Correlation between Methane-concentration and -emission from old Landfills in Sweden

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CORRELATION BETWEEN METHANE-CONCENTRATION AND METHANE-EMISSION FROM OLD LANDFILLS IN SWEDEN

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Abstract

There are several thousands of old landfills in Sweden and they are often located close to cities on valuable land, three of these landfills are Lassabacka in Varberg, Härlövsängar in Kristianstad and Onsjöparken in Eslöv. On these landfill methane- emission and concentration measurements are done with an IR Chamber called ULTRAMAT 23, a probe and the gas analyser LFG 20. This was done to see if there is any correlation between the emission and concentration of methane and to quantify the emission. This is done to see if easier concentration measurements are possible to do to get a realistic estimation of the emission and to get an overview of the paste and future emission and settlement. Theoretical productions on these sites will also be calculated with the US EPA Gas Emission Model to compare it with the measured results.

There is a big difference between theoretical methane emission and measured methane emission at all three landfills. Thus, based on the results the theoretical emission is not a good estimation for the actual emission. From the theoretical results there have been years where it would have been profitable to extract gas for energy production at all the landfills, but today none of the landfills are of any value when looking at energy production.

From the measurements a correlation between emission of methane and the methane concentration in the soil gas could be seen, from that an exposure limit and a lower explosion limit can be set to 0,27 $g/m^2/h$. Based on the relationship it is also possible to use only the measurements with the probe and concentration measurement to evaluate if there is any methane emission from a landfill.

Acknowledgement

Thanks to Tyréns AB in Kristianstad that gave me a desk and a computer and everything else that I needed to do this master thesis and especially to Bertil Sundlöf that came up with the idea for this thesis. Also thanks to all the people at Tyréns in Kristianstad that have treated me like a co-worker and have given me many good advices. Thanks also to my supervisor Mohammad Aljaradin at the department of Water Resource Engineering at Lund University. I also need to thank Jakob Sivertsson for assisting in the field measurements.

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1. Introduction

Climate change is caused by an increasing level of greenhouse gases in the atmosphere. Methane gas is a greenhouse gas that is 23 times more harmful than the same volume of carbon dioxide (IPCC, 2009). One of the main sources for methane is landfills and most of the methane gas produced from the landfills leak into the atmosphere and contribute to global warming. There are several thousands of old landfills in Sweden, some of these landfills are used to utilize methane gas and use it as renewable energy.
Old landfills are often located close to cities on valuable land, these landfills are often converted to parks and walking areas after closure, but due to the production of methane in old landfills there is not much construction on these sites due to the instability of the ground for buildings. Another concern is that there is no clear usable regulation and exposure limits for methane gas from old landfills in order to know at which production rate is dangerous for humans.

The correlation between methane concentration and methane production on old landfills has been investigated earlier by Ljungber (2009) and a correlation was found using laser technology. In this work investigations for the correlation between methane emission and methane concentration at three old landfills in the southern part of Sweden will be conducted. This is done in order to see if the easier concentration measurements are enough to get a realistic estimation. The theoretical productions on these sites will also be calculated to compare it with the measured results.

2. Theory

2.1. Landfills & Methane gas

In developing countries, landfilling is the most common way to dispose municipal solid waste (MSW) (Mor et. al, 2006), and the same applies for industrial countries including Sweden. During the 20th century the economical and cultural development has improved the standard of living and changed consumer habits. This change the physical composition of MSW, the organic and inorganic fractions like food, paper, wood, plastics, glass, metal and other inert materials became of concern. With these contents together with poorly maintained landfills several environmental problems arise for example groundwater contamination and leakage of methane gas (Mor et. al, 2006). However with growing awareness and regulations concerning landfills there has been a change in the waste management in Sweden to fewer, bigger and more controlled landfills. It started with the Swedish Environmental Protection act in 1969, where a permit for disposal operations was introduced (Miljöskyddslag (1969:387)). Followed by the European Union's "Landfill directives" in 1999 which encouraging re-use, recycling and recovery (Council Directive 1999/31/EC) and since 2002, it is prohibited to deposit combustible waste. In 2005 it was extended to ban all organic waste, with some exceptions (SFS 2001:512).

Globally, the most MSW is dumped in non-regulated landfills and generate landfill gas (LFG) as a by-product. LFG is generated when organic material decomposes anaerobically, consisting of 45% to 60% methane gas, 40% to 60% carbon dioxide, and 2% to 9% other gases which are mostly emitted to the atmosphere (Metz, et.al, 2007). The international Panel on Climatate Change (IPCC) has estimated that methane emission from landfills account for 3–19% of the anthropogenic sources in the world and is considered as a large contributor to global warming after agricultural activity and losses from fossil fuel distribution (IPCC, 1996) (Metz et. al, 2007).

When the methane is not emitted to the atmosphere it is flammable. In some cases mixed with air it can be explosive. Methane also has high energy value which makes it economically possible to recover and use (Ljungberg et. al, 2009). Part of the methane generated in landfills can be captured and used as a renewable energy source to generate electricity, as heat or as fuel. Only 10% of the possible energy is used globally so when methane escapes into the atmosphere, it has a global warming potential estimated to be 23 times more harmful than that of the same volume of carbon dioxide (IPCC, 2009) (Themelis et. al, 2007). The concentrations of methane in the atmosphere are increasing globally at 0.6-0.8% per year (Samuelsson et. al, 2001). USEPA have estimated that the global methane emission from landfills in the year 2000 was 30-70 million tonnes (Thermelis et. al, 2007). In Sweden the emissions of methane gas from landfills are approximately 0.3 tonnes every year (Dahlin, 2009), but are decreasing (Ljungberg et. al, 2009).

In order to put regulations on the emissions of methane into the atmosphere, the methane gas leakage must first be identified and measured. In Sweden, there are no official emission limits for landfills, neither qualitative nor quantitative, but the EU has regulations for management of methane emissions from landfills, the E-PRTR regulations that were implemented in 2007. These regulations state that methane emissions from landfills must either be (a) measured on site, (b) calculated using emission models, or (c) estimated by field experts (Ljungberg et. al, 2009).

2.2. The different phases

When waste is landfilled, organic components almost immediately start to decompose and go through a biochemical process; the first phase is hydrolysis, where aerobic bacteria consume oxygen to break down longer molecular chains of carbohydrates, proteins and lipids into monomeric compounds. This will continue for as long as atmospheric air is present, which is often as long as the waste is close to the surface. The by-product of this process is carbon dioxide and the nitrogen level is also high through this phase, as demonstrated in figure 2. This phase can last for days or months depending on how much oxygen is present. (Themelis et. al, 2007, ATSTR, 2001).

The main bioreaction in a landfill is processed in the following anaerobic steps: acidogenesis, acetogenesis and methanogenesis, as shown in figure 1 (El-Fadel et. al, 1997).

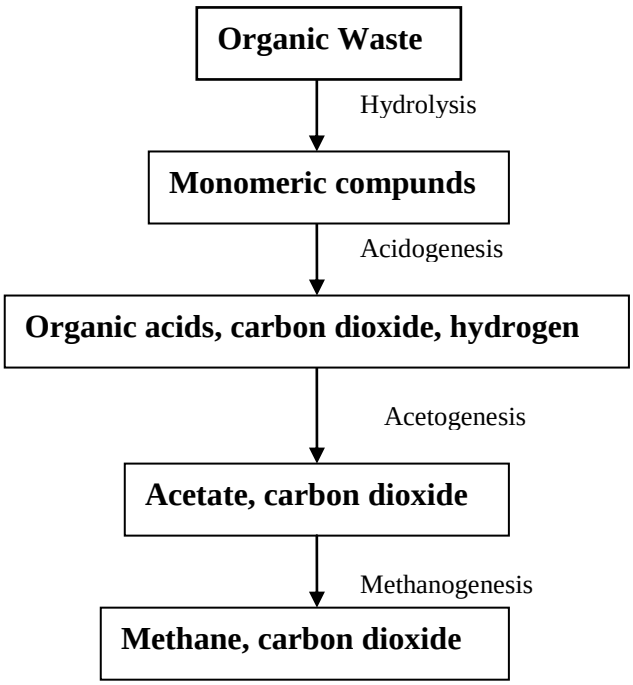

Figure 1. The four phases of decomposition, hydrolysis, acidogenesis, acetogenesis and methanogenesis.

Acidogenesis is the second phase that commences, once all oxygen has been consumed, with an anaerobic process in which the monomeric compounds are converted by acid-forming bacteria to organic acids, carbon dioxide and hydrogen (Themelis et. al, 2007). This makes the landfill very acidic and, together with moisture, makes some nutrients dissolve while making nitrogen and phosphorus available (ATSDR, 2001).

Acetogenesis is the third phase that commences when a special kind of anaerobic bacteria consumes the organic acids from the acidogenesis and forms acetate, also an organic acid. Due to this process, the landfill becomes a more neutral environment and that is the start for the methane-producing bacteria. The methane-producing bacteria and the acid-producing bacteria work in symbiosis. The methane-producing bacteria consume the carbon dioxide and acetate formed by the acid-producing bacteria, which are toxic to the acid producing bacteria

(Themelis et. al, 2007), (ADSTR, 2001). Methane is formed when the methanogenic bacteria, when breaking down the acids to methane and carbon dioxide, or by reducing carbon dioxide with hydrogen.It is important that the landfill keep moist so the anaerobic reaction continue (Themelis et. al, 2007).

Methanogenesis is the fourth phase and begins when both the composition and production rates of landfill gas remain relatively constant; this is shown in figure 2. The landfill gas usually contains 45% to 60% methane, 40% to 60% carbon dioxide, and 2% to 9% other gases. When entering this phase, gas is produced at a stable rate for about 20 years, but gas will continue to be emitted for up to 50 years or even more (ATSDR, 2001).

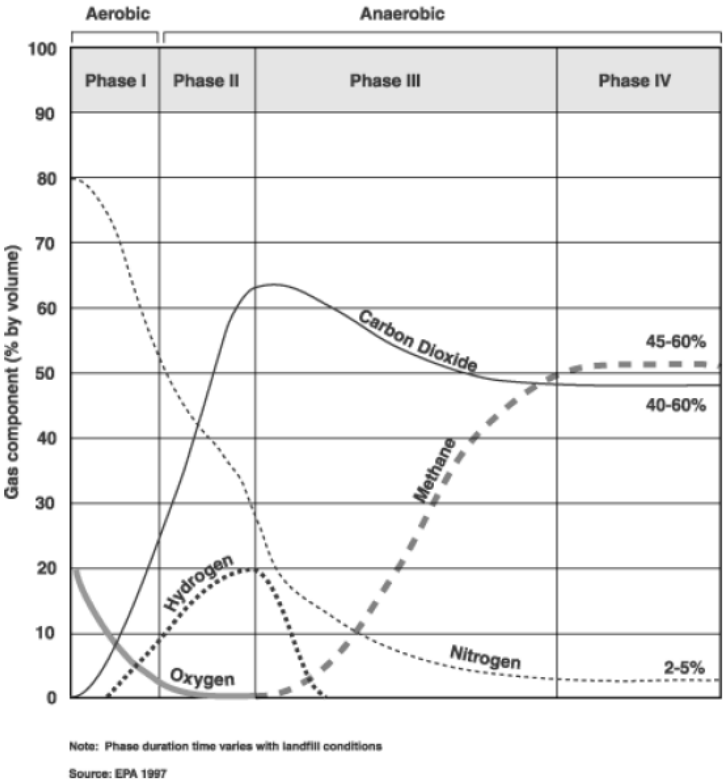

Figure 2. The gas component during the different phases (ATSDR, 2001).

2.3. Gas movement

Landfill gases are lighter than air, so that is why methane naturally moves upwards through the landfill surface. When that is not possible due to compact waste the gas need to move horizontally to other areas where it can continue upward movement (ATSDR, 2001). How gas moves in soil is very complicated, it fills the available space and then seems to migrate from landfills through the surrounding soil where there is least resistance (O´leary & Walsh, 2003). The migration rate depends strongly on weather conditions; for example, when the pressure drops the gas is forced out from the landfill into the surrounding soil. Wet soil and frozen ground trap the gas within the landfill but also force the gas to migrate further away into the soil surrounding the landfill (O´leary & Whalsh, 2003). The different factors that can affect the flow of landfill gas are seen in figure 3.

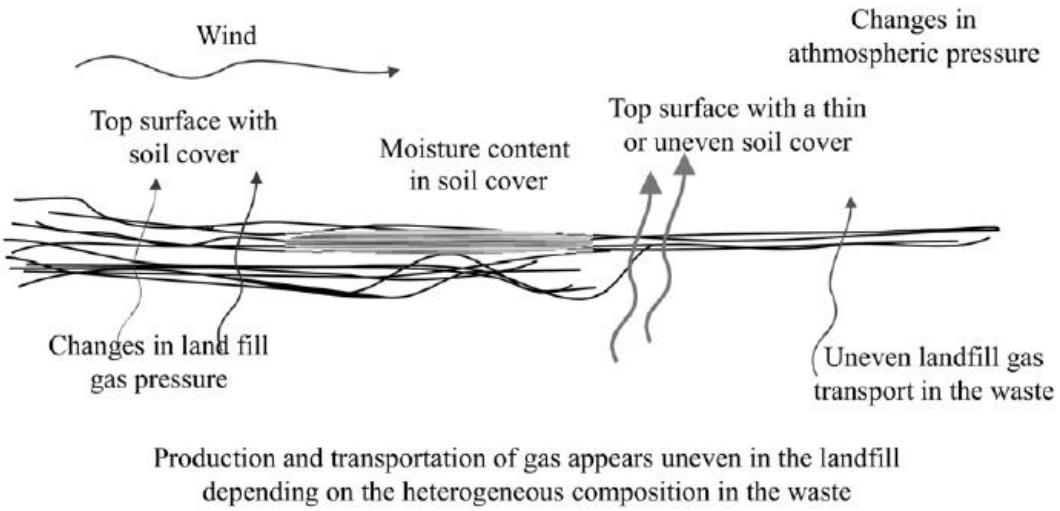

Figure 3. Different variables that influence the flow of landfill gas through the landfill surface. (Ljungberg et.al, 2009)

There are three main factors in the migration of landfill gases: diffusion, pressure and permeability.

