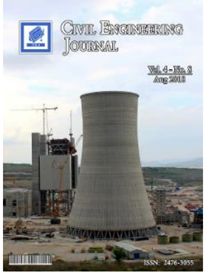
Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 4, No. 8, August, 2018



Investigation and Evaluation of Potential Options to Determine the Methane Gas

Ali Kemal Cakir [a*]

[a] *Department of Mechanical Engineering, Kastamonu University, Kastamonu, Turkey*

Received 18 June 2018; Accepted 05 August 2018

Abstract

Izmir has been one of the cities in our country which firstly began to implement a regular solid waste disposal system with the operation of Harmandali Landfill Facility in 1992. An important part of municipal solid waste produced in contiguous area of Izmir during the period of 25 years was disposed in this facility in order to minimize any possible problems on health and environment caused from that solid waste. The most important factor for deciding on the energy potential of landfill is the amount of landfill methane gas in the landfill area. There are several approaches used to determine the amount of landfill gas. We used one method (When the facility conditions are taken into account (moisture, waste water, landfill leachate etc.) that it is the most appropriate method) and one Literature-Based Approximate Forecast to determine the amount of the landfill gas in Harmandali Landfill. This method is Multi-Phase method. The main objective of this study is to investigate the use of landfill gas as potential energy and electricity provided from municipal solid waste (domestic, industrial, medical waste and sewage sludge) stored regularly in Harmandali Solid Waste Landfill Area, within the boundaries of the contiguous area of Izmir.

Keywords: Landfill; Solid Waste; Landfill Gas; Methane Gas; Energy Production.

---

1. Introduction

Energy recovery from waste represents an important way to reduce the amount of electric energy to be produced using fossil fuels, i.e. non-renewable sources of energy. Moreover, the energy recovery practice can present interesting economic revenues [1]. Despite efforts to reduce generation and increase recycling of municipal solid waste (MSW), open dumps and sanitary landfills remain the most common solid waste management approach globally. For instance, in the US, 54% of the generated solid waste was landfilled in 2008 [2]. According to the results of the Municipal Waste Statistics Survey of 2014 applied to municipalities in Turkey, it was determined that 1391 of the 1396 municipalities provide waste services. It was determined that 28 million tons of waste was collected from municipalities providing waste services.

Of the 28 million tones collected in the municipalities where waste collection and transportation services were provided, 63.5% were sent to the sanitary landfill facilities, 35.5% to the municipal rubbish tips, 0.5% to the composting plants and 0.5% have been disposed with different methods [3]. This situation reveals the fact that sufficient infrastructure services are still not available for the disposal of solid wastes. In this context, especially under the name of examination of the disposal methods of solid waste of big cities, the example of İzmir has been the starting point. Within the scope of the study, the options for disposal and assessment of the emerging landfill gas and presentation of the existing conditions related to the formation of landfill gas and the gas collection system were investigated in

---

* Corresponding author: alikemalcan@hotmail.com

http://dx.doi.org/10.28991/cej-03091117

Harmandalı Sanitary Landfill Area (HSLA) where urban solid wastes formed within İzmir contiguous area boundaries are stored regularly.

1.1. Municipal Solid Waste Amounts

The total amount of solid waste disposed between 1992 and 2010 in Harmandalı Sanitary Solid Waste Landfill Facility, which is the only sanitary solid waste landfill facility in İzmir, is shown in Table 1. When Table 1 examined, it is seen that the amounts of domestic solid waste increased regularly between 1992 and 1994, and showed a parabolic increase between 1994 and 1998. Between 1998 and 1999, the regular increase in the amount of waste continued, despite the slight declines between 1999 and 2007, again an increase is observed between 2007 and 2009.

Table 1. Amount of domestic solid waste disposed at the Harmandalı Solid Waste Landfill Facility between 1992 and 2010 [4]

Years	Municipal Solid Waste Quantities (ton)	Yıllar	Municipal Solid Waste Quantities (ton)
1992	122520	2004	681440
1993	165300	2005	718550
1994	192201	2006	842550
1995	376400	2007	805959
1996	486945	2008	935309
1997	541870	2009	1036334
1998	575240	2010	1037951
1999	654760	2011	1121853
2000	644800	2012	1327554
2001	689870	2013	1271627
2002	674430	2014	1313745
2003	642130		

1.2. Workspace and Properties

Harmandalı Sanitary Landfill Area, located between 38 ° 32 '- 38 ° 33' northern latitudes and 27 ° 05 '- 27 ° 10' eastern longitudes within the provincial borders of Izmir, has a total area of 900 acres. Our worksite is the domestic solid waste lot which is still active (170 acres) [5].

A study has been conducted on a specific area to determine the potential for the formation of landfill gas in HSLA. This area is the currently operated region E, which will enable us to detect the gas composition and the flow rate in the area. This will be achieved on the basis of the existing gas collection system in the area and by making qualitative and quantitative gas measurements of the gas chimneys in this area.

1.2.1 Land Surface Studies

Harmandalı Sanitary Landfill Area is shaped according to the basin of the existing landfill area. The material is compacted on a daily basis with garbage compactors to keep it stable and not to slip, and it is covered with clay over it. In the area, 1/3 slope is given where the incline of slope of garbage is ideal for incline of slope of the garbage to remain stable [6]. The storage of wastes in the landfill area continues in the basin, which can be seen in Figure 1, 2 and 3. Storage is performed from top to bottom.

At this stage of the work, the garbage volumes of the landfill area, the type of waste storage, the soil surface (filling, shavings, etc.) have been examined. In this context, orthophotographs of Harmandalı Sanitary Landfill Area for 1996 and 2010 have been examined (for 1992 and after, these two orthophotographs of the landfill area have been obtained). In the light of this information, HSLA was differentiated into 14 separate sections by MapInfo program. We examined each section individually. The differences in garbage growth in the areas on the surface (North-South, West-East) and in the whole area are shown graphically. In graphical sections, the red lines show the year 2010 and demonstrate the height of the surface sections we have examined as of 2010. The green lines show the year 1996, which is the height of the surface sections of that year [6].

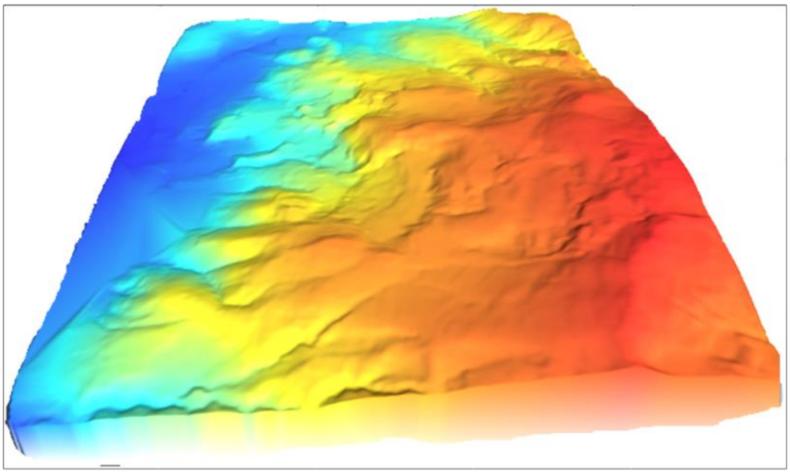


Figure 1. Three-dimensional representation of Harmandalı Sanitary Landfill Area, 2011[6]

