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Quantification of Methane Emissions Rate Using Landgem Model and Estimating the Hydrogen Production Potential from Municipal Solid Waste Landfill Site

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ABSTRACT

In India, solid waste is deposited mostly in uncontrolled open landfills without proper segregation and handling methods. Organic wastes dumped in a landfill undergo anaerobic decomposition and emit landfill gases like methane and carbon dioxide. Landfill gases are a significant contributor to greenhouse gases and greatly impact climate change. In the interim, reducing gas emissions and controlling and recycling such gasses is important from environmental hygienic, and global perspectives. Landfill gas has tremendous potential to convert as a source of alternative fuel. The present study estimates the CH_4 (Methane) and CO_2 (Carbon dioxide) emissions and quantifies the renewable energy available and hydrogen production potential using the LandGEM 3.02 empirical models for the Kanuru, Vijayawada landfill. It was observed that methane emission peaked in 2042 with an emission rate according to the model was 2.51E+08 Metric tons CO_2 equivalents. The gas-recovery system is an essential component in landfills for extracting energy with 75-80% efficiency; the generation rate of greenhouse gases will reduce to around 1.78E06 Mg of CO_2 eq. The predicted methane emissions vary from 1.33E6-9.22E6 cu.m per year for the period of 2010-2042. It was also estimated that annual energy production from LFG emissions was from 1.8-130 GWh per year, and hydrogen production potential was 0.6-43.3 Gg per year. The study concludes that projected scientific data will assist policymakers in creating sustainable MSW management by bridging the gap between sustainable renewable energy production and protecting the environment. The basic objectives of the study include the quantification of landfill gas production using the LandGEM model for Vijayawada, assessing the electricity generation potential of the landfill methane gas emitted, methane and carbon dioxide recovery from landfills with energy conversion could reduce GHG emissions, and estimation of hydrogen generation potential from the landfill methane emissions.

INTRODUCTION

The generation of solid and liquid waste was an unavoidable part of communal and industrial activities. Currently, waste produced is extremely complex in composition, containing a wide range of chemical, physical, biological, and recalcitrant elements. Household municipal solid wastes are classified into hazardous and non-hazardous waste based on their reactivity, chemical compositions, and the potential to affect human and environmental health (Inglezakis & Moustakas 2015, Fazzo et al. 2017, Liu et al. 2021). In developing countries, solid waste disposal is a prevalent challenge for governmental and private agencies compared to liquid waste treatment and disposal (Ramprasad & Rangabhashiyam 2021). In India, rapid urbanization and uncontrolled population growth are the two main reasons for acute solid waste management problems. It is foreseen by researchers that; India's population will reach an ever-time high of 1,823 million by 2051 and generate nearly 300 million tons of municipal solid waste (MSW) per annum. The total land required to dispose of the generated MSW unsystematically is projected to be 1450 sq. km if the Government of India continues to rely only on landfill disposal as the better alternative for MSW management (Joshi & Ahmed 2016, Malav et al. 2020). The common scenario in Indian disposal sites is illegal or wild disposal of rubbish generated from domestic, small-scale industries and other places into open ground, low-lying regions near water bodies or over the sea. The researchers have identified that, In India, the practice of segregating domestic waste and treatment was very little to not practiced, leading to the mixing of biodegradable, recyclable, plastic waste, hazardous e-waste, commercial wastes, and inerts (Leray et al. 2016, Joshi & Ahmed 2016) leading to many environmental and health issues.

Solid waste management is a collective incidence of public health, aesthetics, economic principles, technological advances, ecological conservation, and other environmental aspects. Waste management includes the financial, legal, planning, and technical managerial functions related to the full scope of solving the solid waste moving from the inhabitants to the disposal area (Bui et al. 2020). Apart from domestic solid waste generation, industries generate solid waste from technological and consumptive processes in sequential advancement processes as the raw material into a product. In the Indian metropolitan region, the processes of product manufacturing result in the development of solid waste due to changes in the lifestyle of people, technological advancement, and rapid economic growth. In addition, various operations within the metropolitan regions also produce solid waste, such as street/park cleaning, wastewater treatment, air pollution control measures, and other solid waste output systems (Marshall & Farahbakhsh 2013). The principles of Integrated Solid Waste Management (ISWM) is an appropriate strategy and requires an hour for Indian conditions to manage municipal solid waste. The ISWM is assimilating solid waste segregation, transportation, engaging various technologies for treatment, and management programs to address all forms of solid wastes from various sources to achieve the twin goals of (a) waste reduction and (b) effective waste management after waste reduction (Singh et al. 2020, Prajapati et al. 2021).