Diffusion is movement that depends on concentration, gases normally move move from areas with high gas concentration to areas with lower gas concentration and that is why gas from landfills tends to move to the surrounding area with lower gas concentration (Scheutz et.al, 2009).

Another type of movement is due to pressure. When gas accumulates in landfill it creates areas of high pressure, where gas movements are restricted by compacted soil covers, and areas of low pressure, where the gas can move freely. This variation in pressure causes the gas to move around the landfill, in a process also known as convection (ATSDR, 2001). When more gas is produced, the pressure inside the landfill becomes higher than the atmospheric pressure and it moves out into the atmosphere.

The third factor is permeability, when gas migrates to areas of least resistance, which is how well gases and liquids flow through connected spaces and pores in waste and soil. Gas rather moves through dry, sandy soils with high permeability, rather than moist clay with low permeability (ATSDR, 2001).

2.4. Settlements

Settlements are described by El-Fadel (1997) as losses in volume of decomposing waste. When a landfill is closed the settlements will make it difficult to develop the area further, because of the waste are decomposing and that will weaken the strength of the ground.
The volume losses also depend on whether the wastes are not compacted enough. How fast the landfill will settle depends mainly on what type of waste is in the landfill, how the landfill is managed, and factors that affect the degradation of the wastes – the most important of which is moisture. An estimation of the total settlement of a landfill is from 25 to 50% of its

original thickness, where 15% is due to decomposition of the waste (Stearns, 1987). El-Fadel (1997) also emphasize that it is often an uneven settlement because of the great variation in waste composition which can create extensive damages on all kinds of buildings on the landfill. Most long-term settlement is due to biodegradation, which is also what most effects settlement in old landfills (Leonard and Floom, 2000). To estimate future settlement due to biodegradation, equation 1 is used, but on average the estimated settlement is about 10% higher than if the settlement is measured (Leonard and Floom, 2000).

$$S_T = O \cdot T_R \cdot S_F \qquad \text{(Equation 1)}$$

S_T = Estimated future settlement due to biodegradation
O= The percentage of decomposable organics by weight (0,33)
T_R = Thickness of waste
S_F = Settlement factor = a_1/a_T
a_1 = Future gas generation
a_T = Total gas generation

2.5. Energy use

The great energy value in methane results in that methane gas are captured and used as a renewable energy source, as fuel or to generate electricity or heat. But only 10% of possible energy is captured globally (IPCC, 2009) (Themelis et. al, 2007). Not only do extractions of gas reduce the emissions of methane to minimize climate change, but also substitute fossil fuels like oil and coal that are contributing to global warming. The most common ways according Willumsen (2001) are to use the gas as fuel in a gas engine to run electrical generators, in gas boilers for production of hot water for heating, upgrading the landfill gas to natural gas quality, or compressing it to use as fuel in vehicles or in fuel cells.

A landfill gas plant consists of several different types of extraction and utilization systems; figure 4 shows a typical landfill gas plant.

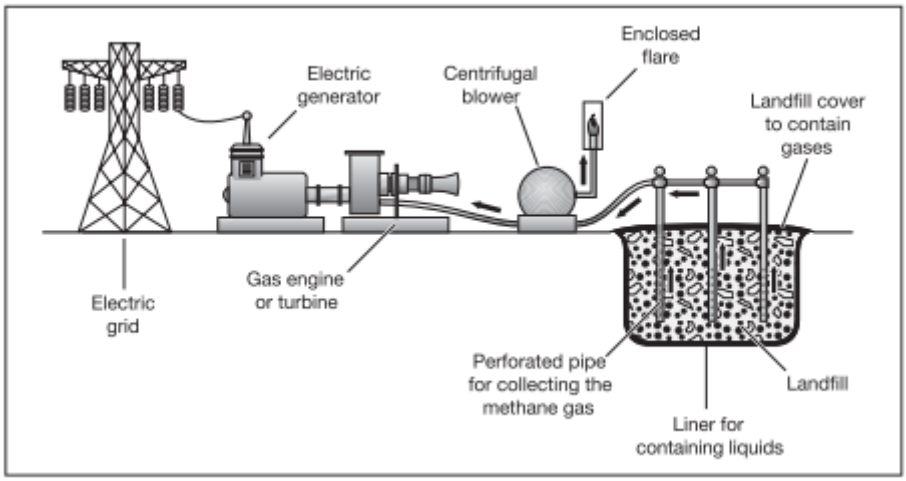

Figure 4. A typical landfill gas plant.
(InfinitePower, 2006)

The extraction system can consist of vertical or horizontal pipes, and sometimes a membrane covering where the gas is collected. The gas is sucked out of the landfill by pumps or a compressor and delivered to the utilization plant (Willumsen, 2001).

Under perfect conditions, one tonne of waste can produce up to 150-200m^3 of gas (Hayles, 2006), and a minimum extraction is 5 m^3 gas per tonne waste and year and every m^3 gives 4-4,75 kWh per year (Gatuförvaltningen Varberg, 1983). A mean value from Willumsen (2001) is 4,75 kWh/m^3.

2.6. Build on old landfills

In many countries there is a lack of land used for building and even in countries where this is not the case, it is still argued that old landfills should be re-used if possible. Settlement and methane gas are the main problems when re-using old landfills, as well as foundation support and workers' health and safety (McLoughlin, 2001). Before anything can be constructed on a landfill site estimations must be made on expected settlement. If the landfills are not deep, approximately three to four meters, it is easiest to find solutions like digging out and replacing the wastes. If that is not possible, buildings are most often erected on base slabs supported on piles that stand firm in the ground below; buildings like this will not have any problems with settlement (Last, 2006). One remaining problem is to prevent landfill gas from accumulating and entering buildings. If accumulated in a confined area with an ignition source, methane can explode, which is why all buildings on or near a landfill should have some landfill gas protection measures (McLoughlin, 2001) (MDNR, 2006). Old landfills can contain hazardous waste like solvents and asbestos which were landfilled before it was regulated, so waste workers have to be properly trained to handle these materials in a safe way when building (McLoughlin, 2001). In Malmö's harbour wastes are dug up and mixed with cement and returned to get a stabilised foundation and to eliminate the risk of settlement and methane leakages (Svevia, 2010).

2.7. Risk for Humans

Methane gas is odourless and colourless and the greatest risk for humans is explosion. The lower explosive limit is 5 % (50000 ppm) by volume air and that is also set as the exposure limit for humans, the upper explosion limit are 15 % (COT, 2000). In higher concentrations (over 30 %), methane displaces oxygen in the air and can have harmful effects like unconsciousness. The odour from landfill gas comes from low-level chemical emissions like sulphides and ammonia which are produced during decomposition. They are also flammable but very unlikely to be present in concentration above their lower explosive limit (ATSDR, 2001).

2.8. Measurements

There are a large number of methods when measuring methane gas, such as on-site and field measurements. They can identify and measure methane gas or generate emission rate information and air concentration data. What is suitable depends on economics, time and equipment available (EPA, 2005). It also depends on what information is needed, it could be detecting point source emissions and measuring concentration, quantifying the size of leakages or measuring areas, or both leakage detection and quantification (Ljungberg et. al., 2009). This could be done by soil gas monitoring, near surface monitoring, emission

monitoring, ambient air monitoring or indoor air monitoring (ATSDR, 2001). For all these different measurements there are many different methods.

Decomposition occur in the soil, that is why it is interesting to measure the concentration of soil gases to get an idea of the accumulation and migration rate of the landfill. It is also done around the landfill to see if surrounding buildings have methane concentrations close to explosion limits (ATSDR, 2001). The soil gas measurements can be done for different types of adsorbents or probes. The adsorbents are buried in the soil for a couple of days and then sent to the lab for analysis while the probe is put in the subsurface and gas is drawn out with a pump and analyzed with a portable instrument (Thompson and Marrin, 1987) (Ljungberg et. al., 2009).
Relatively few methods are fully developed and available for direct quantification of emission of gases from surfaces. The most common is to measure the rate by which chemicals are released with the chamber method, but there are also concentration measurements in combination with a trace gas or Vertical Radial Plume Mapping (VRPM) (Ljungberg et.el., 2009). The chamber method can be divided into static chamber and dynamic chamber. Static chambers are measurements of landfill gas emission on the surface of a landfill using an enclosed chamber. The increase in methane concentration in the chamber is used to calculate the flow from the landfill surface. Dynamic chambers are measurements of landfill gas emission on the surface of a landfill using an open chamber. The flow is calculated through simultaneous measurement through the chamber and the concentration of methane. (Ljunberg et.al., 2009).

For quantification of methane leakage for entire landfills, one method used is tracer gas together with methane measurements. A tracer gas is released with a known flow ocer the landfill, and the plume from this discharge is assumed to correspond with the emission of methane from the landfill. Both the methane and tracer gas concentrations are then measured in the plume that is formed downwind from the landfill (Ljungberg et. al., 2009).

Vertical Radial Plum Mapping (VRPM) is a new method from the U.S. Environmental Protection Agency (US EPA) that measures the flow from parts of the landfill with a laser instrument and reflectors in each corner of the area under investigation (Ljungberg et. el., 2009).

3. Theoretical production

Since landfills are a great source of the global methane emission, it is important to have tools to estimate the emissions. That is because there is often a lack of landfill data, so the calculation is based on many assumptions (Peer et.al., 1993). To be able to use the methane gas from landfills for energy production there is a great importance in having reliable emission estimations to base decisions on. There are several models to estimate the emission from landfills, the main ones used today are the Intergovernmental Panel on Climate Changes **(**IPCCs**)** waste model, FOD (First order decay) and US EPA Gas emission model, which will be used in the calculations.

Data errors include measurement errors that can occur from limitations of equipment or methods. Model uncertainty can be equal to or more important than data errors in its contribution to the uncertainty of emission estimations. Two key variables are the amount of waste annually placed in landfills and the amount of methane emitted from a given mass of waste. The methane potential is a function of the amount of degradable organic carbon in the refuse and the conditions under which it is degraded (Peer et.al., 1993).

3.1. US EPA Gas Emission Model

The Landfill Gas Emissions Model (Land GEM) is an estimation tool, done in a Microsoft Excel spread sheet, which can be used to estimate emission rates for total landfill gas, methane, carbon dioxide, non methane organic compounds, and individual air pollutants from municipal solid waste landfills. Land GEM can use either specific data from the site to estimate emissions or standard parameters if no specific data for the landfill are available (U.S. EPA, 2005). It is based on a first order decomposition rate seen in equation 2, and is used to estimate the emission from the decomposition of the waste at the landfill (U.S. EPA, 2005).

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}} \qquad \text{(Equation 2)}$$

Q_{CH4} = annual methane generation in the year of calculation (m^3/year)
I = 1-year time increment
n = (year of the calculation) – (initial year of waste acceptance)
j = 0,1-year time increment
k = methane generation rate (year $^{-1}$)
L_0 = potential methane generation capacity (m^2/Mg)
M_i = mass of waste accepted in the i^{th} year (Mg)
t_{ij} = age of the j^{th} section of waste mass M_i accepted in the i^{th} year (decimal years, e.g., 3.2 years)

LandGEM is a screening tool, the better the input data, the better the estimations. Often, there are limitations with available data, like waste quantity, composition, different designs and how the landfill is operated (U.S. EPA, 2005).

More information can be found in the Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide.

4. Site description

The landfills that are investigated in this paper are Lassabacka in Varberg, Härlövsängar in Kristianstad and Onsjöparken in Eslöv (figure 5). These landfills are chosen because they have been investigated earlier, and methane gas was detected.