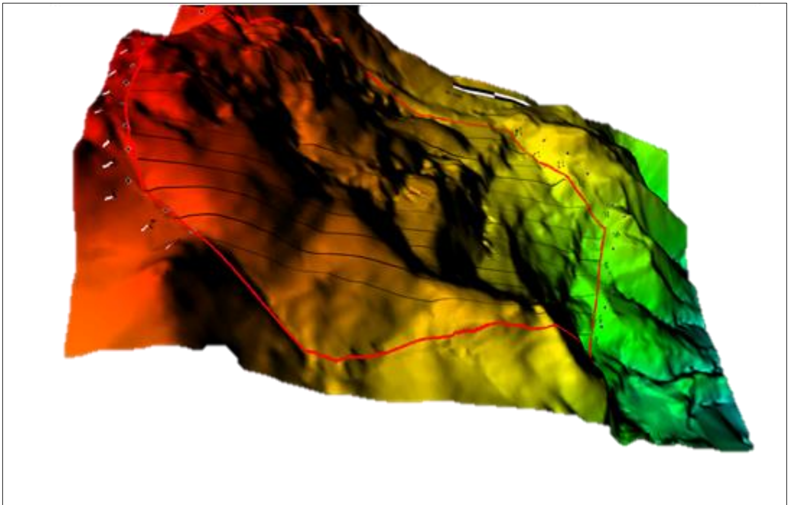


Figure 2. Three-dimensional left side view of HSLA separated by sections, 2011 [6]

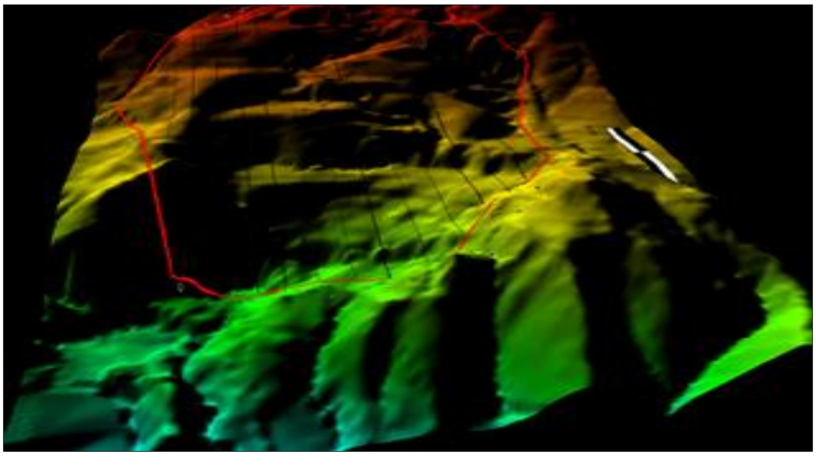


Figure 3. Three-dimensional front view of HSLA separated by sections, 2011 [6]

As can be seen from the graphical section shapes, the red lines showing the cross-sectional values of 2010 in general are on a trend above the green lines showing the cross-sectional surface values of 1996. This shows that with the increase in the volume of garbage, the height has increased and continues to increase. However, the green lines at some points on the graph are above the red lines. This shows that the land is shaved in certain areas (the land is not a flat surface but it is mountainous. With opening new landfill lot areas and the improvements made in the land, land reclamation is performed with heavy equipment). At the same time, it can be understood that the land has slipped due to the slides in the area. As a matter of fact, the fact that some part of the old garbage leachate treatment plant is under the ground proves this situation.

Figure 4 and 5 detail the differentiation of the landfill area into sections and their heights. In the sections, the height is limited to a maximum of 300 meters. After this height, the settlements formed of hills occupy the land [6].

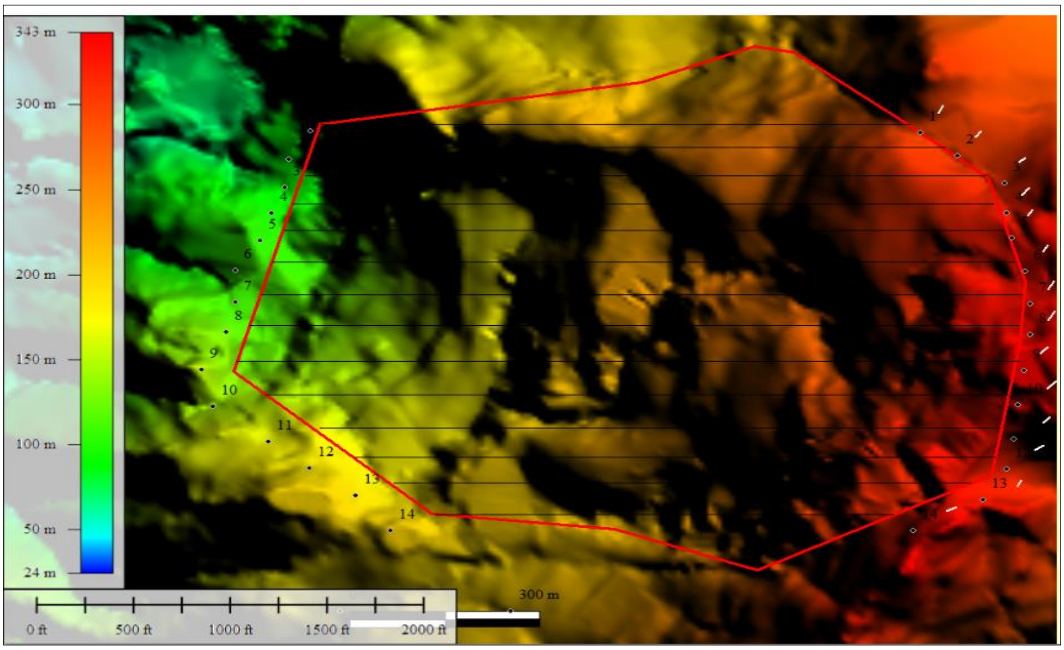


Figure 4. Separation of HSLA into sections, 2011 [6]