India is presently facing a severe problem in the management of solid waste. They are dumped openly throughout the country due to a wrong belief that it's the cheapest and the easiest disposal method. The wastes dumped openly will be more dangerous, naïve, and unavoidable pollutants in the waste will contaminate the girding natural terrain. Then they find their way to humans to affect the quality of life, health, and working conditioning. Therefore, in the ultimate run, society has to pay dearly for open jilting (Krishna et al. 2020, Khatri et al. 2021). The open dumping and burning of unscientifically managed MSW will lead to many environmental hazards like air pollution (greenhouse gaseous and particulate matter emissions), leachate generation (lead to groundwater contamination), and soil and land quality degradation due to chemical and biological activities from wastes (Cremiato et al. 2018). The major greenhouse gases (GHG) emitted from landfills are carbon dioxide, methane, nitrous oxide, water vapor, chlorofluorocarbon gases, and ozone. The MSW will attract useful and harmful bacteria, viruses, and other pathogens due to the nature of solid wastes (Fan et al. 2018) and can result in serious illnesses for living beings nearer to the site and affect wide surrounding areas (Ijaz et al. 2020). Solid waste dumpsites are the third largest source of anthropogenic methane (CH_4) emissions after fossil fuel burning and fermentation and are more potent in CO_2 emissions causing global warming (Singh et al. 2018, Chandrasekaran & Busetty 2022).

Landfill gas is a natural consequence of organic waste degradation in landfills. It highly depends on the degradable organic fraction (DOC) of wastes, waste composition, rate of degradable organics, and environmental factors like pH and temperature (Tan et al. 2014, Chalvatzaki et al. 2015, Hosseini et al. 2018). Landfill gas is made up of around 50% methane (natural gas's major component), 40% carbon dioxide (CO_2), and a minor quantity of non-methane chemical molecules. According to the current research, methane is 28 to 36 times more powerful than CO_2, which traps heat for over 100 years in the atmosphere (Ahmed et al. 2015, Bruce et al. 2017, Randazzo et al. 2020). Landfill gas, especially methane, can be trapped, processed, and used as a renewable hydrogen energy resource instead of escaping into the air (Ansari & Daigavane 2021). The landfill gas can be recovered, which reduces odors and other risks connected with their emissions, as well as the methane migration into the atmosphere, which produces local smog and climatic changes. Hydrogen production from methane is a proven and novel technology, an emerging method to use as an alternative fuel or sustainable energy.

Landfills are the non-point source emissions of methane and have high spatial variability leading to difficulty in the measurements. It is essential to estimate the landfill gas emissions to reduce GHG and meet the sustainability development goals (SDGs) (Chalvatzaki et al. 2015). Landfill gas emissions can be estimated using a few modeling approaches such as Zeroth – order kinetics model (Zheng et al. 2017), German-European Pollutant Emission Register (EPER) model, TNO model, Belgium model (Thompson et al. 2009), First order model, Landfill Gas Emission Model (LandGEM) (Sil et al. 2014, Hosseini et al. 2018, Fallahizadeh et al. 2019, Chandrasekaran & Busetty 2022), Second order generation models, Solid Waste Emission Estimation tool (SWEET), and Scholl Canyon model (Srivastava & Chakma 2020, Alexander Stege et al. 2022, Lu et al. 2022). The researchers have identified that the Belgium model, LandGEM, and Scholl Canyon provided the best result amongst the available models correlating well with field conditions. However, from the above 3 models, there are a few cons, such as lack of landfill gaseous pollutant emissions inventory, complexity in usage, small footprint, topographical features, uncertainty in available data, and economical point of view. Henceforth, the LandGEM model of the three is considered the simplest and insensitive to uncertainties in some design parameters to estimate LFG (Hosseini et al. 2018).

Furthermore, the estimation of Landfill gas and its potential for hydrogen production or power generation over the Vijayawada dumpsite was not studied. Therefore, the present study aimed to determine the landfill gases such as methane and carbon dioxide emissions rates from the Kanuru dump yard, Vijayawada, Andhra Pradesh, India. Additionally, the hydrogen production and power generation potential are also estimated.

MATERIALS AND METHODS

Site Selection

The study was conducted in Vijayawada, considered the second largest city of Andhra Pradesh, with a geographical area of 61.88 sq. km. The city geographically lies in the center of Andhra Pradesh on the banks of River Krishna, within the newly formed NTR district, and also acts as the administrative headquarters of the NTR district. According to Census 2011, it is the second largest populated city in Andhra Pradesh, with a population of nearly 10.34 Lakhs with an annual growth rate of 3.05%. The GPS coordinates for the city are 16.30° N and 80.37° E, and the surface elevation is 11m (36ft) above the mean sea level. The solid waste from the 3 divisions, namely Nandigama, Tiruvuru, and Vijayawada, was transported and dumped into one of the open landfill sites located at Kanuru. The GPS coordinates for the Kanuru dump site are 16°30'08.0" N and 80°41'35.3" E, which is more than 5km from the main city (Fig. 1). The climatic pattern is tropical wet and dry conditions, with an average annual temperature of 28.5°C and the average annual rainfall was 1066.8 mm.