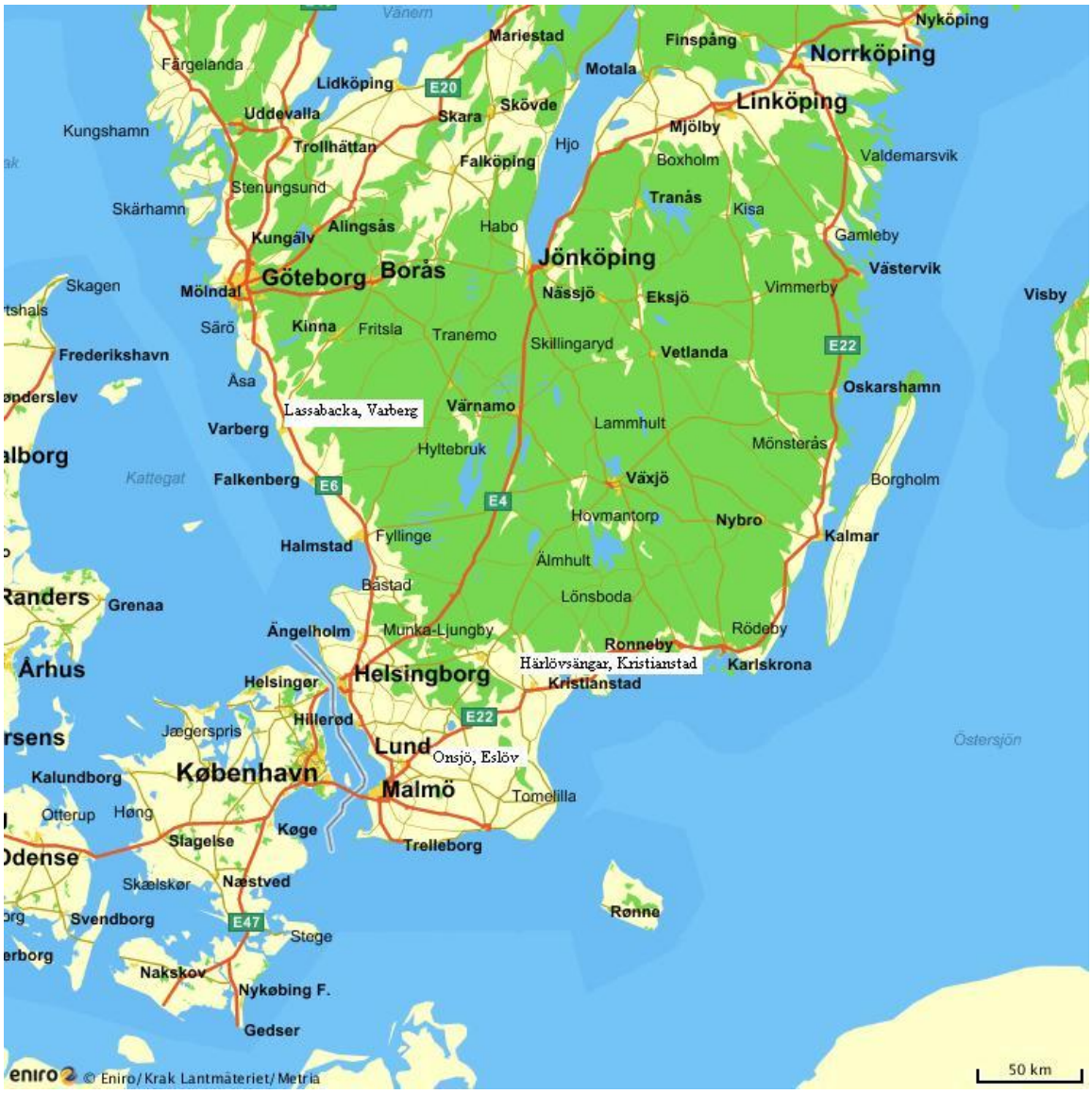

Figure 5. The location of investigated landfills (Lassabacka, Härlövsängar and Onsjöparken). (Eniro, 2010)

4.1. Lassabacka

Lassabacka landfill is located at the shoreline close to Varberg and the Gettön Natural Reserve, as depicted in figure 6 and 7. The size of Lassabacka is approximately 180 000 square meters. A natural area and an ornithological station are also located on the landfill. A rough estimation of the waste in the landfill is 1 152 000 tonnes, with a mean depth of four meters. The waste consists of household-, industrial-, construction-, hospital- and slaughterhouse wastes. The landfill was opened in 1962 and closed in 1979. (Rosander, 2009).

Figure 6. Aerial photo of Lassabacka.

(Eniro, 2010).

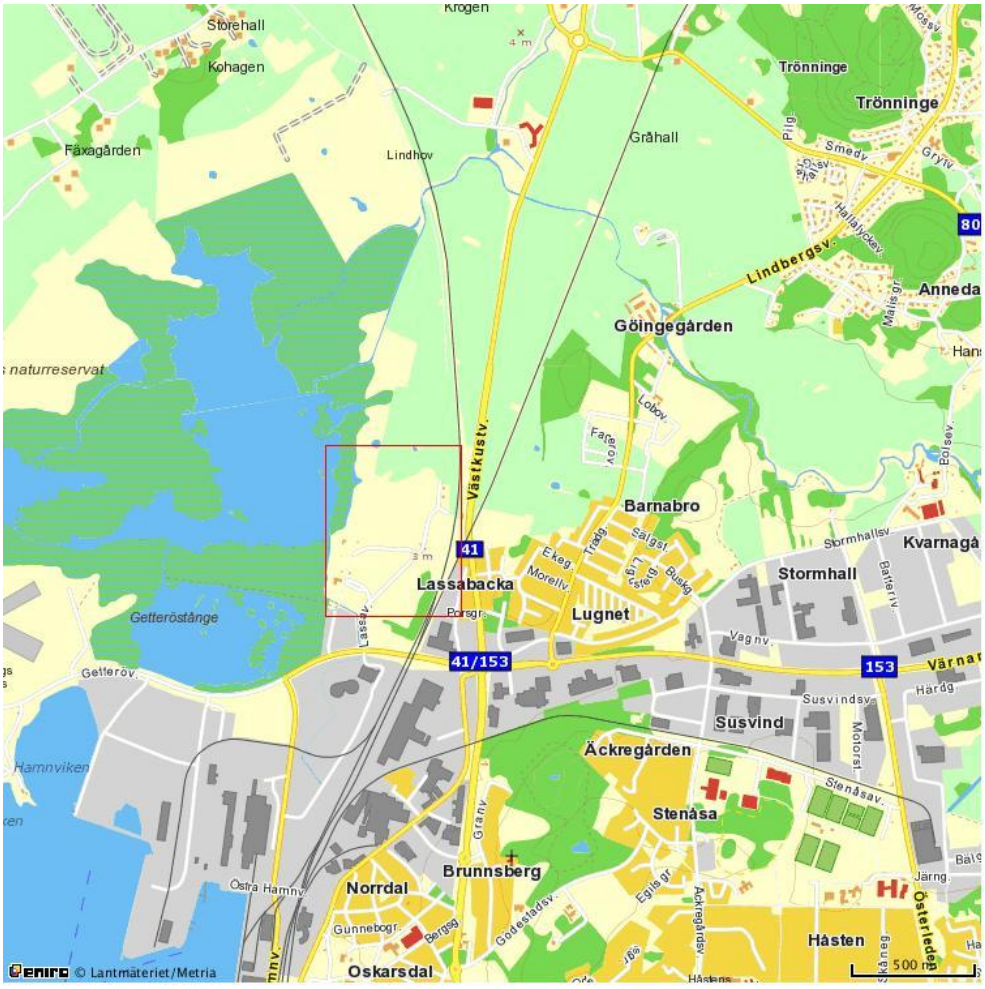

Figure 7. The location of Lassebacka in Varberg.
(Eniro, 2010)

4.2. Härlövs ängar

Härlövs ängar is approximately 560 000 square meters in total, and is divided into western and eastern sides, measuring 340 000 and 220 000 square meters, respectively. A rough estimation of the waste in the landfill is 1 056 000 tonnes with a mean depth of three meters. It is located in Kristianstad (figure 9) and was earlier a wetland, but in the 1960s the area started to be used as a garbage dump. The part closest to the river Helgeå was closed in the beginning of the 1970s and is now covered with grass and used as a strolling area (figure 8), and the eastern part of the landfill was closed in 2002 and is now being converted for planting (Erlandsson et.al., 2003).

Figure 8. Aerial photo of Härlövsängar. (Eniro, 2010).

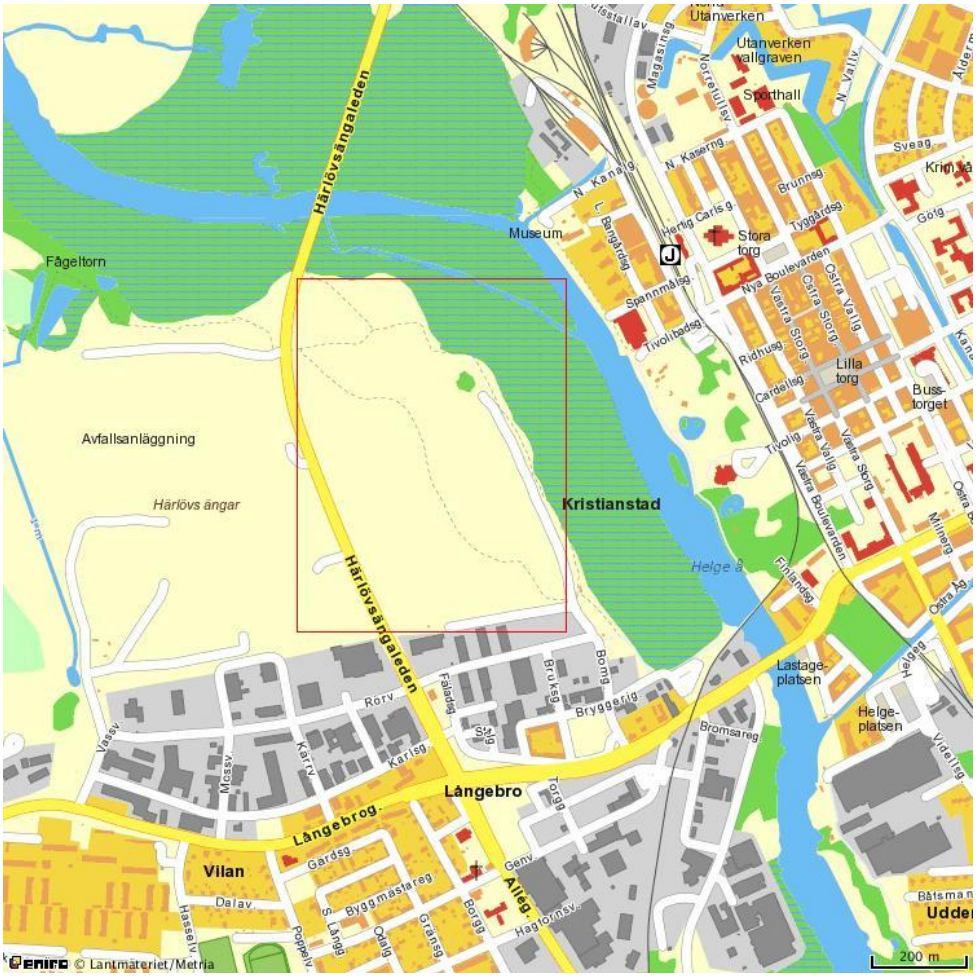

Figure 9. Härlövsängar (Eniro, 2010)

4.3. Onsjö

A third old landfill is located in Eslöv, as depicted in figure 11. The landfill area has been transformed into a recreation area (figure 10). It is approximately 45 000 square meters and consists of a lot of small hills. A rough estimation of the waste in the landfill is 216 000 tonnes. In some places the coverage seems to be very thin. The landfill was used for both household and industry waste and was closed 1976. Very close the landfill are areas with residential houses (Arvidsson, 2007). A elderly neighbour of the park remembered that it was a gravel pit that was started to be used as a landfill when the previously landfill was filled and Edelbergsparken was constructed in 1955 (Nillson, 2008). A big food industry used to landfill food waste there, and at its deepest point was six meters deep, but the mean depth was around three meters.

Figure 10. Aerial photo of Onsjöparken (Eniro, 2010).

Figure 11. The location of Onsjöparken and the old landfill. (Eniro, 2010)

5. Methods & Material

5.1. Methods

The methods used for the measurements in this work were developed after considering different methods used in similar studies and adapted to fit the areas that were to be investigated.

5.1.1. Investigation-area

Based on Ljungberg et. al (2009) the procedure was to investigate an area of 100 m^2, as depicted in figure 12. Two or four areas were used at each landfill. It started with marking the 10*10 areas over a representative part of the landfill, where the emission and soil-gas concentration was to be determined. Then six points in that area were chosen randomly where the measurements were going to take place.

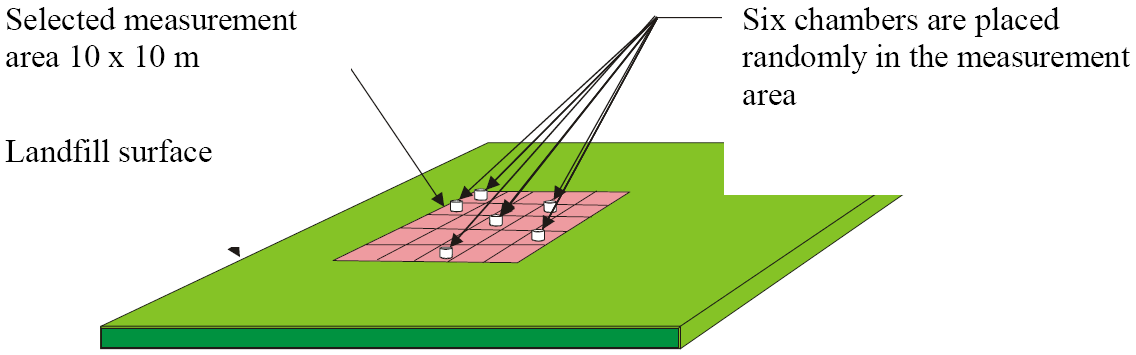

Figure 12. Measurement area and six randomly placed chamber .
(Ljungberg et.al., 2009).

5.1.1.1. Lassabacka

From earlier field studies (Rosander, 2009) the material in the landfill in Lassabacka has been identified in the close surroundings of the measuring points L1, L2, L3 and L4 (figure 13). The waste in measurement area L1 consists of a mixture of household waste and burned material. In measurement point L2 there was more construction waste, such as scrap metal, concrete and bricks. L3 was a mixture of household- and industrial waste. A newspaper dated from 1976 was found but there was also plastic and fabric. It all smelt strongly of oil or petrol. In L4 all material was burned and had a strong smell of hydrogen sulphide.