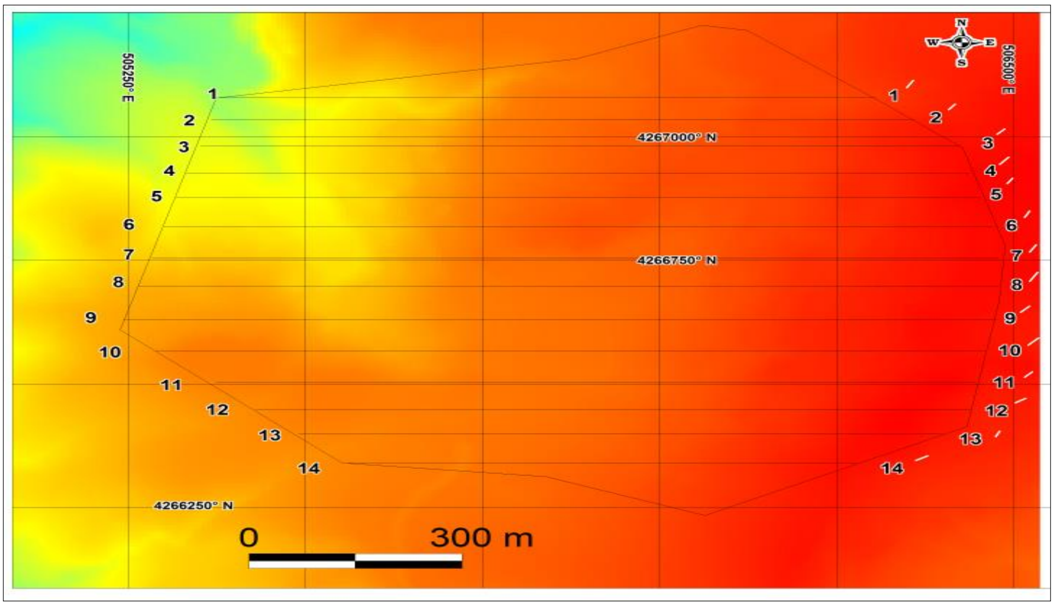


Figure 5. Separation of HSLA into sections on latitude and longitude, 2011 [6]

The information about the sections can be seen in Figures 6-19. By means of the information of the obtained sections, 10.694.242,9 cubic meters of garbage disposed in 666,282.8 m² area that belongs to HSLA, between 1996 and 2010, and a large part of the area was shaved during these years. Within the garbage disposal volume, there are also soil volumes accumulated in the area due to fillings and slips. Within the determined cross-sections of the area, the average height is about 11.5 m [6].