Data Collection

The data on waste generation, waste composition, per capita waste generation, the dumpsite inception year, and the design life of the dump site were obtained from the Municipal Commissioner's office, Vijayawada. The quantity of municipal solid waste generated during the year 2014-15 from the 64 municipal wards is 550 metric tons per day, of which 265 metric tons are wet, and 285 metric tons are dry. The per capita waste generation was in the range of 0.532 – 0.688 kg and is projected to increase to nearly 0.75 kg per capita per day by 2050. The governmental study report states that the average biodegradable portions like fruit, vegetables, and food wastes in the MSW collected were 55%, combustible or recyclable materials such as paper, plastics, and rubber are 35%, and inert's like glasses, sand, and silt were 10% (Unnikrishnan & Singh 2010, Niloufer & Swamy 2015). The design life of the studied landfill was estimated to be 30 years, and wastes were dumped and uniformly

Fig. 1: The photographic view of Kanuru landfill site, Vijayawada.

Table 1: The average yearly solid waste accepted and in place at the Kanuru dump site.

Year	Waste Acceptance [$t.y^{-1}$]	Waste In-place [Tons]
2010 (Inception Year)	0	0
2011	1,76,114	1,76,114
2012	1,81,397	3,57,511
2013	1,86,839	5,44,350
2014	1,92,444	7,36,794
2015	1,99,180	9,35,974
2016	2,04,660	11,40,634
2017	2,11,823	13,52,457
2018	2,19,237	15,71,694
2019	2,26,911	17,98,605
2020	2,30,794	20,29,399

Table 2: Physico-chemical characterization of solid waste from the Kanuru dump site.

S. No	Parameters	Unit	Value
1.	pH	No Unit	6.2-8.0
2.	Moisture Content	%	27.44-51.92
3.	C/ N ratio	No Unit	30-43
4.	Total Organic Carbon	%	10.64-12.03
5.	Ash Content	%	30.17-47.74
6.	Calorific Value	kcal per kg	2016-3216

rolled for compaction. The yearly solid waste generated and accepted in the dump site is tabulated in Table 1. The secondary data on the physico-chemical characterization of the MSW collected from Vijayawada is shown in Table 2. The secondary data on the solid waste characterization was obtained from Niloufer & Swamy 2015 and found that pH was 6.2 to 8.0, the carbon to nitrogen ratio was 30-43, and the calorific value was 2016-3216 Kcal per kg.

LandGEM Model Equation

LandGEM is one of the automated tools to estimate the LFG gases like carbon dioxide, methane, non-methane organic compounds (NMOCs), etc., and their emission rate from the open and uncontrolled MSW landfills. These data, such as yearly waste acceptance, as shown in Table 1, have been entered in the LandGEM model Excel sheet, and the emission rate is determined by considering the equations' default values. The software can enter the site-specific data (if available) for a better estimation rate of LFG gases. The United States Environmental Protection Agencies (USEPA) specialists have developed and made the software universally friendly. The LandGEM model equation is as follows,

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} K L_0 \left(\frac{M_i}{10}\right) e^{-kt_{ij}} \quad \ldots(1)$$

Q_{CH4} = annual CH_4 generation in the calculation yr (cu.m per year)

i = 1year time increment

M_i = In i^{th} year waste mass accepted (Mg)

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

t_{ij} = In the i^{th} year age of the j^{th} section of waste mass M_i accepted

j = 0.1-year time increment

k = CH_4 generation rate (per year) considered as 0.05

L_0 = potential CH_4 generation capacity (cu.m per Mg) considered as 170

Recovery of Methane and Hydrogen Estimates

Modern-day landfills need to adopt an engineered way of disposing of solid waste. The ISWM approach states that the vital component in landfills is an engineered mode of solid waste disposal. The generated solid wastes are dumped in sequences and compacted, with provisions for recovering the landfill gases. The landfill gases can be recovered to 60-85%, depending on the collection system adopted, the landfill cover material used, and the lifetime year of waste (Ansari & Daigavane 2021). The recovered methane can be converted into hydrogen gas, and thereby, electricity can be produced using the following schematic diagram. The steam reforming reaction and the shift reaction for the conversion of methane to hydrogen are also provided in Fig. 2. The clay liner cum cover has the highest recovery of methane than the other natural soils used. The recovery of methane from the landfill gases available for reforming to hydrogen is assumed to be 67%.

The electrical energy generation potential (Ep in kWh per year) from the methane emissions from the Vijayawada Kanuru landfills is estimated by the following equation (Ayodele et al. 2017, Cyril et al. 2018, Rodrigue et al. 2018),

$$E_p = \frac{0.9 \times Q_{CH4} \times LHV_{CH4} \times \eta \times \lambda}{3.6} \quad \ldots(2)$$

