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Prediction of Greenhouse Gas Emissions in Municipal Solid Waste Landfills Using LandGEM and IPCC Methods in Yazd, Iran

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ABSTRACT

Introduction: The increase in greenhouse gas (GHG) emissions has changed the global temperature and had a negative impact on global climate conditions. Landfill gas is one of the major GHG contributors. With the knowledge of GHG inventory, it is possible to carry out disaster prevention measures.

Materials and Methods: In this study, tow Landfill Gas Emissions Modeling (LandGEM) and Intergovernmental Panel on Climate Change (IPCC), were used to determine the GHG quantity of the Yazd county landfill sector using from 2000 to 2020.

Results: During this period, by the IPCC model, the total level of methane emissions from the Yazd county landfill was 23.17 Giga gram/y (Gg/y), while based on the LandGEM model, the total value of methane emissions from the Yazd county landfill was 5.74 Gg/y. The total amount of CO_2 in the Yazd county landfill of the years 2000–2020 is estimated to be 15.75 Gg/y in the LandGEM model. There is the potential to generate 11.88 MWh/year electricity for the Yazd county landfill in 2020.

Conclusion: The results of the present study can be employed to plan and implement a system for collecting methane gas and control the emission of GHG to landfills.

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Introduction

Rapid urbanization, the unregulated population and economic growth have resulted in a municipal solid waste (MSW) in developing nations [1]. About 67 % of the total solid waste produced in the world is disposed in sanitary landfills or discarded in unsanitary landfills or dumps [2]. Processes of the physical, chemical, and microbial that take place in solid waste causes landfill gas (LFG) [3].

The most important parameters of LFG are methane (CH_4) (usually for the 45%–60% limit), carbon dioxide (CO_2) usually for the 40–60% limit), and multiple other materials compounds[4]. The main greenhouse gases (GHGs) include CH_4 and CO_2, which global warming potential of CH_4 (GWP) is 20 - 28 times higher than a CO_2 for a period of one hundred years [5]. The global emissions and GHGs accumulation in our atmosphere are serious concerns; so many countries have pledged to reduce their emissions [6, 7]. About 3.5-7 % emissions of universal CH_4 are related to emissions from landfills [8, 9]. It is estimated that in the United States, the wastes sector is the third-biggest source of emissions following the production of fossil fuel and

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intensive livestock [10].

30% of evaluated emissions of anthropogenic CH_4 in Europe are originated from landfills [8]. In 2010, CH_4 emitted from the landfills were estimated for almost 11% of the total volume of CH_4 emitted [4]. Researchers evaluated that the share of methane to climate warming will attain 50% in 2030 when it becomes the major greenhouse gas [11]. Due to the high population density, Asian countries are one of the most important producers of MSW. Therefore, control of fugitive CH_4 emissions from landfills should be focused on waste management procedures [12].

There are various methods to evaluate methane emissions, such as field testing, location evaluation, and mathematical models [13]. Modeling methods are used due to the problems in the precise control of the CH_4 emissions of whole landfill sites [14]. The most widely used models include Intergovernmental Panel on Climate Change (IPCC) method, First-Order Decay (FOD) process, Triangular method (TM), and Landfill Gas Emission Model (LandGEM) version 3.02 method [15, 16].

LandGEM is developed the equation of the first-order dissociation rate for calculating emissions of the landfill waste in MSW [17]. The software offers a quite simple method to quantifying emissions of landfill gas [13]. IPCC extended a multiphase model in the year 2006 to estimate CH_4 production from all the countries in the world [18].

Literature shows that different researchers have computed the GHG emission potential of landfill sites using several models. The results for Sadeghi et al. presented that in 2023, 2028, and 2033 gas generation will reach 411, 549, and 671 m^3/h, respectively [19]. Sharma et al. studied methane production from the landfill of Panki in India using FOD method, landGem, and IPCC Default model. The average annual methane emission levels from the Panki landfill were reported 24.27, 25.14, and 197.33 Gg by FOD, IPCC and LandGEM method respectively, from 2010 to 2030 [20].