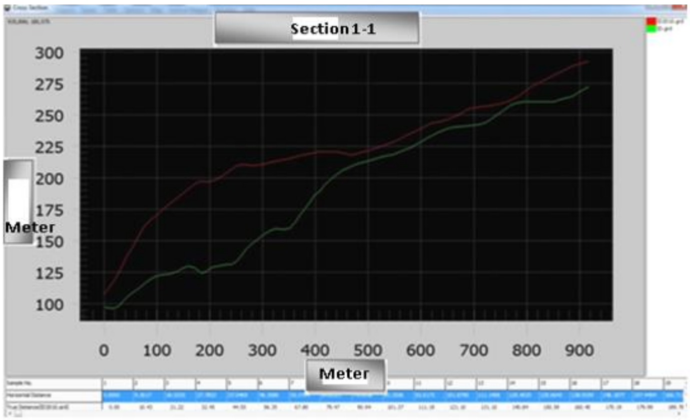


Figure 6. Graphical representation of 1-1 section of HSLA, 2011

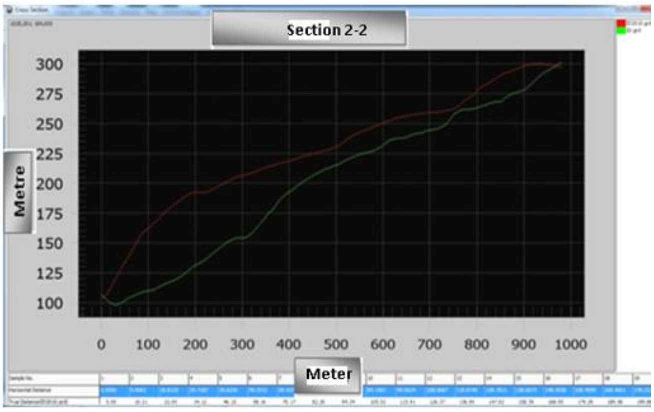


Figure 7. Graphical representation of 2-2 section of HSLA, 2011

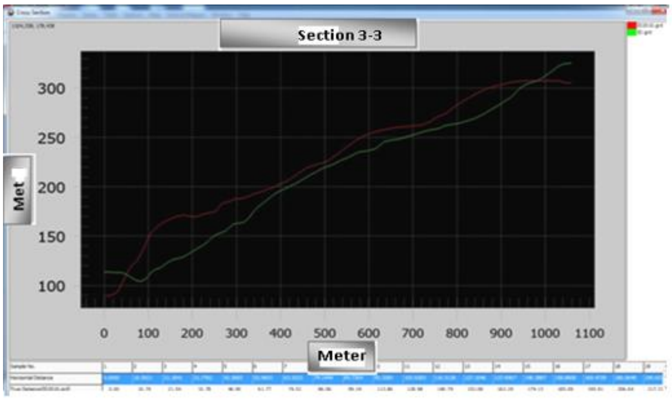


Figure 8. Graphical representation of 3-3 section of HSLA, 2011

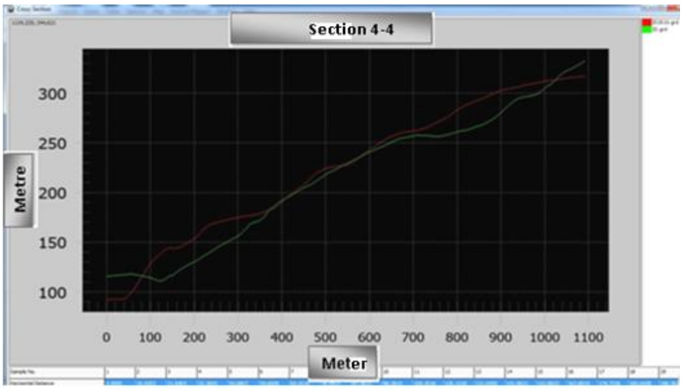


Figure 9. Graphical representation of 4-4 section of HSLA, 2011

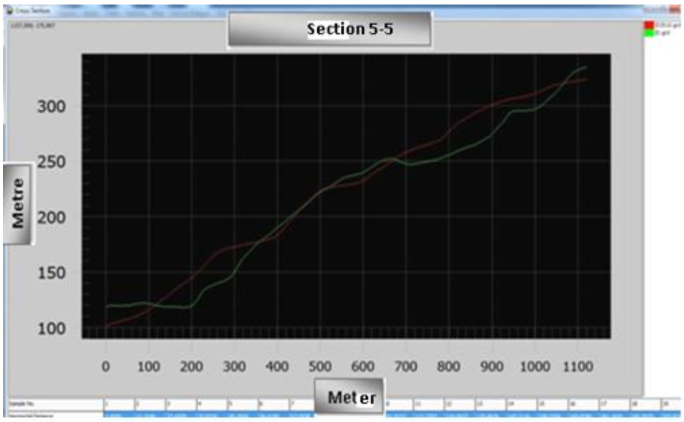


Figure 10. Graphical representation of 5-5 section of HSLA, 2011

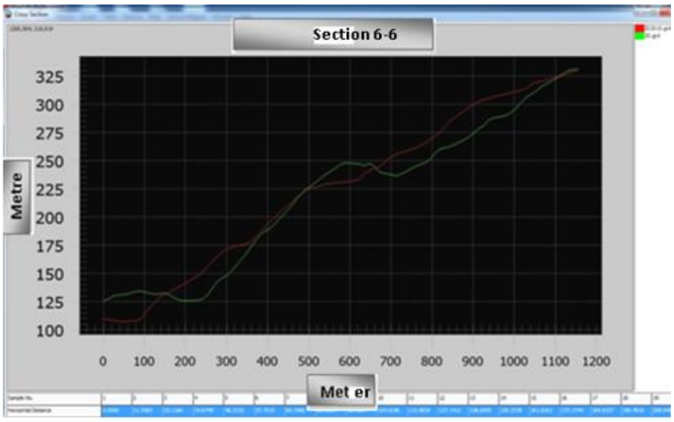


Figure 11. Graphical representation of 6-6 section of HSLA, 2011

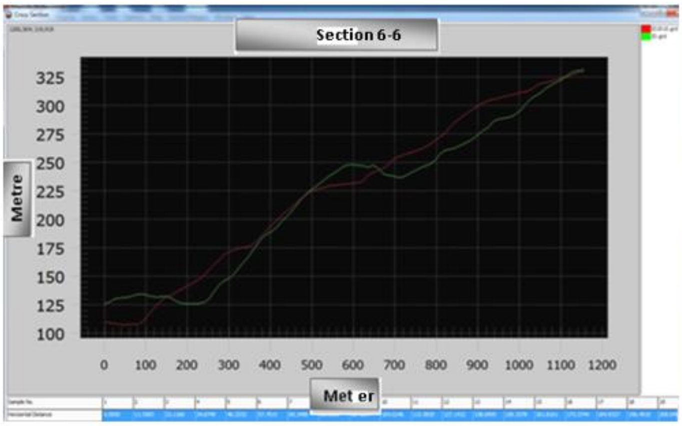


Figure 12. Graphical representation of 7-7 section of HSLA, 2011

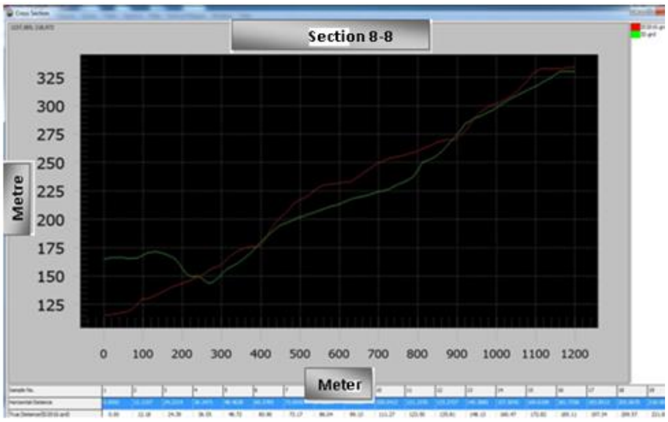


Figure 13. Graphical representation of 8-8 section of HSLA, 2011

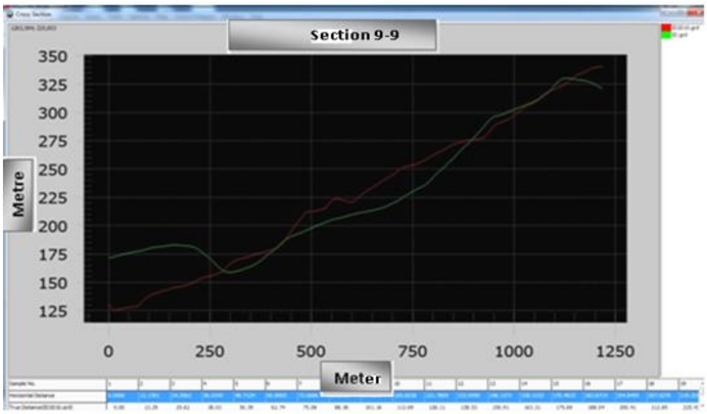


Figure 14. Graphical representation of 9-9 section of HSLA, 2011

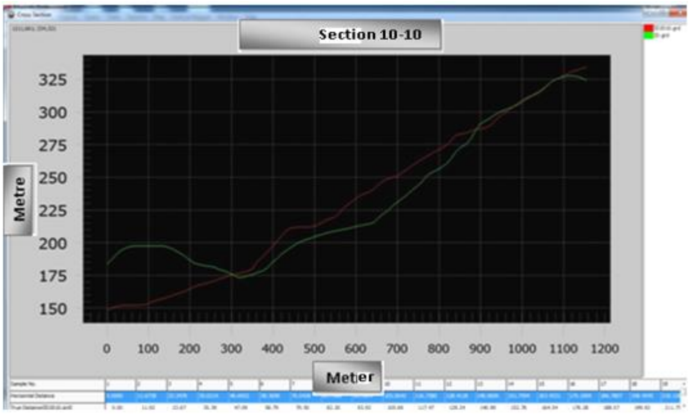


Figure 15. Graphical representation of 10-10 section of HSLA, 2011

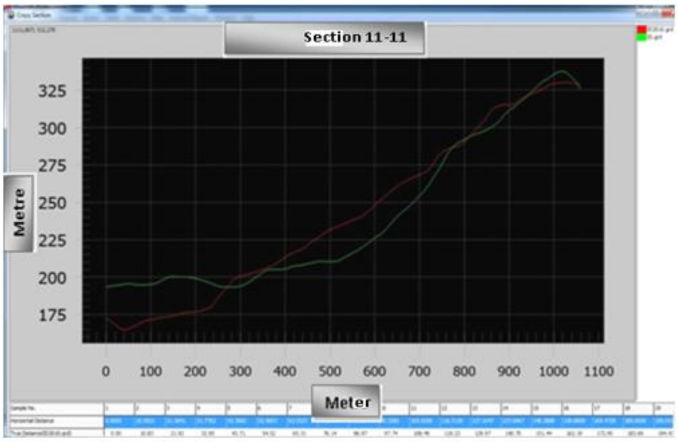


Figure 16. Graphical representation of 11-11 section of HSLA, 2011

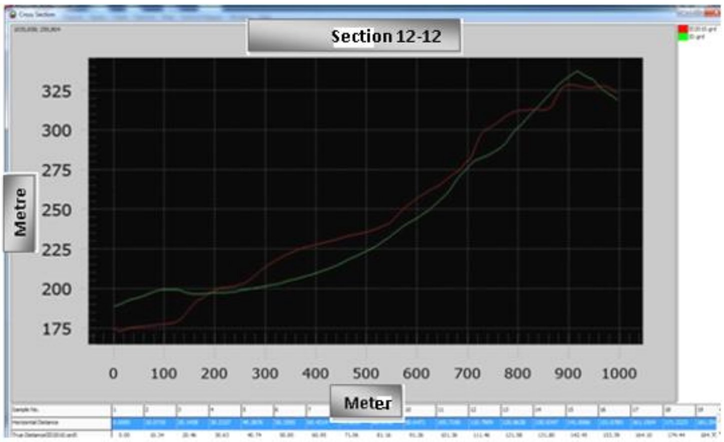


Figure 17. Graphical representation of 12-12 section of HSLA, 2011

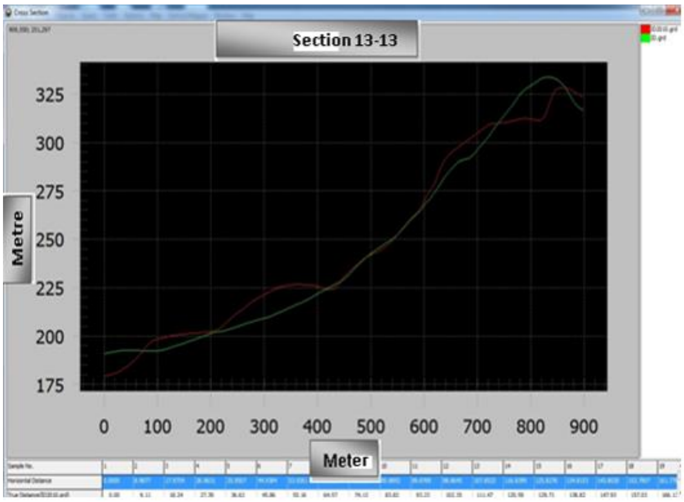


Figure 18. Graphical representation of 13-13 section of HSLA, 2011.

