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# Estimating Methane Gas Generation from Landfill Site - A Case Study of Sisdol Landfill Site, Nuwakot Nepal

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**Abstract**
Methane gas is one of the major greenhouse gases with global warming potential 28 times than Carbon Dioxide ($C0_2$). Landfills, which are common methods of municipal waste disposal, are one of the main sources of anthropogenic methane ($CH_4$) emissions. $CH_4$ not only is source of GHG but also a great source of alternative energy as it has a high potential for energy production and by using proper technology, large amounts of energy can be extracted from it. The aim of the study is to estimate the methane emission rate and total methane emission from the Sisdol landfill under different scenario and find out the possible reduction of methane in each scenario so that best alternative for the municipal waste management can be applied in future for sustainable municipal solid waste management in Kathmandu. One of the common mathematical models used for estimating the amount of methane potential and generation is LandGEM software due to its simplicity and precise, site based estimation of generation of methane, which was applied in this study to estimate the $CH_4$ emitted till date and emission in future from Sisdol landfill site for six different predictive scenarios: S0, S1, S2, S3, S4 and S5 which were developed based on people's perception and economical and technical feasibility and possibility of each scenario in the future. As a result, $CH_4$ in the site was estimated to be 2283.93 Mg/year in 2021 with total 25, 02,999.78 Mg waste disposed in place and 3678.43 Mg/year in 2030 under BAU. Based on the emission under different scenarios and the comparative study of each scenario, it maximum reduction in methane generation was found under integrated scenario (S5) and minimum was for recycling scenario (S4). Without any doubt, increase in emission was the result of worst case scenario. Hence, integrated scenario was concluded to be the best alternative for municipal waste management in Kathmandu. The result of the study could be used for the designing and planning of alternatives for waste management and also for assessing the feasibility of the gas capture system from landfills.

**Keywords**
Methane, municipal Solid Waste, Landfill, Sisdol, LandGEM model

## 1. Introduction

Climate change is the burning environmental issues in today's world and with no doubts it is more vulnerable to developing countries. Greenhouse gas emission have significant adverse effects on climate and catastrophic phenomena like global warming, ice melting, storms, forest fire floods and droughts [1].Methane is one of the major greenhouse gases responsible for global warming having global warming potential 28 times $CO_2$ [2].Methane is 2nd greenhouse gas which attribute to 18% of GHGs. Global anthropogenic methane emissions are projected to increase nearly 20 percent to 8,522 million metric tons of carbon dioxide equivalent (MMT$CO_2$e by 2030 [2]. According to statistics, the developing countries produced 29% of the GHGs in 2000 and is expected that the production shall reach 64% and 76% in 2030 and 2050 respectively [1].Also, with an ever increasing global and urbanized population the generation of waste is also remarkably increasing. Globally, the waste generation rate is expected to reach around 2.2 billion tons by 2025 [3]. Due to economic and technical restraints, recycling and recovery of all the waste is not possible as a result of which landfill stands out to be generic solution to municipal solid waste management [4]as it is low cost and technically feasible method. Landfills are one of the major sources of methane emissions. Besides methane generation, the unavoidable after effects of municipal waste disposal to the landfill are the leachate generation because of climatic condition, refuse properties, disintegration and landfill operations [5].

In most of the developed countries, landfills are designed in such a manner that maximum extractable energy is utilized to generate electricity and energy and transfer the captured methane through pipelines to generators and turbines [6]. The practice is great in terms of generating alternative energy from the landfills as methane has significant potential for producing energy with suitable applications of technology [7].

The present study was conducted to determine the solid waste generation, its composition in Kathmandu valley and calculate emission of GHGs mainly methane generation from the dumping site of the Kathmandu i.e. Sisdol landfill site from the year of start till date and estimate total emission of methane compounds over 15 years (from 2005 to 2021). Also, the study focused on the development of different potential alternative scenarios for the municipal solid waste management in order to reduce the emission sustainably. LandGEM model was employed to determine the emission rate and total emission till date and under different scenarios. The study is needed to know the generation of methane gas from the landfill site so that it can be further utilized as an alternative to LPG with certain inventories as unlike other GHGs, $CH_4$ can be converted to usable energy. Capturing and utilizing methane offers opportunities for the generation of new sources of clean energy and mitigation of climate change. The major objective of the research was to estimate the methane generation from Sisdol landfill site under different scenarios after evaluating the municipal solid waste generation and management methods in Kathmandu.

Figure 1 shows the conceptual frame work of the entire study. The total study is divided into 3 phases. In first phase, emission till date was calculated, then in 2nd phase, scenario development was done and emission calculation based on each scenario was performed and finally, in 3rd phase comparison of each scenario was done and best alternative was concluded.