Where Q_{CH4} is the amount of methane gas emitted in cu.m per year

LHV_{CH4} is the Lower Heating Value of methane and is taken as 37.2 MJ per cu.m

η is the electrical conversion efficiency and taken as 33%

λ is the collection efficiency of methane taken as 75%

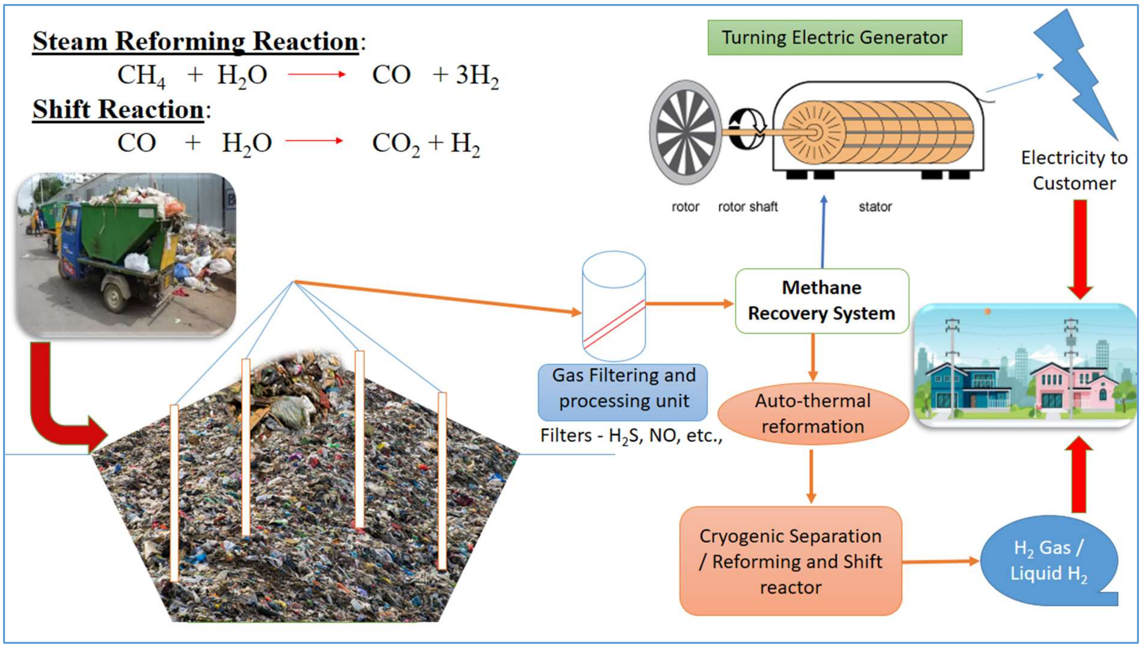

Fig. 2: Schematic representation of methane recovery and processing to obtain hydrogen.

RESULTS AND DISCUSSION

Waste Prediction and Disposal

The waste generation from the city of Vijayawada from 2011 to 2020 was tabulated in Table 1. The average per capita waste generation was 500-690 grams. The prediction for the years 2021 to 2041 was done based on the population growth rate and subsequently based on their per capita waste generation. Table 3 shows the geometrical mean projected population, the subsequent per capita waste generation rate, and waste produced and disposed of annually. The trend of population growth rate during the year 2011-2020 was in the range of 1.03% annually. Hence, the projection of the population for the year 2021-2041 was predicted, assuming an incremental increase for every 7 years with a three-stage growth rate of 1.04%, 1.1%, and 1.35%. The current projected population for the city of Vijayawada was in line with the already published survey report by International Urban Cooperation, European Union, 2021. The per capita waste generation also followed a three-stage growth; the per capita generation rate was 0.569 kg, 0.622 kg, and 0.808 kg. Additionally, the waste produced and disposed into the landfill at a constant collection efficiency of 85% was tabulated in tons per year and tons, respectively. The projected data was in concurrence with Niloufer & Swamy (2015), Pinupolu & Raja Kommineneni (2020) for the Vijayawada landfill site.

The authors Pinupolu & Raja Kommineneni (2020) concluded that the population projection using the geometric method for the year 2031 was 18.9 lakhs, the per capita waste generation rate was 0.66, and the total solid waste generation was 1258 tons per day. The present study results were in concurrence with the published data with less than 5% error. The authors also conclude that the land required and the cost for the disposal of the generated municipal solid waste will be 4800 sq. m and 3.20 crores, respectively. The same trend of disposing into landfills will lead to the degradation of land, soil, air, and the surrounding ecosystem. In the Kanuru landfill site, it's essential to analysis for an alternative approach to handle municipal solid waste due to the lack of land space availability. To achieve sustainability and have a circular economical approach, the cities/ municipalities/corporation should adopt Integrated Solid Waste Management (ISWM) approach (Iqbal et al. 2019, Mukherjee et al. 2020, Ramprasad & Rangabhashiyam 2021).

The ISWM approach uses various sequential techniques. It starts with door-to-door waste collection, segregation, transport of waste, treatment, and disposal (Ramprasad et al. 2019, Prajapati et al. 2021). In the treatment step, the organic fraction can be composted or anaerobically digested, whereas the recyclables, like paper, plastic, etc., can be combusted or co-processed. In this process, many valuables like compost from composting process, methane from the Bio-methanation, bio-char from the combustion process, and heat/energy/biofuel from the incineration process are obtained (Azeta et al. 2021, Harisankar et al. 2021). Whereas,

Table 3: Projected population, waste generation, and disposal for Kanuru landfill site.