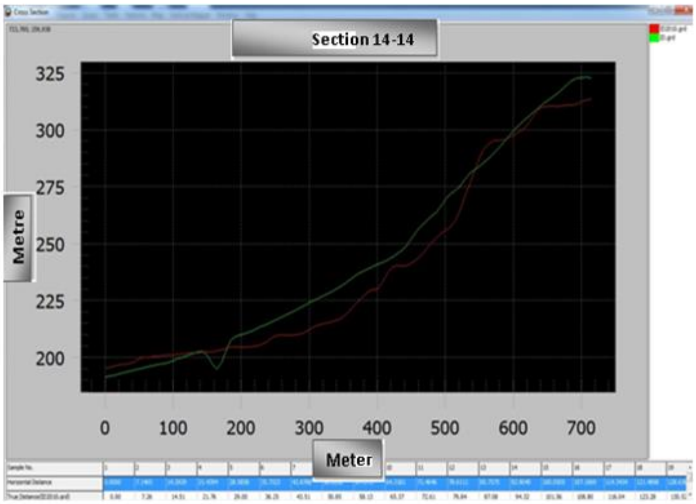


Figure 19. Graphical representation of 14-14 section of HSLA, 2011.

1.3. Landfill Area Gas Measurement

Gas measurements were performed with GEOTECH GA 2000 Range Gas Analyzer (GA 2000) manufactured by Geotechnical Instruments Limited (UK), in 77 chimneys located in Harmandalı Sanitary Landfill Area (HSLA). The GA 2000 is a device designed to detect the rates of gases formed in storage areas [5].

The device has two separate measurement probes. One of them is used for the measurement of the orifice plate based flow rate and the other is used for the measurement of the gas components (CH_4, CO_2, O_2, CO, H_2S parameters). During the measurements it was necessary to isolate the chimney outlet from the atmosphere and direct all the gas to the measuring device. For this reason, a hat suitable for the top of the chimneys was produced in the site works (Figure 20) and sampling was made for the flow rate and gas components from the sampling outlet at the top of the hat [5].

Figure 20. Apparatus specially manufactured for landfill gas measurements [5]

1.3.1. Landfill Gas Measurement Results

The measurements performed in HSLA were carried out at a total of 77 places along with 73 gas chimneys (Z1-Z73) located in E region which is the current dumping area and 4 gas chimneys located in C region which is the old dumping area. The results of the measurements performed are given in Table 2. In the data provided in the table, the measured flow rate and gas component rates (%) in each gas chimney (or test well) are given. However, due to the very low gas velocity from some gas chimneys, the flow rate could not be measured and shown with “Undetectable“ (UD) expression in the Table 2.

Table 2. HSLA gas chimney measurement results, 2011 [5]

Chimney No	Flow (ml/hr)	CH_4 (%)	CO_2 (%)	O_2 (%)	H_2S (ppm)	CO (ppm)
Z 1	UD	2,9	2,9	18,9	17	UD
Z 2	UD	4	3	19,4	1	30
Z 3	UD	11	9	15,2	0	UD
Z 4	UD	10,9	8,3	15,9	UD	UD
Z 5	UD	47,4	35,7	3,3	8	0
Z 6	UD	50,2	36,7	2,8	0	32
Z 7	UD	55,6	41,9	1	27	UD
Z 8	800	56,6	42,6	1	246	UD
Z 9	UD	2,4	3,1	18,3	0	0
Z 10	200	42,4	32,1	4,9	16	27
Z 11	UD	59,4	43,9	0,4	546	>530
Z 12	UD	41,8	32,9	5	24	51
Z 13	100	52,3	37,3	2,2	29	489
Z 14	300	60,5	44,3	0,2	293	37
Z 15	500	58,4	43	0,7	310	>530
Z 16	2600	59,2	45,1	0,2	417	UD
Z 17	UD	53,7	41,5	1,6	181	UD
Z 18	100	53	41,4	1,8	177	17
Z 19	UD	51,2	39,8	2,3	38	>530
Z 20	300	48,6	38,2	3,1	191	UD
Z 21	300	53,7	42	1,5	500	UD
Z 22	400	43	33,5	3,6	16	26
Z 23	UD	29	22,3	9,2	4	0
Z 24	UD	55	39,5	1,7	>530	59
Z 25	3300	58,7	44,2	0,2	>530	UD
Z 26	300	57	44,3	0,5	>530	UD
Z 27	300	51,8	41	1,4	505	UD
Z 28	700	58	43,9	0,5	>530	29
Z 29	UD	36,1	29,1	6,3	8	UD
Z 30	UD	40,6	32	4,7	2	UD
Z 31	UD	56,2	44,1	0,7	84	UD
Z 32	UD	54,3	42,3	1,2	100	UD
Z 33	UD	40,6	33,4	4,8	41	128
Z 34	UD	56,2	42,5	1,1	>530	UD
Z 35	400	57,5	45,5	0,4	>530	UD
Z 36	UD	57	42	0,9	48	UD
Z 37	1600	58,9	44,7	0,5	254	UD
Z 38	400	59	44,5	0,2	335	UD
Z 39	1400	58,7	43,1	0,5	167	UD

Z 40	500	57,6	43,9	0,6	278	UD
Z 41	700	49,7	39,6	2,6	78	UD
Z 42	900	50,5	41,1	1,4	215	UD
Z 43	400	54,6	44,2	0,5	113	UD
Z 44	500	55,7	43,5	0,6	164	>530
Z 45	100	53,3	40,2	1,5	156	19
Z 46	700	55,7	43	0,9	89	96
Z 47	UD	56,1	40,2	1,4	33	UD
Z 48	UD	54,8	42,5	0,3	261	26
Z 49	200	58,6	44,3	0,1	337	0
Z 50	200	60,6	43,5	0,3	UD	65
Z 51	700	60,3	44	0,3	UD	65
Z 52	400	58,9	40,1	0,4	237	UD
Z 53	UD	60,9	44,1	0,2	109	UD
Z 54	UD	60,9	49,9	0,4	98	UD
Z 55	UD	60,5	46,6	0,2	3	UD
Z 56	300	56,6	44,1	0,7	>530	UD
Z 57	900	61,9	45,4	0,1	184	UD
Z 58	UD	19,4	16	12,8	4	UD
Z 59	200	56,1	40,9	0,5	77	UD
Z 60	UD	8,8	0,2	20,6	0	0
Z 61	300	57,8	43,1	1,4	346	49
Z 62	600	64,5	42,4	1	70	137
Z 63	900	57,3	44,1	0,2	18	298
Z 64	1200	58,2	43,5	2	14	428
Z 65	700	52,8	41,3	1,7	319	UD
Z 66	300	45,9	49,1	1,6	26	144
Z 67	200	47,2	43,6	1,9	66	58
Z 68	300	49,6	44,5	1,3	91	UD
Z 69	800	57,2	45,4	0,2	114	112
Z 70	500	59,3	44,1	0,3	177	127
Z 71	1300	58,4	45,4	0,3	134	94
Z 72	600	59	44,5	0,3	215	40
Z 73	1000	58,3	46	0,2	113	98
Z 74	100	27,2	22,8	8,3	4	UD
Z 75	200	41,3	33,7	2,7	4	UD
Z 76	200	51,8	41	1	5	UD
Z 77	UD	52,2	32,5	2	4	UD