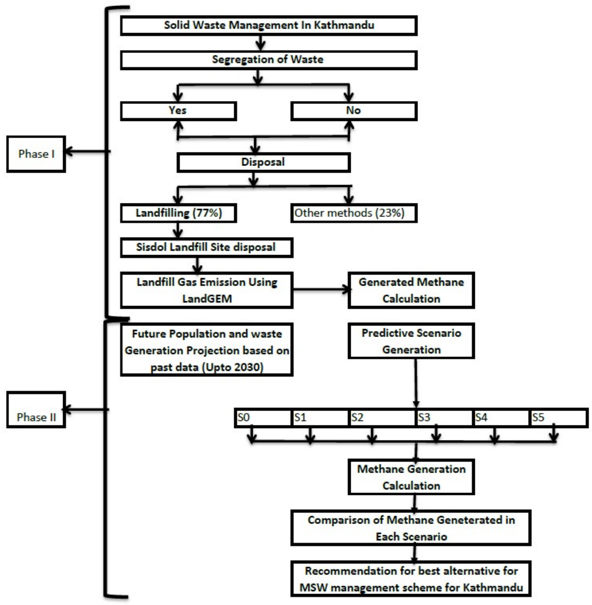


**Figure 1:** Conceptual Framework of the Study.

## 2. Literature Review

Landfill gas is obtained from a series of biochemical reactions under aerobic and anaerobic conditions on a biodegradable organic matter [8]. Such produced landfill gas contains majorly methane (50-60% by volume), carbon dioxide (30-40 % by volume), hydrogen, ammonia, nitrogen, hydrogen sulphide, oxygen and carbon monoxide [9, 10].Anaerobic degradation of the municipal waste in assistance of microorganisms in the landfills effectuates the emission of $CH_4$ and $CO_2$ in larger amount and other gases such as NOx and H2S in considerably lesser amounts [11]. Since, methane has high thermal value, it can be economically remarkable and valuable if can be utilized but in case of failure to collect this gas and its escape into the spaces in amounts of 5-15% of air volume can explode can cause severe damage [12].

Prediction and estimation of methane production in the landfill site is very necessary for designing and exploiting such places. As a matter of fact, the estimation of methane from the landfills contribute in determination of solid waste management sectors contribution in GHGs emission. Since, Nepal is responsible for only 0.027 % of global emission [13], emission from landfill is not matter to worry for now. But, the increasing trend of population growth and urbanization which is leading to increase in municipal solid was and unmanned disposal of waste to landfill site without any doubt is a matter of concern.

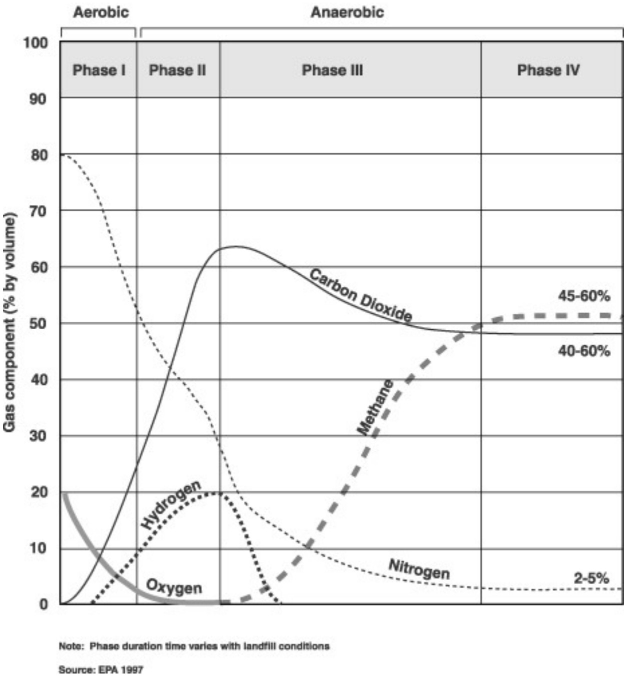


**Figure 2:** Phases of Landfill gas production (Source: [10])

According to [14], developing countries has potential to mitigate national emissions by about 5% and in long term up to 10% if strong coordinated and well managed waste administration is executed. But such execution is not easy job to do. Developing countries such as Nepal has ho face numerous challenges for obtaining proper waste management such as absence of national statistics on the solid waste activities which leads to obstacles in computing and large uncertainties in estimating GHGs emission from such activities. Also, there is difficulty in adopting different approaches due to economic and technical restrictions.

There are different methods to estimate the methane emissions from the landfills which includes site assessment, field-testing and mathematical modeling [15]. According to various latest research works, the emission rate of landfill gas per ton of MSW ranges from 120-300 $m^3$ [16, 17, 18, 19]. 5.9 Kw/h energy can be generated from each cubic meter of landfill gas emission which is equivalent to 66% of energy obtained from the same amount of natural gas [7]. Among several mathematical models used for estimation of methane emission, LandGEM model is one of the most flexible and convenient model which provides precise estimation of methane amount generated over several years [20, 21]. The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas, methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from municipal solid waste landfills [20].

