४) राति ☐

Solid waste weight measured in the concerned house
१४ **सम्बनिधत घरमा उठेको फोहरको बजन** ? ………………………………………….

. Do you pay for solid waste management?
१५ सरसफाई व्यवस्थापनको लागी शुल्क तिर्नु हुन्छ?
Yes No I cannot
१) छु ☐ २)छैन ☐ ३)सक्दिन ☐

Do you agree on solid waste management from the source?
१६ स्रोतमा नै फोहर वर्गीकरण गर्न, र वर्गीकृत फोहर विसर्जनको लागि तयार हुनुहुन्छ ?
Yes No I cannot
१) गर्छु ☐ २)गर्दिन ☐ ३)गर्नसक्दीन ☐

Comments:
सुझाव……………………………………………………………………………………………………
………
…………………………………

नोट (Note): पेशा (Occupations) : १. कृषि Agriculturist २. व्यापार Business ३. नोकरी Job ४. उद्योगधन्दा Small industries ५. रेमिटेन्स (बैदेशिक रोजगार) Remittance ६. ज्याला Daily wage ७. अन्य Others ८.पेशा नभएको आश्रित(विद्यार्थी, गृहिणी, बूढाबूढी अशक्त, बालक ५ बर्षमुनि आदि) Jobless (Elderly people, Child, House wives)

अन्तरवार्ता लिनेको नाम र सहि Interviewers Name and signature : ……………………

सुपरिवेक्षकको नाम र सहि Supervisor Name and signature: …………………………

धन्यवाद Thankyou !

A.5 Kathmandu metropolitan city word population and household

Wards No	Household	Population 2011	Sample Size
1	1,917.00	8,008.00	2
2	3,599.00	13,448.00	4
3	9,145.00	34,866.00	10
4	12,030.00	47,362.00	14
5	4,774.00	18,320.00	5
6	15,434.00	60,344.00	18
7	13,559.00	51,581.00	15
8	2,773.00	10,738.00	3
9	10,417.00	40,371.00	12
10	10,571.00	39,820.00	12
11	4,416.00	17,765.00	5
12	3,173.00	13,262.00	4
13	10,207.00	40,456.00	12
14	15,472.00	58,495.00	17
15	14,093.00	54,476.00	16
16	22,715.00	84,441.00	25
17	6,394.00	25,926.00	8
18	2,746.00	10,746.00	3
19	2,632.00	10,711.00	3
20	2,844.00	10,968.00	3
21	3,389.00	13,727.00	4
22	1,992.00	9,187.00	3
23	1,991.00	8,357.00	2
24	1,530.00	7,619.00	2
25	3,258.00	13,203.00	4
26	947.00	45,052.00	13
27	1,888.00	8,563.00	3
28	1,370.00	16,211.00	5
29	12,252.00	33,316.00	10
30	1,914.00	25,694.00	8
31	4,122.00	66,121.00	20
32	9,298.00	76,299.00	23
Total	212862.00	975453.00	288

Appendix B

B.1 Typical ultimate analysis data for combustible components of MSW

Combustibles	Percent by Weight (dry basis)					
	C	H	O	N	S	Ash
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	-	-	10.0
Textiles	55.0	6.6	31.2	4.6	0.2	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Yard wastes	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5

Source: IPCC guidelines [2000]

B.2 Moisture content of different components of MSW Source: IPCC guidelines [2000]

Component	Range, %	Typical, %
Yard wastes	45–85	60
Wood	15–40	25
Food wastes	45–85	60
Paper	3–8	5
Cardboard	3–8	5
Plastics	1–3	2
Textiles	5–15	10
Rubber	2–4	2
Leather	8–10	9
Misc. organics	10–60	25
Glass	0.5–1	0.5
Tin cans	0.5–1	0.5
Nonferrous	0.5–1	0.5
Ferrous metals	0.5–1	0.5
Dirt, ashes, etc.	6–12	8

B.3 Typical landfill gas components

Gas	Percentage by Volume
Methane (CH4)	45-60
Carbon Dioxide (CO2)	40-60
Nitrogen	2-5
Oxygen (O2)	0.1-1
Ammonia (NH3)	0.1-1
NMOCs	0.01-0.6
Sulfides	0-1
Hydrogen	0-0.2
Carbon Monoxide (CO)	0-0.2

Source: EPA (1995)

B.4 Default DOC values for major waste streams

Waste Stream	Range DOC (by weight Fraction)	Default DOC (by weight Fraction)
Garden waste	0.18-0.22	0.20
Food	0.08-0.20	0.15
Paper	0.36-0.45	0.40
Wood	0.39-0.46	0.43
Textiles	0.20-0.40	0.24

Source: IPCC guidelines [2000]

B.5 Waste characterization and methane potential (L_O)

Waste characterization	Methane generation potential (m^3 CH_4/ton)
Relatively inert	20
Moderately decomposable	120
Decomposable	160

Sources (Keelson, 2013)

B.6 SWDS classification and methane correction factors (M)

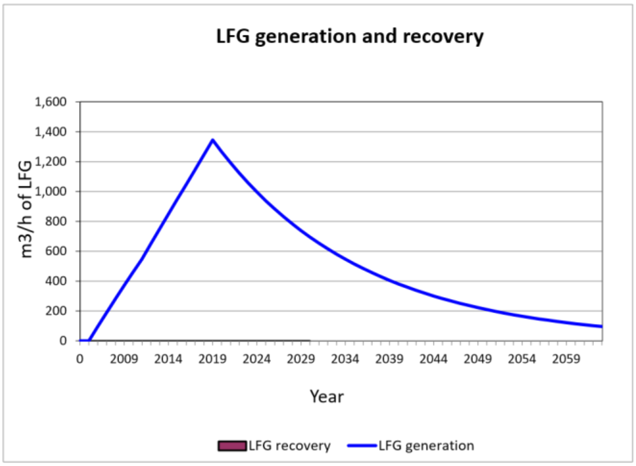
Type of Site	Methane Correction Factor (MCF)
Managed	1.0
Managed – semi-aerobic	0.5
Unmanaged – deep (≥ 5 m waste)	0.8
Unmanaged – shallow (< 5 m waste)	0.4
Uncategorized SWDS	0.6

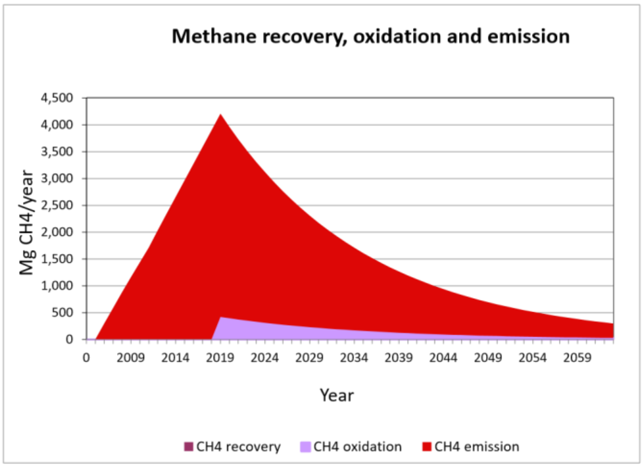
Source: IPCC guidelines [2000]

Appendix C

C.1 KMC emission quantification using afvalzorg model scenario S1 to S4

SCENARIO S1& SO





Parameters to be adapted for modelling (see tab 'manual' for more information)
Step 1: Enter year of start of disposal in cell A47
Step 2: Enter waste mass deposited in column B for each year of operation
Step 3: Enter landfill cell number where waste is placed for each year in column C (default value = 1)
Step 4: Enter Methane Correction Factor (MCF) in column D until the last year of disposal
Step 5: Estimate general waste composition of the landfill in percentages in table 1 (column O)
Step 6: Enter amount of Degradable Organic Carbon (DOC) in MSW in table 1 (cell P32)
Step 7: Enter the reaction rate constant (k) of Municipal Solid Waste in cell D41
Step 8: Enter the percentage of methane oxidised (OX) in the cover layer in cell D42
Step 9: Enter LFG recovery efficiency in column J for each year
Step 10: Please check that moving/editting cells has not impacted the calculations or the graphs

Reaction rate constant (k):	0.060
Oxidation factor (OX):	10%

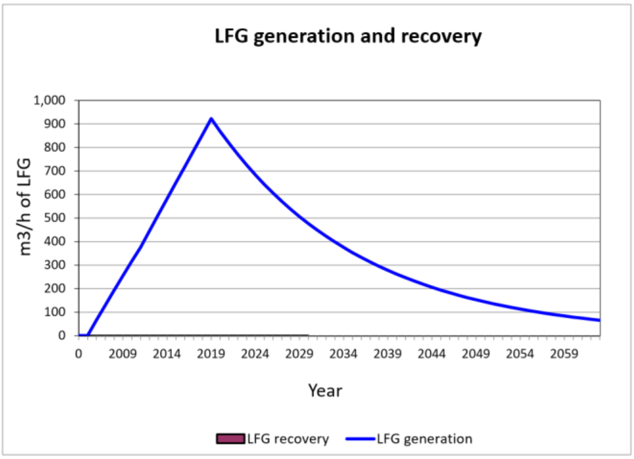
Table 1: Waste composition

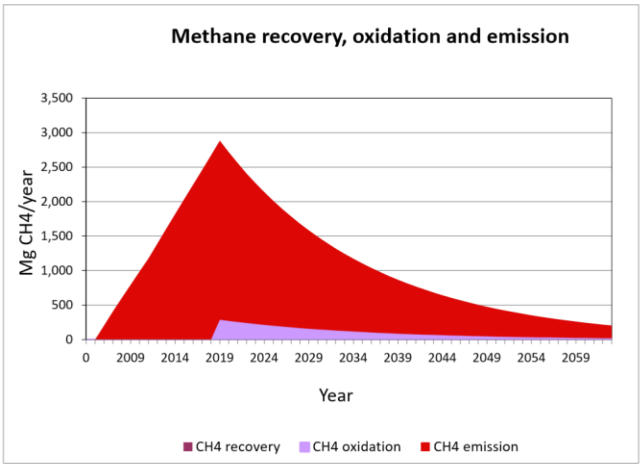
Waste category	**percentage**	**DOC (by weight wet basis)**
Municipal solid waste (MSW)	32%	0.170
Industrial waste	0%	0.150
Sewage sludge	0%	0.050
Garden waste	0%	0.200
Food waste	63%	0.150
Construction and demolition waste	5%	0.043
Soil	0%	0.003
Total	100%	**0.152**

year [a]	waste mass [Mg]	cell number [-]	MCF [-]	DDOCm [Mg]	DDOCma [Mg]	DDOCm decomp [Mg]	CH_4 gen [Mg]	LFG gen [m^3STP/h]	Recovery efficiency [-]	CH_4 rec [Mg]	LFG rec [m^3STP/h]	CH_4 oxid [Mg]	LFG oxid [m^3STP/h]	CH_4 emit [Mg]	LFG emit [m^3STP/h]
0	0	1	1.0	-	-	0	0	0	0.00	0	0	0	0	0	0
2005	101,559	1	1.0	7,704	7,704	-	0	0	0.00	0	0	0	0	0	0
2006	105,367	1	1.0	7,993	15,248	449	299	96	0.00	0	0	0	0	299	96
2007	109,318	1	1.0	8,292	22,652	888	592	189	0.00	0	0	0	0	592	189
2008	113,418	1	1.0	8,603	29,936	1,319	879	281	0.00	0	0	0	0	879	281
2009	117,671	1	1.0	8,926	37,118	1,743	1,162	372	0.00	0	0	0	0	1,162	372
2010	122,084	1	1.0	9,261	44,217	2,162	1,441	461	0.00	0	0	0	0	1,441	461
2011	141,318	1	1.0	10,720	52,362	2,575	1,717	549	0.00	0	0	0	0	1,717	549
2012	146,618	1	1.0	11,122	60,434	3,049	2,033	650	0.00	0	0	0	0	2,033	650
2013	152,116	1	1.0	11,539	68,453	3,519	2,346	750	0.00	0	0	0	0	2,346	750
2014	157,820	1	1.0	11,971	76,438	3,986	2,658	850	0.00	0	0	0	0	2,658	850
2015	163,738	1	1.0	12,420	84,407	4,451	2,968	949	0.00	0	0	0	0	2,968	949
2016	169,879	1	1.0	12,886	92,377	4,915	3,277	1,048	0.00	0	0	0	0	3,277	1,048
2017	176,249	1	1.0	13,369	100,367	5,380	3,586	1,147	0.00	0	0	0	0	3,586	1,147
2018	182,858	1	1.0	13,871	108,393	5,845	3,897	1,246	0.00	0	0	0	0	3,897	1,246
2019	0	0	0.0	-	102,080	6,312	4,208	1,346	0.00	0	0	421	135	3,787	1,211
2020	0	0	0.0	-	96,136	5,945	3,963	1,267	0.00	0	0	396	127	3,567	1,141
2021	0	0	0.0	-	90,537	5,598	3,732	1,193	0.00	0	0	373	119	3,359	1,074
2022	0	0	0.0	-	85,265	5,272	3,515	1,124	0.00	0	0	351	112	3,163	1,012
2023	0	0	0.0	-	80,299	4,965	3,310	1,059	0.00	0	0	331	106	2,979	953

2024	0	0	0.0	-	75,623	4,676	3,118	997	0.00	0	0	312	100	2,806	897
2025	0	0	0.0	-	71,219	4,404	2,936	939	0.00	0	0	294	94	2,642	845
2026	0	0	0.0	-	67,072	4,147	2,765	884	0.00	0	0	276	88	2,488	796
2027	0	0	0.0	-	63,166	3,906	2,604	833	0.00	0	0	260	83	2,344	749
2028	0	0	0.0	-	59,487	3,678	2,452	784	0.00	0	0	245	78	2,207	706
2029	0	0	0.0	-	56,023	3,464	2,310	738	0.00	0	0	231	74	2,079	665
2030	0	0	0.0	-	52,760	3,263	2,175	695	0.00	0	0	218	70	1,958	626
2031	0	0	0.0	-	49,688	3,073	2,048	655	0.00	0	0	205	65	1,844	589
2032	0	0	0.0	-	46,794	2,894	1,929	617	0.00	0	0	193	62	1,736	555
2033	0	0	0.0	-	44,069	2,725	1,817	581	0.00	0	0	182	58	1,635	523
2034	0	0	0.0	-	41,503	2,566	1,711	547	0.00	0	0	171	55	1,540	492
2035	0	0	0.0	-	39,086	2,417	1,611	515	0.00	0	0	161	52	1,450	464
2036	0	0	0.0	-	36,810	2,276	1,517	485	0.00	0	0	152	49	1,366	437
2037	0	0	0.0	-	34,666	2,144	1,429	457	0.00	0	0	143	46	1,286	411
2038	0	0	0.0	-	32,647	2,019	1,346	430	0.00	0	0	135	43	1,211	387
2039	0	0	0.0	-	30,746	1,901	1,267	405	0.00	0	0	127	41	1,141	365
2040	0	0	0.0	-	28,955	1,791	1,194	382	0.00	0	0	119	38	1,074	344
2041	0	0	0.0	-	27,269	1,686	1,124	359	0.00	0	0	112	36	1,012	324
2042	0	0	0.0	-	25,681	1,588	1,059	339	0.00	0	0	106	34	953	305
2043	0	0	0.0	-	24,186	1,496	997	319	0.00	0	0	100	32	897	287
2044	0	0	0.0	-	22,777	1,408	939	300	0.00	0	0	94	30	845	270
2045	0	0	0.0	-	21,451	1,326	884	283	0.00	0	0	88	28	796	254
2046	0	0	0.0	-	20,202	1,249	833	266	0.00	0	0	83	27	750	240
2047	0	0	0.0	-	19,025	1,176	784	251	0.00	0	0	78	25	706	226
2048	0	0	0.0	-	17,917	1,108	739	236	0.00	0	0	74	24	665	213
2049	0	0	0.0	-	16,874	1,043	696	222	0.00	0	0	70	22	626	200
2050	0	0	0.0	-	15,891	983	655	209	0.00	0	0	66	21	590	189
2051	0	0	0.0	-	14,966	925	617	197	0.00	0	0	62	20	555	178
2052	0	0	0.0	-	14,094	872	581	186	0.00	0	0	58	19	523	167
2053	0	0	0.0	-	13,273	821	547	175	0.00	0	0	55	17	492	157
2054	0	0	0.0	-	12,500	773	515	165	0.00	0	0	52	16	464	148
2055	0	0	0.0	-	11,772	728	485	155	0.00	0	0	49	16	437	140
2056	0	0	0.0	-	11,087	686	457	146	0.00	0	0	46	15	411	132
2057	0	0	0.0	-	10,441	646	430	138	0.00	0	0	43	14	387	124
2058	0	0	0.0	-	9,833	608	405	130	0.00	0	0	41	13	365	117
2059	0	0	0.0	-	9,261	573	382	122	0.00	0	0	38	12	344	110
2060	0	0	0.0	-	8,721	539	360	115	0.00	0	0	36	11	324	103
2061	0	0	0.0	-	8,213	508	339	108	0.00	0	0	34	11	305	97
2062	0	0	0.0	-	7,735	478	319	102	0.00	0	0	32	10	287	92
2063	0	0	0.0	-	7,285	450	300	96	0.00	0	0	30	10	270	86

SCENARIO S2





Parameters to be adapted for modelling (see tab 'manual' for more information)
Step 1: Enter year of start of disposal in cell A47
Step 2: Enter waste mass deposited in column B for each year of operation
Step 3: Enter landfill cell number where waste is placed for each year in column C (default value = 1)
Step 4: Enter Methane Correction Factor (MCF) in column D until the last year of disposal
Step 5: Estimate general waste composition of the landfill in percentages in table 1 (column O)
Step 6: Enter amount of Degradable Organic Carbon (DOC) in MSW in table 1 (cell P32)
Step 7: Enter the reaction rate constant (k) of Municipal Solid Waste in cell D41
Step 8: Enter the percentage of methane oxidised (OX) in the cover layer in cell D42
Step 9: Enter LFG recovery efficiency in column J for each year
Step 10: Please check that moving/editting cells has not impacted the calculations or the graphs