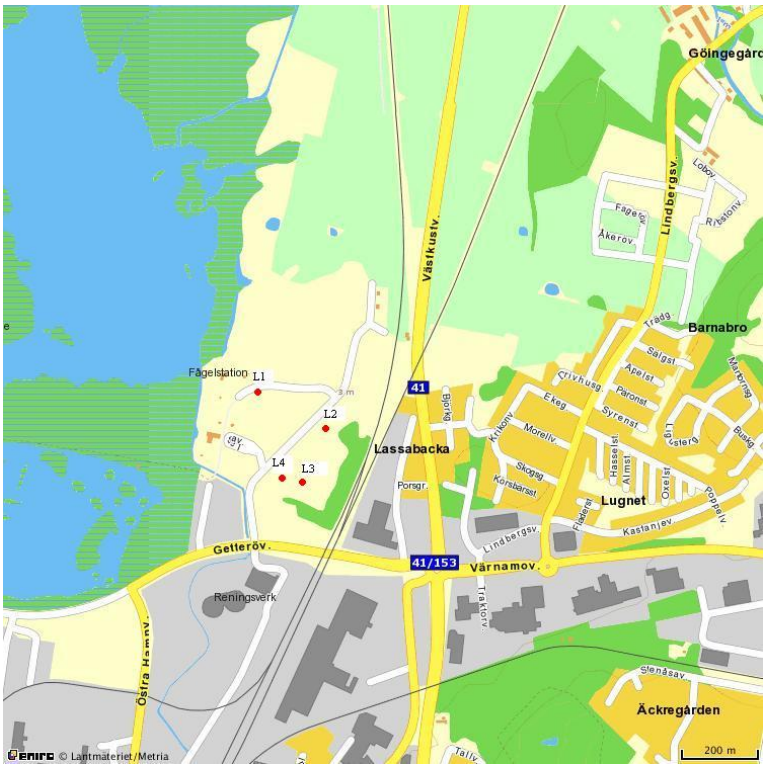

Figure 13. Measuring points Lassabacka.

(Rosander, 2009), (Eniro, 2010)

When doing the measurements, the ground surrounding L1 consisted of sand mixed with plastic waste. Generally the ground was very soft, mostly covered with grass and located close to a path and a bird watching site. L2 was located in soft topsoil, covered with high grass of different types, in an area not seemingly used for a specific purpose. Next to L3 are a well-used pathway and some beehives. The ground is hard, consisting of soil and sand mixed with gravel, as depicted in figure 14. L4 is the one closest to the road Lassavägen, and the ground is flat covered with grass.


Figure 14. Measuring gear at Lassabacka measuring point L3.

5.1.1.2. Härlövsängar

Measuring areas at Härlövsängar H1, H2, H3 and H4 (figure 15) are chosen from field notes (Rosander, 2010a) when the points where investigated and dug out. The soil surrounding the measuring point H1 consists of construction waste, such as bricks, scrap metal and wood. In H2 there was a mixture of badly decomposed household waste that had a dark colour and smelled very strongly. In the ground around H3 was also badly decomposed household waste with a strong smell, and it was noted that the groundwater in the bottom was bubbling substantially. Also at H4 there was badly decomposed household waste and even newspapers from 1972 could be identified. There were also plastic, fabric and cardboards, everything smelt strongly of oil and petroleum.

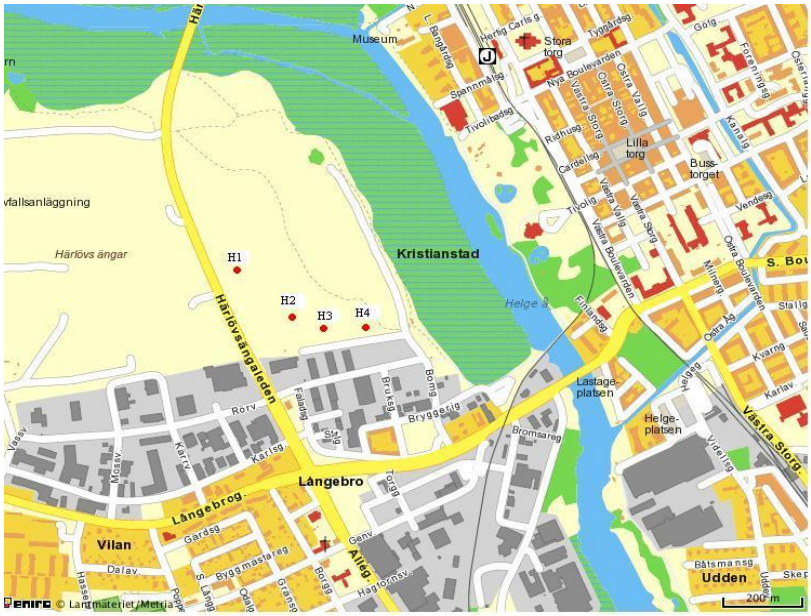

Figure 15. Measurements point at Härlövsängar (Rosander, 2010a) (Eniro, 2010)

When doing the measurements the area surrounding all points are clearly dug out and filled in, so waste is mixed with sand and soil in the soil surface. Mostly of the measurements are done outside of the excavated areas. H1 is located in a field with high grass, in the dug out area there is wood lying in the surface soil together with sand and soil. The area surrounding H2 is similar to the area around H1, the waste showing are tires and other plastic wastes. H3 is located on flat ground close to bushes and also here wastes are mixed with sand in the surface layer. At Härlövsängar there is a walking path, L4 is located close to the path and consist mostly of really soft sand, mixed with plastic wastes like plastic bags, wrappings etc, as depicted in figure 16.

Figure 16. Measurment at Härlövsängar at measurement point H4.

5.1.1.3. Onsjöparken

From earlier field studies done by Rosander (2010a) there is information about the waste in the landfill at each measuring area, O1 and O2 (figure 17). At O1 there is a mixture of household waste that are badly decomposed and some bricks, metal, glass. There could be some contaminated soil because of the strong smell. In measurement point O2 there were badly decomposed garden waste, concrete and wood, everything smelled strongly like diesel.

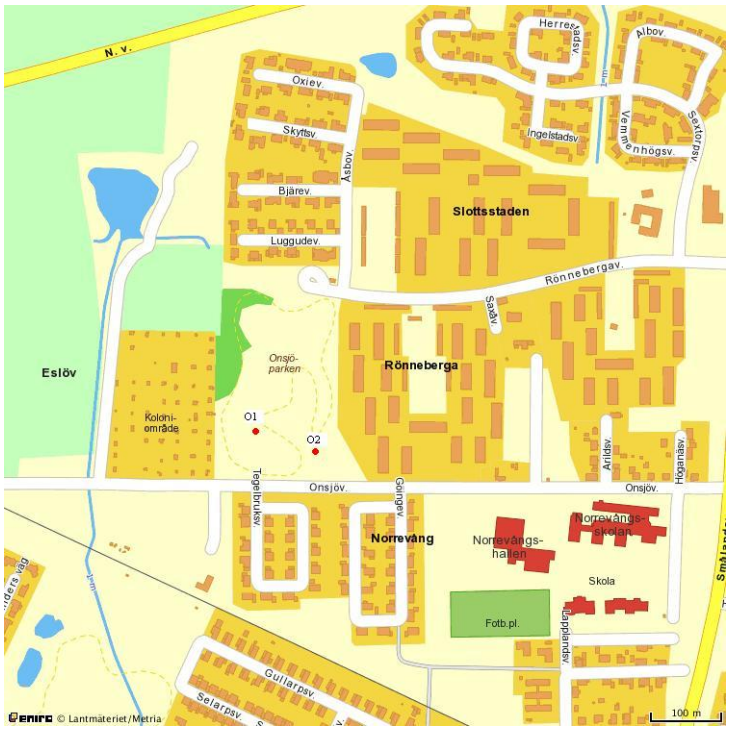

Figure 17. Measurements points Onsjöparken (Rosander, 2010b) (Eniro, 2010)

Both measurements point (O1 and O2) where located on slopes, covered with grass and had some bushes close by, see figure 18.

Figure 18.A measuring point at Onsjöparken, slopes coverded with grass.

5.1.2. Measurement setup and measurement period

The measurements were done between September and October 2010. Every place was visited once or twice depending on the numbers on measurements at each landfill.
The measurement areas were located and then the measurements started with marking the 10*10 meter area and randomly choose six points within the area. To identify the points within the area they are named as in figure 19.

A1	A2	A3	A4	A5
B1	B2	B3	B4	B5
C1	C2	C3	C4	C5
D1	D2	D3	D4	D5
E1	E2	E3	E4	E5

Figure 19. To locate the points in the area they are named A-E from north to south and 1-5 from east to west.

5.1.2.1. Soil gas

A probe and a gas analyser (LFG 20) were used to measure the soil gas concentration of methane, carbon dioxide and oxygen. The probe is a steel tube with six holes in the bottom, the inside of the bottom consists of steel wool to prevent soil particles to enter the gas analyser. The probe is put in the ground, through the grass and down 0,5 meters deep. The gas analyser has to be calibrated in fresh air in one minute before put in the probe. When the tube from the gas analyser is inserted in the probe it takes approximately one minute for the soil gas to reach the analyser and to get a result showing. It takes a little bit longer to get the result as stabilised concentration.

5.1.2.2. Gas flux

To measure the gas flux of carbon dioxide and methane gas an IR-chamber is used (Siemens, Ultramat 23). The chamber is placed in a small hole 0,30*0,30 meters, approximately 0,10 meters under the surface layer. A plastic frame filled with water prevents gas to escape out that way. The gas is transported in small plastic tubes from the chamber to the analyser where the increasing concentration is measured with IR technology. It is important that there is a soil/sand sealing around the bottom of the chamber and the frame so no gas escapes. The IR-chamber powers on electricity and that is why a small generating station has to be carried around with the chamber. The start up time and calibration for this measurement takes up to 45 minutes, but the calibrations between the points only takes approximately two minutes. The concentration measurement is done during the start up time for the IR-chamber. The concentration within the chamber is written down before start, after 10 seconds and after each minute for five minutes (1.10, 2.10, 3.10, 4.10 and 5.10)
The chamber method gives an indication of the gas emission from the specific surface beneath the chamber at a particular time. In order to ensure accuracy in covering all emissions, repeated measurements was taken at different sites under different weather conditions.

5.2. Materials

The materials used in this field study are here presented in detail. They are chosen with the goal of being easy to handle and use to get a quick and precise results without being too expensive.

5.2.1. LFG 20 Carbon dioxide, oxygen and methane measurement

The LFG 20 permits simple and precise measurement of Carbon Dioxide (CO_2), Methane (CH_4), and Oxygen (O_2). This is done by an internal pump at 200 mL per minute that takes in gas-samples, the instrument can be seen in figure 20.
The concentration in the gas-samples are measured and displayed digitally for each gas. Calibration is done with small regulators and is set to 0,00 % for CO_2, CH_4 and 20,9 % O_2. Infrared technology is used for analysing CH_4 and CO_2 and electrochemical cells is used for monitoring of Oxygen (CEA Instruments, 2010).
The LFG 20 is connected with a tube to a probe to be able to measure the soil gas concentration.

Figure 20. LFG20

5.2.3. Probe

The probe used in this study is a steel-tube that has been modified with a steel-tip, six small holes, a hole for the tube and a cap, see figure 21. The bottom of the probe is filled with steel-wool to prevent the soil to entering the holes and block the gas.
The concentration measurements of the soil gas are connected to the result of emission rate on the same point to see if there is any correlation between emission and concentration.

Figure 21. The probe and gas analyzer.

5.2.2. IR Chamber ULTRAMAT 23

Figure 22.Ultramat 23

This gas analyzer can measure up to four gases at the same time, but only three of the infrared sensitive gases such as carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), sulphur dioxide (SO_2) and methane (CH_4). It does also measure oxygen (O_2) with an electrochemical oxygen measuring cell (Alnab, 2001). The instrument can be seen in figure 22, where it is placed inside a wooden box for easier handling and protection. The ULTRAMAT 23 gas analyzer can be used to measure emissions and for monitoring processes. The method with spectroscopic is based on the absorption of nondispersive IR radiation. The oxygen sensor works like fuel cells, the oxygen is transformed at the boundary layer between the cathode and electrolyte and that results in a current that is proportional to the concentration of oxygen (Alnab, 2001).

The chamber is a steel cube, connected with tubes to the gas analyser, the chamber is covering an area of 400 cm^2, a sketch can be seen in figure 23.
The results from the ULTRAMAT 23 are concentration of methane, carbon dioxide and oxygen at different times. The accumulated concentration over time will be used to calculate the emission rate.

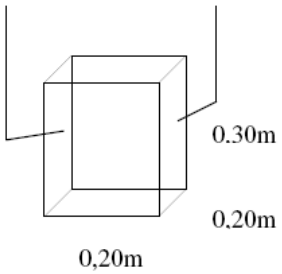

Figure 23. The dimension of the chamber.

6. Data Analysis methods

The theoretical production is calculated through a pre-printed Microsoft excel sheet from Land GEM. Information like emission of methane- or landfill gas can be found in the result sheet. To get the result in desired unit (kg/h), (m^3/h), (kg/h/m^2) or (m^3/h/m^2), a simple calculation is used by dividing the result with 365 days and 24 hours to get the result per hour, and dividing the result with the area of the landfill to get the result per hour per m^2, see equation 4.

The result from the different measurements is analysed and interpreted in different ways. When measuring the soil-gas the result is showing direct at the screen as volume percent of methane (CH_4), carbon dioxide (CO_2) and oxygen (O_2). The result is written down at the right measuring point.

The result from the IR-chamber is concentrations of methane and carbon dioxide at different times, measured in ppm. The information is put together in a Microsoft Excel sheet to be able to calculate the emission from each measuring point with equation 3 from RVF (2004).

$$Methaneemission(mg \cdot m^{-2} \cdot h^{-1}) = \frac{D_{ppm}}{D_{time}} \cdot \frac{P \cdot V_{chamber}}{R \cdot T} \cdot \frac{M}{A_{Chamber}} \quad \text{(Equation 3)}$$

D_{ppm}= The differency in concentration (ppm)
D_{time}=The differency in time (h)
P=Pressure (Pa)
$V_{chamber}$=Chamber Volume (m^3)
R=Gas konstant (8,3145 Pam^3/mole/K)*
T=Temperature (K)
M=Molar weight (kg/mole)
$A_{chamber}$=Chamber area (m^2)

To see if there is any correlation between methane emission and concentration, the results are put together in a plot, with a linear regration and a coefficient of determination (R^2). This is to see how good the correlation is. The coefficient of determination is a fraction between 0,0 and 1,0. 0,0 means that there is no relationship between X and Y and 1,0 means that there is a perfect linear relationship between X and Y, By knowing X, Y can be predicted perfectly. R^2 can also be explained as the percentage of relationship.