Determining CH_4 emission is very serious and urgent, which can provide more awareness on real emissions from landfills, that could then be applied for GHG emission reporting [21]. The shortage of information about measuring methane gas emitted from Yazd county MSW landfill, this study pointed to characterize the Land GEM and IPCC model for gas emitted in Yazd county MSW the landfill with the evaluation results of CO_2 and CH_4 production.

Material and methods

Study area

Yazd County is located at 31.89° N and 4.35° E (Figure 1), has a landfill that it receives than 382 tons of waste per day. In this region, there is no opportunity for the recovery of methane. Yazd county landfill site located in the northeast of the county, the area of almost 222 hectares began in 1981. The depth of the Yazd County Landfill is about 18 meters. Then the disposed waste is hidden with a substrate of soil at a depth of 30 to 40 cm. The soil composition of the landfill is sandy-Lumi.

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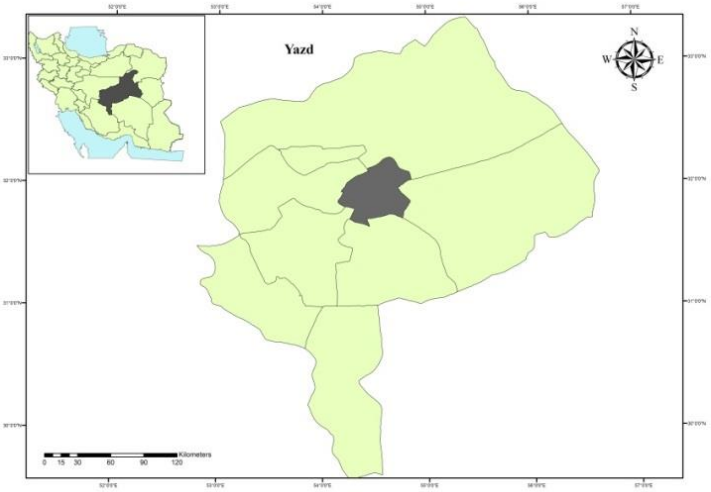

Figure 1: Map of the location of Yazd County in Iran

Population prediction and the development of potential waste in Yazd County

An estimate of the population of the future is necessary to determine values of wastes to be generated [22]. The urban population of the Yazd county landfill was determined to be 656474 in 2016 from the National Portal of Statistics of Iran. According to Eq. 1 [23], the population for future waste production of this area was estimated from 2000 to 2020.

$$P_n = P_0 (1+ r)^n \quad \text{Equation (1)}$$

In Eq.1, P_n is the number of population Year n, P_0 is the number of population in the first year, r is the annual rate of population growth, and n is number of years. To evaluate solid waste generation rate in 2016, the total generated wastes this year were distributed by the population that was 580 g per person. Consequently, by multiplying the generation rate of wastes by the evaluated population, the value of generated waste in the desired years was computed.

Assumptions and Calculation

In two models, LandGEM and IPCC can be applied either with default values or site-special data, which is the site-specific used in this study.

LandGEM model

LandGEM is established a first-order decay rate equation given follow by [24]:

$$Q_{CH4}=\sum_{i=1}^{n}\sum_{j=0.1}^{1} KL_0 \frac{M_i}{10} e^{-KT_{ij}}$$

Equation (2)

where: Q_{CH4} = annual of methane production in the year in which the estimate is made (Giga gram/y), i = increment of 1 year time, n = (year of calculation) - (early year of waste receipt), j = 0.1 increment of year time, k = methane production rate ($year^{-1}$), L_0 = production potential of methane (m^3/Mega gram), M_i = processing potential for methane in the i^{th} year (Mega gram), t_{ij}= age of the j^{th} part of waste weight M_i admitted in the i^{th} year (decimal years, for example., 3.2 years).