Reaction rate constant (k):	0.060
Oxidation factor (OX):	10%

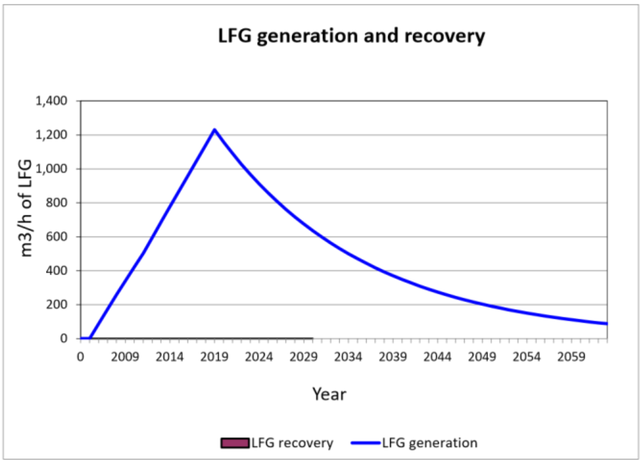
Table 1: Waste composition

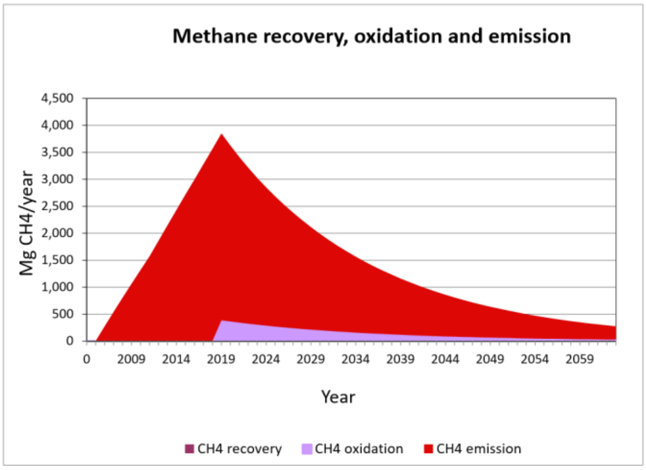
Waste category	**percentage**	**DOC (by weight wet basis)**
Municipal solid waste (MSW)	47%	0.170
Industrial waste	0%	0.150
Sewage sludge	0%	0.050
Garden waste	0%	0.200
Food waste	46%	0.150
Construction and demolition waste	7%	0.043
Soil	0%	0.003
Total	100%	**0.152**

year [a]	waste mass [Mg]	cell number [-]	MCF [-]	DDOCm [Mg]	DDOCma [Mg]	DDOCm decomp [Mg]	CH₄ gen [Mg]	LFG gen [m^{3}STP/h]	Recovery efficiency [-]	CH₄ rec [Mg]	LFG rec [m^{3}STP/h]	CH₄ oxid [Mg]	LFG oxid [m^{3}STP/h]	CH₄ emit [Mg]	LFG emit [m^{3}STP/h]
0	0	1	1.0	-	-	0	0	0	0.00	0	0	0	0	0	0
2005	69,451	1	1.0	5,282	5,282	-	0	0	0.00	0	0	0	0	0	0
2006	72,055	1	1.0	5,480	10,454	308	205	66	0.00	0	0	0	0	205	66
2007	74,757	1	1.0	5,685	15,531	609	406	130	0.00	0	0	0	0	406	130
2008	77,561	1	1.0	5,899	20,525	904	603	193	0.00	0	0	0	0	603	193
2009	80,469	1	1.0	6,120	25,449	1,195	797	255	0.00	0	0	0	0	797	255
2010	83,487	1	1.0	6,349	30,316	1,482	988	316	0.00	0	0	0	0	988	316
2011	96,640	1	1.0	7,350	35,900	1,765	1,177	376	0.00	0	0	0	0	1,177	376
2012	100,264	1	1.0	7,625	41,435	2,091	1,394	446	0.00	0	0	0	0	1,394	446
2013	104,024	1	1.0	7,911	46,933	2,413	1,609	514	0.00	0	0	0	0	1,609	514
2014	107,925	1	1.0	8,208	52,407	2,733	1,822	583	0.00	0	0	0	0	1,822	583
2015	111,972	1	1.0	8,516	57,871	3,052	2,035	651	0.00	0	0	0	0	2,035	651
2016	116,171	1	1.0	8,835	63,336	3,370	2,247	718	0.00	0	0	0	0	2,247	718
2017	120,528	1	1.0	9,166	68,814	3,688	2,459	786	0.00	0	0	0	0	2,459	786
2018	125,048	1	1.0	9,510	74,316	4,007	2,672	854	0.00	0	0	0	0	2,672	854
2019	0	0	0.0	-	69,988	4,328	2,885	923	0.00	0	0	289	92	2,597	830
2020	0	0	0.0	-	65,912	4,076	2,717	869	0.00	0	0	272	87	2,445	782
2021	0	0	0.0	-	62,074	3,838	2,559	818	0.00	0	0	256	82	2,303	736
2022	0	0	0.0	-	58,459	3,615	2,410	771	0.00	0	0	241	77	2,169	694
2023	0	0	0.0	-	55,055	3,404	2,270	726	0.00	0	0	227	73	2,043	653
2024	0	0	0.0	-	51,849	3,206	2,137	683	0.00	0	0	214	68	1,924	615
2025	0	0	0.0	-	48,829	3,019	2,013	644	0.00	0	0	201	64	1,812	579
2026	0	0	0.0	-	45,986	2,844	1,896	606	0.00	0	0	190	61	1,706	546
2027	0	0	0.0	-	43,308	2,678	1,785	571	0.00	0	0	179	57	1,607	514
2028	0	0	0.0	-	40,786	2,522	1,681	538	0.00	0	0	168	54	1,513	484
2029	0	0	0.0	-	38,410	2,375	1,583	506	0.00	0	0	158	51	1,425	456

2030	0	0	0.0	-	36,174	2,237	1,491	477	0.00	0	0	149	48	1,342	429
2031	0	0	0.0	-	34,067	2,107	1,404	449	0.00	0	0	140	45	1,264	404
2032	0	0	0.0	-	32,083	1,984	1,323	423	0.00	0	0	132	42	1,190	381
2033	0	0	0.0	-	30,215	1,868	1,246	398	0.00	0	0	125	40	1,121	358
2034	0	0	0.0	-	28,455	1,760	1,173	375	0.00	0	0	117	38	1,056	338
2035	0	0	0.0	-	26,798	1,657	1,105	353	0.00	0	0	110	35	994	318
2036	0	0	0.0	-	25,237	1,561	1,040	333	0.00	0	0	104	33	936	299
2037	0	0	0.0	-	23,768	1,470	980	313	0.00	0	0	98	31	882	282
2038	0	0	0.0	-	22,384	1,384	923	295	0.00	0	0	92	30	830	266
2039	0	0	0.0	-	21,080	1,304	869	278	0.00	0	0	87	28	782	250
2040	0	0	0.0	-	19,852	1,228	818	262	0.00	0	0	82	26	737	236
2041	0	0	0.0	-	18,696	1,156	771	246	0.00	0	0	77	25	694	222
2042	0	0	0.0	-	17,608	1,089	726	232	0.00	0	0	73	23	653	209
2043	0	0	0.0	-	16,582	1,025	684	219	0.00	0	0	68	22	615	197
2044	0	0	0.0	-	15,616	966	644	206	0.00	0	0	64	21	579	185
2045	0	0	0.0	-	14,707	909	606	194	0.00	0	0	61	19	546	174
2046	0	0	0.0	-	13,851	856	571	183	0.00	0	0	57	18	514	164
2047	0	0	0.0	-	13,044	807	538	172	0.00	0	0	54	17	484	155
2048	0	0	0.0	-	12,284	760	506	162	0.00	0	0	51	16	456	146
2049	0	0	0.0	-	11,569	715	477	153	0.00	0	0	48	15	429	137
2050	0	0	0.0	-	10,895	674	449	144	0.00	0	0	45	14	404	129
2051	0	0	0.0	-	10,261	634	423	135	0.00	0	0	42	14	381	122
2052	0	0	0.0	-	9,663	598	398	127	0.00	0	0	40	13	359	115
2053	0	0	0.0	-	9,100	563	375	120	0.00	0	0	38	12	338	108
2054	0	0	0.0	-	8,571	530	353	113	0.00	0	0	35	11	318	102
2055	0	0	0.0	-	8,071	499	333	106	0.00	0	0	33	11	299	96
2056	0	0	0.0	-	7,601	470	313	100	0.00	0	0	31	10	282	90
2057	0	0	0.0	-	7,159	443	295	94	0.00	0	0	30	9	266	85
2058	0	0	0.0	-	6,742	417	278	89	0.00	0	0	28	9	250	80
2059	0	0	0.0	-	6,349	393	262	84	0.00	0	0	26	8	236	75
2060	0	0	0.0	-	5,979	370	246	79	0.00	0	0	25	8	222	71
2061	0	0	0.0	-	5,631	348	232	74	0.00	0	0	23	7	209	67
2062	0	0	0.0	-	5,303	328	219	70	0.00	0	0	22	7	197	63
2063	0	0	0.0	-	4,994	309	206	66	0.00	0	0	21	7	185	59

SCENARIO S3





Parameters to be adapted for modelling (see tab 'manual' for more information)
Step 1: Enter year of start of disposal in cell A47
Step 2: Enter waste mass deposited in column B for each year of operation
Step 3: Enter landfill cell number where waste is placed for each year in column C (default value = 1)
Step 4: Enter Methane Correction Factor (MCF) in column D until the last year of disposal
Step 5: Estimate general waste composition of the landfill in percentages in table 1 (column O)
Step 6: Enter amount of Degradable Organic Carbon (DOC) in MSW in table 1 (cell P32)
Step 7: Enter the reaction rate constant (k) of Municipal Solid Waste in cell D41
Step 8: Enter the percentage of methane oxidised (OX) in the cover layer in cell D42
Step 9: Enter LFG recovery efficiency in column J for each year
Step 10: Please check that moving/editting cells has not impacted the calculations or the graphs

Reaction rate constant (k):	0.060
Oxidation factor (OX):	10%

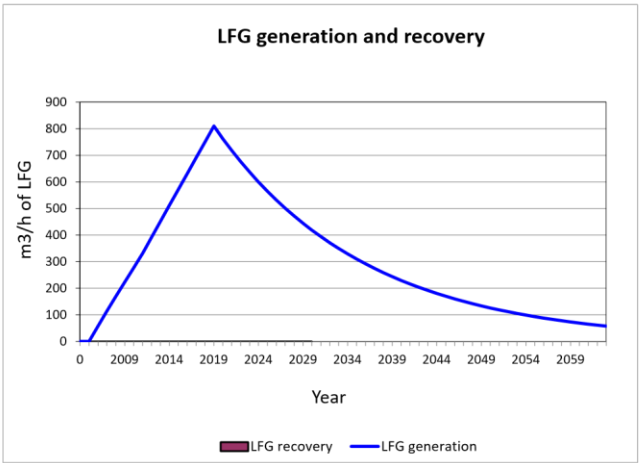
Table 1: Waste composition

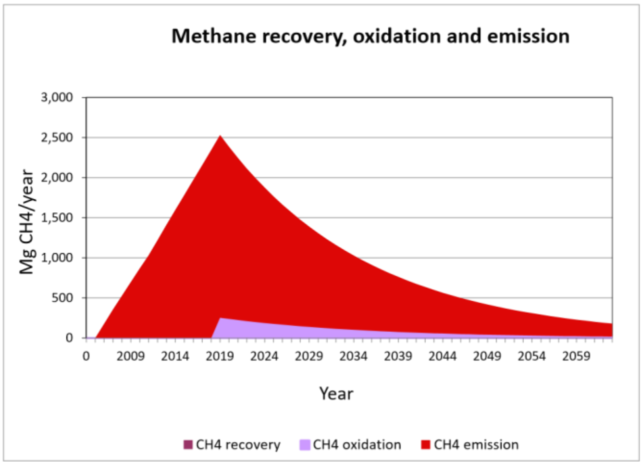
Waste category	**percentage**	**DOC (by weight wet basis)**
Municipal solid waste (MSW)	27%	0.170
Industrial waste	0%	0.150
Sewage sludge	0%	0.050
Garden waste	0%	0.200
Food waste	69%	0.150
Construction and demolition waste	4%	0.043
Soil	0%	0.003
Total	100%	**0.152**

year [a]	waste mass [Mg]	cell number [-]	MCF [-]	DDOCm [Mg]	DDOCma [Mg]	DDOCm decomp [Mg]	CH$_4$ gen [Mg]	LFG gen [m^{3}STP/h]	Recovery efficiency [-]	CH$_4$ rec [Mg]	LFG rec [m^{3}STP/h]	CH$_4$ oxid [Mg]	LFG oxid [m^{3}STP/h]	CH$_4$ emit [Mg]	LFG emit [m^{3}STP/h]
0	0	1	1.0	-	-	0	0	0	0.00	0	0	0	0	0	0
2005	93,012	1	1.0	7,047	7,047	-	0	0	0.00	0	0	0	0	0	0
2006	96,500	1	1.0	7,312	13,949	410	274	87	0.00	0	0	0	0	274	87
2007	100,119	1	1.0	7,586	20,722	812	542	173	0.00	0	0	0	0	542	173
2008	103,874	1	1.0	7,870	27,386	1,207	805	257	0.00	0	0	0	0	805	257
2009	107,769	1	1.0	8,166	33,957	1,595	1,063	340	0.00	0	0	0	0	1,063	340
2010	111,810	1	1.0	8,472	40,451	1,977	1,318	422	0.00	0	0	0	0	1,318	422
2011	129,426	1	1.0	9,806	47,902	2,356	1,570	502	0.00	0	0	0	0	1,570	502
2012	134,280	1	1.0	10,174	55,286	2,790	1,860	595	0.00	0	0	0	0	1,860	595
2013	139,315	1	1.0	10,556	62,622	3,220	2,146	686	0.00	0	0	0	0	2,146	686
2014	144,540	1	1.0	10,952	69,927	3,647	2,431	777	0.00	0	0	0	0	2,431	777
2015	149,960	1	1.0	11,362	77,217	4,072	2,715	868	0.00	0	0	0	0	2,715	868
2016	155,583	1	1.0	11,788	84,509	4,497	2,998	959	0.00	0	0	0	0	2,998	959
2017	161,418	1	1.0	12,230	91,818	4,921	3,281	1,049	0.00	0	0	0	0	3,281	1,049
2018	167,471	1	1.0	12,689	99,160	5,347	3,565	1,140	0.00	0	0	0	0	3,565	1,140
2019	0	0	0.0	-	93,385	5,775	3,850	1,231	0.00	0	0	385	123	3,465	1,108
2020	0	0	0.0	-	87,947	5,438	3,626	1,159	0.00	0	0	363	116	3,263	1,043
2021	0	0	0.0	-	82,825	5,122	3,414	1,092	0.00	0	0	341	109	3,073	983
2022	0	0	0.0	-	78,002	4,823	3,216	1,028	0.00	0	0	322	103	2,894	925
2023	0	0	0.0	-	73,459	4,542	3,028	968	0.00	0	0	303	97	2,725	872
2024	0	0	0.0	-	69,181	4,278	2,852	912	0.00	0	0	285	91	2,567	821
2025	0	0	0.0	-	65,153	4,029	2,686	859	0.00	0	0	269	86	2,417	773
2026	0	0	0.0	-	61,358	3,794	2,529	809	0.00	0	0	253	81	2,277	728
2027	0	0	0.0	-	57,785	3,573	2,382	762	0.00	0	0	238	76	2,144	686
2028	0	0	0.0	-	54,420	3,365	2,243	717	0.00	0	0	224	72	2,019	646
2029	0	0	0.0	-	51,251	3,169	2,113	676	0.00	0	0	211	68	1,902	608

2030	0	0	0.0	-	48,266	2,985	1,990	636	0.00	0	0	199	64	1,791	573
2031	0	0	0.0	-	45,455	2,811	1,874	599	0.00	0	0	187	60	1,686	539
2032	0	0	0.0	-	42,808	2,647	1,765	564	0.00	0	0	176	56	1,588	508
2033	0	0	0.0	-	40,315	2,493	1,662	531	0.00	0	0	166	53	1,496	478
2034	0	0	0.0	-	37,968	2,348	1,565	500	0.00	0	0	157	50	1,409	450
2035	0	0	0.0	-	35,756	2,211	1,474	471	0.00	0	0	147	47	1,327	424
2036	0	0	0.0	-	33,674	2,082	1,388	444	0.00	0	0	139	44	1,249	400
2037	0	0	0.0	-	31,713	1,961	1,307	418	0.00	0	0	131	42	1,177	376
2038	0	0	0.0	-	29,866	1,847	1,231	394	0.00	0	0	123	39	1,108	354
2039	0	0	0.0	-	28,127	1,739	1,160	371	0.00	0	0	116	37	1,044	334
2040	0	0	0.0	-	26,489	1,638	1,092	349	0.00	0	0	109	35	983	314
2041	0	0	0.0	-	24,946	1,543	1,028	329	0.00	0	0	103	33	926	296
2042	0	0	0.0	-	23,494	1,453	969	310	0.00	0	0	97	31	872	279
2043	0	0	0.0	-	22,126	1,368	912	292	0.00	0	0	91	29	821	262
2044	0	0	0.0	-	20,837	1,288	859	275	0.00	0	0	86	27	773	247
2045	0	0	0.0	-	19,624	1,213	809	259	0.00	0	0	81	26	728	233
2046	0	0	0.0	-	18,481	1,143	762	244	0.00	0	0	76	24	686	219
2047	0	0	0.0	-	17,405	1,076	717	229	0.00	0	0	72	23	646	206
2048	0	0	0.0	-	16,391	1,014	676	216	0.00	0	0	68	22	608	194
2049	0	0	0.0	-	15,436	955	636	203	0.00	0	0	64	20	573	183
2050	0	0	0.0	-	14,538	899	599	192	0.00	0	0	60	19	539	172
2051	0	0	0.0	-	13,691	847	564	180	0.00	0	0	56	18	508	162
2052	0	0	0.0	-	12,894	797	532	170	0.00	0	0	53	17	478	153
2053	0	0	0.0	-	12,143	751	501	160	0.00	0	0	50	16	451	144
2054	0	0	0.0	-	11,436	707	471	151	0.00	0	0	47	15	424	136
2055	0	0	0.0	-	10,770	666	444	142	0.00	0	0	44	14	400	128
2056	0	0	0.0	-	10,142	627	418	134	0.00	0	0	42	13	376	120
2057	0	0	0.0	-	9,552	591	394	126	0.00	0	0	39	13	354	113
2058	0	0	0.0	-	8,996	556	371	119	0.00	0	0	37	12	334	107
2059	0	0	0.0	-	8,472	524	349	112	0.00	0	0	35	11	314	101
2060	0	0	0.0	-	7,978	493	329	105	0.00	0	0	33	11	296	95
2061	0	0	0.0	-	7,514	465	310	99	0.00	0	0	31	10	279	89
2062	0	0	0.0	-	7,076	438	292	93	0.00	0	0	29	9	263	84
2063	0	0	0.0	-	6,664	412	275	88	0.00	0	0	27	9	247	79