Year	Projected population	Per capita waste generation [kg/ capita/ day]	Waste produced [t.y^{-1}]	Waste disposed of @85% collection efficiency [Tons]
2021	13,96,853	0.569	3,19,696	2,71,742
2022	14,52,727	0.569	3,32,484	2,82,611
2023	15,10,836	0.569	3,45,783	2,93,916
2024	15,71,270	0.569	3,59,615	3,05,673
2025	16,34,120	0.569	3,73,999	3,17,899
2026	16,99,485	0.569	3,88,959	3,30,615
2027	17,67,465	0.569	4,04,518	3,43,840
2028	18,38,163	0.569	4,20,698	3,57,594
2029	19,11,690	0.569	4,37,526	3,71,897
2030	19,88,157	0.569	4,55,027	3,86,773
2031	21,86,973	0.622	5,47,152	4,65,080
2032	24,05,670	0.622	6,01,868	5,11,587
2033	26,46,237	0.622	6,62,054	5,62,746
2034	29,10,861	0.622	7,28,260	6,19,021
2035	32,01,947	0.622	8,01,086	6,80,923
2036	35,22,142	0.622	8,81,194	7,49,015
2037	38,74,356	0.622	9,69,314	8,23,917
2038	42,61,792	0.622	10,66,245	9,06,308
2039	46,87,971	0.808	12,97,322	11,02,724
2040	63,28,761	0.808	17,51,385	14,88,677
2041	85,43,827	0.808	23,64,370	20,09,714

in the disposal step, the quantity of waste and the surface area for disposal will substantially get reduced. Hence, the Kannur landfill by the year 2041 needs to dispose of/ manage 20 Lakh tons of solid waste in a year in the open land if the scenario continues. Many of the developed and developing countries have practiced the ISWM approach and have succeeded, like Jaipur in India (Prajapati et al. 2021), USA (Mukherjee et al. 2020), Malaysia (Liew et al. 2021) and South Africa (Dlamini et al. 2019). Therefore, they need to adopt different alternatives, such as organics having to be composted/anaerobic digested to get methane and recyclables needing to be pyrolyzed to get bio-fuel and syngases such as hydrogen.

Methane Emissions

The methane emission calculated according to LandGEM model equation 1 for the Kanuru landfill site starting from 2011 was presented in Fig. 3. The methane concentration follows a gradually increasing trend. It is observed to have a peak concentration of 9.266E+07 cu.m during the year 2042. After the peak emission of methane, the concentration decreased gradually and reached a value of 5.099E+06 cu.m per year during the year 2100. Methane is a gaseous product produced from the anaerobic bacterial decomposition of organic matter in landfills. The amount of methane gas produced is correlated to the quantity of organic waste within the landfill. Hence, higher methane concentration indicates a higher portion of organic waste presence (Ghosh et al. 2019, Sun et al. 2019, Oukili et al. 2022). There are various physical, chemical, and ecological parameters that influence the methane emissions like the waste composition, pH of the waste, average rainfall depth in the site, air temperature, pressure, topography, and microbial interactions (Fei et al. 2019, Monster et al. 2019). The ambient atmospheric temperature, relative humidity, and rainfall exhibit strong correlations with landfill gas components (Yang et al. 2015, Delkash et al. 2016). The present study site has an average annual temperature of 28.5°C and an average annual rainfall of 1066.8 mm, hence having a high potential to produce landfill gases. Similar results were projected earlier (Zhang et al. 2013). The landfills without proper gas collection systems will substantially emit methane (the most vital GHG) into the atmosphere without any control and huge spatial and seasonal variability.

The Kanuru dumpsite is in the active phase of methane production, and hence the concentration of methane was