IPCC model

The determining of the CH_4 emissions from the landfill were conducted in Microsoft Excel 2007 based on the IPCC guidelines[25] [26]. The IPCC approach is based on the following equation for the calculation of methane released from landfill [18]:

$$CH_4 \text{ emission} = (MSWT\times MSWF\times MCF\times DOC\times DOCF \times F\times \frac{16}{12} - R) \times (1-OX) \quad \text{Equation (3)}$$

where: MSWT = Total value of waste produced (Gg/year), MSWF = Disposed waste fraction, MCF = Correction variable of the waste that produces landfill methane gas, DOC = part of Organic carbon that is biodegradable, DOCF = a part of Easily-accessible biodegradable organic carbon for decay, F = methane biogas fraction, OX = part of CH_4 gas that is oxidized into CO_2,

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R = Recovered CH_4 (Gg/yr) [27].

To estimate CH_4 emission using two models of landGEM and IPCC, specific hypotheses for each model are discussed in the relevant section as follows:

(a) CH_4 Correction Factor (MCF): The MCF for different categories of landfill/dumping sites is given in Table 1.

Table 1: Default MCF values for various landfills/dumping sites [28]

Type of site	Depth	MCF values
Controlled site for MSW	-	1.0
Uncontrolled site for deep MSW	≥ 5 m	0.8
Uncontrolled site for shallow MSW	< 5 m	0.4
Uncategorized site for SWDS	-	0.6

(b) Degradable of organic carbon (DOC): It is determined the waste material and can be measured using the following formulas:

$$DOC = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D) \quad \text{Equation (4)}$$

Where A: Paper and textiles fraction; B: garden waste and park waste fraction or other organic non-food waste; C: food wastes fraction and D: MSW as wood fraction.

(c) DOC_F: fraction of the DOC that can be decomposed. It represents the amount of organic and can be computed as EPA LandGEM index [24]:

$$DOC_F = (0.014 \times T) + 0.28 \quad \text{Equation (5)}$$

Where, T: The temperature of the area atmospheric.

(d) Recovery of CH_4 (R): This is the quantity of CH_4 produced at the landfill that can be recovered as well as an energy source. The default amount of CH_4 recovery is discussed as zero as the recovery of CH_4 is not discussed in the current study.

(e) Oxidation parameter (OX): It is the value of CH_4 from the landfill that is oxidized to the soil or to other substances of the waste. If OX is zero, it indicates that no oxidation has happened, and OX equals 1 indicates 100% CH_4 oxidation [29].

(f) The CH_4 Fraction for landfill gas (F): The CH_4 fraction (F) is generally considered as 0.5, but it could shift between 0.4 and 0.6, depending on the components of the waste and situations of the site[28]. It is presumed to be 0.5 for CH_4 for the Yazd County landfill site.

(h) Constant output value of CH_4 (K): The value of waste degradation and production of CH_4 can be determined using the following formula:

$$K = 3.2 \times 10^{-5} \times (R) + 0.01 \quad \text{Equation (6)}$$

Where R: Total annual rainfall in mm. amount of K for Yazd county landfill in Table 2.

(i) Production Potential of CH_4 (L_0): This is the value of CH_4 (m^3) produced by per Mg of MSW decayed. It can be computed by the following formula:

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \quad \text{Equation (7)}$$

Table 2: Assumption made for Yazd county landfill

Model parameter	IPCC method	LandGEM model
Methane correction factor (MCF)	0.80	0.80
The fraction of CH_4 in Landfill gas (F)	0.50	0.50
CH_4 recovery (R)	0.0	-
Oxidation factor (OX)	0.0	-
The CH_4 generation rate constant (K) ($year^{-1}$)	-	0.01
CH_4 Generation Potential (L_0) (m^3/mg)	-	57.88

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Electrical Energy production Potential

The electrical energy (kWh/year) from the CH_4 amount of gathered landfill gas can be computed by the following formula:

$$E_p = \frac{LHV_{CH_4} \times 0.9 \times Q_{CH_4} \times \lambda \times \eta}{3.6}$$ Equation (8)

where LHV_{CH4} is the Lower heater amount of CH_4 and is expressed as 37.2 MJ/m^3, QCH_4 = annual methane production in the year of the computing (Gg /year), 3.6 is the alteration factor from MJ to kWh, where λ is collection output (60%)[30], η is the electrical alteration output for internal ignition engine offered as 33%[31].