SCENARIO S4





Parameters to be adapted for modelling (see tab 'manual' for more information)

Table 1: Waste composition

0.060
10%

Step 1: Enter year of start of disposal in cell A47
Step 2: Enter waste mass deposited in column B for each year of operation

Step 3: Enter landfill cell number where waste is placed for each year in column C (default value = 1)
Step 4: Enter Methane Correction Factor (MCF) in column D until the last year of disposal
Step 5: Estimate general waste composition of the landfill in percentages in table 1 (column O)
Step 6: Enter amount of Degradable Organic Carbon (DOC) in MSW in table 1 (cell P32)
Step 7: Enter the reaction rate constant (k) of Municipal Solid Waste in cell D41
Step 8: Enter the percentage of methane oxidised (OX) in the cover layer in cell D42
Step 9: Enter LFG recovery efficiency in column J for each year
Step 10: Please check that moving/editting cells has not impacted the calculations or the graphs

Reaction rate constant (k): Oxidation factor (OX):

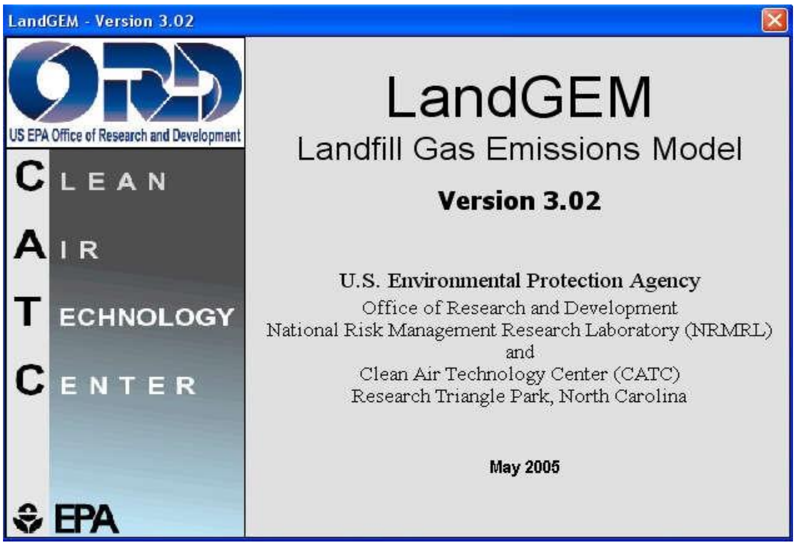
Waste category	**percentage**	**DOC (by weight wet basis)**
Municipal solid waste (MSW)	42%	0.170
Industrial waste	0%	0.150
Sewage sludge	0%	0.050
Garden waste	0%	0.200
Food waste	53%	0.150
Construction and demolition	6%	0.043
waste Soil	0%	0.003
Total	100%	**0.152**

year [a]	waste mass [Mg]	cell number [-]	MCF [-]	DDOCm [Mg]	DDOCma [Mg]	DDOCm decomp [Mg]	CH_4 gen [Mg]	LFG gen [m^{3}STP/h]	Recovery efficiency [-]	CH_4 rec [Mg]	LFG rec [m^{3}STP/h]	CH_4 oxid [Mg]	LFG oxid [m^{3}STP/h]	CH_4 emit [Mg]	LFG emit [m^{3}STP/h]
0	0	1	1.0	-	-	0	0	0	0.00	0	0	0	0	0	0
2005	60,905	1	1.0	4,639	4,639	-	0	0	0.00	0	0	0	0	0	0
2006	63,189	1	1.0	4,813	9,181	270	180	58	0.00	0	0	0	0	180	58
2007	65,558	1	1.0	4,993	13,640	535	356	114	0.00	0	0	0	0	356	114
2008	68,017	1	1.0	5,180	18,026	794	530	169	0.00	0	0	0	0	530	169
2009	70,567	1	1.0	5,375	22,351	1,050	700	224	0.00	0	0	0	0	700	224
2010	73,213	1	1.0	5,576	26,626	1,302	868	277	0.00	0	0	0	0	868	277
2011	84,749	1	1.0	6,455	31,530	1,551	1,034	331	0.00	0	0	0	0	1,034	331
2012	87,927	1	1.0	6,697	36,390	1,836	1,224	391	0.00	0	0	0	0	1,224	391
2013	91,224	1	1.0	6,948	41,219	2,119	1,413	452	0.00	0	0	0	0	1,413	452
2014	94,645	1	1.0	7,209	46,027	2,400	1,600	512	0.00	0	0	0	0	1,600	512
2015	98,194	1	1.0	7,479	50,826	2,680	1,787	571	0.00	0	0	0	0	1,787	571
2016	101,876	1	1.0	7,759	55,625	2,960	1,973	631	0.00	0	0	0	0	1,973	631
2017	105,697	1	1.0	8,050	60,436	3,239	2,160	691	0.00	0	0	0	0	2,160	691
2018	109,660	1	1.0	8,352	65,269	3,520	2,346	750	0.00	0	0	0	0	2,346	750
2019	0	0	0.0	-	61,468	3,801	2,534	810	0.00	0	0	253	81	2,281	729
2020	0	0	0.0	-	57,888	3,580	2,386	763	0.00	0	0	239	76	2,148	687
2021	0	0	0.0	-	54,517	3,371	2,247	719	0.00	0	0	225	72	2,023	647

2022	0	0	0.0	-	51,342	3,175	2,117	677	0.00	0	0	212	68	1,905	609
2023	0	0	0.0	-	48,352	2,990	1,993	637	0.00	0	0	199	64	1,794	574
2024	0	0	0.0	-	45,537	2,816	1,877	600	0.00	0	0	188	60	1,689	540
2025	0	0	0.0	-	42,885	2,652	1,768	565	0.00	0	0	177	57	1,591	509
2026	0	0	0.0	-	40,387	2,497	1,665	532	0.00	0	0	166	53	1,498	479
2027	0	0	0.0	-	38,035	2,352	1,568	501	0.00	0	0	157	50	1,411	451
2028	0	0	0.0	-	35,820	2,215	1,477	472	0.00	0	0	148	47	1,329	425
2029	0	0	0.0	-	33,734	2,086	1,391	445	0.00	0	0	139	44	1,252	400
2030	0	0	0.0	-	31,770	1,965	1,310	419	0.00	0	0	131	42	1,179	377
2031	0	0	0.0	-	29,920	1,850	1,233	394	0.00	0	0	123	39	1,110	355
2032	0	0	0.0	-	28,177	1,742	1,162	371	0.00	0	0	116	37	1,045	334
2033	0	0	0.0	-	26,536	1,641	1,094	350	0.00	0	0	109	35	985	315
2034	0	0	0.0	-	24,991	1,545	1,030	329	0.00	0	0	103	33	927	296
2035	0	0	0.0	-	23,536	1,455	970	310	0.00	0	0	97	31	873	279
2036	0	0	0.0	-	22,165	1,371	914	292	0.00	0	0	91	29	822	263
2037	0	0	0.0	-	20,874	1,291	861	275	0.00	0	0	86	28	774	248
2038	0	0	0.0	-	19,659	1,216	810	259	0.00	0	0	81	26	729	233
2039	0	0	0.0	-	18,514	1,145	763	244	0.00	0	0	76	24	687	220
2040	0	0	0.0	-	17,436	1,078	719	230	0.00	0	0	72	23	647	207
2041	0	0	0.0	-	16,420	1,015	677	216	0.00	0	0	68	22	609	195
2042	0	0	0.0	-	15,464	956	637	204	0.00	0	0	64	20	574	183
2043	0	0	0.0	-	14,563	901	600	192	0.00	0	0	60	19	540	173
2044	0	0	0.0	-	13,715	848	565	181	0.00	0	0	57	18	509	163
2045	0	0	0.0	-	12,917	799	532	170	0.00	0	0	53	17	479	153
2046	0	0	0.0	-	12,164	752	501	160	0.00	0	0	50	16	451	144
2047	0	0	0.0	-	11,456	708	472	151	0.00	0	0	47	15	425	136
2048	0	0	0.0	-	10,789	667	445	142	0.00	0	0	44	14	400	128
2049	0	0	0.0	-	10,161	628	419	134	0.00	0	0	42	13	377	121
2050	0	0	0.0	-	9,569	592	394	126	0.00	0	0	39	13	355	114
2051	0	0	0.0	-	9,012	557	371	119	0.00	0	0	37	12	334	107
2052	0	0	0.0	-	8,487	525	350	112	0.00	0	0	35	11	315	101
2053	0	0	0.0	-	7,993	494	329	105	0.00	0	0	33	11	297	95
2054	0	0	0.0	-	7,527	465	310	99	0.00	0	0	31	10	279	89
2055	0	0	0.0	-	7,089	438	292	93	0.00	0	0	29	9	263	84
2056	0	0	0.0	-	6,676	413	275	88	0.00	0	0	28	9	248	79
2057	0	0	0.0	-	6,287	389	259	83	0.00	0	0	26	8	233	75
2058	0	0	0.0	-	5,921	366	244	78	0.00	0	0	24	8	220	70
2059	0	0	0.0	-	5,576	345	230	74	0.00	0	0	23	7	207	66
2060	0	0	0.0	-	5,252	325	216	69	0.00	0	0	22	7	195	62
2061	0	0	0.0	-	4,946	306	204	65	0.00	0	0	20	7	183	59
2062	0	0	0.0	-	4,658	288	192	61	0.00	0	0	19	6	173	55
2063	0	0	0.0	-	4,386	271	181	58	0.00	0	0	18	6	163	52

Note: yellow highlighted input parameters

C.2 LandGEM model output on KMC emissions quantification, 2005-2018


LandGEM - Version 3.02

US EPA Office of Research and Development

CLEAN AIR TECHNOLOGY CENTER

EPA

LandGEM
Landfill Gas Emissions Model
Version 3.02

U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory (NRMRL)
and
Clean Air Technology Center (CATC)
Research Triangle Park, North Carolina

May 2005

Summary Report

Landfill Name or Identifier: Sisdole Landfill

Date: Wednesday, 21 October 2020

Description/Comments:

About LandGEM:

First-Order Decomposition Rate Equation:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}}$$

Where,

Q_{CH4} = annual methane generation in the year of the calculation (*m^3/year*)

i = 1-year time increment M_i = mass of waste accepted in the ith year (*Mg*)

n = (year of the calculation) - (initial year of waste acceptance) t_{ij} = age of the jth section of waste mass M_i accepted in the ith year

j = 0.1-year time increment (*decimal years*, e.g., 3.2 years) k = methane generation rate (*year^{-1}*)

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

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available. Further guidance on EPA test methods, Clean Air Act (CAA) regulations, and other guidance regarding landfill gas emissions and control technology requirements can be found at http://www.epa.gov/ttnatw01/landfill/landflpg.html.

LandGEM is considered a screening tool — the better the input data, the better the estimates. Often, there are limitations with the available data regarding waste quantity and composition, variation in design and operating practices over time, and changes occurring over time that impact the emissions potential. Changes to landfill operation, such as operating under wet conditions through leachate recirculation or other liquid additions, will result in generating more gas at a faster rate. Defaults for estimating emissions for this type of operation are being developed to include in LandGEM along with defaults for convential landfills (no leachate or liquid additions) for developing emission inventories and determining CAA applicability. Refer to the Web site identified above for future updates.

Input Review

LANDFILL CHARACTERISTICS

Landfill Open Year	**2005**
Landfill Closure Year (with 80-year limit)	**2018**
Actual Closure Year (without limit)	***2018***

Have Model Calculate Closure Year?	**No**	
Waste Design Capacity		*megagrams*

MODEL PARAMETERS

Methane Generation Rate, k	**0.050**	*year* $^{-1}$
Potential Methane Generation Capacity, L_o	**170**	*m* ^{3}*/Mg*
NMOC Concentration	**4,000**	*ppmv as hexane*
Methane Content	**50**	*% by volume*

GASES / POLLUTANTS SELECTED

Gas / Pollutant #1:	**Total landfill gas**
Gas / Pollutant #2:	**Methane**
Gas / Pollutant #3:	**Carbon dioxide**
Gas / Pollutant #4:	**NMOC**

WASTE ACCEPTANCE RATES

Year	**Waste Accepted**		**Waste-In-Place**	
	(Mg/year)	***(short tons/year)***	***(Mg)***	***(short tons)***
2005	126,283	138,911	0	0
2006	131,018	144,120	126,283	138,911
2007	135,932	149,525	257,301	283,031
2008	141,029	155,132	393,233	432,556
2009	146,318	160,949	534,262	587,688
2010	151,804	166,985	680,579	748,637
2011	181,818	200,000	832,384	915,622
2012	188,636	207,500	1,014,202	1,115,622
2013	195,710	215,281	1,202,838	1,323,122
2014	203,049	223,354	1,398,548	1,538,403
2015	210,663	231,730	1,601,597	1,761,757
2016	218,563	240,420	1,812,261	1,993,487
2017	226,760	249,435	2,030,824	2,233,906
2018	235,263	258,789	2,257,584	2,483,342
2019	0	0	2,492,847	2,742,131
2020	0	0	2,492,847	2,742,131
2021	0	0	2,492,847	2,742,131
2022	0	0	2,492,847	2,742,131
2023	0	0	2,492,847	2,742,131
2024	0	0	2,492,847	2,742,131
2025	0	0	2,492,847	2,742,131
2026	0	0	2,492,847	2,742,131
2027	0	0	2,492,847	2,742,131
2028	0	0	2,492,847	2,742,131
2029	0	0	2,492,847	2,742,131
2030	0	0	2,492,847	2,742,131
2031	0	0	2,492,847	2,742,131
2032	0	0	2,492,847	2,742,131
2033	0	0	2,492,847	2,742,131
2034	0	0	2,492,847	2,742,131
2035	0	0	2,492,847	2,742,131
2036	0	0	2,492,847	2,742,131
2037	0	0	2,492,847	2,742,131
2038	0	0	2,492,847	2,742,131
2039	0	0	2,492,847	2,742,131
2040	0	0	2,492,847	2,742,131
2041	0	0	2,492,847	2,742,131
2042	0	0	2,492,847	2,742,131
2043	0	0	2,492,847	2,742,131
2044	0	0	2,492,847	2,742,131

WASTE ACCEPTANCE RATES (Continued)

Year	**Waste Accepted**		**Waste-In-Place**	
	(Mg/year)	***(short tons/year)***	***(Mg)***	***(short tons)***
2045	0	0	2,492,847	2,742,131
2046	0	0	2,492,847	2,742,131
2047	0	0	2,492,847	2,742,131
2048	0	0	2,492,847	2,742,131
2049	0	0	2,492,847	2,742,131
2050	0	0	2,492,847	2,742,131
2051	0	0	2,492,847	2,742,131
2052	0	0	2,492,847	2,742,131

2053	0	0	2,492,847	2,742,131
2054	0	0	2,492,847	2,742,131
2055	0	0	2,492,847	2,742,131
2056	0	0	2,492,847	2,742,131
2057	0	0	2,492,847	2,742,131
2058	0	0	2,492,847	2,742,131
2059	0	0	2,492,847	2,742,131
2060	0	0	2,492,847	2,742,131
2061	0	0	2,492,847	2,742,131
2062	0	0	2,492,847	2,742,131
2063	0	0	2,492,847	2,742,131
2064	0	0	2,492,847	2,742,131
2065	0	0	2,492,847	2,742,131
2066	0	0	2,492,847	2,742,131
2067	0	0	2,492,847	2,742,131
2068	0	0	2,492,847	2,742,131
2069	0	0	2,492,847	2,742,131
2070	0	0	2,492,847	2,742,131
2071	0	0	2,492,847	2,742,131
2072	0	0	2,492,847	2,742,131
2073	0	0	2,492,847	2,742,131
2074	0	0	2,492,847	2,742,131
2075	0	0	2,492,847	2,742,131
2076	0	0	2,492,847	2,742,131
2077	0	0	2,492,847	2,742,131
2078	0	0	2,492,847	2,742,131
2079	0	0	2,492,847	2,742,131
2080	0	0	2,492,847	2,742,131
2081	0	0	2,492,847	2,742,131
2082	0	0	2,492,847	2,742,131
2083	0	0	2,492,847	2,742,131
2084	0	0	2,492,847	2,742,131