When Table 2 is examined, we can see that the CH_4 ratios are between 2.4 and 61.9%, and when the 77 chimneys we examined are considered, the CH_4 average is 49.38%. In this context, we can take the methane average as 50% in the landfill gas modeling calculations to be made for the area. The CH_4 average of 48 chimneys is 55.53%, if we exclude the chimneys where the gas flow rate cannot be detected. This value is a good CH_4 ratio according to the literature based information.

Percentage of CO_2 gas which is another important gas component in the landfill area was measured between 0.2 and 49.9 and the average of 77 chimney measurement results was 37.9%. The CO_2 gas average of the 48 chimneys excluding the gas chimneys of which the gaseous flow rate cannot be determined is 42.8%. The ratio found in carbon dioxide gas as well as in methane gas is a good rate based on the literature and it is at an evaluable level.

It has been determined that the ratio of oxygen gas in the chimney in the region where the measurements have been performed is between 0.1-20.6%. It has been observed that methane gas ratios are low in the chimneys where the oxygen gas ratios are high. This is due to the fact that oxygen is inversely proportional to the bacterial growth in the landfill. Therefore, in places where the oxygen gas is high, there are few bacteria that will produce methane gas. On the other hand, the amount of oxygen shows how much the landfill area is connected to the atmosphere.

Regarding the other gases being measured; it has been found that the hydrogen sulphure gas changes between 0-546 ppm and the average value is calculated as 168 ppm. The carbon monoxide gas exchange interval is 0-530 ppm and the average value is 137 ppm.

2. Harmandali Sanitary Landfill Area (Hsla) Landfill Gas Modeling Studies

2.1. Modeling Studies

The most important factor in determining the energy potential of sanitary solid waste storage areas is the amount of methane gas released from the landfill area. There are various approaches used to determine the amount of landfill gas.

In order to have information about the potential of gas in HSLA, theoretical estimation methods have been applied. All approaches other than the measurement-based approach are based on the current data about the site. This data shows the amount of garbage stored according to the years, the waste characteristic, the duration of operation of the site, and etc.

2.1.1. Literature Based Approximate Estimation

A range of 50-400 L / kg (m^3 / ton) has been given for the amount of theoretical landfill gas (LFG) that can emerge for full-scale solid waste landfill sites [7]. The fact that the given range is such wide (there is a-8-fold difference between the minimum and maximum values) is an indicator that as mentioned above, the garbage characteristics, climate and landfill site-specific characteristics affect the amount of gas to be released.

When the figures given above are used specifically for HSLA, it can be said that the gas potential to be generated for approximately 4 million tons of garbage (2007-2010) stored in the existing domestic waste lot may vary between 200-1,600 million cubic meters.

2.1.2. Estimation with Multi-Phase Model

One of the models used for predicting the formation of landfill gas is the multi-phase model. In this model, the calculations are based on the proportion of biodegradable organic carbon in the waste and the amount of cumulative waste. The mathematical expression of the model is as expressed in Equation 1 [8]:

$$\alpha_t = \varsigma \sum_{i=1}^{3} 1{,}87 A C_{0,i} k_{1,i} e^{-k_{1,i} t} \tag{1}$$

Explanation of the parameters in Equation 1:

αt: The amount of landfill gas formation (Nm^3 / year)

A: Amount of waste (ton)

ς: Factor of production

$C_{o,i}$: The amount of organic carbon (kg C / ton waste)

k1,i: Model variables (given separately for slow, medium and fast degradation)

t: It is expressed with the time elapsed (by years) from the first year when the waste began to be stored

Only fast, medium and slow degradable organic wastes are included in the model. In the model, the types of degradable wastes in the waste are treated in three groups according to their degradation rates. In the literature, it is expressed that for the fast degradable wastes kt, i can be taken as 0,076-0,694 year-1, for medium degradable wastes as 0,046-0,116 years-1, for slow degradable wastes as 0,013-0,076 years-1 [9, 10]. The amount of landfill gas to be formed in the multi-phase model is obtained by the cumulative sum of waste quantities at different degradation rates.

In the scope of the study, considering the stated drawbacks related to the measurement and verification in the light of this information, using the parameters and variables of the multi-phase model, applied specifically in the HSLA. The factor of production (ς) for running the model is 0.58; the amount of organic carbon in the stored waste (Co) is 170 kg/ton waste; the landfill gas formation rate constant (kt, i) was accepted for fast, medium and slow degradable wastes as 0,185years-1, 0,100years -1, 0.030years-1, respectively. At the same time, the characteristics of organic wastes in domestic solid wastes have been included in the calculations and were summarized in Table 3. Fraction-1 in Table 3 demonstrates the proportion of kitchen wastes that is the fast-degradable organic waste in HSLA, Fraction-2 shows medium degradable park-garden wastes in HSLA and Fraction-3 presents the proportion of slow-degradable wastes of paper and derivatives in HSLA [6].

Table 3. Degradation rates of organic wastes in domestic solid waste at different speeds [6]

Category	Fraction-1 (Fast-degradation)	Fraction-2 (Medium-degradation)	Fraction-3 (Slow degradation)
Domestic Waste Component (%)	45	3	12
Rate constant (k)	0,185	0,100	0,030

2.1.2.1. The Multi-Phase Model Estimation Results

In the model, the garbage dump times were taken for a total of four years that it is from of the 2007 year to 2010 year. We considered that storage will not be made after 2010 year.

It was obtained to be the order of about 290 million cubic meters, the amount of gas that may occur by the 2050 year, in the collection of the annual gas quantities. We predict landfill gas formation values that will be emerged until 2050 year. The maximum value of the gas is in 2011, the lowest gas value is in 2050 for this model according to Table 4 [6].