Literatures revealed that several researchers have estimated the GHGs potential for different landfill sites using different models globally. [16], determined the total gas and methane emission from a landfill located in Hamedan (west of Iran) from 2011 to 2030 using LandGEM model [16]. The results showed that 4.371 X $10^8$ $m^3$ methane would be produced after 20 years, mostly (4.053 X $10^6$ $m^3$) in the first year. In addition, methane production capacity in Hamedan landfill site was 107 $m^3$/Mg [16]. Similarly, Farideh Atabi [19] calculated the methane and carbon dioxide emission in Kahrizak Landfill Site which had been a dumping site for daily solid waste of about 7000 ton/day for past 40 years with Land GEM Mathematical Model . According to the results of their study, the higher the value of k, the faster the methane generation rate increases and then decays over time. Also it shows, through gas-recovery and extracting energy from landfills with 75 percent efficiency, the generation rate of greenhouse gases was reduced significantly. [6] Estimated methane from Panki Open Dump Site of Kanpur, India using IPCC Default, FOD method and LandGEM model, version 3.02. The annual average $CH_4$ emission rates from Panki open dump site is found as 197.33, 24.27 and 25.14 Gg by IPCC Default method, FOD and LandGEM respectively for the period 2010-2030 and LandGEM provided the best result among the 3 models. **Kumar et al. (2004)** used default method and modified triangular method and found that total $CH_4$ generation is approximately the same by both the methods. LandGEM adopted by USEPA (2005) has been used to prepare prefeasibility report for Deonar. And Okhla landfill sites. [22] also used LandGEM model, to predict the amount and type of the landfill gases, produced for 30 years (from 2016 to 2045) in Jiroft which had population 120,746 per capita waste generation of Jiroft was 1.08 kg/day person, with results that showed in 2045, total about 3 million tons of waste will be disposed in municipal landfills of Jiroft and the total amount of produced gas, methane, carbon dioxide, and non-methane organic compounds will be 32, 994 ton/year, 8813ton/year, 24,181ton/year, and 378.8 tons/year, respectively.

## 3. Materials and Methods

### 3.1 Study Area

The Sisdol landfill site is located about 24 km northwest from Kathmandu on the northern bank of Kolpu River in Okharpauwa of Kakani Rural Municipality Ward 2 in Nuwakot district at an elevation of 1,150 masl. The VDC situated between 27° 46' north latitude and 85° 13' east longitude. The designed SLS (excluding the waste processing plant of 5 ha) covers a total area of 15 ha, out of which the actual landfill area covers 2 ha, site protection/ buffer zone covers 12 ha, and the rest 1 ha is covered by other facilities for waste management. During the design phase, SLS consisted of two valleys: Valley I with an area of 11,200 $m^2$ and a volume capacity of 166,085 $m^3$ and Valley II with an area of 9,501 $m^2$ and a volume capacity of 108,910 $m^3$. Sisdol landfill site was developed by SWMRMC by as a semi-aerobic landfill. A general schematic of the site and its location are presented in figure 3.

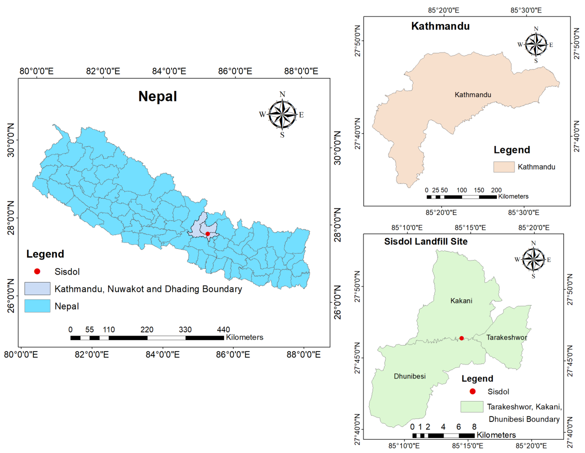


**Figure 3:** Location of Sisdol Landfill Site

### 3.2 Methods

This study is a descriptive cross sectional study in which software based on mathematical approach was used to estimate the methane generation at the Sisdol landfill site till date and in future under different predicative scenarios. This research area is selected purposely as Sisdol landfill site as it is the largest dumping site of Nepal. So, the purposive sampling method has been adopted for the research. This research includes limited geographical area and limited households involvement. Also questionnaire and inquiries are done to selected people such as some key person like manager of the area, staffs of KMC environmental department, social workers and local activists.

With this motive, firstly all the information regarding the Sisdol landfill was collected through different articles and by site visit and interviews with the stakeholders. Also, the demographic data such as population over different years and waste generated per capita were used for the prediction of population and total waste generation in the future. Based on the studies of different possibilities of solid waste management in Kathmandu valley, different scenarios were designed. The basis for the scenario generation was the study of perception of people towards segregation of waste, interest and possibility of composting of organic wastes and organizations involvement in it. Similarly, the study of effectiveness recycling and recovery of recyclable wastes and also the practicality and possibility of landfill gas recovery inventory at the landfill site. To achieve this, different stakeholders involved were interviewed. Review of work by the active private entrepreneurs involved in such as Doko Recylcers, Khalisisi.com, Praramva Boitech, Blue waste to Value were done to evaluate the posssibilty of composting and recycling.

### 3.3 Data Collection

Demographic and solid waste Data The population of Kathmandu city is increasing rapidly leading to increase in waste generation which demands special attention for sustainable municipal waste management. In last 15 years, the population of the Kathmandu city has grown from 7, 90,000 in 2005 to 14, and 24,000 in 2020. The growth rate of population is 3.4% in 2021 according to world population review. The waste generation growth trends shows the growth rate of about 1.3 %.