Pollutant Parameters

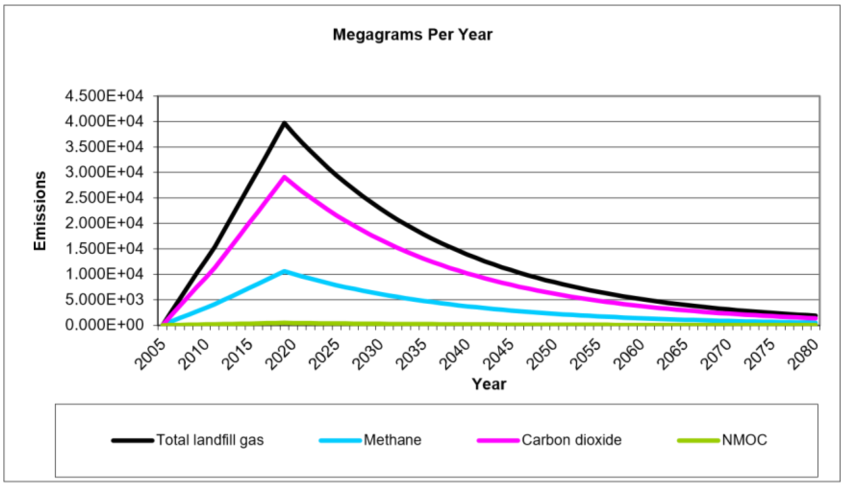
		Gas / Pollutant Default Parameters:		***User-specified Pollutant Parameters:***	
	Compound	Concentration (*ppmv*)	Molecular Weight	Concentration (*ppmv*)	Molecular Weight
Gase	Total landfill gas		0.00		
	Methane		16.04		
	Carbon dioxide		44.01		
	NMOC	4,000	86.18		
Pollutar	1,1,1-Trichloroethane (methyl chloroform) - HAP	0.48	133.41		
	1,1,2,2-Tetrachloroethane - HAP/VOC	1.1	167.85		
	1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	2.4	98.97		
	1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	0.20	96.94		
	1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	0.41	98.96		
	1,2-Dichloropropane (propylene dichloride) - HAP/VOC	0.18	112.99		
	2-Propanol (isopropyl alcohol) - VOC	50	60.11		
	Acetone	7.0	58.08		
	Acrylonitrile - HAP/VOC	6.3	53.06		
	Benzene - No or Unknown Co-disposal - HAP/VOC	1.9	78.11		
	Benzene - Co-disposal - HAP/VOC	11	78.11		
	Bromodichloromethane - VOC	3.1	163.83		
	Butane - VOC	5.0	58.12		

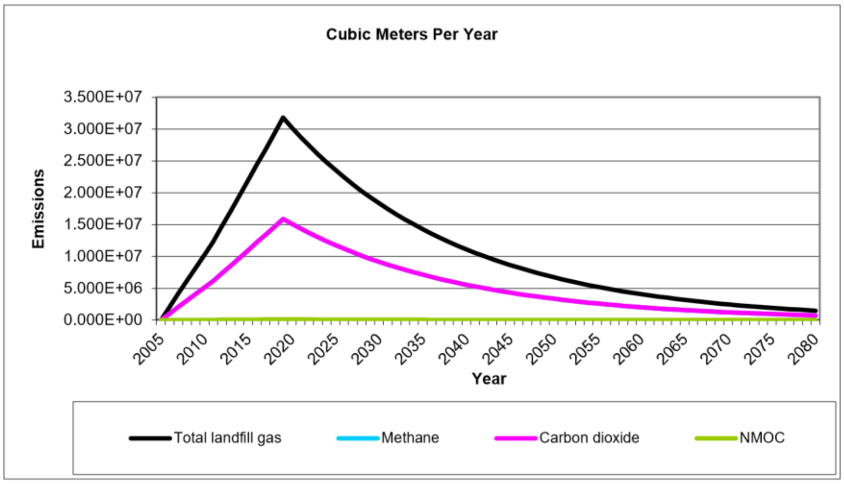
	Carbon disulfide - HAP/VOC	0.58	76.13		
	Carbon monoxide	140	28.01		
	Carbon tetrachloride - HAP/VOC	4.0E-03	153.84		
	Carbonyl sulfide - HAP/VOC	0.49	60.07		
	Chlorobenzene - HAP/VOC	0.25	112.56		
	Chlorodifluoromethane	1.3	86.47		
	Chloroethane (ethyl chloride) - HAP/VOC	1.3	64.52		
	Chloroform - HAP/VOC	0.03	119.39		
	Chloromethane - VOC	1.2	50.49		
	Dichlorobenzene - (HAP for para isomer/VOC)	0.21	147		
	Dichlorodifluoromethane	16	120.91		
	Dichlorofluoromethane - VOC	2.6	102.92		
	Dichloromethane (methylene chloride) - HAP	14	84.94		
	Dimethyl sulfide (methyl sulfide) - VOC	7.8	62.13		
	Ethane	890	30.07		
	Ethanol - VOC	27	46.08		

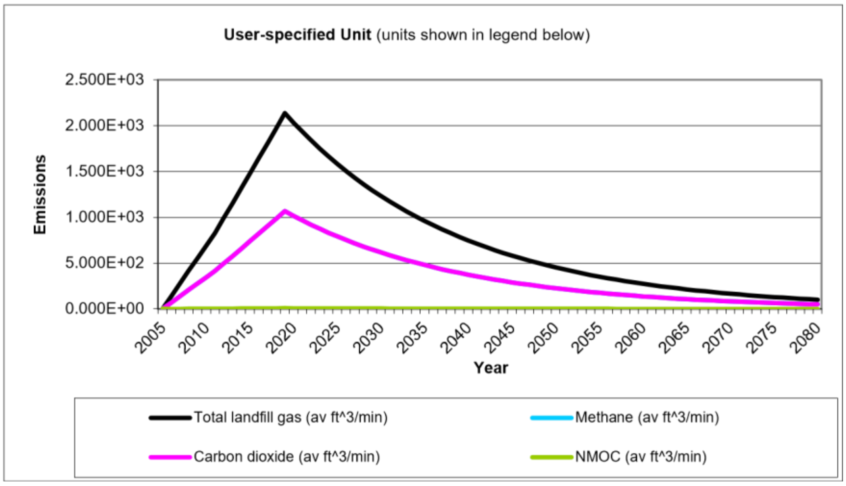
Pollutant Parameters (Continued)

		Gas / Pollutant Default Parameters:		*User-specified Pollutant Parameters:*	
	Compound	Concentration (*ppmv*)	Molecular Weight	Concentration (*ppmv*)	Molecular Weight
Pollutan	Ethyl mercaptan (ethanethiol) - VOC	2.3	62.13		
	Ethylbenzene - HAP/VOC	4.6	106.16		
	Ethylene dibromide - HAP/VOC	1.0E-03	187.88		
	Fluorotrichloromethane - VOC	0.76	137.38		
	Hexane - HAP/VOC	6.6	86.18		
	Hydrogen sulfide	36	34.08		
	Mercury (total) - HAP	2.9E-04	200.61		
	Methyl ethyl ketone - HAP/VOC	7.1	72.11		
	Methyl isobutyl ketone - HAP/VOC	1.9	100.16		
	Methyl mercaptan - VOC	2.5	48.11		
	Pentane - VOC	3.3	72.15		
	Perchloroethylene (tetrachloroethylene) - HAP	3.7	165.83		
	Propane - VOC	11	44.09		
	t-1,2-Dichloroethene - VOC	2.8	96.94		
	Toluene - No or Unknown Co-disposal - HAP/VOC	39	92.13		
	Toluene - Co-disposal - HAP/VOC	170	92.13		
	Trichloroethylene (trichloroethene) - HAP/VOC	2.8	131.40		
	Vinyl chloride - HAP/VOC	7.3	62.50		
	Xylenes - HAP/VOC	12	106.16		

Graphs


Megagrams Per Year
Emissions
4.500E+04
4.000E+04
3.500E+04
3.000E+04
2.500E+04
2.000E+04
1.500E+04
1.000E+04
5.000E+03
0.000E+00
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
Year
Total landfill gas
Methane
Carbon dioxide
NMOC


Cubic Meters Per Year
Emissions
3.500E+07
3.000E+07
2.500E+07
2.000E+07
1.500E+07
1.000E+07
5.000E+06
0.000E+00
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
Year
Total landfill gas
Methane
Carbon dioxide
NMOC


User-specified Unit (units shown in legend below)
Emissions
2.500E+03
2.000E+03
1.500E+03
1.000E+03
5.000E+02
0.000E+00
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
Year
Total landfill gas (av ft^3/min)
Methane (av ft^3/min)
Carbon dioxide (av ft^3/min)
NMOC (av ft^3/min)

Results

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2005	0	0	0	0	0	0
2006	2.622E+03	2.099E+06	1.410E+02	7.003E+02	1.050E+06	7.052E+01
2007	5.214E+03	4.175E+06	2.805E+02	1.393E+03	2.087E+06	1.403E+02
2008	7.781E+03	6.231E+06	4.187E+02	2.078E+03	3.115E+06	2.093E+02
2009	1.033E+04	8.271E+06	5.558E+02	2.759E+03	4.136E+06	2.779E+02
2010	1.286E+04	1.030E+07	6.921E+02	3.436E+03	5.150E+06	3.460E+02
2011	1.539E+04	1.232E+07	8.279E+02	4.110E+03	6.161E+06	4.139E+02
2012	1.841E+04	1.474E+07	9.906E+02	4.918E+03	7.372E+06	4.953E+02
2013	2.143E+04	1.716E+07	1.153E+03	5.724E+03	8.580E+06	5.765E+02
2014	2.445E+04	1.958E+07	1.315E+03	6.530E+03	9.788E+06	6.577E+02
2015	2.747E+04	2.200E+07	1.478E+03	7.338E+03	1.100E+07	7.390E+02
2016	3.050E+04	2.443E+07	1.641E+03	8.148E+03	1.221E+07	8.206E+02
2017	3.355E+04	2.687E+07	1.805E+03	8.962E+03	1.343E+07	9.026E+02
2018	3.662E+04	2.933E+07	1.970E+03	9.783E+03	1.466E+07	9.852E+02
2019	3.972E+04	3.181E+07	2.137E+03	1.061E+04	1.590E+07	1.069E+03
2020	3.779E+04	3.026E+07	2.033E+03	1.009E+04	1.513E+07	1.016E+03
2021	3.594E+04	2.878E+07	1.934E+03	9.601E+03	1.439E+07	9.669E+02
2022	3.419E+04	2.738E+07	1.839E+03	9.132E+03	1.369E+07	9.197E+02
2023	3.252E+04	2.604E+07	1.750E+03	8.687E+03	1.302E+07	8.749E+02
2024	3.094E+04	2.477E+07	1.664E+03	8.263E+03	1.239E+07	8.322E+02
2025	2.943E+04	2.356E+07	1.583E+03	7.860E+03	1.178E+07	7.916E+02
2026	2.799E+04	2.241E+07	1.506E+03	7.477E+03	1.121E+07	7.530E+02
2027	2.663E+04	2.132E+07	1.433E+03	7.112E+03	1.066E+07	7.163E+02
2028	2.533E+04	2.028E+07	1.363E+03	6.765E+03	1.014E+07	6.814E+02
2029	2.409E+04	1.929E+07	1.296E+03	6.435E+03	9.646E+06	6.481E+02
2030	2.292E+04	1.835E+07	1.233E+03	6.122E+03	9.176E+06	6.165E+02
2031	2.180E+04	1.746E+07	1.173E+03	5.823E+03	8.728E+06	5.865E+02
2032	2.074E+04	1.661E+07	1.116E+03	5.539E+03	8.303E+06	5.578E+02
2033	1.973E+04	1.580E+07	1.061E+03	5.269E+03	7.898E+06	5.306E+02
2034	1.876E+04	1.502E+07	1.010E+03	5.012E+03	7.512E+06	5.048E+02
2035	1.785E+04	1.429E+07	9.603E+02	4.768E+03	7.146E+06	4.801E+02
2036	1.698E+04	1.360E+07	9.135E+02	4.535E+03	6.798E+06	4.567E+02
2037	1.615E+04	1.293E+07	8.689E+02	4.314E+03	6.466E+06	4.345E+02
2038	1.536E+04	1.230E+07	8.265E+02	4.103E+03	6.151E+06	4.133E+02
2039	1.461E+04	1.170E+07	7.862E+02	3.903E+03	5.851E+06	3.931E+02
2040	1.390E+04	1.113E+07	7.479E+02	3.713E+03	5.565E+06	3.739E+02
2041	1.322E+04	1.059E+07	7.114E+02	3.532E+03	5.294E+06	3.557E+02
2042	1.258E+04	1.007E+07	6.767E+02	3.360E+03	5.036E+06	3.384E+02
2043	1.196E+04	9.580E+06	6.437E+02	3.196E+03	4.790E+06	3.219E+02
2044	1.138E+04	9.113E+06	6.123E+02	3.040E+03	4.557E+06	3.062E+02
2045	1.083E+04	8.669E+06	5.824E+02	2.892E+03	4.334E+06	2.912E+02
2046	1.030E+04	8.246E+06	5.540E+02	2.751E+03	4.123E+06	2.770E+02
2047	9.795E+03	7.844E+06	5.270E+02	2.616E+03	3.922E+06	2.635E+02
2048	9.318E+03	7.461E+06	5.013E+02	2.489E+03	3.731E+06	2.507E+02
2049	8.863E+03	7.097E+06	4.769E+02	2.367E+03	3.549E+06	2.384E+02
2050	8.431E+03	6.751E+06	4.536E+02	2.252E+03	3.376E+06	2.268E+02
2051	8.020E+03	6.422E+06	4.315E+02	2.142E+03	3.211E+06	2.157E+02
2052	7.629E+03	6.109E+06	4.104E+02	2.038E+03	3.054E+06	2.052E+02
2053	7.257E+03	5.811E+06	3.904E+02	1.938E+03	2.905E+06	1.952E+02
2054	6.903E+03	5.527E+06	3.714E+02	1.844E+03	2.764E+06	1.857E+02

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2055	6.566E+03	5.258E+06	3.533E+02	1.754E+03	2.629E+06	1.766E+02
2056	6.246E+03	5.001E+06	3.360E+02	1.668E+03	2.501E+06	1.680E+02
2057	5.941E+03	4.757E+06	3.197E+02	1.587E+03	2.379E+06	1.598E+02
2058	5.651E+03	4.525E+06	3.041E+02	1.510E+03	2.263E+06	1.520E+02
2059	5.376E+03	4.305E+06	2.892E+02	1.436E+03	2.152E+06	1.446E+02
2060	5.114E+03	4.095E+06	2.751E+02	1.366E+03	2.047E+06	1.376E+02
2061	4.864E+03	3.895E+06	2.617E+02	1.299E+03	1.948E+06	1.309E+02
2062	4.627E+03	3.705E+06	2.489E+02	1.236E+03	1.853E+06	1.245E+02
2063	4.401E+03	3.524E+06	2.368E+02	1.176E+03	1.762E+06	1.184E+02
2064	4.187E+03	3.353E+06	2.253E+02	1.118E+03	1.676E+06	1.126E+02
2065	3.983E+03	3.189E+06	2.143E+02	1.064E+03	1.595E+06	1.071E+02
2066	3.788E+03	3.033E+06	2.038E+02	1.012E+03	1.517E+06	1.019E+02
2067	3.604E+03	2.886E+06	1.939E+02	9.625E+02	1.443E+06	9.694E+01
2068	3.428E+03	2.745E+06	1.844E+02	9.156E+02	1.372E+06	9.221E+01
2069	3.261E+03	2.611E+06	1.754E+02	8.709E+02	1.305E+06	8.771E+01
2070	3.102E+03	2.484E+06	1.669E+02	8.285E+02	1.242E+06	8.344E+01
2071	2.950E+03	2.362E+06	1.587E+02	7.881E+02	1.181E+06	7.937E+01
2072	2.806E+03	2.247E+06	1.510E+02	7.496E+02	1.124E+06	7.550E+01
2073	2.670E+03	2.138E+06	1.436E+02	7.131E+02	1.069E+06	7.181E+01
2074	2.539E+03	2.033E+06	1.366E+02	6.783E+02	1.017E+06	6.831E+01
2075	2.416E+03	1.934E+06	1.300E+02	6.452E+02	9.671E+05	6.498E+01
2076	2.298E+03	1.840E+06	1.236E+02	6.137E+02	9.200E+05	6.181E+01
2077	2.186E+03	1.750E+06	1.176E+02	5.838E+02	8.751E+05	5.880E+01
2078	2.079E+03	1.665E+06	1.119E+02	5.553E+02	8.324E+05	5.593E+01
2079	1.978E+03	1.584E+06	1.064E+02	5.283E+02	7.918E+05	5.320E+01
2080	1.881E+03	1.506E+06	1.012E+02	5.025E+02	7.532E+05	5.061E+01
2081	1.789E+03	1.433E+06	9.628E+01	4.780E+02	7.165E+05	4.814E+01
2082	1.702E+03	1.363E+06	9.158E+01	4.547E+02	6.815E+05	4.579E+01
2083	1.619E+03	1.297E+06	8.712E+01	4.325E+02	6.483E+05	4.356E+01
2084	1.540E+03	1.233E+06	8.287E+01	4.114E+02	6.167E+05	4.143E+01
2085	1.465E+03	1.173E+06	7.883E+01	3.913E+02	5.866E+05	3.941E+01
2086	1.394E+03	1.116E+06	7.498E+01	3.723E+02	5.580E+05	3.749E+01
2087	1.326E+03	1.062E+06	7.132E+01	3.541E+02	5.308E+05	3.566E+01
2088	1.261E+03	1.010E+06	6.785E+01	3.368E+02	5.049E+05	3.392E+01
2089	1.200E+03	9.605E+05	6.454E+01	3.204E+02	4.803E+05	3.227E+01
2090	1.141E+03	9.137E+05	6.139E+01	3.048E+02	4.568E+05	3.069E+01
2091	1.085E+03	8.691E+05	5.840E+01	2.899E+02	4.346E+05	2.920E+01
2092	1.032E+03	8.267E+05	5.555E+01	2.758E+02	4.134E+05	2.777E+01
2093	9.821E+02	7.864E+05	5.284E+01	2.623E+02	3.932E+05	2.642E+01
2094	9.342E+02	7.480E+05	5.026E+01	2.495E+02	3.740E+05	2.513E+01
2095	8.886E+02	7.116E+05	4.781E+01	2.374E+02	3.558E+05	2.391E+01
2096	8.453E+02	6.769E+05	4.548E+01	2.258E+02	3.384E+05	2.274E+01
2097	8.041E+02	6.439E+05	4.326E+01	2.148E+02	3.219E+05	2.163E+01
2098	7.648E+02	6.125E+05	4.115E+01	2.043E+02	3.062E+05	2.058E+01
2099	7.275E+02	5.826E+05	3.914E+01	1.943E+02	2.913E+05	1.957E+01
2100	6.921E+02	5.542E+05	3.723E+01	1.849E+02	2.771E+05	1.862E+01
2101	6.583E+02	5.271E+05	3.542E+01	1.758E+02	2.636E+05	1.771E+01
2102	6.262E+02	5.014E+05	3.369E+01	1.673E+02	2.507E+05	1.685E+01
2103	5.957E+02	4.770E+05	3.205E+01	1.591E+02	2.385E+05	1.602E+01
2104	5.666E+02	4.537E+05	3.049E+01	1.513E+02	2.269E+05	1.524E+01
2105	5.390E+02	4.316E+05	2.900E+01	1.440E+02	2.158E+05	1.450E+01
2106	5.127E+02	4.105E+05	2.758E+01	1.369E+02	2.053E+05	1.379E+01
2107	4.877E+02	3.905E+05	2.624E+01	1.303E+02	1.953E+05	1.312E+01
2108	4.639E+02	3.715E+05	2.496E+01	1.239E+02	1.857E+05	1.248E+01
2109	4.413E+02	3.534E+05	2.374E+01	1.179E+02	1.767E+05	1.187E+01
2110	4.198E+02	3.361E+05	2.258E+01	1.121E+02	1.681E+05	1.129E+01
2111	3.993E+02	3.197E+05	2.148E+01	1.067E+02	1.599E+05	1.074E+01
2112	3.798E+02	3.041E+05	2.043E+01	1.015E+02	1.521E+05	1.022E+01
2113	3.613E+02	2.893E+05	1.944E+01	9.650E+01	1.447E+05	9.719E+00
2114	3.437E+02	2.752E+05	1.849E+01	9.180E+01	1.376E+05	9.245E+00
2115	3.269E+02	2.618E+05	1.759E+01	8.732E+01	1.309E+05	8.794E+00
2116	3.110E+02	2.490E+05	1.673E+01	8.306E+01	1.245E+05	8.365E+00
2117	2.958E+02	2.369E+05	1.591E+01	7.901E+01	1.184E+05	7.957E+00