Table 4. The values of potential gas accounted from Multi-Phase model in the Harmandali landfill [6]

Years	Landfill Gas Quantity(Nm^3)	Years	Landfill Gas Quantity (Nm^3)	Years	Landfill Gas Quantity (Nm^3)
2008	11204402,25	2023	5028217,45	2038	1283579,34
2009	20339111,50	2024	4428763,76	2039	1213038,86
2010	27299163,36	2025	3921111,47	2040	1149630,07
2011	31604624,37	2026	3490231,00	2041	1092333,55
2012	26684051,55	2027	3123598,45	2042	1040292,45
2013	22575365,10	2028	2810775,21	2043	992785,67
2014	19142658,95	2029	2543058,24	2044	949205,56
2015	16272882,99	2030	2313189,15	2045	909039,34
2016	13871991,62	2031	2115112,37	2046	871853,63
2017	11861741,93	2032	1943773,76	2047	837281,44
2018	10177031,91	2033	1794953,28	2048	805011,47
2019	8763687,58	2034	1665125,59	2049	774779,10
2020	7576623,24	2035	1551344,19	2050	746358,83
2021	6578311,87	2036	1451144,89	Total	291897215,34
2022	5737513,44	2037	1362465,57		

3. Hsla Landfill Gas Energy Evaluation

Controlling the landfill gas is essential due to the adverse environmental conditions it causes (global warming, bad smell, explosion risk, etc.) and is important because of the calorific value of the methane in the gas and as a result the possibility of it to produce energy.

Energy value of the study area; the amount of energy that can be obtained from the landfill gas can be calculated using the methane gas amount of the landfill and the calorific value of the methane. In the literature, the calorific value of 1 m^3 methane gas is given as 8500 kcal. Accordingly; the amount of energy can be calculated using the Equation 2 [11].

Gross Energy Amount (kWh/year) (2)

Where:

MG: Annual amount of methane gas (Nm^3 methane/year)

MCV: Methane calorific value (8500 kcal/ Nm^3 methane)

(1kcal-kWh conversion 1/860= 1,163 $\times 10^{-3}$ and one year 8760 hours).

The issue to be considered when assessing the landfill gas is that a significant proportion of the total amount of gas has been released within a few years following the dumping of the waste. Therefore, in a covered area, a significant portion of the gas will be released in the first few years following closure, and lower gas exits will be achieved in subsequent years. In this case, the gas values of the yearly basis are as important as the total gas value in the feasibility of an investment to be made in order to obtain (electric) energy.

Within the scope of the HSLA Landfill Gas Measurement Studies, the methane gas ratio obtained in the measurements made in the land and as taken in the literature, the methane ratio of landfill gas was considered to be 50%. Anaerobic digestion (AD) is a biological process that can convert organic substrates to biogas in the absence of oxygen [12]. The gas at the bottom of the reservoir is in contact with the oxygen because the gas does not exit at a higher level.

In the light of this information, the electric energy values to be obtained from the landfill gas are presented in Table 5 electric energy potential values have been calculated for Multi-Phase Model (model used to determine gas quantity) [6].

Table 5. The landfill gas energy values accounted from Multi-Phase model in the Harmandali landfill

Years	Values of energy (kWh)	Years	Values of energy (kWh)	Years	Values of energy (kWh)
2008	6320,84	2023	2836,62	2038	724,12
2009	11474,09	2024	2498,44	2039	684,32
2010	15400,53	2025	2212,05	2040	648,55
2011	17829,41	2026	1968,98	2041	616,23
2012	15053,52	2027	1762,14	2042	586,87
2013	12735,65	2028	1585,67	2043	560,07
2014	10799,13	2029	1434,64	2044	535,48
2015	9180,17	2030	1304,96	2045	512,82
2016	7825,74	2031	1193,22	2046	491,85
2017	6691,68	2032	1096,56	2047	472,34
2018	5741,26	2033	1012,60	2048	454,14
2019	4943,94	2034	939,36	2049	437,08
2020	4274,27	2035	875,17	2050	421,05
2021	3711,08	2036	818,65	Total	164670,70
2022	3236,76	2037	768,62		

4. Results and Discussion

The application of renewable energy sources might modify not only the background system, but also further downstream aspects, such as consumer behavior. This effect is, however, strongly context and technology dependent [13]. In this context, the data obtained in HSLA plant gas is important.

The results of approaches used to determine the potential of Harmandali Landfill Gas (literature based approximations, mathematical model) and electrical energy values obtained from these models are summarized in Table 6 following.

The results we have obtained from the mathematical estimation method we use to determine the potential of the area's depositional gas are highly optimistic.

Table 6. Total Values and Electric Energy Values of Models Used in Determining Landfill Gas Potential in Harmandali Landfill

Name of the Estimation Method	Methane Gas Quantities Generated (Nm3) and Electricity Values (kWh)
Literature Based Approximate Prediction – Low Speed	100.000.000
High Speed	800.000.000
Multi-Phase model estimated gas quantity	145.948.608
Multi-Phase Model estimated electrical value	164670,70 (kWh)

Electrical energy potential values of model (the model used to determine the amount of gas) are calculated separately. The approaches are used to determine the potential for landfill gas in the Harmandali landfill (approximately estimated based on the literature and mathematical model) and the results of electrical energy values obtained from these models as follows:

Test chimneys: 10,000 Nm^3, the multi-phase model: 291,897,215 Nm^3. Based Literature-based approximate estimation; low speed: 200,000,000 Nm^3, High speed: 1,600,000,000 Nm^3. The results obtained from the landfill gas (as the potential gas used in the mathematical method) in the Harmandali Landfill are quite optimistic.

The amount of the landfill gas was calculated on the annual basis through mathematical method while it was achieved by summing the total amount of the gas. This enabled us to consider the advantages of the gas provided in terms of energy aspects. The amount of the methane gas was calculated on an annual basis, as shown in Figure 21 graphically. The maximum formation of the methane gas over a period from 2010 to 2013 was determined using the mathematical method.

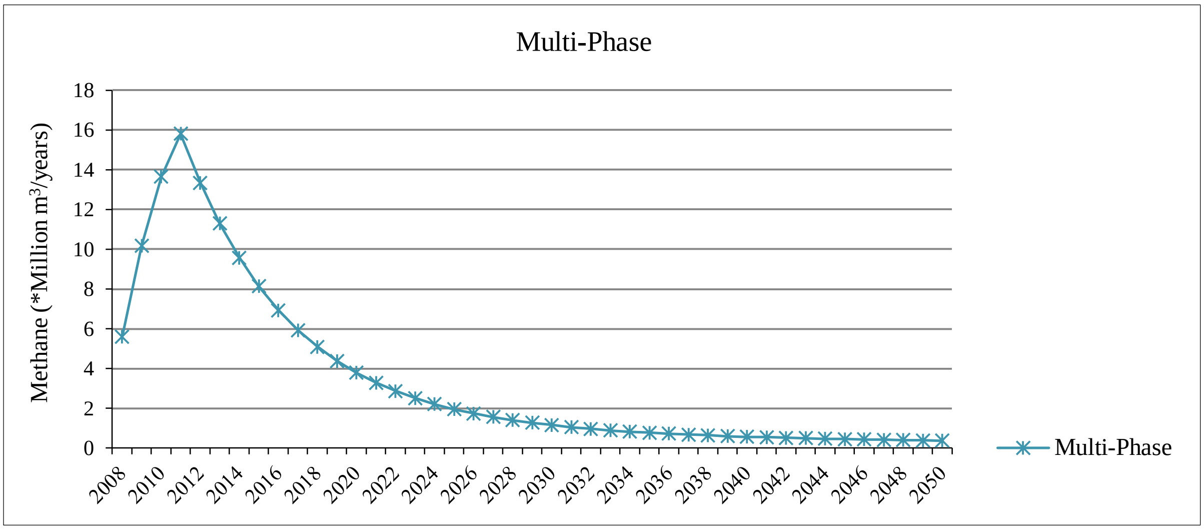


Figure 21. Variation of Annual Methane Gas Amount of Models (Literature Based Approximate Prediction and Multi-Phase Model) Used in Landfill Gas Calculation [6]

It has been determined that the amount of domestic solid waste that is examined in Harmandali Landfill and the mathematical modeling calculations considered has a high amount of depot gas potential. However, when considering an energy investment to be made in the field, the account must account for 60% of the gas potential of storage areas to be generated over the first 10 years [6].