Results

Population and waste generation

According to the Statistical Center of Iran, in 2016, the population growth rate in Yazd county is 2.41%[32]. To estimate methane emissions quantity by LandGEM and IPCC models, the mass of wastes produced over various years of design period must be almost calculated. Based on Pitchel estimates, the per capita waste generation value over 20 years in developed countries depending on the annual population of 2 - 5% annually [19]. Table 3 presents the population, the volume of solid waste manufactured and the quantity of disposed of solid waste in Yazd County during the plan period. Figure 2 shows the components of Yazd county municipal solid waste include 59% food waste, 11% paper, 16% plastic, 4% textile, 3% glass, 1% metals, 0.05% woods, and 5% other materials.

Table 3: Population of the County of Yazd County and the amount of solid waste disposed of on a daily and yearly

Year	Population growth rate	Population	value of generated solid waste (tons/day)	value of disposed solid waste (tons/year)
2000	2.55	452350	129.31	47198
2001	2.55	463885	131.44	47975
2002	2.55	475714	147.13	53704
2003	2.55	487845	140.11	51140
2004	2.55	500285	190.35	69477
2005	2.55	513042	194.92	71145
2006	2.06	526276	226.86	82804
2007	2.06	537117	268.73	98088
2008	2.06	548182	230.63	84179
2009	2.06	559474	322.09	117563
2010	2.06	570999	334.60	122129
2011	2.41	582682	335.78	122561
2012	2.41	596725	342.07	124855
2013	2.41	611106	350.55	127952
2014	2.41	625834	352.98	128839
2015	2.41	640916	361.73	132032
2016	2.41	656474	370.75	135325
2017	2.13	670457	365.46	133391
2018	2.13	684738	366.60	133811
2019	2.13	699323	381.62	139292
2020	2.13	714219	389.96	142336

The annual amount of solid waste disposal related to the growth of population. Figure 3 presented the trends of population growth and solid waste that was disposed of the landfill site from 2000 to 2020. The amount of disposed of MSW was nearly calculated 47198 tons/year in 2000, which increased to 142336 tons/year in 2020. The people of Yazd county landfill produced 382 tons of MSW daily in 2018. It has been found that the rate of solid waste generation in the Yazd county landfill is 560 g/cap/day (Table 3).

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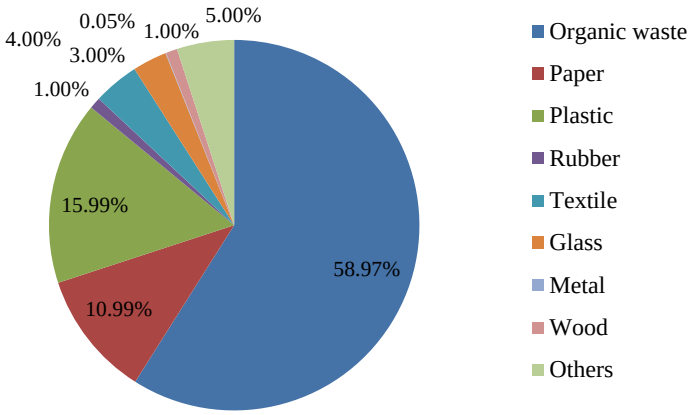