2118	2.814E+02	2.253E+05	1.514E+01	7.516E+01	1.127E+05	7.569E+00
2119	2.676E+02	2.143E+05	1.440E+01	7.149E+01	1.072E+05	7.200E+00
2120	2.546E+02	2.039E+05	1.370E+01	6.800E+01	1.019E+05	6.849E+00
2121	2.422E+02	1.939E+05	1.303E+01	6.469E+01	9.696E+04	6.515E+00
2122	2.304E+02	1.845E+05	1.239E+01	6.153E+01	9.223E+04	6.197E+00
2123	2.191E+02	1.755E+05	1.179E+01	5.853E+01	8.773E+04	5.895E+00
2124	2.084E+02	1.669E+05	1.121E+01	5.568E+01	8.346E+04	5.607E+00
2125	1.983E+02	1.588E+05	1.067E+01	5.296E+01	7.939E+04	5.334E+00
2126	1.886E+02	1.510E+05	1.015E+01	5.038E+01	7.551E+04	5.074E+00
2127	1.794E+02	1.437E+05	9.653E+00	4.792E+01	7.183E+04	4.826E+00
2128	1.707E+02	1.367E+05	9.182E+00	4.558E+01	6.833E+04	4.591E+00
2129	1.623E+02	1.300E+05	8.734E+00	4.336E+01	6.500E+04	4.367E+00
2130	1.544E+02	1.237E+05	8.308E+00	4.125E+01	6.183E+04	4.154E+00
2131	1.469E+02	1.176E+05	7.903E+00	3.924E+01	5.881E+04	3.951E+00
2132	1.397E+02	1.119E+05	7.518E+00	3.732E+01	5.594E+04	3.759E+00
2133	1.329E+02	1.064E+05	7.151E+00	3.550E+01	5.321E+04	3.575E+00
2134	1.264E+02	1.012E+05	6.802E+00	3.377E+01	5.062E+04	3.401E+00
2135	1.203E+02	9.630E+04	6.470E+00	3.212E+01	4.815E+04	3.235E+00
2136	1.144E+02	9.160E+04	6.155E+00	3.056E+01	4.580E+04	3.077E+00
2137	1.088E+02	8.714E+04	5.855E+00	2.907E+01	4.357E+04	2.927E+00
2138	1.035E+02	8.289E+04	5.569E+00	2.765E+01	4.144E+04	2.785E+00
2139	9.846E+01	7.884E+04	5.297E+00	2.630E+01	3.942E+04	2.649E+00
2140	9.366E+01	7.500E+04	5.039E+00	2.502E+01	3.750E+04	2.520E+00
2141	8.909E+01	7.134E+04	4.793E+00	2.380E+01	3.567E+04	2.397E+00
2142	8.475E+01	6.786E+04	4.560E+00	2.264E+01	3.393E+04	2.280E+00
2143	8.061E+01	6.455E+04	4.337E+00	2.153E+01	3.228E+04	2.169E+00
2144	7.668E+01	6.140E+04	4.126E+00	2.048E+01	3.070E+04	2.063E+00
2145	7.294E+01	5.841E+04	3.924E+00	1.948E+01	2.920E+04	1.962E+00

Year	**Carbon dioxide**			**NMOC**		
	(Mg/year)	***(m^3/year)***	***(av ft^3/min)***	***(Mg/year)***	***(m^3/year)***	***(av ft^3/min)***
2005	0	0	0	0	0	0
2006	1.921E+03	1.050E+06	7.052E+01	3.010E+01	8.397E+03	5.642E-01
2007	3.821E+03	2.087E+06	1.403E+02	5.986E+01	1.670E+04	1.122E+00
2008	5.703E+03	3.115E+06	2.093E+02	8.934E+01	2.492E+04	1.675E+00
2009	7.570E+03	4.136E+06	2.779E+02	1.186E+02	3.309E+04	2.223E+00
2010	9.427E+03	5.150E+06	3.460E+02	1.477E+02	4.120E+04	2.768E+00
2011	1.128E+04	6.161E+06	4.139E+02	1.767E+02	4.929E+04	3.312E+00
2012	1.349E+04	7.372E+06	4.953E+02	2.114E+02	5.897E+04	3.962E+00
2013	1.571E+04	8.580E+06	5.765E+02	2.460E+02	6.864E+04	4.612E+00
2014	1.792E+04	9.788E+06	6.577E+02	2.807E+02	7.831E+04	5.261E+00
2015	2.013E+04	1.100E+07	7.390E+02	3.154E+02	8.799E+04	5.912E+00
2016	2.236E+04	1.221E+07	8.206E+02	3.502E+02	9.770E+04	6.565E+00
2017	2.459E+04	1.343E+07	9.026E+02	3.852E+02	1.075E+05	7.221E+00
2018	2.684E+04	1.466E+07	9.852E+02	4.205E+02	1.173E+05	7.882E+00
2019	2.911E+04	1.590E+07	1.069E+03	4.561E+02	1.272E+05	8.549E+00
2020	2.769E+04	1.513E+07	1.016E+03	4.338E+02	1.210E+05	8.132E+00
2021	2.634E+04	1.439E+07	9.669E+02	4.127E+02	1.151E+05	7.735E+00
2022	2.506E+04	1.369E+07	9.197E+02	3.925E+02	1.095E+05	7.358E+00
2023	2.383E+04	1.302E+07	8.749E+02	3.734E+02	1.042E+05	6.999E+00
2024	2.267E+04	1.239E+07	8.322E+02	3.552E+02	9.909E+04	6.658E+00
2025	2.157E+04	1.178E+07	7.916E+02	3.379E+02	9.426E+04	6.333E+00
2026	2.051E+04	1.121E+07	7.530E+02	3.214E+02	8.966E+04	6.024E+00
2027	1.951E+04	1.066E+07	7.163E+02	3.057E+02	8.529E+04	5.730E+00
2028	1.856E+04	1.014E+07	6.814E+02	2.908E+02	8.113E+04	5.451E+00
2029	1.766E+04	9.646E+06	6.481E+02	2.766E+02	7.717E+04	5.185E+00
2030	1.680E+04	9.176E+06	6.165E+02	2.631E+02	7.341E+04	4.932E+00
2031	1.598E+04	8.728E+06	5.865E+02	2.503E+02	6.983E+04	4.692E+00
2032	1.520E+04	8.303E+06	5.578E+02	2.381E+02	6.642E+04	4.463E+00
2033	1.446E+04	7.898E+06	5.306E+02	2.265E+02	6.318E+04	4.245E+00
2034	1.375E+04	7.512E+06	5.048E+02	2.154E+02	6.010E+04	4.038E+00
2035	1.308E+04	7.146E+06	4.801E+02	2.049E+02	5.717E+04	3.841E+00
2036	1.244E+04	6.798E+06	4.567E+02	1.949E+02	5.438E+04	3.654E+00
2037	1.184E+04	6.466E+06	4.345E+02	1.854E+02	5.173E+04	3.476E+00
2038	1.126E+04	6.151E+06	4.133E+02	1.764E+02	4.921E+04	3.306E+00
2039	1.071E+04	5.851E+06	3.931E+02	1.678E+02	4.681E+04	3.145E+00
2040	1.019E+04	5.565E+06	3.739E+02	1.596E+02	4.452E+04	2.991E+00
2041	9.691E+03	5.294E+06	3.557E+02	1.518E+02	4.235E+04	2.846E+00
2042	9.218E+03	5.036E+06	3.384E+02	1.444E+02	4.029E+04	2.707E+00
2043	8.768E+03	4.790E+06	3.219E+02	1.374E+02	3.832E+04	2.575E+00

Year	Carbon dioxide			NMOC		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2044	8.341E+03	4.557E+06	3.062E+02	1.307E+02	3.645E+04	2.449E+00
2045	7.934E+03	4.334E+06	2.912E+02	1.243E+02	3.467E+04	2.330E+00
2046	7.547E+03	4.123E+06	2.770E+02	1.182E+02	3.298E+04	2.216E+00
2047	7.179E+03	3.922E+06	2.635E+02	1.125E+02	3.137E+04	2.108E+00
2048	6.829E+03	3.731E+06	2.507E+02	1.070E+02	2.984E+04	2.005E+00
2049	6.496E+03	3.549E+06	2.384E+02	1.018E+02	2.839E+04	1.907E+00
2050	6.179E+03	3.376E+06	2.268E+02	9.680E+01	2.700E+04	1.814E+00
2051	5.878E+03	3.211E+06	2.157E+02	9.208E+01	2.569E+04	1.726E+00
2052	5.591E+03	3.054E+06	2.052E+02	8.759E+01	2.443E+04	1.642E+00
2053	5.318E+03	2.905E+06	1.952E+02	8.331E+01	2.324E+04	1.562E+00
2054	5.059E+03	2.764E+06	1.857E+02	7.925E+01	2.211E+04	1.486E+00
2055	4.812E+03	2.629E+06	1.766E+02	7.539E+01	2.103E+04	1.413E+00
2056	4.578E+03	2.501E+06	1.680E+02	7.171E+01	2.001E+04	1.344E+00
2057	4.354E+03	2.379E+06	1.598E+02	6.821E+01	1.903E+04	1.279E+00
2058	4.142E+03	2.263E+06	1.520E+02	6.488E+01	1.810E+04	1.216E+00
2059	3.940E+03	2.152E+06	1.446E+02	6.172E+01	1.722E+04	1.157E+00
2060	3.748E+03	2.047E+06	1.376E+02	5.871E+01	1.638E+04	1.101E+00
2061	3.565E+03	1.948E+06	1.309E+02	5.585E+01	1.558E+04	1.047E+00
2062	3.391E+03	1.853E+06	1.245E+02	5.312E+01	1.482E+04	9.958E-01
2063	3.226E+03	1.762E+06	1.184E+02	5.053E+01	1.410E+04	9.472E-01
2064	3.068E+03	1.676E+06	1.126E+02	4.807E+01	1.341E+04	9.010E-01
2065	2.919E+03	1.595E+06	1.071E+02	4.572E+01	1.276E+04	8.571E-01
2066	2.776E+03	1.517E+06	1.019E+02	4.349E+01	1.213E+04	8.153E-01
2067	2.641E+03	1.443E+06	9.694E+01	4.137E+01	1.154E+04	7.755E-01
2068	2.512E+03	1.372E+06	9.221E+01	3.935E+01	1.098E+04	7.377E-01
2069	2.390E+03	1.305E+06	8.771E+01	3.744E+01	1.044E+04	7.017E-01
2070	2.273E+03	1.242E+06	8.344E+01	3.561E+01	9.934E+03	6.675E-01
2071	2.162E+03	1.181E+06	7.937E+01	3.387E+01	9.450E+03	6.349E-01
2072	2.057E+03	1.124E+06	7.550E+01	3.222E+01	8.989E+03	6.040E-01
2073	1.956E+03	1.069E+06	7.181E+01	3.065E+01	8.551E+03	5.745E-01
2074	1.861E+03	1.017E+06	6.831E+01	2.915E+01	8.134E+03	5.465E-01
2075	1.770E+03	9.671E+05	6.498E+01	2.773E+01	7.737E+03	5.198E-01
2076	1.684E+03	9.200E+05	6.181E+01	2.638E+01	7.360E+03	4.945E-01
2077	1.602E+03	8.751E+05	5.880E+01	2.509E+01	7.001E+03	4.704E-01
2078	1.524E+03	8.324E+05	5.593E+01	2.387E+01	6.659E+03	4.474E-01
2079	1.449E+03	7.918E+05	5.320E+01	2.271E+01	6.334E+03	4.256E-01
2080	1.379E+03	7.532E+05	5.061E+01	2.160E+01	6.026E+03	4.049E-01
2081	1.311E+03	7.165E+05	4.814E+01	2.054E+01	5.732E+03	3.851E-01
2082	1.248E+03	6.815E+05	4.579E+01	1.954E+01	5.452E+03	3.663E-01
2083	1.187E+03	6.483E+05	4.356E+01	1.859E+01	5.186E+03	3.485E-01
2084	1.129E+03	6.167E+05	4.143E+01	1.768E+01	4.933E+03	3.315E-01
2085	1.074E+03	5.866E+05	3.941E+01	1.682E+01	4.693E+03	3.153E-01
2086	1.021E+03	5.580E+05	3.749E+01	1.600E+01	4.464E+03	2.999E-01
2087	9.716E+02	5.308E+05	3.566E+01	1.522E+01	4.246E+03	2.853E-01
2088	9.242E+02	5.049E+05	3.392E+01	1.448E+01	4.039E+03	2.714E-01
2089	8.791E+02	4.803E+05	3.227E+01	1.377E+01	3.842E+03	2.581E-01
2090	8.362E+02	4.568E+05	3.069E+01	1.310E+01	3.655E+03	2.456E-01
2091	7.955E+02	4.346E+05	2.920E+01	1.246E+01	3.476E+03	2.336E-01
2092	7.567E+02	4.134E+05	2.777E+01	1.185E+01	3.307E+03	2.222E-01
2093	7.198E+02	3.932E+05	2.642E+01	1.128E+01	3.146E+03	2.114E-01
2094	6.847E+02	3.740E+05	2.513E+01	1.073E+01	2.992E+03	2.010E-01
2095	6.513E+02	3.558E+05	2.391E+01	1.020E+01	2.846E+03	1.912E-01
2096	6.195E+02	3.384E+05	2.274E+01	9.705E+00	2.707E+03	1.819E-01
2097	5.893E+02	3.219E+05	2.163E+01	9.231E+00	2.575E+03	1.730E-01
2098	5.605E+02	3.062E+05	2.058E+01	8.781E+00	2.450E+03	1.646E-01
2099	5.332E+02	2.913E+05	1.957E+01	8.353E+00	2.330E+03	1.566E-01
2100	5.072E+02	2.771E+05	1.862E+01	7.946E+00	2.217E+03	1.489E-01
2101	4.825E+02	2.636E+05	1.771E+01	7.558E+00	2.109E+03	1.417E-01
2102	4.589E+02	2.507E+05	1.685E+01	7.189E+00	2.006E+03	1.348E-01
2103	4.366E+02	2.385E+05	1.602E+01	6.839E+00	1.908E+03	1.282E-01
2104	4.153E+02	2.269E+05	1.524E+01	6.505E+00	1.815E+03	1.219E-01
2105	3.950E+02	2.158E+05	1.450E+01	6.188E+00	1.726E+03	1.160E-01
2106	3.757E+02	2.053E+05	1.379E+01	5.886E+00	1.642E+03	1.103E-01