To calculate how much energy that can be produced (equation 10 and 11), the total volume of landfill gas is multiplied with 4,75 kWh/m^3. To compare it with number of household, 23 980 kWh per year is used as the totally amount of energy one household use yearly and 6 000 kWh for heating a house (Energimyndigheten, 2007).

To get the measured methane gas to the equivalent amount of landfill gas, the methane gas emission is first transformed from g/m^2/h to m^3/m^2/h with the specific volume of methane gas (1,48 m^3/kg) and then multiplied with 2, this because landfill gas consist of 50 % methane gas (equation 6 and 7). To get the assumed measured result from earlier or future year's equation 8 is used. It is the same proportion between the measured and the theoretical results.

7. Results

7.1. Lassabacka

From Land GEM the theoretical methane production for 2010 was 960 tonnes per year, it is equivalent with 1 440 000 m^3 methane gas. If looking at the maximum production of methane- and landfill gas it was in 1980 with 4 300 tonnes methane gas or 16 200 tonnes landfill gas, in volume it was 6 500 000 m^3 methane gas or 13 000 000 m^3 landfill gas, this can be seen in figure 24. All results from Land GEM Lassabacka can be found in appendix 1. The landfill gas in 2010 was 2 900 000 m^3 from Lassabacka and expressed in m^3/h it is 330 m^3 LFG/hour. If the result for methane gas emission from Land GEM for 2010 is transformed according to equation 4 the result is 0,61 g/m^2/h.

$$CH_4(g/m^2/h) = \frac{CH_4(tonne/year)\cdot 1000000\ (g/tonne)}{24(h/day)\cdot 365(days/year)\cdot Area(m^2)} \qquad \text{(Equation 4)}$$

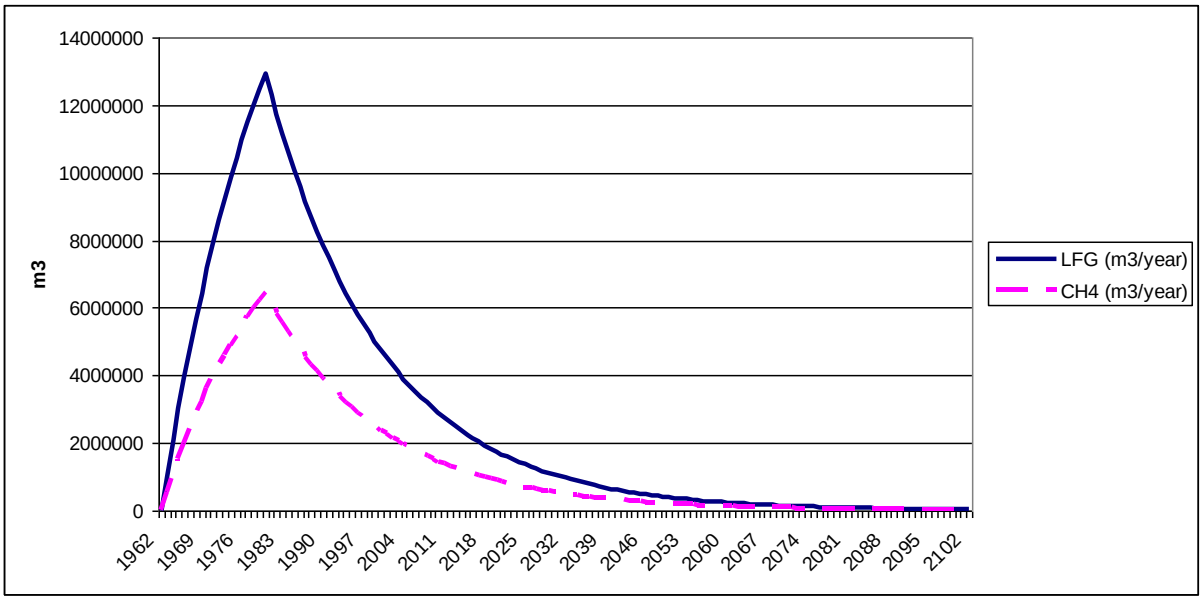

Figure 24. Theoretical LFG and CH4 production at Lassabacka.

The measured results from Lassabacka can be seen in table 1 and in appendix 2, and shows that the mean flow of methane gas was approximately 0,06 g/m^2/h, and the maximum flow was approximately 0,7 g/m^2/h. Totally during 2010, calculated with equation 5 and 6 it would be approximately 94 tonne or 139 600 m^3 methane gas and from equation 7 it would be approximately 279 300 m^3 landfill gas. The total amount of gas both theoretical and measured can be seen in table 2.
From the results it can be seen that the mean flow of carbon dioxide was 1,26 g/m^2/h and the maximum flow was 3,92 g/m^2/h. Most extreme concentrations in the soil gas was 21,8% carbon dioxide, 11,8% methane and 17,0% oxygen, but they are not measured at the same point.

$$CH_4(tonne/year) = \frac{CH_4(g/m^2/h) \cdot Area(m^2) \cdot 24(h/day) \cdot 365(days/year)}{1000000(g/tonne)} \quad \text{(Equation 5)}$$

$$CH_4(m^3/year) = CH_4(tonne/year) \cdot 1{,}48(m^3/kg) \cdot 1000\,(kg/tonne) \quad \text{(Equation 6)}$$

$$LFG_{measured2010}(m^3/year) = CH_4(m^3/year) \cdot 2 \quad \text{(Equation 7)}$$

Table 1.The results from Lassabacka, concentration and flow of methane (CH4) and carbon dioxide (CO2).

CO2		CH4	
conc. (%)	flow (g/m2/h)	conc. (%)	flow (g/m2/h)
3,72	3,53641	4,24	0,218588
0,97	3,920367	0,12	0,007368
0,07	0,45805	0	0
0,03	0,343537	0	0,002456
0	0,700547	0	0,004912
0,03	0,464786	0	0
0	1,96692	0	0
0	0,88242	0	0
0,18	3,671134	0	0,007368
0	0,478929	0	0
0,22	1,764839	0,24	0,027017
3,28	0,69453	6,03	0,034393
0,1	0,895891	0	0
3,2	1,057556	11,8	0,729446
0,73	0,62645	0,5	0,027017
21,84	1,104708	2,82	0,240693
2,05	0,660131	0	0
0,06	0,511938	0	0
0,04	0,417634	0	0,002456
0,19	1,340469	0,04	0,009824
0,06	0,754435	0,01	0,004912
0,14	1,596438	0	0
Mean flow	1,265824	Mean flow	0,059839

The maximum emission of landfill gas was in 1980. The theoretical value was 13 000 000 m^3 and the measured result from equation 8 was approximately 987 000 m^3. If worth extracting it should be over 5 m^3LFG/tonne waste. From equation 9 it was approximately 11 m^3 LFG/tonne waste for the theoretical result and for the measured result it would be approximately 0,8 m^3LFG/tonne waste, see figure 25. The energy that could have been produced that year (equation 10 and 11) from the theoretical LFG was 61 490 000 kWh, which is the same as the totally energy consumption per year for approximately 2 500 houses

or heating for 10 000 houses. From the measured result the same result would be 5 937 500 kWh, 250 and 1000 houses (Energimyndigheten, 2007). 2010 the theoretical amount was 2 900 000 m^3 LFG and resulted in 2 m^3 LFG/tonne waste, the measured result was 279 300 m^3 and it would result in 0,2 m^3LFG/tonne waste. From the theoretical result in figure 25 it would have been worth extracting gas between the years of 1967-2002.

$$LFG_{measured1980}(m^3/year) = LFG_{measured2010}(m^3/year) \cdot \frac{LFG_{theoretical1980}}{LFG_{theoretical2010}} \quad \text{(Equation 8)}$$

$$\text{LFG } (m^3/\text{tonne}) = \frac{LFG(m^3/year)}{Waste(tonne)} \quad \text{(equation 9)}$$

$$Energy(kWh) = LFG(m^3) \cdot 4{,}75 kWh/m^3 \quad \text{(Equation 10)}$$

$$Houses = \frac{Energy(kWh)}{Energy_{total/heat}(kWh/house)} \quad \text{(Equation 11)}$$

$Energy_{total}$=23 980kWh/year
$Energy_{heat}$=6 000kWh/year

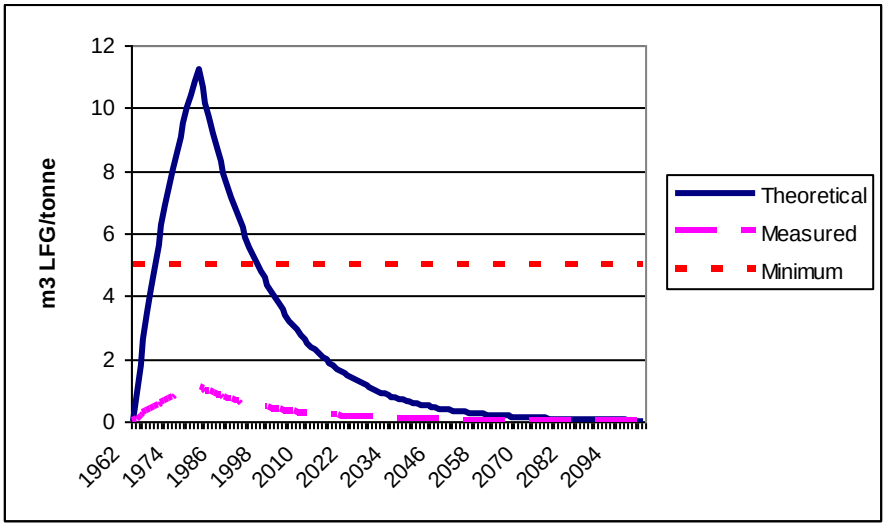

Figure 25. Theoretical and measured LFG/tonne waste.

The future settlement due to biodegradation was calculated according to equation 1. This was done for 2010 and for 1980, with a mean depth of four meters. In 2010 the future settlement was 0,2 meters and in 1980 it was 0,85 meters.

Table 2. Theoretical and measured results for Lassabacka.

	2010		*1980*	
	Theoretical	Measured	Theoretical	Measured
CH_4 (m^3/year)	1 440 000	139 600	6 500 000	490 000
LFG (m^3/year)	2 900 000	279 300	13 000 000	987 000
Energy (kWh)	13 800 000	1 330 000	61 490 000	5 937 500
LFG/tonne waste (m^3/tonne)	2	0,2	11	0,8
Future settlement (m)	0,2	0,2	0,85 (21%)	0,85 (21%)

7.2. Härlövsängar

From Land GEM the theoretical methane production for 2010 was approximately 610 tonnes per year, it is equivalent to 920 000 m^3 methane gas. Looking at the maximum emission of methane gas and landfill gas it was in 1976 with 3 400 tonnes or 5 000 000 m^3 methane gas or 12 500 tonnes or 10 000 00 m^3 landfill gas, this can be seen in figure 26. All results from Land GEM Härlövsängar can be found in appendix 3. The landfill gas from Härlövsängar 2010 was 1 850 000 m^3, expressed in m^3/h it would be 210 m^3 LFG per hour. To get the result for methane gas emission from Land GEM 2010 equation 4 is used and it results in 0,3 g/m^2/h.

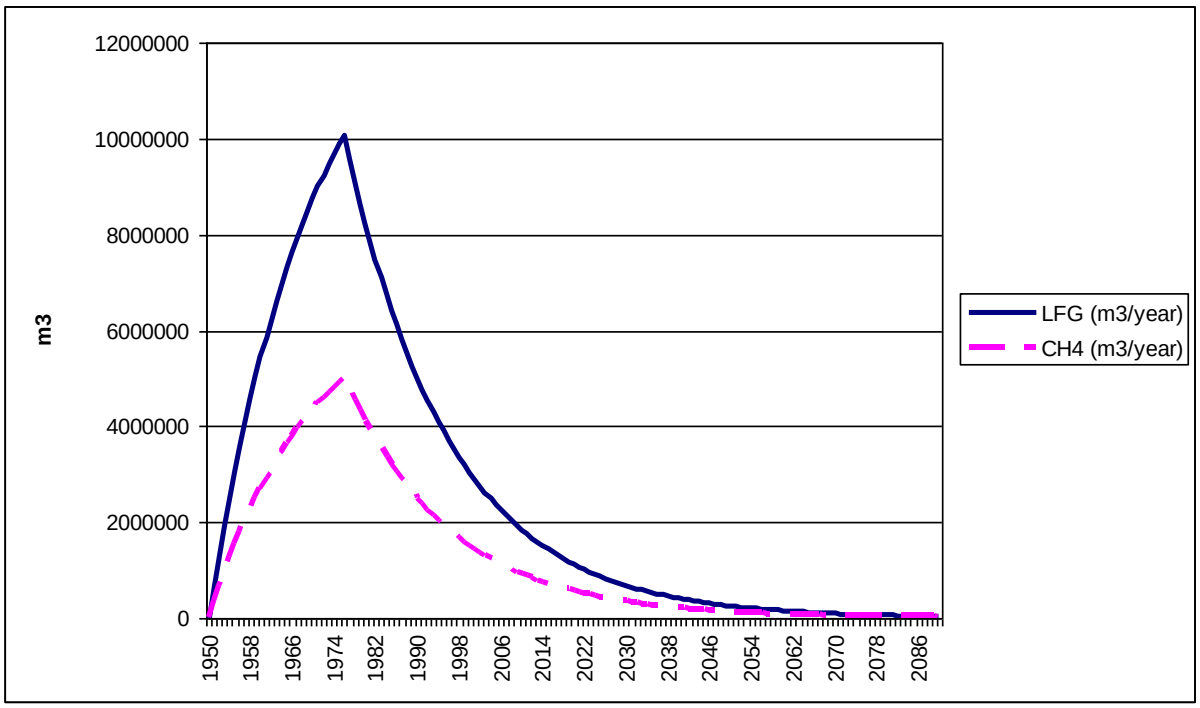

Figure 26. Theoretical LFG and CH4 production at Härlövsängar.