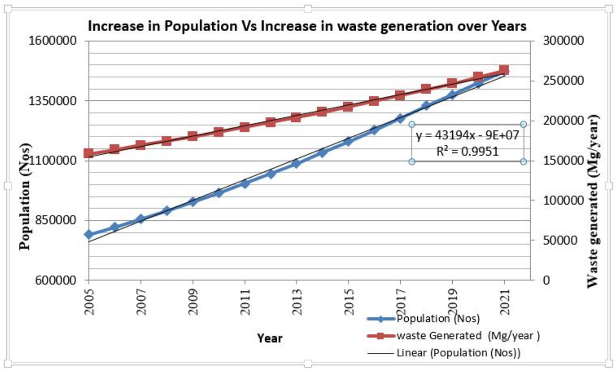


**Figure 4:** Waste generated per capita in Kathmandu

As illustrated in figure 4, there exists a strong linear relationship between waste generation and population in Kathmandu with the coefficient of regression R2=0.998.On the basis of trend of population growth and this regression, the population of Kathmandu is predicted to be 19,89,369 with total waste generation of about 3,48,879 tonnes.

## 3.4 Scenario generation

Figure 5 shows the average composition of waste generated in Kathmandu valley. It is clearly noticeable that an average 69% of municipal waste generated, is organic waste. 10.2% of waste is plastic waste, followed by paper waste which is 7.8%, 4% construction and demolition waste, next in row glass waste with 3.5%. 2.3% Textiles waste, 0.8% rubber waste, 0.7% Metal, 0.2% electronic waste and remaining 3% other wastes covers the entire municipal waste [23, 14].

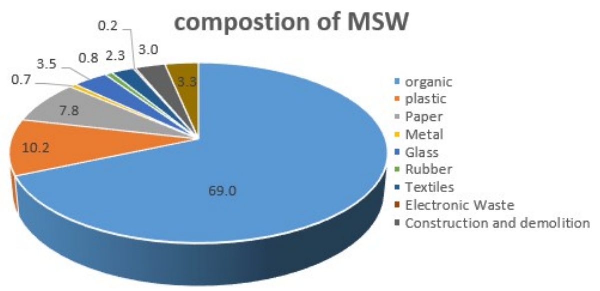


**Figure 5:** Average composition of Municipal Waste generated in Kathmandu over years

The six scenarios proposed in this research with system boundaries are illustrated in Table 1. The baseline scenario (S0) represents the existing MSW management system which is the current status of solid waste management where 77% of waste is landfilled in Sisdol and remaining 23% is managed by other ways such as composting and recycling [24]. All other the subsequent scenarios reflect alternative options, including composting and recycling, and also gas capture from the existing landfill site.S1 scenarios is the worst case scenario where all the waste generated shall be landfilled without any segregation of the waste, S2 scenario is same as S0 scenario but with upgrading of the landfill gas capture system where 50% of the generated gas shall be trapped for extraction of energy [25]. Similarly, S3 is the composting scenario where 50% of the generated organic waste shall be composted [24] and remaining 50%with other waste shall be sent to landfill. In the same way, S4 scenario is the recycling scenario in

**Table 1:** Different Scenarios for Municipal Waste Management of Kathmandu

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

which recyclable waste shall be separated and 50% of it shall be recycled and remaining shall be disposed to landfill. The most optimistic scenario is the S5 scenario which is integrated scenario in which 50% of organic waste shall be composted, 50% of the recyclable waste shall be recycled and remaining shall be sent to the landfill. Also, 50% of the generated methane shall be captured for energy generation.

## 3.5 Selection of model

For Sisdol site, due to lack of proper data, actual IPCC model and other models which require details cannot be used for estimation of methane emission. Therefore, a modified model has been used. The modified model the LandGEM 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 was composition can be taken into consideration. Furthermore, among the traditional models frequently referenced in different literature, the LandGEM has interesting advantages for our study as it has shown good agreement with field measurements and the possibility, though rough, to take into account the landfills location in a tropical area for different studies. For example, in studies conducted by Paraskaki and Lazaridis [and Chalvatzaki and Lazaridis, three different landfills gas emission models were used in Greece: the triangular model, the stoichiometric model and a first order model the Landfill Gas Emissions Model (LandGEM). After comparing the measurements in the field with the output of 3 models, the LandGEM presented the best results. Thus, based on various literature reviews and availabity of data LandGEM model has been selected for the study.

A constant value of methane emission rate and the potential of methane production under different scenario at Sisdol landfill was obtained based on climatic condition of the site and the composition of the waste generated under different scenario. The input data were inserted into the LandGEM software and the methane emission was calculated under each scenario over different years of the study. The emission reduction in compared to business as usual condition was evaluated for each scenario and the best alternative based on comparative analysis was suggested for further municipal waste management plan .