2107	3.574E+02	1.953E+05	1.312E+01	5.599E+00	1.562E+03	1.050E-01
2108	3.400E+02	1.857E+05	1.248E+01	5.326E+00	1.486E+03	9.984E-02
2109	3.234E+02	1.767E+05	1.187E+01	5.066E+00	1.413E+03	9.497E-02
2110	3.076E+02	1.681E+05	1.129E+01	4.819E+00	1.344E+03	9.034E-02
2111	2.926E+02	1.599E+05	1.074E+01	4.584E+00	1.279E+03	8.593E-02
2112	2.784E+02	1.521E+05	1.022E+01	4.361E+00	1.217E+03	8.174E-02
2113	2.648E+02	1.447E+05	9.719E+00	4.148E+00	1.157E+03	7.775E-02
2114	2.519E+02	1.376E+05	9.245E+00	3.946E+00	1.101E+03	7.396E-02
2115	2.396E+02	1.309E+05	8.794E+00	3.753E+00	1.047E+03	7.035E-02
2116	2.279E+02	1.245E+05	8.365E+00	3.570E+00	9.960E+02	6.692E-02
2117	2.168E+02	1.184E+05	7.957E+00	3.396E+00	9.474E+02	6.366E-02
2118	2.062E+02	1.127E+05	7.569E+00	3.230E+00	9.012E+02	6.055E-02
2119	1.962E+02	1.072E+05	7.200E+00	3.073E+00	8.573E+02	5.760E-02
2120	1.866E+02	1.019E+05	6.849E+00	2.923E+00	8.155E+02	5.479E-02
2121	1.775E+02	9.696E+04	6.515E+00	2.780E+00	7.757E+02	5.212E-02
2122	1.688E+02	9.223E+04	6.197E+00	2.645E+00	7.379E+02	4.958E-02
2123	1.606E+02	8.773E+04	5.895E+00	2.516E+00	7.019E+02	4.716E-02
2124	1.528E+02	8.346E+04	5.607E+00	2.393E+00	6.676E+02	4.486E-02
2125	1.453E+02	7.939E+04	5.334E+00	2.276E+00	6.351E+02	4.267E-02
2126	1.382E+02	7.551E+04	5.074E+00	2.165E+00	6.041E+02	4.059E-02
2127	1.315E+02	7.183E+04	4.826E+00	2.060E+00	5.747E+02	3.861E-02
2128	1.251E+02	6.833E+04	4.591E+00	1.959E+00	5.466E+02	3.673E-02
2129	1.190E+02	6.500E+04	4.367E+00	1.864E+00	5.200E+02	3.494E-02
2130	1.132E+02	6.183E+04	4.154E+00	1.773E+00	4.946E+02	3.323E-02
2131	1.077E+02	5.881E+04	3.951E+00	1.686E+00	4.705E+02	3.161E-02
2132	1.024E+02	5.594E+04	3.759E+00	1.604E+00	4.475E+02	3.007E-02
2133	9.741E+01	5.321E+04	3.575E+00	1.526E+00	4.257E+02	2.860E-02
2134	9.266E+01	5.062E+04	3.401E+00	1.452E+00	4.049E+02	2.721E-02
2135	8.814E+01	4.815E+04	3.235E+00	1.381E+00	3.852E+02	2.588E-02
2136	8.384E+01	4.580E+04	3.077E+00	1.313E+00	3.664E+02	2.462E-02
2137	7.975E+01	4.357E+04	2.927E+00	1.249E+00	3.485E+02	2.342E-02
2138	7.586E+01	4.144E+04	2.785E+00	1.188E+00	3.315E+02	2.228E-02
2139	7.216E+01	3.942E+04	2.649E+00	1.130E+00	3.154E+02	2.119E-02
2140	6.864E+01	3.750E+04	2.520E+00	1.075E+00	3.000E+02	2.016E-02
2141	6.529E+01	3.567E+04	2.397E+00	1.023E+00	2.854E+02	1.917E-02
2142	6.211E+01	3.393E+04	2.280E+00	9.730E-01	2.714E+02	1.824E-02
2143	5.908E+01	3.228E+04	2.169E+00	9.255E-01	2.582E+02	1.735E-02
2144	5.620E+01	3.070E+04	2.063E+00	8.804E-01	2.456E+02	1.650E-02
2145	5.346E+01	2.920E+04	1.962E+00	8.375E-01	2.336E+02	1.570E-02

Appendix D

D.1 Copy of the journal paper published.

A Comparative Analysis of CH_4 Emission Reduction from Municipal Solid Waste (MSW) under Different Scenarios in Kathmandu, Nepal

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Abstract-Currently 516 tonnes of municipal solid waste per day are generated in Kathmandu, Nepal, the majority of which is taken to landfill. This is projected to rise to 745 tons per day by 2025. Landfill is a source of greenhouse gas emissions, most notably methane (CH_4). This study assessed the CH_4 emissions from a landfill site in Kathmandu for five scenarios: S0, S1, S2, S3 and S4. The results showed that CH_4 emissions are extremely high at 15,136 thousand m^3 for scenario S0 - "Business as usual". A significant reduction of 53% of CH_4 emissions was achieved with gas capture (S1). Composting (S2) achieved a reduction of 35% reflecting the high organic content of waste that is currently landfilled. Recycling (S3) achieved a reduction of only 10%. Unsurprisingly, the greatest reduction in CH_4 emissions occurred with a combination of gas capture, composting and recycling (S4) with a 73% reduction. The results suggest that gas capture and composting are feasible alternatives. Recycling material should also be considered, as plastics may in the future take up a greater proportion of the waste material over time.

Keywords- Greenhouse gas (GHG), Kathmandu, Methane (CH_4), Municipal solid waste

I. INTRODUCTION

In the Paris Climate Change Conference, 12th December 2015, 196 nations signed an agreement to combat environmental change, specifically to control greenhouse gas (GHG) emissions [1]. Essentially, the Paris Agreement prescribes that GHG emissions should come down to a 'net zero' level by the end of the century [2]. The Paris Agreement sets a long run temperature objective of holding the worldwide normal temperature increment to well below 2 °C and pursue efforts to limit this to 1.5 °C above pre- industrial levels [3]. It set the worldwide environmental change endeavors on a totally new and dedicated balance: each of the 196 Parties to the UN Framework Convention on Climate Change concurred on a shared objective and way to deal with combatting environmental change and accomplishing worldwide greenhouse neutrality [4]. As part of this there are nationally determined commitments, with each country deciding their own contribution which should be ambitious and progress positively over time.

As indicated by the Intergovernmental Panel on Climate Change IPCC [5] the seven GHGs are: methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and nitrogen triflouride (NF_3). The three main GHGs, based on their global warming potential are CH_4, CO_2 and N_2O. The primary sources of GHGs emissions are energy-related production accounting for 65% (mainly from electricity and heat: 28%, transportation: 12%, and manufacturing: 12%), agriculture (14%), land-use change and forestry (12%), and others (6%) [6]. Solid waste contributes 3% of total global GHGs emissions [7].

Solid waste management is of concern, as with an ever increasing global and urbanized population the generation of waste also increasing. This waste has historically been disposed of in open dumps and landfill sites. These destinations produce gas because of the anaerobic disintegration of organic matter. Landfill gas contains roughly equivalent measures of CH_4 (45 to 60%) and CO_2 (40 to 60%) [8]. However, the global warming capability of CH_4 gas is 21 times higher compared to that of CO_2 [6]. Therefore, effective management of CH_4 is important.

The US Environmental Protection Agency [9] has detailed that the landfill site was the biggest source of CH_4 emissions in the United States, representing about 90% of all CH_4 discharges from the waste segment. Landfill sites are also adding to an expansion in GHG discharges in developing countries. For example, in 2000, developing countries were responsible for around 29 % of total GHG emissions, and this is anticipated to increase to 64% by 2030 and 76% by 2050, with landfills being the main reason behind this expansion [10]. In contrast, in developed countries the corresponding GHG outflow is reducing. For instance, the European Union (EU) municipal waste sector diminished from 69×10^6 tonnes CO_2-e in 1990 to 32×10^6 tonnes CO_2-e by 2007 and further decreases have been anticipated [11]. This shows decreases in GHG discharges is conceivable.

[12] suggested that developing countries can possibly relieve national emissions by around 5% and in the long term to 10% when coordinated strong waste administration is executed. However, developing countries are facing numerous challenges. First, there is an absence of national statistics on solid waste activity leading to difficulties in computing and large uncertainty in estimating GHG emissions from such activities [13]. Second, difficulties in adopting appropriate approaches. This has led to difficulties in establishing a GHG inventory and subsequent targets for reduction in the solid waste sector.

This study examines the level of solid waste generation and associated GHG emissions and then develops alternative scenarios on ways to reduce these emissions using Kathmandu Metropolitan City (KMC) lying in Kathmandu, Nepal as a developing country case study.

Overview of the Solid Waste Management system in KMC

According to the 2011 Census, the number of inhabitants in KMC was more than 1 million and the normal solid waste generation was 0.3 kg/person/day. The everyday waste generation from various sources was found as 516 ton/day in 2015 [14] with waste collection effectiveness at 86.9% [15]. In 2015, the fundamental source of KMC solid waste was household waste (50%) followed by commercial (44%) and institutional (6%). The largest component of the waste is organic followed by plastics and paper [16].

The waste from households is stored in household bins and unsegregated. Some waste is thrown in the community bins, on roadsides, abandoned spaces and on riverbanks. Most of the waste generated goes directly to the only landfill site called 'Sisdole landfill site', located in Sisdole, which is around 28 km away from Kathmandu city. The landfill site was established with the assistance of JICA (Japan International Cooperation Agency) in 2005 with a project life of 3 years but, as there is no alternative waste disposal site, the waste from Kathmandu valley is still being dumped there [17].

KMC is the focal organization accountable for handling the waste generated in KMC. A total of 1,320 staff are engaged to manage the solid waste [14]. These staff are spread across 32 ward offices, each has tractors or tippers and 20-30 sweepers, amounting to 927 street sweepers in total. Some private sector and Non-Government Organization (NGOs) also have sweepers to clean the streets. Figure shows a detail schematic representation of the municipal solid waste flow in KMC.

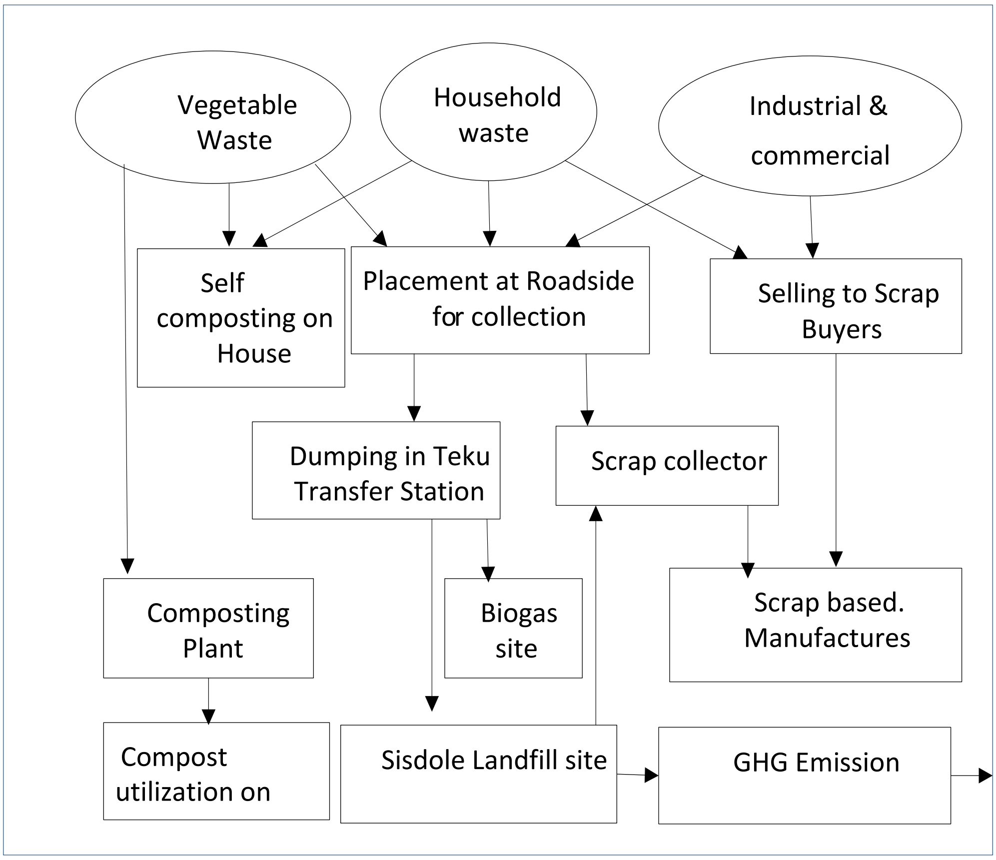

Figure 1: Municipal solid waste flow of Kathmandu Metropolitan city (develop by Author)

II. RESEARCH METHODOLOGY

Study area

The study area Kathmandu Metropolitan City (85° 20’ East and 27° 42' north) lies in Kathmandu Valley of Nepal. It covers an area of 50.67 km^2. The elevation of Kathmandu lies 1,350 meters above mean sea level [18]. The Kathmandu valley has a mild climate most of the year with summer temperatures ranging from 19-27°C, and winter temperatures ranging from 2-20°C. Total annual rainfall in the area is 1,505 mm with around 80% rain occurs during rainy season (June to August) [19]. The Kathmandu City is divided into 5 major sectors and 32 wards as the decentralized units as shown in Figure 2**.**

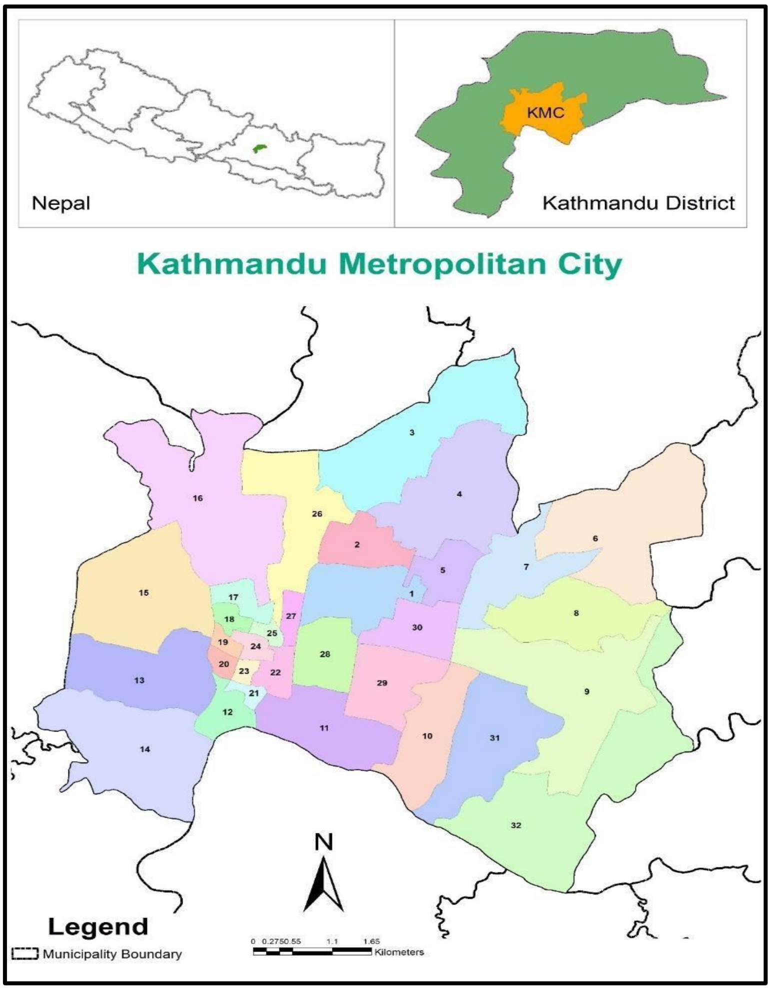

Figure 2: shows the location of the study area, Kathmandu, Nepal [20]

In the last 20 years the population of the city has grown at an annual growth rate of 4.8% from 0.67 million in 2001 to 1.0 million in 2011[21] . Due to rapid population growth and urbanization the quantity of waste generated in Kathmandu city is increasing rapidly, demanding special attention for proper Solid Waste Management (SWM).

Figure 3 shows that there is a strong linear relationship between waste generation and population with coefficient of regression R^2 =

0.99. Based on this regression waste quantity by 2025 is predicted to be 271,965 tonnes.

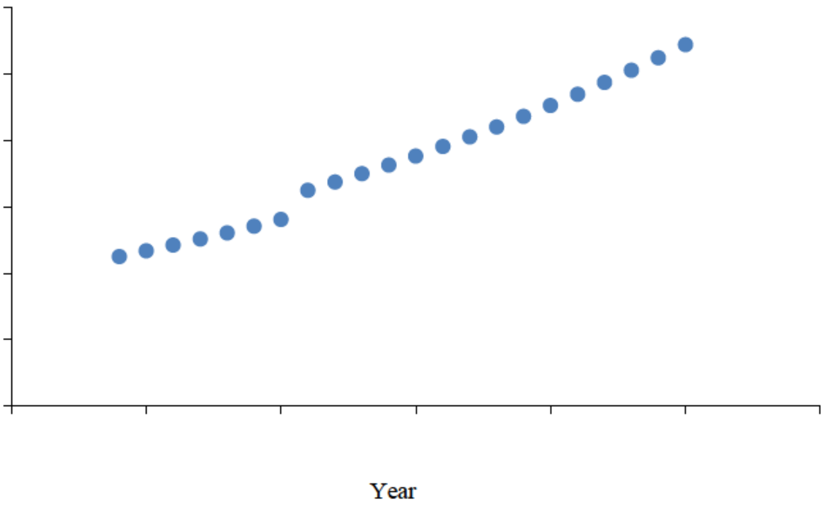

Figure 3: Yearly waste generation trend in Kathmandu city, Nepal [22]

Framework for Research Methodology

The framework for the research methodology is shown in Figure 4. In Phase 1 Life Cycle Assessment (LCA) is proposed as the key research strategy. The principles and framework for LCA include defining the goals and scope, Life Cycle Inventory (LCI) analysis, Life Cycle Impact Analysis (LCIA) and Life Cycle Interpretation [23]. In view of the structure of LCA, the objective and extent of the investigation will be re-imagined. Likewise, predictive scenarios will be structured, and discharge stock techniques will be chosen. Most of the calculations will be made based on Inventory Analysis, as the purpose of the study will be to analyse potential environmental benefits through alternative scenarios. The focus of the scenarios is on the current situation in Kathmandu and potential future waste treatment facilities which fit with the waste characteristics of Kathmandu targeting less energy consumption, low emissions whilst being cost effective with maximum social benefits acceptable to society.

Phase 2 involves emission accounting and evaluates CH_4 discharges by utilizing two numerical models: IPCC default; and first order decay (FOD) model [24]. The results for every situation are then evaluated and compared to determine the best MSW management for Kathmandu in regard to reducing GHG emissions.