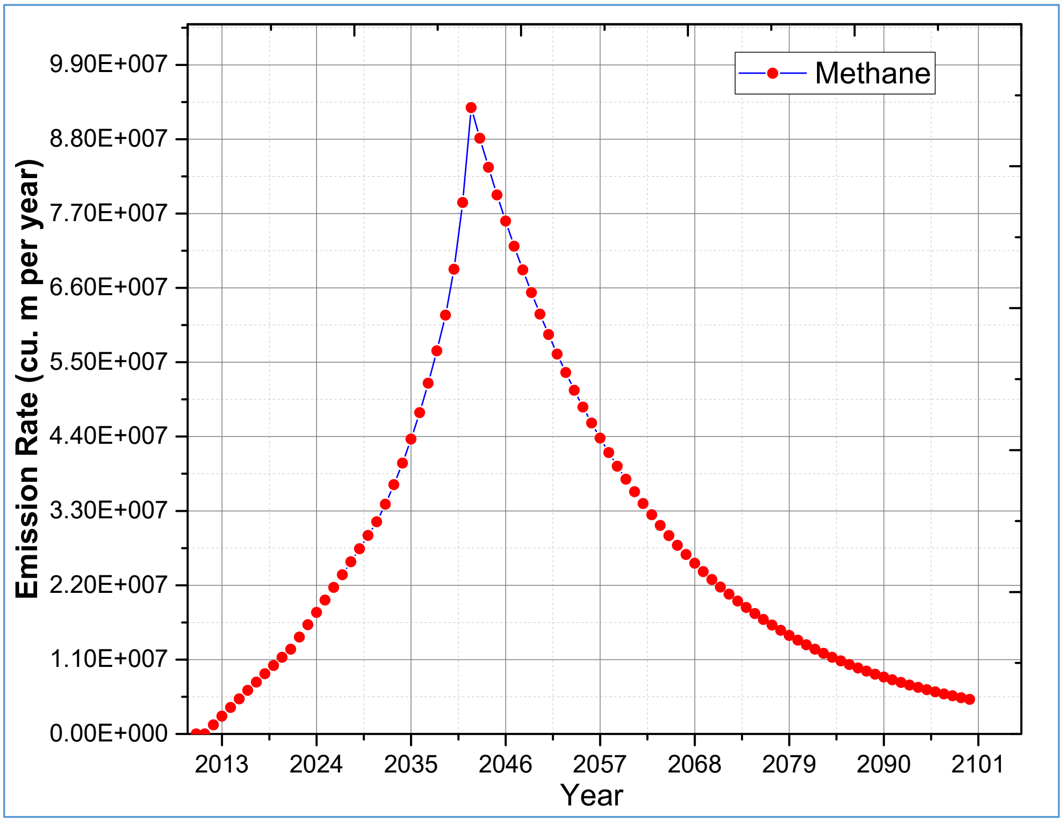

Fig. 3: Projected methane concentration from the Kanuru landfill site.

slightly higher than the other reported values. Henceforth, few remedial measures can be adopted to interlude the GHG emissions and generate/find a renewable energy source. Firstly, the Kanuru open dumpsite should be upgraded to an engineered landfill site, with a provision for a methane recovery system and proper landfill cover to avoid the escape of generated methane. Secondly, the adopting the strategy of integrated waste management and accommodating more waste from all the localities, segregation of recyclables, composting of organics, and incineration for combustible portions. Finally, the long-term strategy is to convert the methane to renewable hydrogen gas by thermocatalytic decomposition or utilization of methane for renewable electricity generation.

Energy Potential and Hydrogen Production

The annual electrical energy generation potential (Ep) feasible from the Kanuru dump site was calculated based on equation 2. The energy potential depends on the concentration of methane liberated in cu.m per year, the lower heating value of methane (usually in the range of 34-52 MJ per cu.m), collection, and electrical conversion efficiency (Thema et al. 2019). During the early stages (2011-2021) of landfilling, the energy potential was 1.8-16 GWh per year and started to increase rapidly afterward. The electrical energy potential peaked during 2042 at 130.8 GWh per year. The plot showing the projected electrical energy potential trend from the Kanuru dumpsite is shown in Fig. 4. As the methane generation rate increases, the amount of electrical energy production potential also increases. A similar trend was observed for the uncontrolled Mohammedia- a Benslimane landfill (Oukili et al. 2022). The authors obtained a maximum electrical energy production 2032 valued at 35.2 GWh. The results obtained from the study conclude that improvement in waste management is a vital factor for a country like India, and the use of the energy content of waste could be one of the leading ideas for sustainable progress. The potential energy content from the solid waste can be resource recovered by either thermo-chemical processes (combustion, pyrolysis, or gasification), biological processes (anaerobic digestion), or engineered landfilling.

The biogas/methane emissions gradually increased and peaked in 2042 (9.266E+07 cu.m per year). Correspondingly, the energy potential also followed a similar trend. The carbon

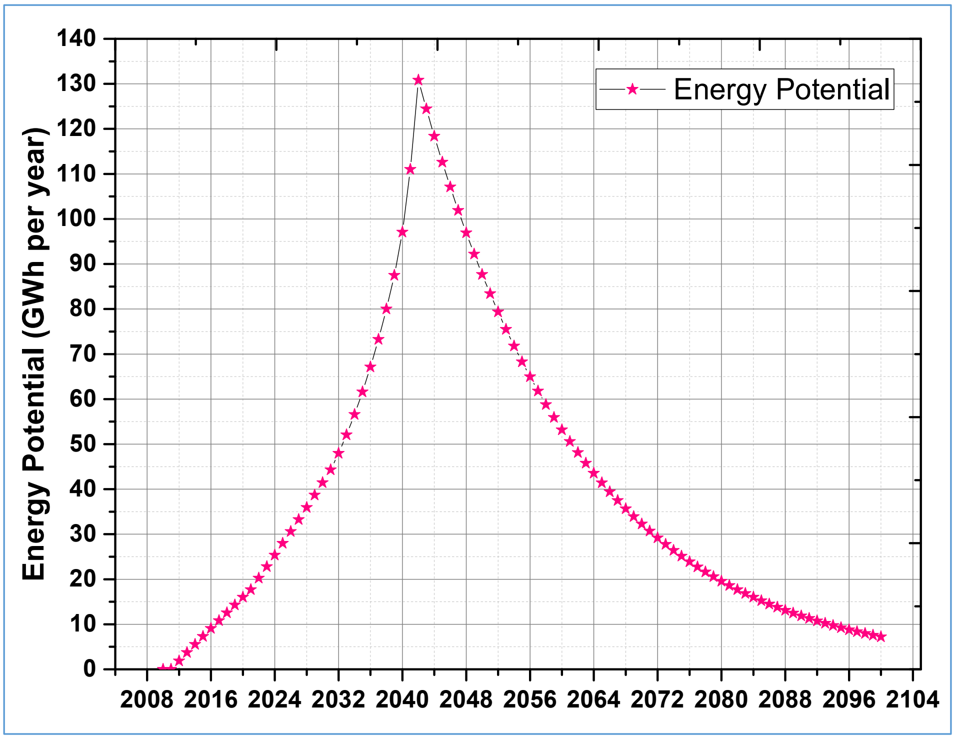

Fig. 4: Projected electrical energy potential from the Kanuru landfill site.