Figure 2: Components of Yazd County landfill municipal solid waste

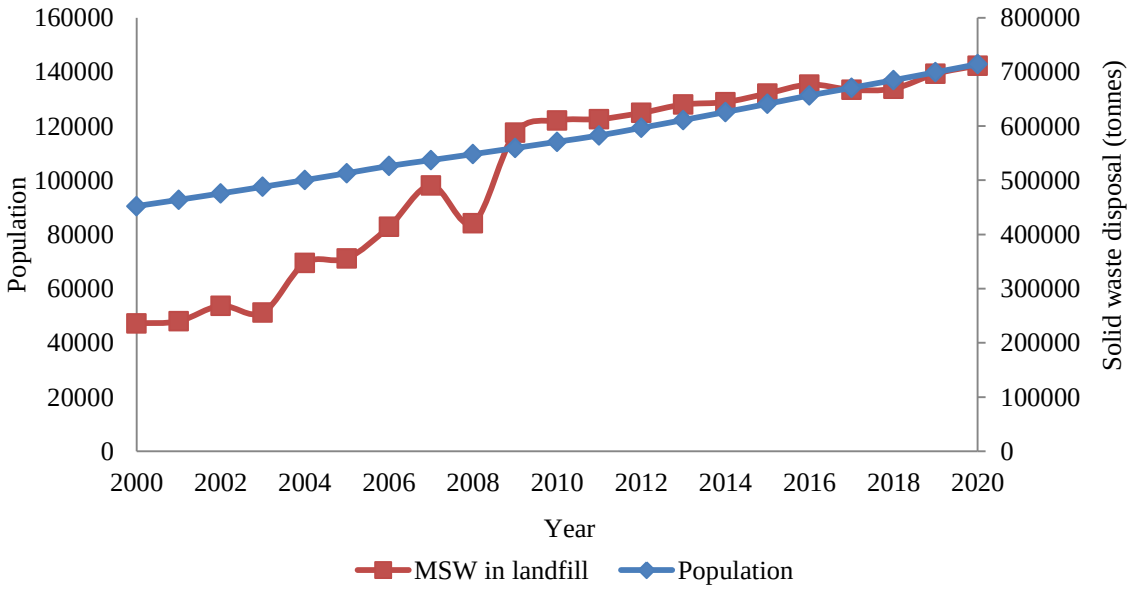

Figure 3: Population number of Yazd county and solid waste disposal at studied area

Amount of greenhouse gas emitted

In the current study, several methods like LandGEM and IPCC models were applied to calculate CH_4 emitted from the landfill of Yazd County (Figure 4). On the base of usable data of waste disposed in landfill, the methane emissions were calculated from 2000-2020 (Table 3). Based on the model suggestion, For the first year of MSW deposit, the model has no gas escape. The calculation of CH_4 emissions using the LandGEM model shows lower results than calculations with the IPCC model. The accumulative methane emissions from the Yazd county landfill were realized to enhance from negligible 0.02 and 0.28 Gg/y in 2001 to as great as 5.74 and 23.17 Gg/y in 2020 as estimate by and LandGEM and IPCC models, respectively. IPCC predicted the highest cumulative methane emissions during 2000-2020. Figure. 5 indicate that in 2001 and 2020, the CO_2 generation rate is estimated to be 0.04 and 1.77 Gg/y, respectively. The results of the cumulative calculation of the estimated CO_2 emission during 2000-2020 are equal to15.75 Gg/y by LandGEM.

Calculation of Electrical Energy production Potential

The electrical energy (MWh/year) of CH_4 value from Yazd county landfill in from 2000-2020 was

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given in Figure 6. The amount of potential electrical energy has been generated in the 2001 Yazd countylandfill 0.3 MWh/year. In 2020, the recovered landfill methane would be generating 11.88 MWh/year.