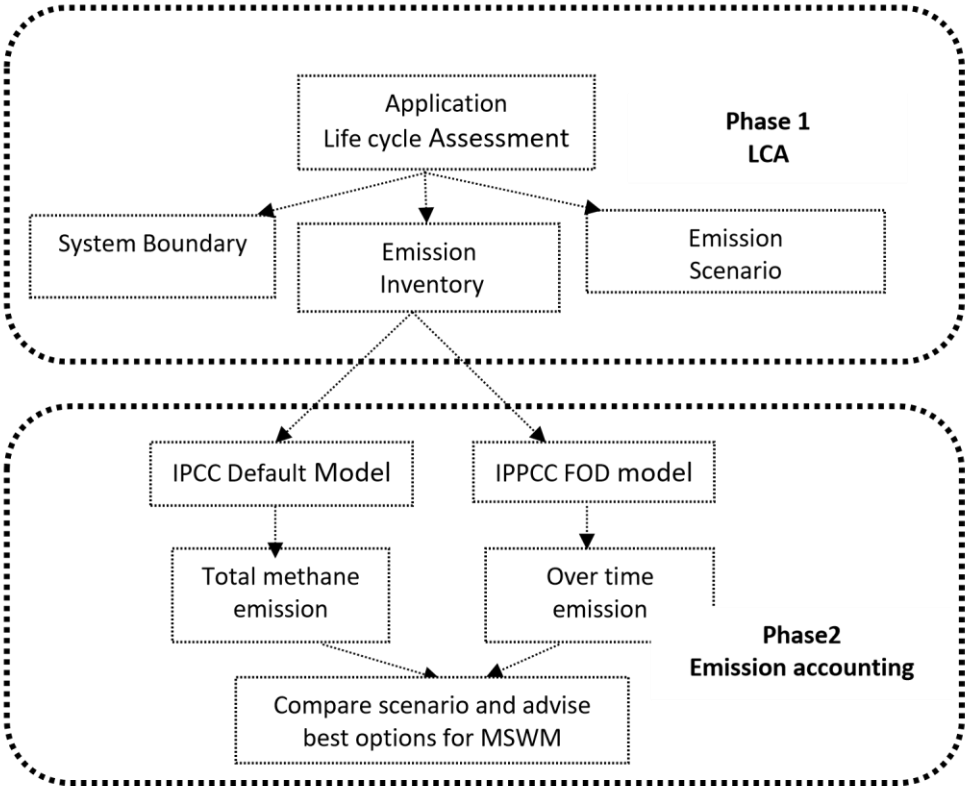

Figure 4: framework for Research Methodology

Scenario development in LCA

In this section, scenarios are defined and created for analysis in LCA. The scenario design in this research investigates the potential decrease of the environmental impacts associated with a potential decrease in CH_4 emissions as a result of the alternative scenarios identified.

MSW in KMC is collected waste without segregation at the source, mixed with other waste and conveyed to Sisdole landfill site. The existing Sisdole landfill site, however, is overloaded. Accepted Government policy is focused on improving MSW management systems, especially, with the rate of increase in food waste and recyclable components in MSW. This has led to some segregation of food waste and inorganic waste at source to be treated by composting and recycling, rather than landfill.

The five scenarios proposed in this study with system boundaries are illustrated in Table I. The baseline scenario (S0) represents the existing MSW management system which is the status of MSW undertaken by KMC, and the subsequent scenarios reflect alternative options, including composting and recycling, and also gas capture from the existing landfill site.

Table I: Description of scenarios used in this study

Scenarios	Explanation of Scenarios Used
S0	Current 'Business as usual' (Landfilling of 87% of collected MSW)
S1	Upgrade to landfill gas capture (70% Methane recovery)
S2	Composting 50% of organic waste
S3	Recycling 25% of recyclable materials
S4	Integration of gas capture, recycling and composting

Current 'Business as usual' (S0)

The business-as-usual scenario includes the collection, transport and landfilling of MSW. This is the status of MSW undertaken by KMC. A very small fraction of the waste is recovered as recycled materials, but this is not considered here. According to the environmental audit report [14], MSW is not isolated at the source and roughly 448 tons of waste for each day are discarded in the Sisdole Landfill site with no further treatment. Sisdole Landfill site is structured as a semi anaerobic landfill site, without a recuperation framework or an LFG catch system. Data on the solid waste composition of Kathmandu Metropolitan City during the years 2003, 2005, 2009, 2013 and 2015 are shown in Table II [15],[16],[14]). The waste composition data of the year 2015 is considered for the calculation in this study work.

Table II: The physical composition of solid waste of KMC (%)

Year	Organic Waste	Plastics	Paper	Glass	Metals	Textiles	Rubbers	Con.s and demolition	Others
2003	70.00	9.50	8.50	2.50	-	3.00	-	4.50	2.00
2005	69.00	9.00	9.00	3.00	1.00	3.00	1.00	2.00	3.00
2009	63.00	10.00	9.50	6.00	0.50	2.00	1.00	5.00	3.00
2013	73.22	11.43	6.89	2.10	1.06	1.61	0.62	-	3.07
2015	63.22	10.80	9.02	5.42	0.42	2.30	1.20	4.50	3.12

Upgrade of Landfill gas capture (S1)

The landfill gas capture scenario is the same as S0 but assumes 70% of CH_4 gas is gathered. Landfill gas (LFG) is naturally produced by the decomposition of organic materials (also known as biomass) and increasing moisture content can accelerate the waste decay process. The rate of LFG production thus also increases with moisture content, peaking at waste moisture contents of 60 to 78% [25]. Sisdole landfill waste has an average moisture content of about 35.3 %, with a high volume of food and vegetable waste having a higher moisture content [26]. After waste placement, rainfall, surface water and groundwater infiltration, together with the products of waste breakdown, can contribute additional moisture. Based on these existing conditions, and observations of existing vent pipe placements to allow methane gas to escape alongside discussion with KMC staff, this scenario assumes that the introduction of a gas capture system will be effective at gathering 70% of the gas produced (R=0.7). Other parameters in the scenario are the same as S0.

The estimation of the model parameters for scenario S1 are shown in Table 3.

Composting of organic waste (S2)

In this scenario the composting of 50% of organic waste from 86.9% of the landfilled waste is isolated, gathered and composted with the remaining waste sent to landfill. This figure is based upon discussions with KMC staff on the feasibility of the process. In this scenario using input data, 50% of organic waste is identical to 51,743 tons of the 103,486 tons of organic waste which can be treated as compost. The adjustment in the waste amount and level of the waste composition for the input scenario S2 are shown in Table 3.

Recycling prior to landfill (S3)

Based on the study of Kathmandu solid waste management Bank [15], 25 % of household waste and a much higher proportion of institutional and commercial waste could be either reused or recycled. This is excluding organic waste. This scenario therefore assumes that 25% of the MSW from the amount of buried MSW, including paper, metals, glass, plastic, construction and demolition waste, and textiles is separated at the source and recycled with the remaining waste sent to landfill. It is assumed that a similar measure of MSW, with a similar composition as in S0 is covered. The adjustment in the waste amount and level of the waste composition for the input scenario S3 are shown in Table 3.

Integration of capture, recycling and composting (S4)

Firstly, 50% of organic waste from landfilled MSW will be gathered and treated by fertilizing the soil to make compost in S2. Moreover, recyclable materials, for example, paper, metals, glass, plastic, wood and material will be recycled at a 25 % rate in the material recycling facility. The remaining waste is sent to the landfill. Lastly, in assumption S0, 70% of CH4 emissions will be collected and recovered. The same amount of MSW, with the same composition in S0, is delivered and treated at the landfill site.

System boundaries

The practical unit in this examination is the aggregate sum of waste produced in KMC in a year, i.e., household, commercial, and institutional. This amounts to 163,666 tons in terms of solid waste collected. The functional system boundaries selected for this LCA only includes the direct emission from the waste after landfill where waste was characterized as the minute when material stops to have value.

In this examination, figure 5 presents the key points for each scenario for the MSW management system in Kathmandu. The upstream limit begins with MSW being dumped in the landfill site. The procedure of collection and transport is excluded in the framework stream for all scenarios. It is on the grounds that it is hard to recognize and isolate the GHG outflows produced from the collection and the transportation that might be conveyed to either landfilling or other treatment destinations.

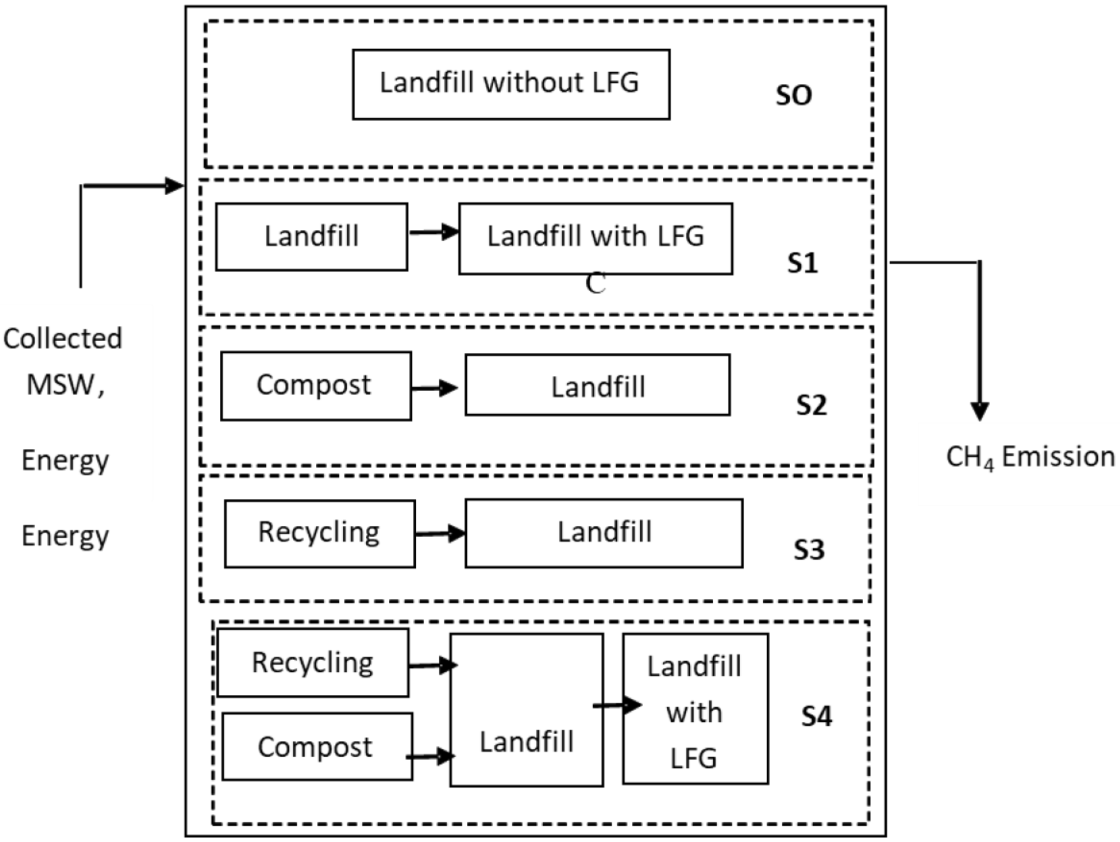

Figure 5: System boundary

Unit procedures incorporated into the emissions scenarios are: (1) foundation of landfill, for example, establishment of LFG catch framework; (2) integrated composting to landfill; (3) coordinated recycling to landfill. Deciding the unit forms and isolating each and every unit procedure from the principal framework help to assess their environmental impacts inside the framework. Any change will prompt changes in the first framework

IPCC Model / IPCC default method

The IPCC suggests two methods for calculating methane emissions from landfill sites, the default method and the first order decay method. The least complex one for the estimation of methane outflows from landfills depends on a mass equalization approach. This is the default methodology (DM). DM is fundamentally an empirical model. Various empirical constants have been considered while building up the DM. The empirical constants vary according to the composition of waste, management of the landfill site and depth of landfill. The method assumes all emissions of methane occur in the same year as the waste is deposited at the landfill site [27]. Even though this is not the case, the IPCC state that the DM gives a sensible annual estimate of actual emissions, and this has been broadly utilized in the circumstances where point by point information is not available [13]. The Default model requires the MSW amount and composition that is sent to the landfill site and data on the current activity of the site. As per IPCC Guidelines, the equation for determining GHG emission from solid waste landfills is as per the following [28]

Methane Emission- ECH_4 (Gg/yr) = (MSWT x MSWF x MCF x DOC x DOCF x F x (16/12 –R) x (1-OX) - Eq 1

Where: 1 Gg/yr: 1000 Mg/yr

Where: ECH_4 = Methane emission from landfills. MSWT = Total MSW generated (Gg/year), MSWF = Percentage of urban waste actually land filled; MCF = methane correction factor (fraction), DOC = degradable organic carbon (fraction) (kg C/ kg MSW) DOCF: fraction DOC dissimilated, F = fraction of CH_4 in landfill gas (IPCC default is 0.5), 16/12 = conversion of C to CH_4, R = recovered CH_4 (Gg/year), OX = oxidation factor

Modified FOD method

In the First Order Decay (FOD) model methane generation from landfill is a function of time mirroring the actual time that it takes material to decay. The FOD model requires information on current waste amounts, composition and disposal practices extending over decades [27]. At present due to lack of data, this method cannot be used for estimation of methane emission. Therefore, a modified model has been used. The modified model is the NV Afvalzorg Multiphase Landfill Gas Generation and Recovery Model, which is a first order decay model based on IPCC mathematics and default parameters and the model estimates methane generation, recovery, and emission on individual landfills for which limited data on waste composition are available [29]. Various sorts of waste contain different fractions of organic matter that degrade at various rates. The advantage of the NV Afvalzorg Multiphase model is that the typical waste composition can be considered [30]. The estimation approach IPCC 2006 rules for solid waste disposal site was followed. Furthermore, IPCC default values were adopted as much as possible [24]. The formula used in this model for calculating methane generation (G) is as follows. For this model the time horizon is 100 Years.

$G = WLo\ [F(f)\ (K(f)e{-}K(f)(t{-}t(1))) + F(s)(K(s)e{-}K(s)(t{-}t(1)))]$ - Eq 2

Where:

G = Methane generation (million cubic meters per year), W = Waste disposed of (Tonnes), Lo = Methane yield potential (cubic meter per tonne of waste), T = Time after waste placement (year), T1 = lag time (between placement and start of gas generation), K (f) = First-order decay rate constant for rapidly decomposing waste, K(S) = First-order decay rate constant for slowly decomposing waste,

F(f) = Fraction of rapidly decomposing waste, (S) = Fraction of rapidly decomposing waste

Information parameters for models

Municipal Solid Waste Tonnage (MSWT): Based on the existing MSW management practices in Kathmandu, along with its landfill features, climatic condition, the wet tropical climate, the default parameters for all factors used in the models is presented in detail in Table III. Total municipal solid waste (MSW) generated Ga/year (MSWT) was calculated from population (in thousand persons) multiplied by annual MSW generation rate.

According to the environmental audit report [14] total MSW is equal to 163,666 tonnes of solid waste and therefore this is the amount that was applied to the model.

Methane correction factor (MCF): the value of the methane correction factor (MCF) reflects the status of landfill management of the site. To accommodate different types of landfill sites, the IPCC recommends default MCF values, ranging from 0.4 to 1. This corresponds to a range of unmanaged to well-managed landfill sites. In Sisdole Landfill site, the burial areas of MSW is well managed with a top cover of soil, supposing that the value of MCF is 1, this is applied for all scenarios.

Degradable organic carbon (fraction): DOC substance is fundamental in processing methane generation. It relies upon the composition of waste and changes from scenario to scenario. The organic fraction of each type of organic waste is considered as having different decay rates [31] shown in the following equation.

$$DOC = (0.4 * A) + (0.17 * B) + (0.15 \bullet C) + (0.3 * D) - \qquad \text{Eq 3}$$

Where, DOC is degradable organic carbon, A: fraction of paper and textiles; B: fraction of garden waste and park waste; C: fraction of food wastes and D: fraction of MSW as wood or straw.

Applying measurable information on waste composition in the KMC MSW, the level of DOC in MSW is 14.1%. This figure is for scenario S0 and S1. In contrast with S0 and S1, the estimations of DOC applied to the remainder of the scenarios are 13.7% for S2,
14.1% for S3 and 13.69% for S4 (Table 3).

Fraction DOC dissimilated: This is the DOCF that is changed over to LFG. The theoretical model is linked to the temperature in the anaerobic zone of a landfill site. The model is depicted as 0.014T+0.28, where T=temperature in ˚C [27]. It is expected that temperature stays steady at 35˚C in the anaerobic zone of the landfill. This results in a figure of 0.77.

Fraction of methane (F) in LFG (default is 0.5): The division of methane in LFG is expected to be 0.5, and is the figure used here.

R (Recovered methane) (Gg/year): Recovery of LFG does not yet take place in Nepal. For scenario S1 and S4 it is assumed that if a gas capture system is introduced it would be effective at collecting 70% of the gas produced (R0.7). Additionally, using a landfill top cover of soil the default parameter for the oxidation factor will be 0.1 [13].

Table III: Input parameters used in calculation for scenarios

Input Parameters	MCF*	D0C	DOCF*	F*	R	OX*
S0	1	14.11%	0.77	0.5		0.1
S1		14.11%			- 0.7	
S2		13.70%			-	
S3		14.10%			-	
S4		13.69%			0.7	

*All scenarios Average value

MSW is classified into rapidly, moderately, and slowly degradable organics. Rapidly biodegradable organics (food waste) starts decomposing a few days after waste is placed in the landfill and take up to five years to complete decomposition. Moderately degradable organics (garden and park waste, leaves, grass trimmings) start the degradation process after a few months and finish after seven to ten years of burial. Paper, textile, leather, rubber, and wood are slow to biodegrade and begin decomposing about five years after they are buried in a landfill site and might take up to 50 years to complete the process [32]. In this calculation data from 2005 to 2018 on annual deposited waste in Sisdole landfill site from KMC was used.

In this study, the consideration of value k was dependent on the climate condition at the Sisdole Landfill site, the waste component and reference of IPCC default k values. Sisdole landfill site is located in near Kathmandu valley under a warm humid tropical climate with precipitation being around 1505 mm per year and the annual average temperature being about 19-27°C. Therefore, default values of k and the corresponding half-lives have been taken from 2006 IPCC Guidelines for a tropical climate zone with mean annual temperature over 20°C and mean annual precipitation over 1,000 mm. According to the equation K=3.2*10-5 (R) +0.01 of US [9]) where R is the annual precipitation, the calculated value of k is 0.06 and corresponding t1/2 is 10 years.