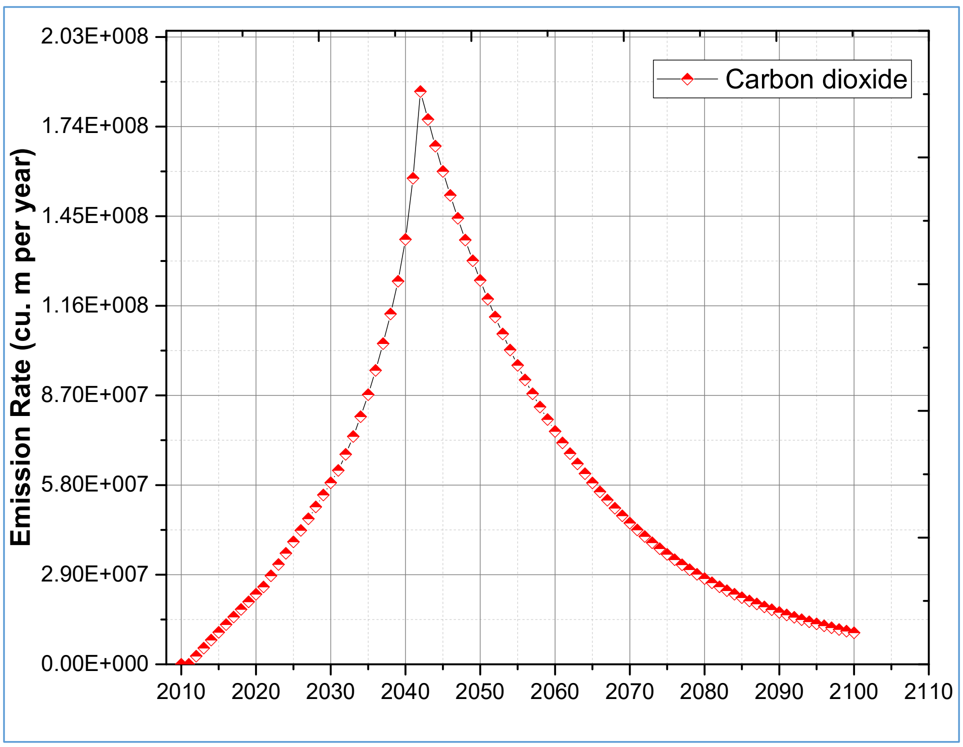

Fig. 5: Projected carbon dioxide concentration from the Kanuru Landfill Site.

dioxide equivalent's also calculated considering the global warming potential (GWP). Hence, the Kanuru landfill site contributes to 2.32E08 cu.m of CO_2 equivalents per year and, thereby, greenhouse effects (Fig. 5.). This significant contribution to the greenhouse effect is explained by the high organic content of the waste buried in the landfill and the meteorological conditions.

After the peak emissions and peak electrical energy potential in 2042, the contributions decreased exponentially and reached a zero value after 100 years of landfill closure. It implies that the landfills emit enormous amounts of greenhouse gases, especially methane gas, besides having the potential to convert into electrical energy. The gas recovery system installation on the landfill site will substantially reduce greenhouse emissions into the atmosphere. Similar study results were obtained by Tayyeba et al. (2011) and Villarino et al. (2020), with a GWP of 21 for methane, estimating around 80% - 90% of methane capture efficiency. The present study also concludes coherent with the reported data; the landfill gas recovery system has an achievable GHG emission reduction of 1.78E06 Mg of CO_2 equivalents. In the future, the Kanuru landfill site, due to the very efficient recovery system installation and active managerial participation, will create the Kanuru, Vijayawada, a carbon green site or carbon sequestration pool.

The analysis estimates the production of renewable hydrogen using the steam methane reforming (SMR) technology with a 70% net energy efficiency. The energy conversion from methane to hydrogen depends on the higher heating value and the disposed solid waste's ultimate analysis energy level to hydrogen energy. The estimated recoverable methane in Gg per year was plotted in Fig. 6, showing a value of 13.2, 61.8, 41.4, and 11.8 Gg per year during 2025, 2042, 2050, and 2075, respectively. Subsequently, the renewable hydrogen produced from the Kanuru landfill site was about 9.3 Gg per year in 2025 and increased to 43.3 Gg per year during 2042. The value gradually exponentially decreased from the year 2042 to reach a value of 8.3 Gg per year by the end of 2075. The results were in concurrence with renewable energy produced from the California landfill site of 160-