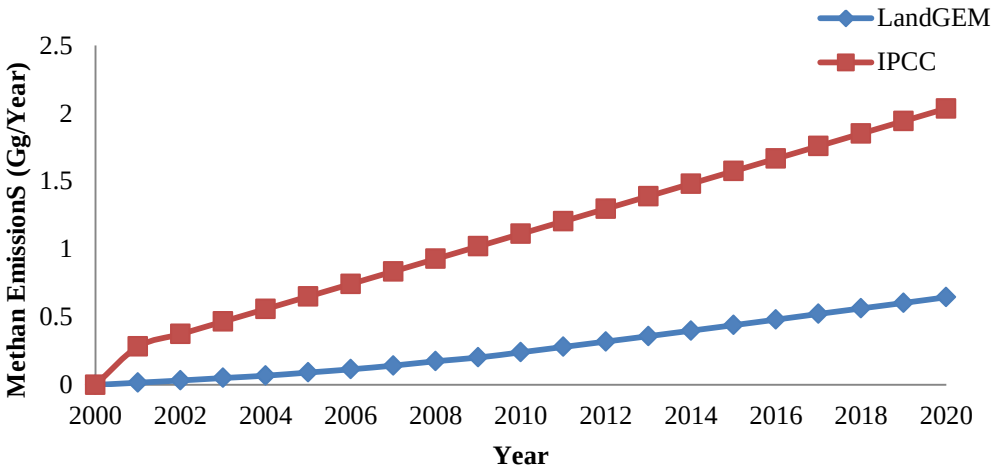

Figure 4: Comparison of estimated methane emission by different models

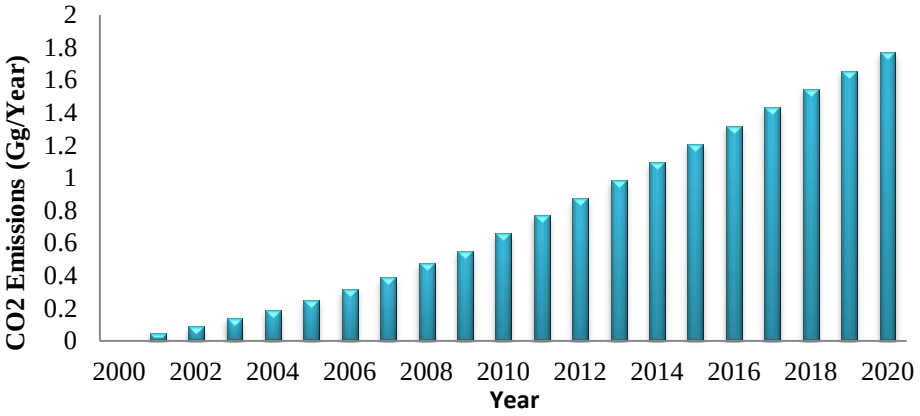

Figure 5: CO_2 emission from Yazd County landfill site by LandGEM model

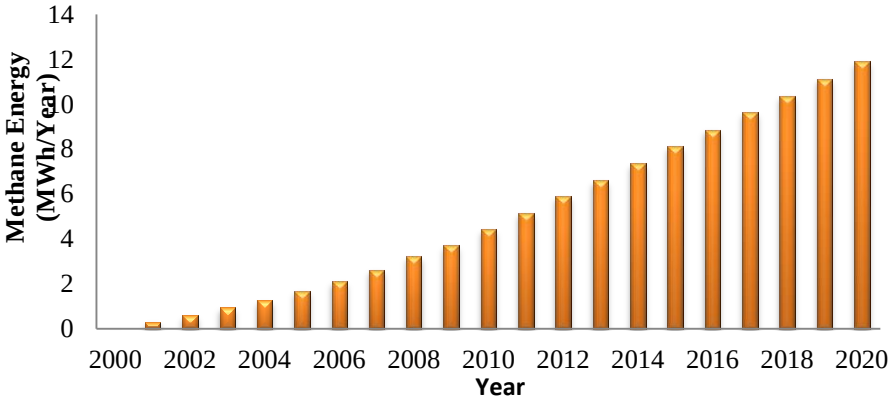

Figure 6: Energetic potential of methane from Yazd County landfill

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Discussion

Variation of the population affects lifestyle changes and thus increases the production of solid waste per capita and finally increases CH_4 emissions [30]. The results of this study indicated that a larger population leads to higher waste generation (Figure 3). There is a high relation between the MSW production and the population growth and CH_4 emission level. The level of solid waste delivered to the landfill site rapidly elevated after 2009 because of the growth of population, more efficiency on solid waste collection, and governmental policy on solid waste management (Table 3). In this study, the LandGEM and IPCC waste models are used to quantify the CH_4 and CO_2 generated, influenced by important parameters such as the methane potential (L_0) and the decadence rate (k) of landfill waste. These parameters significantly affect the quality of solid landfill waste and estimate the amount of gas produced by considering MSW information, degradable organic carbon (DOC), and the decadence rate of MSW. Therefore, the impact of quality and quantity of organic waste is more significant than other wastes.

We compared the CH_4 emission results from the current study with the results of other studies. In this study, the LandGEM model estimated the total CH_4 emission as 5.74 Gg/y, while Fallahizadeh et al. (2019) reported the generation of CH_4 gas in Yasuj city during the years 2009-2012 was reported to be 250-330 m^3/h (219-289.08 Gg/y) respectively[13]. Talaiekhozani et al. studied the 114 million m^3(11400 Gg/y) of CH_4, between 1997 and 2023, it will be published with the capacity to generate 188100 MW of electrical energy. [22]

According to the studies, CH_4 is 21 as efficient in trapping heat than CO_2 [5] , but in this study, the results showed that CH_4 emissions were lower than CO_2 emission by the LandGEM model, which it is comparable with the outcomes of Talaiekhozani et al. in Shahrekord city [22]. In this study, the IPCC model showed higher values for CH_4, which contradicts Silva et al. study.