III. RESULTS AND DISCUSSION

Waste composition under different scenario in KMC

One significant aspect of solid waste in KMC from a management perspective is the huge volume of organic materials in the solid waste stream. The remainder of the waste contains glass, metal, rubber and other materials. Organic waste accounts for 60–70% of all solid waste and the level of this waste which is biodegradable is strikingly high. The official figures of KMC for the year 2015 demonstrate that practically 63.22% (by weight) of the waste produced in KMC is organic followed by plastic and paper. A similar amount of waste with an unchanged composition is used in the computation for this study. Thus, the waste creation information for the year 2015 is used in scenario Current 'Business as usual' (SO). It remains the same for the gas recovery scenario (S1). For

Scenarios S2, S3, and S4, the expansion in recycling and composting of MSW decreases the aggregate sum of solid waste sent to the landfill site. This gives rise to new percentages for the composition of waste (Table IV).

For S0 and S1 scenarios, the MSW in Kathmandu contains a high extent of organic waste, representing over half (63.23%) of the landfilled waste. Similar levels are seen in scenario S3 with 69.04% of organic waste. On the other hand, scenarios S2 and S4 have a lower extent of organic waste (46.23% and 52.72% individually), they additionally have the highest level (percentage) of gradually degrading waste (paper, material, plastic, glass, and metal). This determines the varying levels of CH_4 outflows and the age of the landfill in every scenario.

Table IV: Solid Waste material composition stream of scenarios

		Solid Waste composition (%) in different scenarios								
scenarios	Amount of Waste (tonnes)	Organic	Plastic	Paper	Glass	Metal	Textiles	Rubber	Demolition Waste	Others
S0 &S1	163,666	63.23	10.80	9.02	5.42	0.42	2.30	1.20	4.50	3.11
S2	111,923	46.23	15.79	13.19	7.93	0.61	3.36	1.75	6.58	4.55
S3	149,894	69.04	8.84	7.39	4.44	0.34	1.88	0.98	3.69	3.40
S4	98,151	52.72	13.51	11.28	6.78	0.53	2.88	1.50	5.63	5.19

For Scenarios S2, S3 and S4 there will be a change in the aggregate sum of waste sent to landfill with the expansion of composting in S2, in recycling for S3 and both composting and recycling in S4. Figure 6 illustrates the tonnage composition for each scenario.

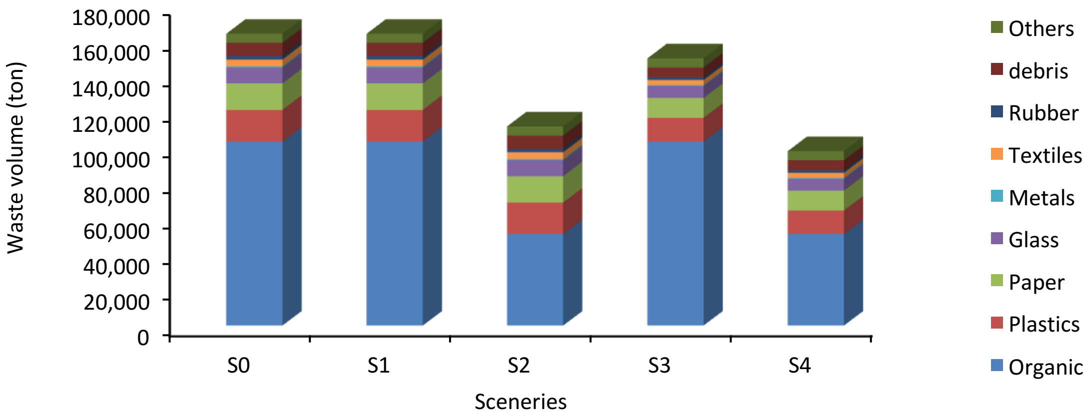

Figure 6: Waste fraction volume follow stream in different sceneries

Potential methane (CH4) emissions

The potential outflows of CH_4 from the Sisdole Landfill site using the IPCC default model varies between the five scenarios as shown in Table V. Scenario S0 (Business as usual) demonstrates that the aggregate sum of CH_4 discharged is 15,136 m^3 while the scenario S4 (Landfill, recycle and compost) reduces CH_4 emissions by 11,049 m^3 to 4,114 m^3. If a gas recuperation framework is introduced (S1), it would by itself lessen CH_4 outflows by 8,022 m^3 down to 7,069 m^3. The next best alternative is S2 (Composting) which reduces the CH_4 outflows by 5,298 m^3 to 9,882 m^3. S3 (Recycling) is the least effective option reducing CH_4 emissions by only 1,514 m^3 to 13,663 m^3.

Table V: The Potential emissions of various scenario utilizing IPCC default model

Scenarios	Amount of waste (tonnes)	CH_4 emissions (m^3)	Emission Reduction (m^3)
S0 (Business as Usual)	163,666	15,136	-
S1 (Gas Capture)	163,666	7,069	8,022
S2 (Landfill/Compost)	111,923	9,882	5,298
S3 (Landfill/Recycle)	149,894	13,663	1,514
S4 (Landfill/Recycle & Compost)	98,151	4,114	11,049

Figure 7 shows the emission reduction for each scenario in percentage terms. All scenarios reduce CH_4 emissions, with minimal advantage from recycling reflecting the relatively limited amount of recyclable material that is actually landfilled. Composting leads to a much greater reduction in emissions, related to the greater amount of organic material that is currently collected and landfilled. This also has implications for gas capture. The greatest reduction understandably is with the integration of all three scenarios.

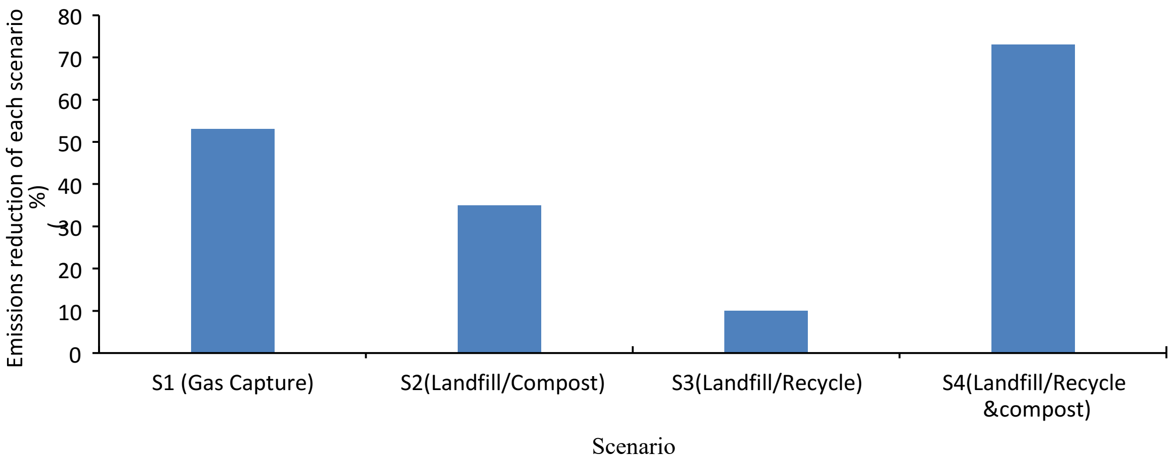

Figure 7: The total emissions (%) reduction of each scenario

Volume Disposal of landfill Waste

In the S0 (Business as Usual) scenario of Figure 8, the volume of waste coming to the landfill site is 163,666 tons per year, which takes up a large volume in the landfill as compared to scenario 2 and 4. Waste coming to landfill indicates that its life will decrease faster due to the huge volume of the waste. The volume of the waste scenario 0 and 1 is the same at 163,666 tonnes per year respectively. The only difference is that in scenario 1 the waste is used to generate gas through the 70% gas capture system. In scenario S0, there is no gas capture and mixed waste is directly disposed as usual. In scenario 2, the volume of the waste decreases to 111,923 tonnes per year due to more recycling of recyclable materials and recovery of organic materials. In scenario 4 Furthermore, the volume of landfill waste decreases to 98,151tonnes in scenario 4. This is due to 50% of compost recycling, 70% of methane recovery at the landfill and 25% inorganic waste recycling as integration method.

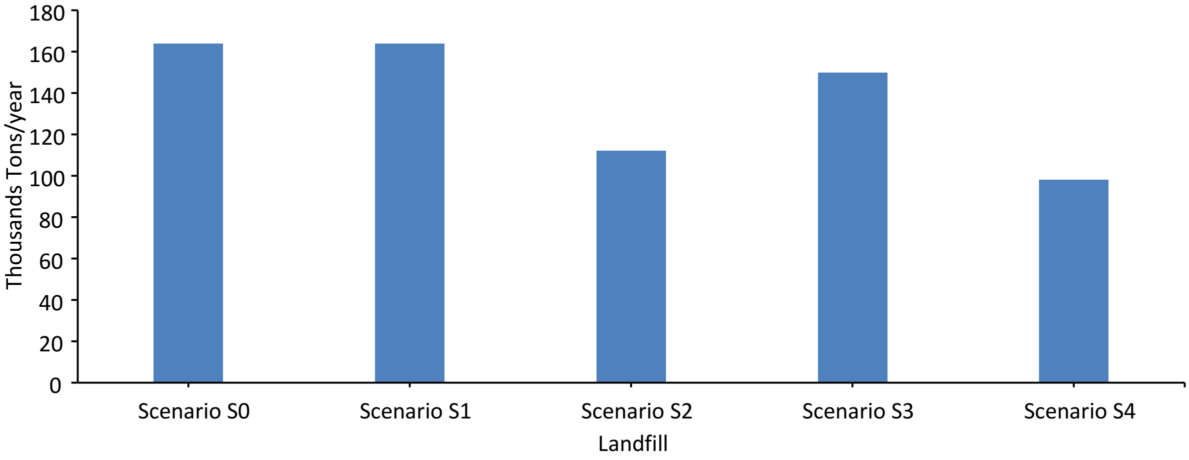

Figure 8: Final disposal of waste volume in different scenarios

Difference in Methane (CH_4) Production over time

The methane emission values from solid waste landfill estimated for 2005 to 2018 using the default method and NV Afvalzorg model are shown in Figure 9. The assumption made in DM is that the potential methane is emitted in the same year that waste is deposited. This may not be realistic. The values used in the FOD model assume that the gas generation takes up to 13 years to take place. Although it appears that the FOD model shows lower emission than the DM model, what is not considered in this analysis is the emissions that will occur because of previous waste deposition as this has not been calculated here. This should be considered in the following analyses.

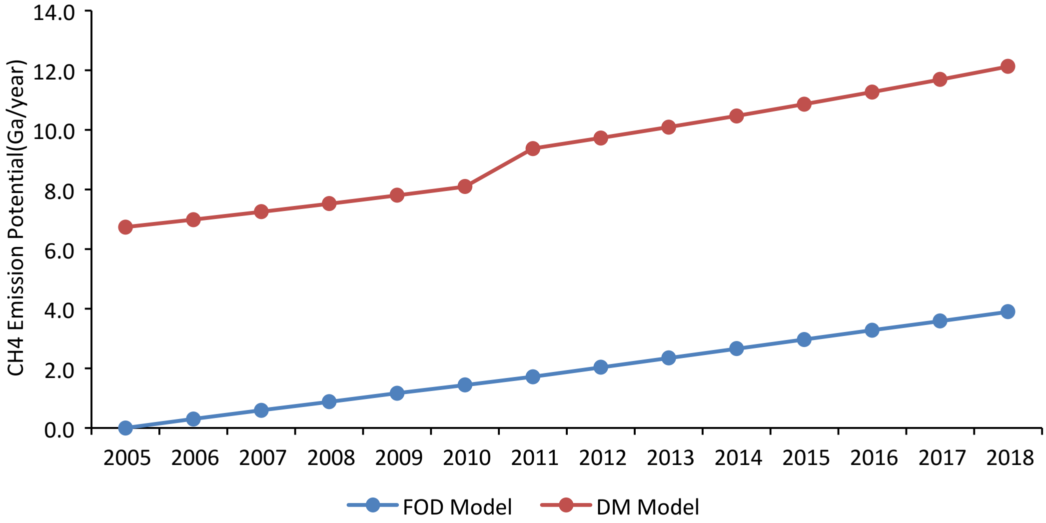

Figure 9: CH_4 emissions in Sisdole landfill site using various Models

Using the FOD base NV Afvalzorg model alongside the DM model for historic and projected CH4 emissions and the annual 20052018 waste disposal quantity (tonnes/year) current and future methane emissions were estimated for each scenario, these are shown in Figure 10, where scenario S0 and S1 overlaps since same volume of waste are disposed in landfill under these scenarios. It is also assumed that the degradation takes place in two stages. The first stage starts after 1 year of MSW deposition and rate increases, which continue for 10 years. Therefore, there is no CH_4 creation in the primary year of 2005, when landfilled was started.

The NV Afvalzorg model simulations demonstrate that 'quickly and moderately biodegradable' organic wastes start decaying after a year after being placed in the landfill. Production of CH_4 occurs from 2006 at an increasing rate for each scenario, peaking in 2018 after 13 years. Emissions peak at 3,897 (mg/year) for S0; 2,672 mg/year for S2; 3,565(mg/year) for S3; and 2,346(mg/year) for S4, followed by a decrease throughout the following 20 years. The 'gradually biodegradable' portions start disintegrating around 5 years after burial peaking by 2018, 10 years after landfilling. Over the initial 30 years, roughly 80% of all CH4 will be created. Emission continues until 2100. Accordingly, the life expectancy of the landfill site is around 100 years and the most reasonable time to capture CH4 is from 2006 to 2035.

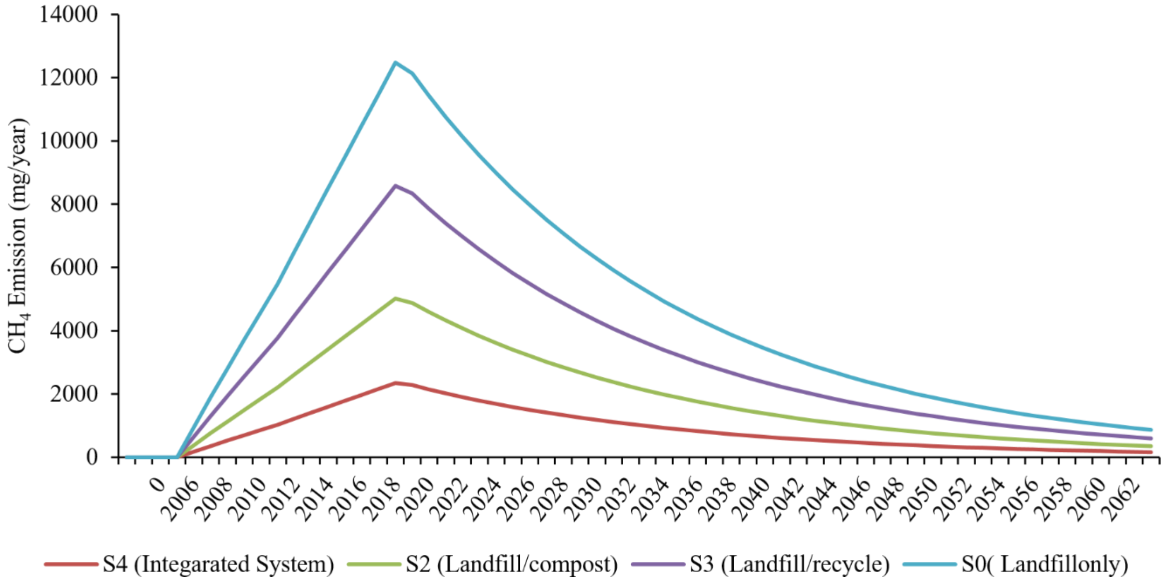

Figure 10: Methane emissions in Sisdole landfill site over time for scenarios

IV. CONCLUSION

This research was carried out to determine the Kathmandu Metropolitan City (KMC) solid waste management system which has the potential to achieve the greatest reduction in methane (CH_4) emissions based on the five suggested scenarios developed for the study: S0, S1, S2, S3, and S4, where is S0 is Business as usual and other are alternative scenarios tested to reduce CH4 emission. The scenarios were tested using the Life Cycle Assessment (LCA) tool alongside the default and first order decay methods as suggested by Intergovernmental Panel on Climate Change (IPCC), and methane emissions under different scenarios were compared.

The results showed that CH_4 emissions are extremely high at 15,136 thousand m^3 for scenario S0 - “Business as usual”. A significant reduction of 53% of CH_4 emissions is achieved with gas capture (S1). Composting (S2) achieves a reduction of 35% reflecting the high organic content of waste that is currently landfilled. Recycling (S3) only achieves a reduction of 10%. Unsurprisingly, the greatest reduction in CH_4 emissions occurs with a combination of gas capture, composting and recycling (S4) with a 73% reduction.

The NV Afvalzorg model simulations demonstrate that production of CH_4 starts from 2006 i.e., after one year from landfill being placed in 2005 at an increasing rate for each scenario, peaking in 2018 after 13 years. The measure of CH_4 outflows determined by the
NV Afvalzorg FOD model is far lower than the IPCC default model because only decomposable materials which produce CH_4 (organic waste, paper, textile, rubber, and leather) are considered in the latter model.

The average total volume of Municipal Solid Waste (MSW) generated in KMC between 2005 and 2018 was approximately 516 tonnes/day. This has been projected to increase by 9.6% per year creating many challenges in the management of solid waste in KMC. The unit rate of waste generation in KMC is 0.3 kg/person/day, with organic waste being the highest percentage (63%) in total waste.

Given the current composition of waste that is deposited at Sisdole landfill site, it is suggested that the feasibility of gas capture and composting is investigated as alternatives. Recycling material should also be considered long term as plastics and similar may in the future take up a greater proportion of the waste material over time.

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