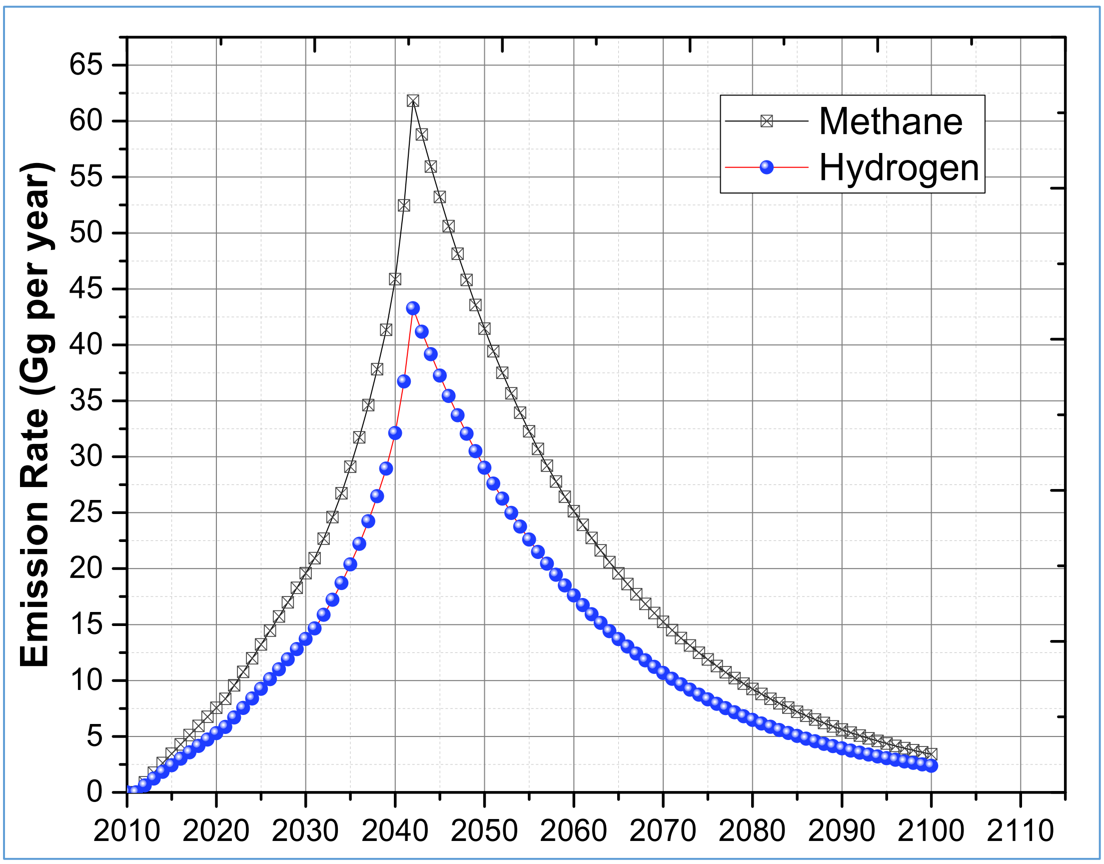

Fig. 6: Projected methane and hydrogen production potential from the Kanuru Landfill Site.

300 Gg per year (Ansari & Daigavane 2021). However, the reason for the lower hydrogen produced compared to the reported value is not evident. Still, it may be due to lower gas quality, the composition of solid waste dumped, and other meteorological conditions.

CONCLUSION

Methane, the most vital greenhouse gas, must be monitored and controlled to combat the global crisis on climate change, as well as Landfills are one significant contributor of methane gas and a preferred disposal option in developing countries. This study is the first to estimate the quantity of methane emitted from the Kanuru landfill site, Vijayawada, and thereby project the electrical energy potential and renewable hydrogen production capacity for this landfill. The methane generation rate for the Kanuru open uncontrolled landfill site from inception (2010) to more than 100 years was projected using Landgem 3.03 model. The estimation of methane for the landfill site was based on the amount of waste disposed of every year, the methane generation rate (k), and the methane generation potential (Lo). The anaerobic decomposition of the solid waste dumped inside the Kanuru dumpsite produces methane, a good approach to protect the environment, and greenhouse gas mitigation is to generate electrical energy or to produce renewable hydrogen. Methane gas is a promising contributor to global warming and a source of green energy. It needs to be sequestered. According to the landGEM model, an exponential increase in methane emissions was observed, and the maximum methane production rate was predicted as 9.266E+07 cu.m per year during the year 2042. The year 2042 corresponds to the closure of the Kanuru landfill site, and hence the production decreased afterward. The study also concludes that the electrical energy potential of the Kanuru landfill site was 130.8 GWh per year for the year 2042.

Additionally, the Kanuru landfill site has the potential to produce renewable hydrogen based on steam reforming reaction to yield a maximum of 43.3 Gg per year during 2042. Therefore, it can be concluded that the Kanuru, Vijayawada landfill is a source of energy production and can be used as an alternative to fossil fuels. There needs to be a policy reformation to convert all the open dumpsites into engineered landfills with a gas recovery system. As well as the use of excessive liberated methane needs to be converted into electrical energy or renewable hydrogen.

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