### 3.6 LandGEM data Analysis

LandGEM is based on a first-order decomposition rate equation which is used for quantifying emissions from the decomposition of landfilled waste in MSW landfills [19].The representative formula for the estimation of methane generation is presented in Equation 1 :

$$Q = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_{\mathrm{o}} \exp^{kt_{\mathrm{ij}}} \tag{1}$$

Where,
Q = annual methane generation in the year of the calculation ($m^3$ /year)
i = 1 year time increment
n = (year of the calculation) - (initial year of waste acceptance)
j = 0.1 year time increment
k = methane generation rate (year-1)
$L_o$ = potential methane generation capacity ($m^3$/Mg)
$M_i$ = mass of waste
$M_i$ accepted in the $i_th$ year (decimal years, e.g., 3.2 years) accepted in the $i_th$ year (Mg)
$t_{ij}$ = age of the $j_th$ section of waste mass

The basic condition to obtain modeling results that are as suited as possible to the actual production of gas is the right choice of assumption, with regard to the constants of the $CH_4$ generation potential (L0) and $CH_4$ generation rate (k) [26]. These parameters are strongly dependent on the chemical composition, properties of waste, and the condition of the process [19]. In order to calculate potential methane production capacity, IPCC methodology [12] was used and it was calculated using equation 2:

$$L_{\mathrm{o}} = DOC * DOC_{\mathrm{f}} * MCF * F * \frac{16}{12} \tag{2}$$

Where,
DOC = the organic carbon in waste that is accessible to biochemical decomposition.
$DOC_f$ = the fraction of DOC that can decompose.
MCF = the CH4 correction factor for aerobic decomposition.
F = CH4 volume concentration in the gas.
$\frac{16}{12}$is the molecular weight ratio of $CH_4$ and C

To calculate DOC equation 3 is used:

$$DOC_{\mathrm{i}} = OC_{\mathrm{i}} * Fb_{\mathrm{i}} * (1 - U_{\mathrm{i}}) * P_{\mathrm{i}} \tag{3}$$

Where,

**Table 2:** Characteristics of Municipal Waste

| Materials | OCi (kgC/Kg) | Ui (Kg H2O/Kg) | (Fb)i (kg biodeg.C/Kg) |
|---|---|---|---|
| organic | 0.48 | 0.6 | 0.8 |
| Paper | 0.44 | 0.08 | 0.5 |
| Textiles | 0.55 | 0.1 | 0.2 |

Based on potential for each scenario for Sisdol landfill was the characteristics of municipal waste, the organic carbon in the waste that can convert to LFG was calculated using data in table 2 and on the basis of composition of municipal waste under different scenarios. DOCf is temperature dependent (0.014T+0.28) and it is expected that temperature stays steady at 35°C in the anaerobic zone in the landfill and about 80% of the DOC would convert to LFG under this temperature, so DOCf is taken as 0.77. Similarly, MCF reflects the status of the landfill management of the site. Table 3 shows the MCF values for various landfill sites. Since, Sisdol Landfill is semi aerobic type with depth greater than 5 m, MCF value used is 0.5. F gives fraction of methane in LFG and the value was assumed to be 0.6.

Based on these values, the methane generation calculated as shown in Table 4. According to [21],the L0 value depends almost exclusively on the waste

**Table 3:** MCF value for Different landfill condition

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

composition and it is a function of the organic content of the waste. The higher the organic content of the waste, the higher the L0. The value of L0 varies across different landfills and is site specific and ranges from 6-270 $m^3$/Mg as specified by US EPA.

**Table 4:** Methane generation potential under different Scenarios

| Scenarios | L0 ( $m^3$/Mg) | DOC | DOCf | MCF | F |
|---|---|---|---|---|---|
| S0 | 42.68 | 138.57 | 0.77 | 0.5 | 0.6 |
| S1 | 42.68 | 138.57 | 0.77 | 0.5 | 0.6 |
| S2 | 42.68 | 138.57 | 0.77 | 0.5 | 0.6 |
| S3 | 21.35 | 69.33 | 0.77 | 0.5 | 0.6 |
| S4 | 42.67 | 138.53 | 0.77 | 0.5 | 0.6 |
| S5 | 21.33 | 69.28 | 0.77 | 0.5 | 0.6 |

Similarly, methane generation rate is calculated using following equation:

$$K = (3.2x10^-5xannualprecipitationinmm + 0.01 \quad (4)$$

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

Figure 6 illustrates the overall methods and steps followed during entire study from start to its end.