The measured results from Härlövsängar can be seen in table 3 and in appendix 4, and shows that the mean flow of methane gas was 0,00047 g/m^2/h and the maximum flow was measured to 0,0068 g/m^2/h. Totally during 2010, calculated with equation 5 and 6 it would be approximately 0,9 tonne or 1350 m^3 methane gas, looking at landfill gas according to equation 7 it would be approximately 2 700m^3. The total amount of gas both theoretic and

measured can be seen in table 4. If looking at carbon dioxide that is a big part of landfill gas the mean flow was 4,45 m^2/h and the maximum flow was 13,2 m^2/h. Most extreme concentrations in the soil gas was 2,15 % carbon dioxide, 0,09 % methane and 12,0% oxygen, but they are not measured at the same point.

Table 3. The results from Härlövsängar, concentration and flow of methane (CH4) and carbon dioxide (CO2).

CO2		CH4	
conc. (%)	flow (g/m2/h)	conc. (%)	flow (g/m2/h)
1,02	6,9448	0	0
0,18	0,969239	0,02	0,006822
0,62	2,465386	0	0
0,15	0,847617	0	0
0,26	2,546218	0	0
0,32	2,0949	0	0
2,15	8,238159	0	0
3,1	13,19587	0	0
1,11	10,73273	0,09	0,004053
0,46	1,390123	0	0
0,54	6,459849	0	0
0,01	0,918018	0	0
0,03	1,852407	0	0
0,76	4,290848	0	0
0,76	4,290848	0	0
0,77	5,180004	0	0
0	0,842003	0	0
0,5	2,546218	0	0
0,46	5,274308	0	0
0,32	6,224088	0	0
0,4	2,48559	0	0
0,38	7,530877	0	0
0,62	8,015871	0	0
0,15	1,54255	0	0
Mean flow	4,453272	Mean flow	0,000453

From the result the maximum landfill gas obtained was in 1976, the theoretical production was 10 000 000 m^3 and measured was 14 800 m^3. If worth extracting it should be over 5 m^3LFG/(tonne waste). It was 9,5 m^3 LFG/tonne waste for the theoretical result and the measured result was 0,014 m^3LFG/tonne waste, see figure 27. The energy that could have been produced that year from the theoretical LFG is 48 000 000 kWh, which is the same as the totally energy consumption per year for approximately 2 000 houses or heating for 8 000 houses (Energimyndigheten, 2007). From the measured result the same would be 70 300 kWh, 3 and 12 houses (Energimyndigheten, 2007). 2010 the amount of landfill gas was 1 840 000 m^3 LFG and resulted in 1,7 m^3 LFG/tonne waste, the measured result was 2 700 $m^3$and it resulted in 0,003 m^3LFG/tonne waste. From the theoretical result in figure 27 it would have been worth extracting gas between the years of 1960-1988.

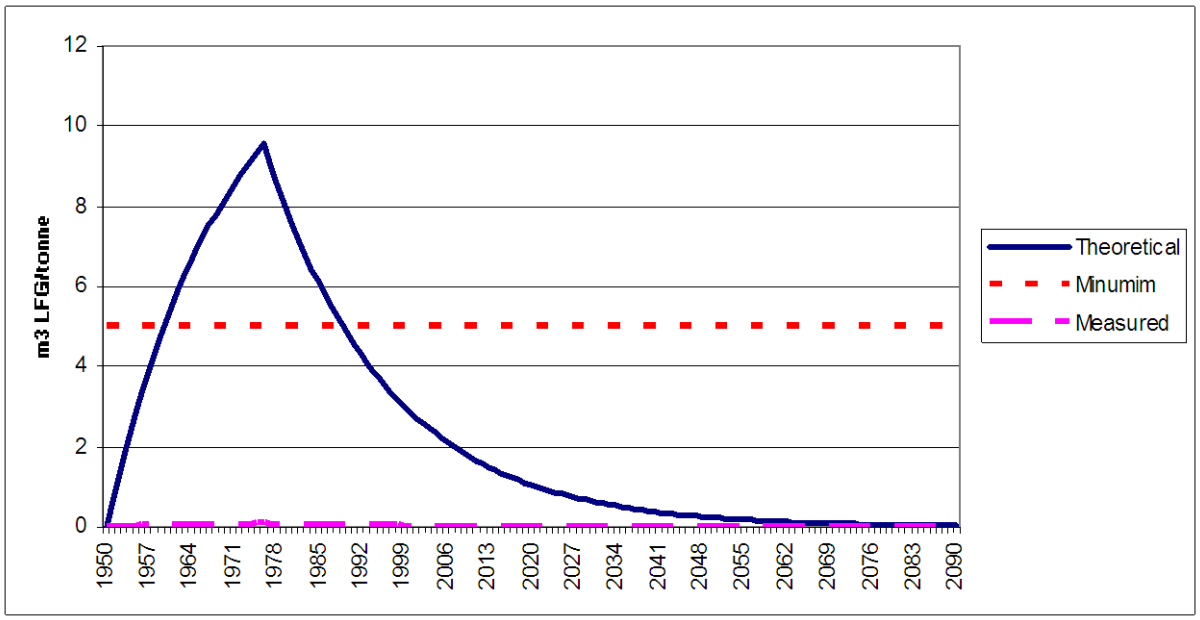

Figure 27. Theoretical and measured LFG/tonne waste at Härlövsängar.

The future settlement due to biodegradation was calculated according to equation 1 for 2010 and for 1976m with the mean depth of three meters. In 2010 the future settlement was 0,1 meters and in 1976 it was 0,5 meters.

Table 4. Theoretical and measured results for Härlövsängar.

	2010		***1976***	
	Theoretical	Measured	Theoretical	Measured
CH_4 (m^3/year)	920 000	1350	5 000 000	7 300
LFG (m^3/year)	1 840 000	2 700	10 000 000	14 800
Energy (kWh)	27 700 000	12 800	48 000 000	70 300
LFG/tonne waste (m^3/tonne)	1,7	0,003	9,5	0,014
Future settlement (m)	0,1	0,1	0,5 (18%)	0,5 (18%)

7.3. Onsjöparken

From Land GEM the theoretical methane production for 2010 was approximately 110 tonnes, it is equivalent to 165 000 m^3 methane gas. Looking at the maximum emission of methane- and landfill gas it was in 1968 with 900 tonnes or 1 350 000 m^3 methane gas or 3 380 tonnes or 2 700 00 m^3 landfill gas, this can be seen in figure 28. All results from Land GEM Onsjöparken can be found in appendix 5. The landfill gas from Onsjöparken 2010 was approximately 330 000 m^3, expressed in m^3/h it would be 38 m^3 LFG per hour. To get the result for methane gas emission from Land GEM 2010 equation 4 was used and resulted in 0,28 g/m^2/h.

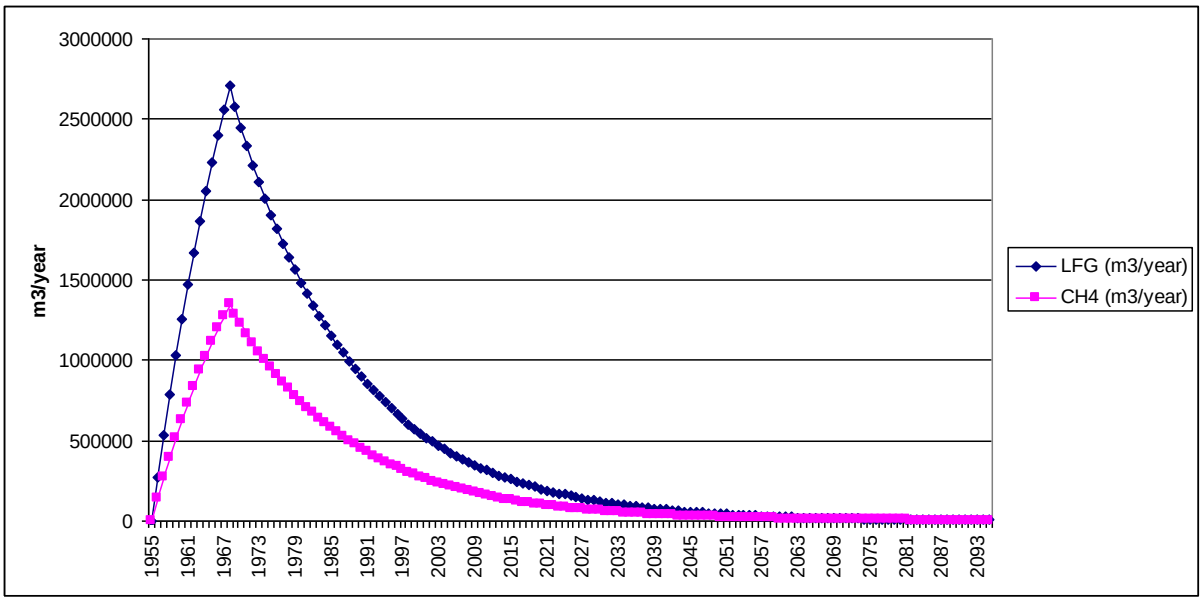

Figure 28. Theoretical LFG and CH4 production at Onsjöparken.

The measured results from Onsjöparken can be seen in table 5 and in appendix 6, and shows that the mean flow of methane gas was approximately 0,0015 g/m^2/h, the maximum flow was measured to 0,0074 g/m^2/h. Totally during 2010, calculated with equation 5 and 6 it would be approximately 0,6 tonne or 870 m^3 methane gas, according to equation 7 it would be approximately 1 750 m^3 landfill gas. The totally amount of gas both theoretic and measured can be seen in table 6. If looking at carbon dioxide the mean flow was 2,9 m^2/h and the maximum flow was 5,2 m^2/h. Most extreme concentrations in the soil gas was 0,69 % carbon dioxide, 0,3 % methane and 20,0 % oxygen, but they are not measured at the same point.

Table 5. The results from Onsjöparken, concentration and flow of methane (CH4) and carbon dioxide (CO2).

CO2		CH4	
conc. (%)	conc. (%)	flow (g/m2/h)	flow (g/m2/h)
0,14	4,23	0	0
0,27	2,95	0	0
0,25	5,18	0,03	0
0,65	3,98	0	0,00175
0,3	3,28	0	0
0,69	3,967	0	0
0,18	1,7985	0,03	0
0,3	0,6569	0	0,007368
0,1	3,238	0	0
0,42	2,5837	0	0,001754
0,08	2,3239	0,03	0,002408
0,3	1,045234	0,3	0,004913
Mean flow	2,936103	Mean flow	0,001516

From the results the maximum landfill gas obtained was in 1968, the theoretical production was 2 700 000 m^3 and measured was 14 000 m^3. If worth extracting it should be over 5 m^{3}LFG/(tonne waste), the theoretical result was 12,5 m^3 LFG/(tonne waste) and the measured

result was 0,06 m^3LFG/(tonne waste), see figure 29. The energy that could have been produced that year from the theoretical LFG are 12 800 000 kWh, which is the same as the totally energy consumption for approximately 110 houses or heating for 450 houses (Energimyndigheten, 2007). From the measured result it would be 66 500 kWh, 3 and 11 houses (Energimyndigheten, 2007). 2010 the theoretical amount of landfill gas was 330 000 m^3 LFG and resulted in 1,5m^3 LFG/tonne waste, the measured result was 1 750 $m^3$and it resulted in 0,008 m^3LFG/(tonne waste). From the theoretical result in figure 29 it would have been worth extracting gas between the years of 1960-1986.

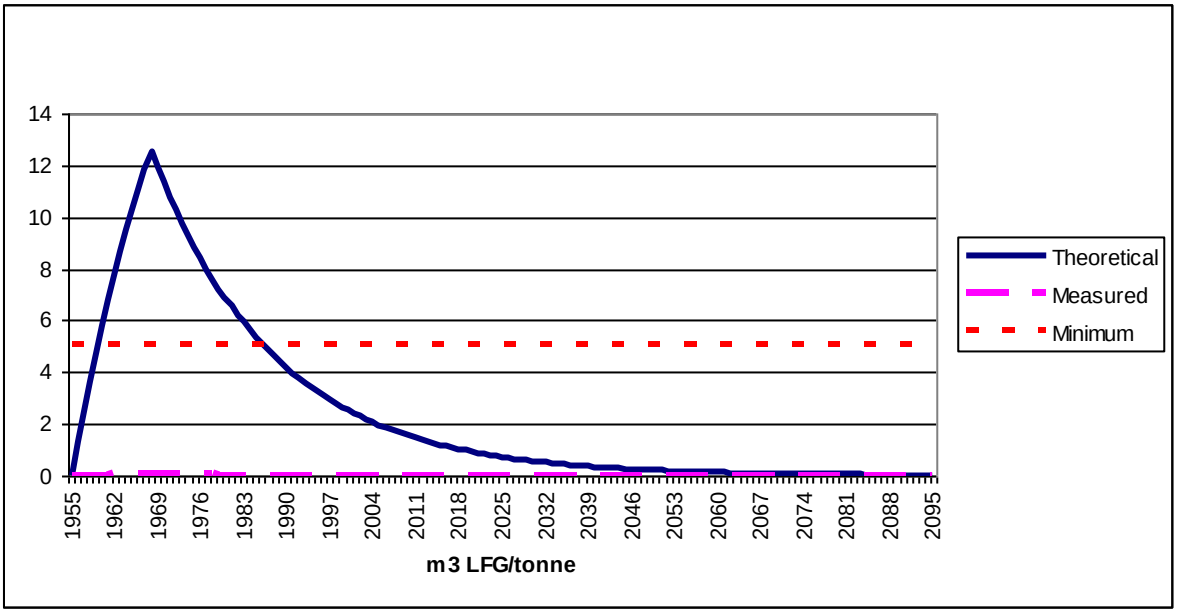

Figure 29. Theoretical and measured LFG/tonne waste with the minimum of 5m3 LFG/tonne at Onsjöparken.