When we think about the field in which we are working, the multi-phase model will give better results in the investment study. Because the Multi-Phase model estimates the organic-based waste (high carbon content) in the waste in calculations. Therefore, the amounts of gas to be released from the field will be close to real values. In this context, the data for the energy plant to be constructed based on the depot gas to be produced by the Multi-Phase model are given in Table 5.

The data in Table 5 reflects only the process of establishing and operating the energy plant to be built in the area (does not include information on operating and operating conditions of the area).

According to the results obtained from the two different models used, the time period for which methane gas formation is highest is between 2010 and 2013.

In the following, the results obtained from the models used are discussed and compared with each other (literature based approximations, mathematical model). 69% of the gas in the multi-phase model were emerged over the ten years in the Harmandali landfill.

5. Conclusions

Harmandali Landfill have high landfill gas potential obtained from municipal solid waste in area taken into account the measurement and mathematical modeling. Especially, due to the high energy values of solid waste materials, modeling calculations were high.

An important benefit of the leachate recycle is that the biochemical cycle required for the anaerobic digestion of the solid wastes in the repository becomes homogenous. Thus, the time required for stabilization of organic materials can be reduced 80-90%. In this system, the leaking water can be recycled by being sprayed on the waste site or given to injection wells. This will provide a significant benefit to the Harmandali landfill.

Landfill gas in the current circumstances in Harmandali Landfill is outside from area to the atmosphere. It is not desirable due to pose health and environmental impacts to giving freely into the atmosphere without being subjected to any processing. It can be reduced the impact of the environment and human health with landfill gas is collected and precautions to be taken to evaluate. Precautions to control landfill gas are summarized below;

- The layer of the upper cover of landfill should be made impermeable; points of gas leakage caused by shifts in the structure should be closed with the impermeable area or the soil, the improvement of compacting.
- Landfill gas should be burned in the flare unit or the use of energy production to prevent giving atmosphere free.
- The gas collection system is required for the establishment of a landfill gas collection, so that steps have been taken for the establishment of electric generation facility.

- At the first stage, a 4.5 MW power plant to be established in the Harmandali Landfill will provide the following contributions;
  - 8964 tons CH_4/yr will be reduced with methane emitted directly from landfill
  - This value (8964 tons CH_4/yr) is equivalent annual greenhouse gas emissions from 33486 passenger vehicles. Also, this value is equivalent carbon sequestered annually 36414 acres of pine or fir forests
  - It will be offset 21277 tons CO_2/yr carbon dioxide from avoiding the use of fossil fuels
  - Power plant will be powered approximately 2657 homes based on project size entered.

The Kyoto Protocol, the environment and affect climate as negative and six gases that cause the greenhouse effect [Carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), sulfur hexafluoride (SF6)], which aims at reducing the release into the atmosphere.

According to Article 3 of the Kyoto Protocol of the United Nations Framework Convention on Climate Change, it is envisaged to reduce the atmospheric emissions of gases causing the greenhouse effect in 1990 for the period of 2008-2012 by 5%.

Given the law and the Kyoto Protocol, Turkey will need to reduce greenhouse gas emissions. Within this scope, reduction of greenhouse gas emissions to be achieved without working in Izmir will contribute to our country in a significant respect and contribution.

6. Acknowledgements

The work has been presented at the 2nd Renewable Energy Sources - Research and Business (RESRB) conference held on 19-21 June 2017 in Wrocław (Poland).

I would like to extend my gratitude to the Izmir Mega Municipality staff and managers for making it possible for me to be informed in this study.

7. References

[1] Bove, Roberto, and Piero Lunghi. “Electric Power Generation from Landfill Gas Using Traditional and Innovative Technologies.” Energy Conversion and Management 47, no. 11–12 (July 2006): 1391–1401. doi:10.1016/j.enconman.2005.08.017.

[2] US EPA, Municipal solid waste generation, recycling, and disposal in the United States: Facts and figures for 2008. <www.epa.gov/osw/nonhaz/ municipal/pubs/msw2008rpt.pdf> (Accessed on 12 August 2010).

[3] TUIK, İstatistiklerle çevre, http://www.tuik.gov.tr (Erişim Tarihi: 2016) (In Turkish).

[4] IBB, İzmir Büyükşehir Belediyesi Katı Atık İşletmeler Şube Müdürlüğü Entegre Atık Yönetim Planı, Mayıs, 2012 (In Turkish).

[5] IBB, “Atıkların Düzenli Depolanmasına Dair Yönetmelik Kapsamında Hazırlanan HDDA İyileştirme Planı”, İzmir Büyükşehir Belediyesi İzsu Genel Müdürlüğü, İzmir, Türkiye, 2011 (In Turkish).

[6] Çakır, A.K., İzmir Harmandalı Deponisindeki Metan Gazı Potansiyelinin Belirlenmesi ve Elektrik Enerjisi Eldesinin Sağlanması, Doktora Tezi, Fen Bilimleri Enstitüsü, Ege Üniversitesi, Eylül, 2012 (In Turkish).

[7] Ham R.R. and Barlaz M.A. Measurements and prediction of landfill gas quality and quantity / ISWA International sanitary landfill symposium. Cagliari, Italy, P. VIII-1 VIII-23, 1987.

[8] Jacobs J. and Scharff H., “Comparison of Methane Emission Models and Methane Emission Measurements”, NV Afvalzorg, Netherlands, 2001.

[9] Scharff, Heijo, and Joeri Jacobs. “Applying Guidance for Methane Emission Estimation for Landfills.” Waste Management 26, no. 4 (January 2006): 417–429. doi:10.1016/j.wasman.2005.11.015.

[10] Kamalan, H., M. Sabour, and N. Shariatmad. “A Review on Available Landfill Gas Models.” Journal of Environmental Science and Technology 4, no. 2 (February 1, 2011): 79–92. doi:10.3923/jest.2011.79.92.

[11] Pecora, V., Figueiredo, N.J.V., Coelho, S.T., Velazquez, S.M.S.G., “Electricity and Illumination Generation Potential by Gas through Utulization of Biogas from Sanitary Landfill”, World Climate&Energy Event, 2009.

[12] Zhang, Quanguo, Jianjun Hu, and Duu-Jong Lee. “Biogas from Anaerobic Digestion Processes: Research Updates.” Renewable Energy 98 (December 2016): 108–119. doi:10.1016/j.renene.2016.02.029.

[13] Pehnt, Martin. “Dynamic Life Cycle Assessment (LCA) of Renewable Energy Technologies.” Renewable Energy 31, no. 1 (January 2006): 55–71. doi:10.1016/j.renene.2005.03.002.