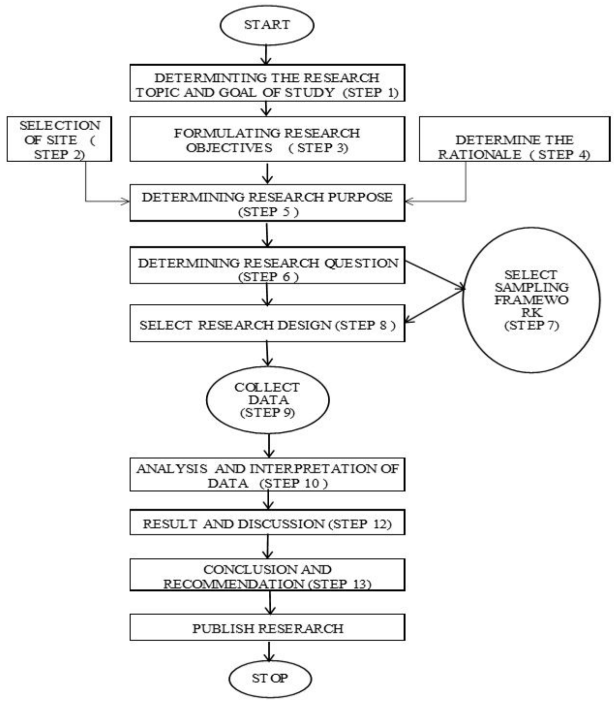


**Figure 6:** Overall methodological Framework of the study

## 4. Results and Discussion

Firstly, the methane emission till date was calculated based on the present condition and status of the landfill site and average waste composition of the disposed waste to the landfill site. At present 77% of the generated waste is landfilled with about 69% of organic waste in it [24]. Based, on this data, the analysis was done in LandGEM software to obtain the emission by the end of 2021. Table 5 shows the result of the disposed solid waste quantity in Sisdol landfill during last 16 years since the opening of the site. The amount of disposed municipal waste was approximately estimated 122,228.645 Mg in 2005 which increased to 196,050.727 Mg in 2020. According to Table 5, total quantity of disposed waste is estimated to be 2,502,990.783 Mg by the end of 2021.It shows the rapid growth in municipal waste generation in the area. Methane emission by the end of 2021 in the site closes till then is estimated based on LandGEM using the modified parameters according to the site condition and waste composition.

**Table 5:** Waste disposed to Sisdol landfill over years

| Year | Waste Accepted (Mg/year) | Waste-In-Place (Mg) |
|---|---|---|
| 2005 | 122229 | - |
| 2006 | 126140 | 122229 |
| 2007 | 130176 | 248369 |
| 2008 | 134342 | 378545 |
| 2009 | 138641 | 512887 |
| 2010 | 143078 | 651528 |
| 2011 | 147656 | 794606 |
| 2012 | 152381 | 942262 |
| 2013 | 157257 | 1094643 |
| 2014 | 162289 | 1251900 |
| 2015 | 167483 | 1414189 |
| 2016 | 172842 | 1581672 |
| 2017 | 178373 | 1754514 |
| 2018 | 184081 | 1932887 |
| 2019 | 189972 | 2116968 |
| 2020 | 196051 | 2306940 |
| 2021 | 202324 | 2502991 |

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

**Table 6:** Landfill Gas and Methane Production for Sisdol Landfill over Year

| Year | Landfill Gas (Mg/Year) | Methane (Mg/Year) |
|---|---|---|
| 2005 | - | - |
| 2006 | 482.44 | 146.8 |
| 2007 | 960.01 | 292.11 |
| 2008 | 1,433.42 | 436.16 |
| 2009 | 1,903.34 | 579.14 |
| 2010 | 2,370.45 | 721.28 |
| 2011 | 2,835.41 | 862.75 |
| 2012 | 3,298.88 | 1,003.77 |
| 2013 | 3,761.48 | 1,144.54 |
| 2014 | 4,223.87 | 1,285.23 |
| 2015 | 4,686.65 | 1,426.04 |
| 2016 | 5,150.45 | 1,567.17 |
| 2017 | 5,615.89 | 1,708.79 |
| 2018 | 6,083.57 | 1,851.09 |
| 2019 | 6,554.09 | 1,994.26 |
| 2020 | 7,028.07 | 2,138.48 |
| 2021 | 7,506.08 | 2,283.93 |

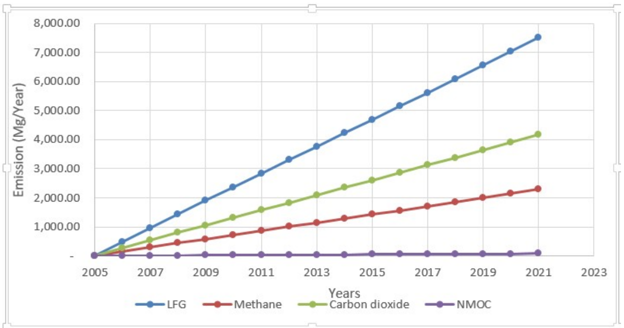


**Figure 7:** Emission of different LFGs till 2021

Figure 7 shows the emission of different LFG till 2021. It indicates the increasing trend of different LFGs and shows the production of methane by the end of 2021 shall be 2283.93 Mg.

Figure 8 indicates the production of LFG occurs from 2006 at an increasing rate, peaking in 2022 with the emission of methane 2,431 Mg/year followed by a decrease rate throughout in the landfill closes in 2021. The most reasonable time to capture methane is from 2006 to 2037.