The future settlement due to biodegradation was calculated for 2010 and for 1968 and with the mean depth of three meters. In 2010 the future settlement was 0,09 meters and in 1980 it was 0,7 meters.

Table 6. Theoretical and measured results for Onsjöparken**.**

	2010		***1968***	
	Theoretical	Measured	Theoretical	Measured
CH_4 (m^3/year)	165 000	870	1 350 000	7 200
LFG (m^3/year)	330 000	1 750	2 700 00	14 000
Energy (kWh)	1 570 000	8 300	12 800 000	66 500
LFG/tonne waste (m^3/tonne)	1,5	0,008	12,5	0,06
Future settlement (m)	0,09	0,09	0,7 (24%)	0,7 (24%)

7.4. Correlation

From almost sixty measurements of concentration and emission from methane there was only thirteen points where both concentration and emission could be detected, they can be found in table 7. Most of the useful measurements were done at Lassabacka landfill, but some are also from the landfills at Härlövsängar and Onsjöparken.

Table 7. The usefull measurements of methane-flow and methane-concentration.

CH4 (%)	CH4 (g/m2/h)
4,24	0,218588
0,12	0,007368
0,24	0,27017
6,03	0,034393
11,8	0,729446
0,5	0,027017
2,82	0,240693
0,04	0,009824
0,01	0,004912
0,02	0,006822
0,09	0,004053
0,03	0,002408

The data from the interesting points where put together in figure 30 with a linear regression to visualise any correlation. The coefficient of determination (R^2) was 0,69 which mean that the linear relationship fit with approximately 70 % of the results.

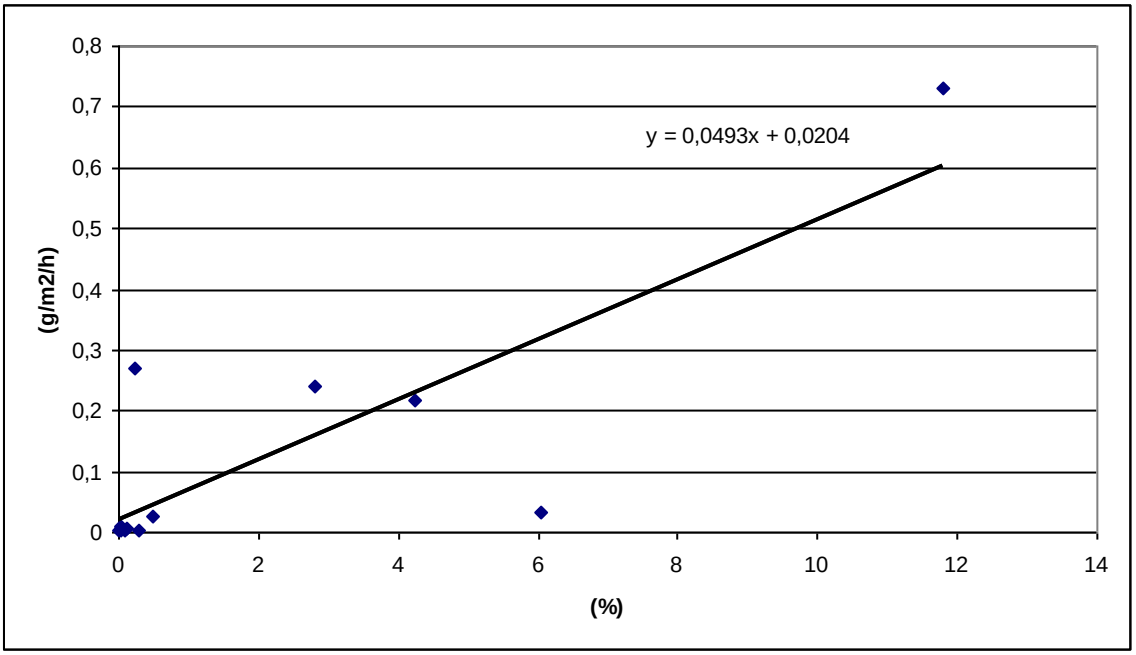

Figure 30. Relationship between methane emissions from the landfills and the soil gas concentration in the landfill.

The equation for the linear regression can be seen in equation 12.

$y = 0{,}0493x + 0{,}0204$ (Equation 12)

y= Emission CH_4 ($g/m^2/h$)
x= Concentration CH_4 (%)

If looking at the exposure limits of methane gas for humans that is set to 5 %. That would be 0,27 $g/m^2/h$ if using equation 12. The lower explosion limit is the same as the exposure limit and the upper explosion limit that is 15 % would be 0,76 $g/m^2/h$.

If only using the measured results from Lassabacka the coefficient of determination for the linear regression was 0,64, see figure 31.

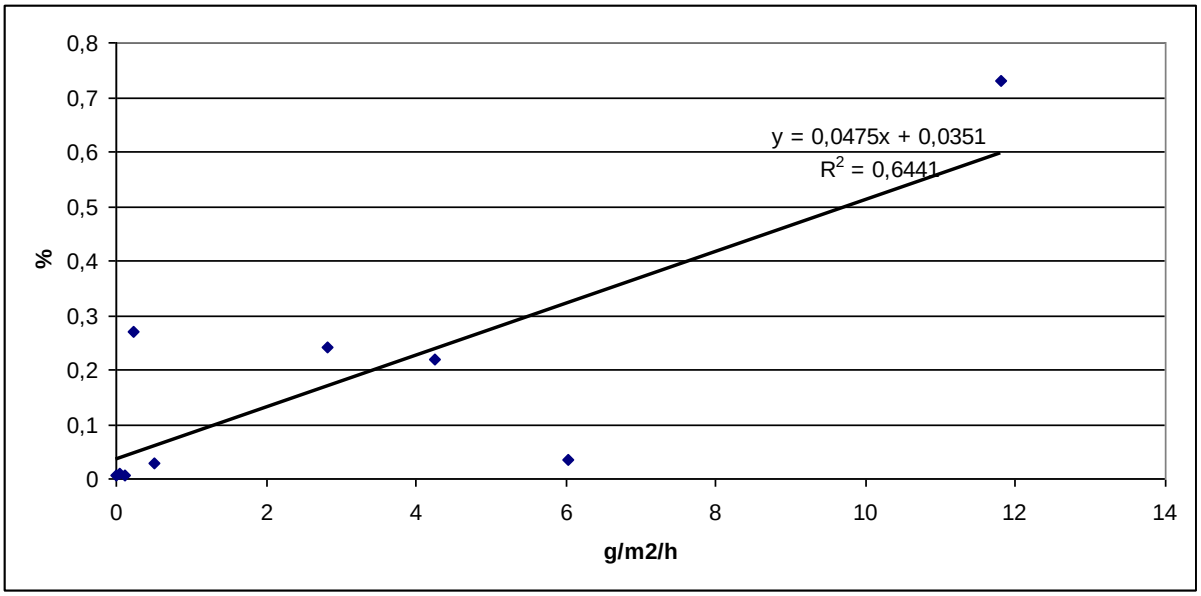

Figure 31. Relationship between methane emissions from the landfills and the soil gas concentration at Lassabacka..

8. Discussion

8.1. Methods and material

The limitations of available resources and budget reflected the choice of material and instruments. The chosen method was based on previous study done by Ljungberg et. al (2009). The study area was 100 m^2 for each measurement. The areas investigated are only a small part of the entire landfill, so to get a more representative result for the total emission it would have been preferred to have several more areas at each landfill. The measurements where also done during a limited time with similar weather conditions. To get more accuracy in the result, repeated measurements have to be done at different sites at different times throughout a year and thereby with different weather conditions as mentioned as important in chapter 5.1.2.2.
The chamber method used to measure emissions is recommended to be used when measuring in which rate chemicals is released from the surface and not to be used when quantifying emissions from the total landfill, as mentioned in chapter 2.8. With the relatively few measurements that where done during such a short period of time. It was not very representative for the total emission for the landfill during a year. But it was the best and most reliable method that could have been used with the limited budget and the limited time.
When measuring the emissions from the surface it only gives the emission rate from the surface, it does not give information of the production rate. The gas that leaves the surface could be gas that have been accumulated for years in the soil and is leaking out and have no relationship with the production rate. So the production rate of methane gas cannot be measured when measuring the emission rate.
The concentration measurement was done with a probe connected to a methane concentration measurement. The probe was constructed from a steel-tube with inspiration from probes that have been used in investigations in other landfills. There were no test on how many holes there should be in the bottom, or how much steel wool that was enough to keep soil out but also allow soil gas in. From the measurements with the probe it was also very clear that the results can vary allot when just moving the probe 0,10 meters or putting it deeper down. If the probe and the concentration measurements will be used as the only method to evaluate if there is any methane gas in a landfill it will take a lot of measurements but if there is methane in the soil-gas there have always been a methane emission at the same place.

8.2. Data analysis

When looking at the conversion to emission rate, this was done with the change in concentration over time and the ideal gas law as shown in equation 3. When calculating the change in concentration over time the first and the last result are used and this could result in some errors regarding the rate. The temperature used was only from the weather forecast and can be wrong with a couple of degrees. Pressure was another parameter and was not measured at all, it was only assumed to be at normal pressure.
When from the measured methane emission 2010 the assumed methane and landfill gas emission were calculated according to equation 8 and that was based on the result from the theoretical emissions from methane and landfill gas. Landfill gas was assumed to consist of 50 % carbon dioxide and 50 % methane gas and the result would be very different with landfill gas that consists of 45-60 % methane gas and 40-60 % carbon dioxide. Also the same

weaknesses from the theoretical result will follow in the measured result for the other years except for 2010.

8.3. Measured compared to theoretical results of gas emissions

The results from methane emission from 2010 are the only ones that are actually measured so if comparing the measured and theoretical methane emission for 2010 there is a big difference at all landfills, see table 4. At Lassabacka the measured emission is approximately 7 % of the theoretical emission, at Härlövsängar and in Onsjöparken the measured result is only 0,15 % respectively 0,5 % of the theoretical result.

Table 4. Measured/Theoretical result for Lassabacka, Härlövsängar and Onsjöparken.

2010	***LASSABACKA***	***HÄRLÖVSÄNGAR***	***ONSJÖPARKEN***
Measured/Theoretical	7 %	0,15 %	0,5 %

The reasons for this could be many, if starting by looking at the model used for the theoretical emission, LandGEM. The model are done by US EPA and may not be reliable to use for old Swedish landfills. One thing is that the fractions of the different kinds of waste are not known and to calculate the theoretical production standard values are used, and may not correspond at all with the actual composition. Also the mean values for the waste in place are used for the years the landfills are in use and that assumption may not be correct. Because the lack of information about old landfills even things like what year the landfill started and ended sometimes needs to be assumed, the same thing with the depth of the landfill and also the volume of the wastes in place. As mention in chapter 2.2 it is very important to keep the landfill moist so the anaerobic reaction can continue, so if it is not moist enough, there will be no methane production. Another reason is the gas movements, the gas can move in other directions or be trapped in the ground so it will not be measured when measuring the emission from the surface.
This big difference in measured and theoretical result are reflected in all the other results based on the measured and theoretical methane emission, like LFG emission, energy and LFG/tonne waste that can be seen in the tables for each landfill (table 2,4 and 6).

8.4. Settlements

As mentioned in chapter 2.4 the estimated total settlement of a landfill was 25 % to 50 % where the long term settlement was due to biodegradation. When using equation 1 the estimated total settlement from biodegradation was 21 % for Lassabacka, 18 % at Härlövsängar and 24 % at Onsjöparken, this results can be seen in table 5. Most settlement has already occurred 2010 but there is still some settlement that can take place. It is also known that the estimated settlement is about 10 % higher than the measured so the results in table 5 are probably a bit higher than if it should be measured.

Table 5. Settlement at Lassabacka, Härlövsängar and Onsjöparken 2010 and total settlement.

SETTLEMENT	2010	MAXIMUM	TOTAL
Lassabacka	0,2	0,85	**21%**
Härlövsängar	0,1	0,5	**18%**
Onsjöparken	0,09 m	0,7 m	**24%**

Based on equation 1 there was no difference in settlement if calculating on measured- or theoretical results. It was only the proportion between future gas generation and total gas generation that affect the settlement and because the measured result is based on the difference in the theoretical results the proportions will be the same. It feels reasonable that it should have an impact on the settlement, if there is a lower production of gas and a lower biodegradation it would be less settlement. That could also depend on the percentage of decomposable organics at the different landfills does not correspond to the mean value of decomposable organics in general household waste. When calculating the settlement the same thickness has been used for the result both for 2010 and for the maximum settlement, maybe the thickness of waste for 2010 should be calculated when taking away the expected settlement up until 2010, which would lead to even less settlement in 2010.

In Lassabacka there can still be expected some settlement, but in Härlövsängar and in Onsjöparken the settlements for 2010 was low and the risk of damages due to settlement if building on the landfills are much lower because most biodegradation has already taken place. This was if the biodegradation has been taken place as expected as discussed in chapter 8.3.

8.5. Energy

From table 6 it is seen that there was no use in extracting gas from any of the landfills in 2010, all of them are under 5 m^3LFG/tonne waste, which is the minimum for extraction as mentioned in chapter 2.5. From the theoretical results there have been years at all three landfills where there would have profitable to extract gas for energy production. There is a big investment in building a gas plant and it is not sure that even if the amount of gas is over 5m^3 LFG/tonne waste it will be economically valuable, because the years where there will be enough gas are too few. Under perfect conditions, one tonne of waste can produce up to 150-200 m^3 of gas as mentioned in chapter 2.5, and there are no results even close to that based at the results from these three landfills.

Table 6. LFG/tonne at Lassabacka, Härlövsängar and Onsjöparken 2010 and maximum.