Results of the IPCC model in the present study illustrate a CH_4 emission potential of nearly 23.17 Gg/y, while Silva et al. was predicted an estimate of 23 $\times 10^5$ m^3(230 Gg) of CH_4 gas for the IPCC model[33]. In the figure. 4, it is apparent that there is significant variation in outputs of the model. This can be due to types factors, such as differences in input information and assumptions used during the implementation of the models[11].

Suryawan et al. reported that total GHG for 2021 is 2.3×10^7 m^3 /year (2.3×10^3 Gg/y) with LandGEM model, 2.2×10^7 m^3 /year (2.2×10^3 Gg/y) with IPCC model [34]. The average CH_4 values for Ghazipur, Bhalswa, and Okhla landfills respectively were recorded by Abhishek et al. (2020) as 20.36, 24.10, and 17.51 Gg/year and 9.90, 9.81, 8.40 Gg/year by LandGEM, respectively [11], which the difference between the outputs of the two models is similar to our study.

Landfills release GHGs directly into the environment, which leads to global warming, which is destroying the climate and human health[33]. If properly planed landfills are created, recovered landfill gases can be worked as a main source of energy and for power production or can be enhanced into vehicle fuel. In the present study, there is the potential to generate 11.88 MWh/year electricity in 2020.

Conclusion

Yazd County's rapid urbanization, economic development, and population growth have dramatically increased its total waste generation over the past decade. In this study, the greenhouse gas emissions (GHG) have been estimated by using the LandGEM and IPCC models from the Yazd county landfill site for the period of 2000-2020. Results for the IPCC model illustrate a CH_4 emission potential of nearly 23.17 Gg/y during this period. The total CH_4 emission was evaluated at 5.74 Gg/y using the LandGEM model. It is also noticed that the LandGEM model is found the first degree equation, so measuring the reduction in MSW and hence emissions decrease over time, while the default IPCC model does not conceive. Accordingly, the LandGEM model results in the lowest annual landfill emissions of CH4 sites

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compared to the IPCC process. The results of the calculation of the estimated CO_2 emission for the period of 2000-2020 are equal to15.75 Gg/y. The potential for electricity generation in 2020 will be 11.88 MWh/year, which provides an opportunity to generate significant energy. Significant knowledge is given by the findings of this research that can be used for the enhancement of the country-specific factor of emissions for estimating the emissions of methane in the waste disposal class.

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Conflict of interest

The authors of this article declare that there is no conflict of interest.

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