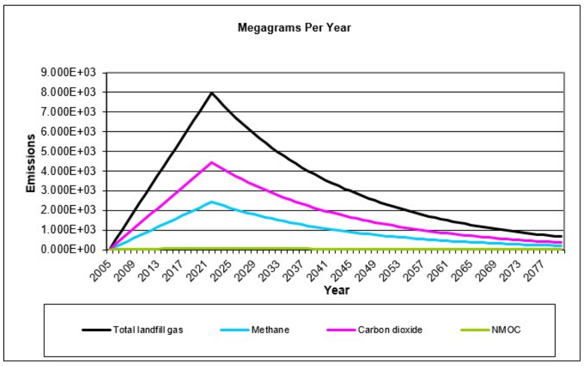


**Figure 8:** Emission of LFGs for Sisdol landfill over Years

United Nations Development Program (UNDP) suggested the waste generation per capita for the citizens of developing countries are between 500 and 900 grams daily [20]. In current study, the amounts of waste generation per capita for the Kathmandu was found around 360 gram, which is lower than the UNPD range. [9] Found that population and total MSW are directly correlated. [5] in Yasuj landfill showed emission of 29.02 Mg methane in 1992 and 1610 Mg methane in 2010 with total disposal of waste being 5756 Mg and 42,973 Mg respectively. According to [17] The methane ($CH_4$) and carbon dioxide ($CO_2$) emitted from the Thohoyandou Landfill estimated from LandGEM will peak in the year 2026 at 3517 Mg/year and 9649 Mg/year, respectively. The LandGEM model showed that total LFG, $CH_4$ and $CO_2$ emitted from the landfill between 2005 and 2040 (Mg/year) are 293,239, 78,325 and 214,908, respectively.
Similarly, according to [6] annual average $CH_4$ emission rates from Panki open dump site was found as 25,140 Mg by LandGEM for the period 2010-2030 with 1500 Mg/day disposal of waste to the site. The generation under BAU scenario for Sisdol landfill in 2030 is 3,678.53 Mg with average disposal of 1200 Mg/day to the landfill site. Comparing the results of other research with the result of this study, the amount of generation of methane was found to be higher may be because of higher the amount of waste generated per capita in Kathmandu, amount of moisture in the waste sample, higher proportion of organic waste present in the waste disposed to the landfill site and climatic condition of the site.

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


**Figure 9:** Total waste accumulated at Sisdol landfill by 2030 under different Scenarios

As seen in figure 9, Largest amount of waste shall be accumulated under worst case i.e. S1 scenario with total 51, 33,806.36 Mg waste in place in 2030 and it would be least under S3 i.e. composting scenario with total 39, 33,023.09 Mg waste in place in 2030.

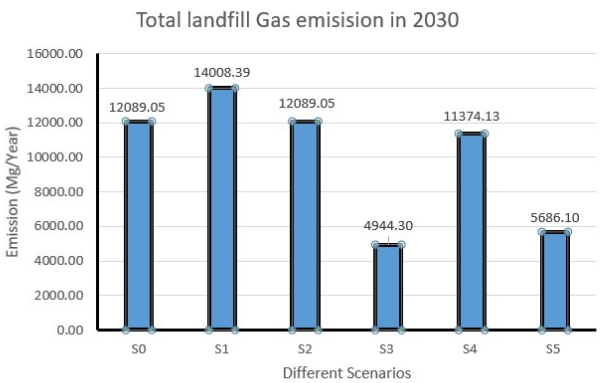


**Figure 10:** Total landfill gas emission in Sisdol

The total landfill gas emission under S1 scenario is predicted to be 14,008.39 Mg/year and 4,944.30 Mg/year in S3 Scenario in the year 2030 as seen in figure 10. According to this, it can be which supports composting of organic waste as better approach for landfill gas emission reduction from landfills.

As illustrated by figure 11, the total emission of landfill gases are maximum for S1 scenario and minimum for S3 scenario. S4 scenario does not show significant variation from BAU S0 scenario. This shows a great dependency of the landfill gas generation upon the proportion of organic waste present in the total amount of disposed waste to the landfill.

The amount of methane generated for BAU scenario

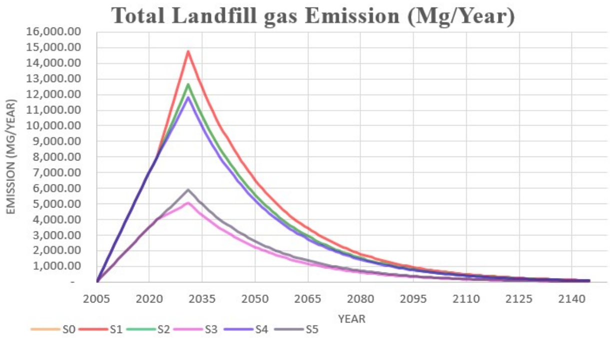


**Figure 11:** Total Landfill gas emission for sisdol landfill under different scenarios

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

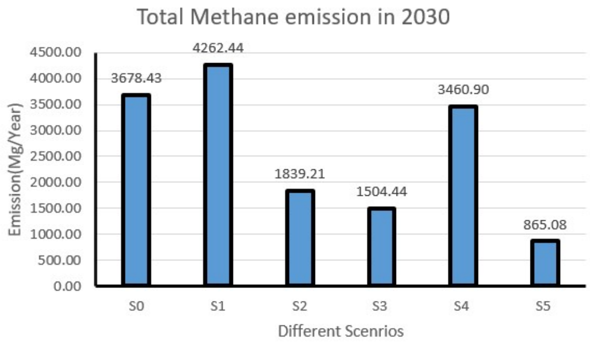


**Figure 12:** Total emission of methane in year 2030 under different Scenarios

Figure 13 shows the trend of methane gas emission in different years of the project at the waste disposal Sisdol site under different predictive scenarios. The results showed that the amount of annual production of methane is maximum for S1 scenario. Significant reduction in atmospheric methane emission was seen under landfill gas capture S2 scenario as 50% of the generated gas was supposed to be captured by the gas capture inventories. Also, least emission was seen under integrated S5 scenario. Best yield period for capture of methane could be 2025 to 2055. S4 scenario d not show must effectiveness in reduction of emission.

Table 7 shows the reduction in emission under different scenarios. The pessimistic S1 scenario predicted an increased emission of 4,262.44 Mg with an increase of 15.88 %. for the same event, the gas capture scenario i.e. S2 gave the emission as 1,839.21

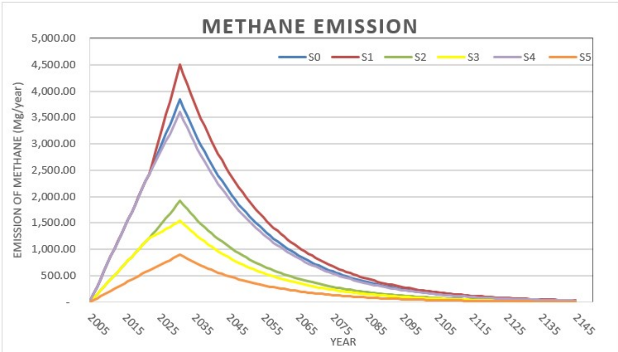


**Figure 13:** Methane emission under different scenario for Sisdol landfill

Mg and S3 scenario predicted it to be 1,504.44 Mg with decrease of reduction about 50% and 59.10% respectively. The least effective option i.e. recycling, S4 predicted emission of 3,460.90 Mg with reduction of only 5.91% whereas the best option i.e. integrated approach assumed it to be 865.08 Mg/year with reduction in emission of methane by 76.48% in 2030.

**Table 7:** Reduction of Emission in various Scenarios in year 2030

| Scenarios | Total waste disposed (Mg) | $CH_4$ emission (Mg) | Reduction |
|---|---|---|---|
| **S0** | 4,575,253 | 3,678 | |
| **S1** | 5,133,806 | 4,262 | 15.88 |
| **S2** | 4,575,253 | 1,839 | -50 |
| **S3** | 3,933,023 | 1,504 | -59.1 |
| **S4** | 4,368,158 | 3,461 | -5.91 |
| **S5** | 4,368,158 | 865 | -76.48 |

## 5. Conclusions

The study was carried out to estimate the methane emission from the Sisdol landfill and also to determine the alternative scenarios for solid waste management system which has the potential to achieve the greatest reduction in methane emission. LandGEM model was used for the estimation of methane over years after the modification in its default parameters such as methane generation potential (L0) and methane generation rate (K) according to the composition of waste disposed to the site and the climatic condition of the site.

The LandGEM model simulations demonstrated the production of LFGs and methane from 2006 i.e. after 1 year of start of disposal of waste to the landfill site and at an increasing rate at business as usual condition till 2021. Alternative scenarios were proposed from year 2022 till 2030.Reduction in $CH_4$ emission of S1, S2, S3, S4 and S5 alternative scenarios were tested against Business as usual S0 scenario.

The results showed that highest production of waste in S1 scenario with increase in emission by 15.88% and unsurprisingly, least production of methane in S5 scenario with reduction in emission by 76.48%, while most of the wastes are perishable organic materials. Recycling of waste was least effective in reduction of the methane emission. High Potential years for trapping of methane gas from the landfill site was found to be between 2025 to 2045. If the segregation of organic waste is done by 50% ,with reduction of half of recyclable waste before dumping to the site, the emission of landfill gases would reduce drastically. Moreover, when generated methane gas trapped by using certain inventories, the emission of methane to the atmosphere would reduce to 1/4th compared to BAU.

## 6. Recommendations

Based on the results and conclusion of the study, it is suggested that on one hand, feasibility of collection of methane from the Sisdol landfill site should be given priority and investigated properly as energy production from it has high potential. On the other hand, segregation of waste at generation point should be emphasized and organic waste should be separated for composting which can reduce about 70% the waste disposal to the landfills and hence reduce of the emission of the methane from the landfill. Though, recycling alone did not seem much effective in reduction of $CH_4$ reduction, it should be considered in long term.

The results of the study can be utilized by the environmentalist to evaluate the contribution of the landfill site to GHG emission. It would also be useful for the policy maker to formulate and implement the best scenario for MSW management.

Also, further research could be conducted considering seasonal variation in generation of waste, Seasonal Variation in the emission. Also, if the GHG emission by the transportation sector during transport of the waste from collection to the landfill site is considered, the emission scenario may change.

## 7. Limitations

- The study was limited to only the area of landfill site that is Sisdol.

- The waste that are disposed to Sisdol landfill site are mostly unsegregated so the parameters for LandGEM model was determined based on avaiable data so cannot be generalized for other sites.
- The amount of GHG emitted during transportation of the waste to the landfill site is not taken into consideration

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