		2010		MAXIMUM	
		Theoretical	**Measured**	**Theoretical**	**Measured**
Lassabacka	**LFG/tonne (m^3/tonne)**	2	0,2	11	0,8
Härlövsängar	**LFG/tonne (m^3/tonne)**	1,7	0,003	9,5	0,014
Onsjöparken	**LFG/tonne (m^3/tonne)**	1,5	0,008	12,5	0,06

If the gas is collected but it can no longer be used for extracting energy, it is still important to take care of it, for example flared methane will transform to carbon dioxide with a much lower global warming potential than methane gas, as mentioned in chapter 2.1.

8.6. Correlations

The correlation between emission and concentration from all three landfills can be seen in figure 30 and are based on thirteen measurements point where both emission and concentration of methane gas were detected. All together approximately sixty measurements where done but only thirteen gave useful results. In figure 31 only the measurements from Lassabacka were used and there can also a linear relationship clearly bee seen. The correlation would have been much more reliable if all the sixty points could have been used. To make that possible it would have been better if the measurements where done closer to the wastes, maybe only 0,10 meters above so there would be nothing to disturb the emission like surface layers of sand, soil etc. It would only have been necessary to find areas with methane emission and do repeated measurements there to get a high number of measurements of emission and concentration. But then the result could not have been used to estimate the total emission.
The useful data where put together in figure 30 and approximated with a linear regression to get an equation that can be useful in different ways. The coefficient of determination for the linear regression was 0,69 for all landfills together and 0,64 for Lassabacka. Often the coefficient of determination is off high quality if it is over 0,70. More useful measurement points would have helped to improve the value. From an earlier investigation done by Ljungberg et. al. (2009) mentioned in chapter 1, a relationship between emission and concentration was found there as well.
Equation 12 can be used to evaluate what the explosion limit would be as emission rate and also at what emission rate it is harmful to humans. From these measurements and from this equation the exposure limit for humans and the lower explosion limit whould be 0,27 $g/m^2/h$. With that result it can be seen from table 7 that there was only one measurement point where the emission exceeds that limit and that was at Lassabacka. There were also two measurement points close to the limit that would be harmful for humans.

8.7. Future improvements

If a similar study is done in the future it is important to have a clear focus. If the main focus is to find a correlation between methane concentration and methane emission the measurements will be done just for that reason. It is also important to find areas with methane so that repeatedly measurements can be done to get more useful values for getting a better and more reliable linear regression.
To get a useful estimation for the total emission from a landfill using the chamber method, it is important to do repeated measurements at different sites in the landfill at different times during the year. That will also result in that the measurements are done in different weather conditions because that greatly affects the emission rate.

9. Conclusions

With the correlation between methane emission and the methane concentration in the soil gas an exposure limit and a lower explosion limit can be set to 0,27 $g/m^2/h$. Based on the relationship it is also possible to use only the measurements with the probe and concentration measurement to evaluate if there is any methane emission from a landfill. The concentration measurement with the probe is enough to determine if there is any methane emission, but if the question instead is how much methane gas the IR-chamber give a more accurate answer.

There is a big difference between the theoretical methane emission and the measured methane emission at all three landfills. Based on the result the theoretical emission is not a good estimation for the actual emission at Lassabacka, Härlövsängar or Onsjöparken. Based from the theoretical emissions there have been years at all the landfills where there would have profitable to extract gas for energy production, but no one of the landfills are today of any value based on energy production.

All the landfills are located close to the city centres and are located on valuable and desired land. From the estimations on settlement, Lassabacka is the only landfill that still has substantially settlement left to occur and also the only landfill that exceed the explosion- and exposure limit of methane emission.

The results in this text are based on these three landfills that are representative for the thousands of old landfills in Sweden. All of them need to be investigated in the same way to get an idea on how methane emission and settlement affect future exploitation of the areas. Not only to evaluate the risk or potential energy production, also to get an estimation on how much methane gas that is emitted yearly to the atmosphere from old landfills in Sweden.

First when all sources of green house gases are identified and quantified, there can be clear goals on how to lower the emissions to ease the climate change.

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Appendix

Appendix 1. Theoretical result with Land GEM at Lassabacka

Results

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
1962	0	0	0	0	0	0
1963	4,013E+02	3,214E+05	2,159E+01	1,072E+02	1,607E+05	1,080E+01
1964	7,831E+02	6,271E+05	4,213E+01	2,092E+02	3,135E+05	2,107E+01
1965	1,146E+03	9,179E+05	6,167E+01	3,062E+02	4,589E+05	3,084E+01
1966	1,492E+03	1,195E+06	8,026E+01	3,985E+02	5,973E+05	4,013E+01
1967	1,820E+03	1,458E+06	9,794E+01	4,862E+02	7,288E+05	4,897E+01
1968	2,133E+03	1,708E+06	1,148E+02	5,697E+02	8,540E+05	5,738E+01
1969	2,430E+03	1,946E+06	1,308E+02	6,491E+02	9,730E+05	6,538E+01
1970	2,713E+03	2,172E+06	1,460E+02	7,247E+02	1,086E+06	7,298E+01
1971	2,982E+03	2,388E+06	1,604E+02	7,965E+02	1,194E+06	8,022E+01
1972	3,238E+03	2,593E+06	1,742E+02	8,649E+02	1,296E+06	8,711E+01
1973	3,481E+03	2,788E+06	1,873E+02	9,299E+02	1,394E+06	9,365E+01
1974	3,713E+03	2,973E+06	1,998E+02	9,918E+02	1,487E+06	9,988E+01
1975	3,933E+03	3,150E+06	2,116E+02	1,051E+03	1,575E+06	1,058E+02
1976	4,143E+03	3,317E+06	2,229E+02	1,107E+03	1,659E+06	1,114E+02
1977	4,342E+03	3,477E+06	2,336E+02	1,160E+03	1,738E+06	1,168E+02
1978	4,532E+03	3,629E+06	2,438E+02	1,210E+03	1,814E+06	1,219E+02
1979	4,712E+03	3,773E+06	2,535E+02	1,259E+03	1,887E+06	1,268E+02
1980	4,884E+03	3,911E+06	2,627E+02	1,304E+03	1,955E+06	1,314E+02
1981	4,645E+03	3,720E+06	2,499E+02	1,241E+03	1,860E+06	1,250E+02
1982	4,419E+03	3,538E+06	2,377E+02	1,180E+03	1,769E+06	1,189E+02
1983	4,203E+03	3,366E+06	2,261E+02	1,123E+03	1,683E+06	1,131E+02
1984	3,998E+03	3,202E+06	2,151E+02	1,068E+03	1,601E+06	1,076E+02
1985	3,803E+03	3,046E+06	2,046E+02	1,016E+03	1,523E+06	1,023E+02
1986	3,618E+03	2,897E+06	1,946E+02	9,664E+02	1,448E+06	9,732E+01
1987	3,441E+03	2,756E+06	1,852E+02	9,192E+02	1,378E+06	9,258E+01
1988	3,274E+03	2,621E+06	1,761E+02	8,744E+02	1,311E+06	8,806E+01
1989	3,114E+03	2,493E+06	1,675E+02	8,318E+02	1,247E+06	8,377E+01
1990	2,962E+03	2,372E+06	1,594E+02	7,912E+02	1,186E+06	7,968E+01
1991	2,818E+03	2,256E+06	1,516E+02	7,526E+02	1,128E+06	7,580E+01
1992	2,680E+03	2,146E+06	1,442E+02	7,159E+02	1,073E+06	7,210E+01
1993	2,549E+03	2,041E+06	1,372E+02	6,810E+02	1,021E+06	6,858E+01
1994	2,425E+03	1,942E+06	1,305E+02	6,478E+02	9,710E+05	6,524E+01
1995	2,307E+03	1,847E+06	1,241E+02	6,162E+02	9,236E+05	6,206E+01
1996	2,194E+03	1,757E+06	1,181E+02	5,861E+02	8,786E+05	5,903E+01
1997	2,087E+03	1,671E+06	1,123E+02	5,575E+02	8,357E+05	5,615E+01
1998	1,985E+03	1,590E+06	1,068E+02	5,303E+02	7,949E+05	5,341E+01
1999	1,889E+03	1,512E+06	1,016E+02	5,045E+02	7,562E+05	5,081E+01
2000	1,797E+03	1,439E+06	9,666E+01	4,799E+02	7,193E+05	4,833E+01
2001	1,709E+03	1,368E+06	9,194E+01	4,565E+02	6,842E+05	4,597E+01
2002	1,626E+03	1,302E+06	8,746E+01	4,342E+02	6,508E+05	4,373E+01
2003	1,546E+03	1,238E+06	8,320E+01	4,130E+02	6,191E+05	4,160E+01
2004	1,471E+03	1,178E+06	7,914E+01	3,929E+02	5,889E+05	3,957E+01
2005	1,399E+03	1,120E+06	7,528E+01	3,737E+02	5,602E+05	3,764E+01
2006	1,331E+03	1,066E+06	7,161E+01	3,555E+02	5,329E+05	3,580E+01
2007	1,266E+03	1,014E+06	6,811E+01	3,382E+02	5,069E+05	3,406E+01
2008	1,204E+03	9,643E+05	6,479E+01	3,217E+02	4,822E+05	3,240E+01
2009	1,146E+03	9,173E+05	6,163E+01	3,060E+02	4,586E+05	3,082E+01
2010	1,090E+03	8,726E+05	5,863E+01	2,911E+02	4,363E+05	2,931E+01
2011	1,037E+03	8,300E+05	5,577E+01	2,769E+02	4,150E+05	2,788E+01

Results (Continued)

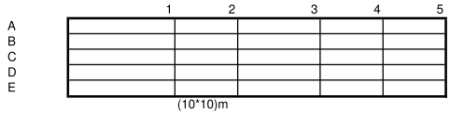
Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2012	3,264E+03	2,614E+06	1,756E+02	8,718E+02	1,307E+06	8,780E+01
2013	3,105E+03	2,486E+06	1,670E+02	8,293E+02	1,243E+06	8,352E+01
2014	2,953E+03	2,365E+06	1,589E+02	7,889E+02	1,182E+06	7,945E+01
2015	2,809E+03	2,250E+06	1,511E+02	7,504E+02	1,125E+06	7,557E+01
2016	2,672E+03	2,140E+06	1,438E+02	7,138E+02	1,070E+06	7,189E+01
2017	2,542E+03	2,035E+06	1,368E+02	6,790E+02	1,018E+06	6,838E+01
2018	2,418E+03	1,936E+06	1,301E+02	6,459E+02	9,681E+05	6,505E+01
2019	2,300E+03	1,842E+06	1,237E+02	6,144E+02	9,209E+05	6,187E+01
2020	2,188E+03	1,752E+06	1,177E+02	5,844E+02	8,760E+05	5,886E+01
2021	2,081E+03	1,667E+06	1,120E+02	5,559E+02	8,333E+05	5,599E+01
2022	1,980E+03	1,585E+06	1,065E+02	5,288E+02	7,926E+05	5,326E+01
2023	1,883E+03	1,508E+06	1,013E+02	5,030E+02	7,540E+05	5,066E+01
2024	1,791E+03	1,434E+06	9,638E+01	4,785E+02	7,172E+05	4,819E+01
2025	1,704E+03	1,364E+06	9,168E+01	4,551E+02	6,822E+05	4,584E+01
2026	1,621E+03	1,298E+06	8,720E+01	4,329E+02	6,489E+05	4,360E+01
2027	1,542E+03	1,235E+06	8,295E+01	4,118E+02	6,173E+05	4,148E+01
2028	1,467E+03	1,174E+06	7,891E+01	3,917E+02	5,872E+05	3,945E+01
2029	1,395E+03	1,117E+06	7,506E+01	3,726E+02	5,586E+05	3,753E+01
2030	1,327E+03	1,063E+06	7,140E+01	3,545E+02	5,313E+05	3,570E+01
2031	1,262E+03	1,011E+06	6,792E+01	3,372E+02	5,054E+05	3,396E+01
2032	1,201E+03	9,615E+05	6,460E+01	3,207E+02	4,807E+05	3,230E+01
2033	1,142E+03	9,146E+05	6,145E+01	3,051E+02	4,573E+05	3,073E+01
2034	1,086E+03	8,700E+05	5,846E+01	2,902E+02	4,350E+05	2,923E+01
2035	1,033E+03	8,276E+05	5,560E+01	2,761E+02	4,138E+05	2,780E+01
2036	9,831E+02	7,872E+05	5,289E+01	2,626E+02	3,936E+05	2,645E+01
2037	9,351E+02	7,488E+05	5,031E+01	2,498E+02	3,744E+05	2,516E+01
2038	8,895E+02	7,123E+05	4,786E+01	2,376E+02	3,561E+05	2,393E+01
2039	8,461E+02	6,776E+05	4,552E+01	2,260E+02	3,388E+05	2,276E+01
2040	8,049E+02	6,445E+05	4,330E+01	2,150E+02	3,223E+05	2,165E+01
2041	7,656E+02	6,131E+05	4,119E+01	2,045E+02	3,065E+05	2,060E+01
2042	7,283E+02	5,832E+05	3,918E+01	1,945E+02	2,916E+05	1,959E+01
2043	6,928E+02	5,547E+05	3,727E+01	1,850E+02	2,774E+05	1,864E+01
2044	6,590E+02	5,277E+05	3,545E+01	1,760E+02	2,638E+05	1,773E+01
2045	6,268E+02	5,019E+05	3,373E+01	1,674E+02	2,510E+05	1,686E+01
2046	5,963E+02	4,775E+05	3,208E+01	1,593E+02	2,387E+05	1,604E+01
2047	5,672E+02	4,542E+05	3,052E+01	1,515E+02	2,271E+05	1,526E+01
2048	5,395E+02	4,320E+05	2,903E+01	1,441E+02	2,160E+05	1,451E+01
2049	5,132E+02	4,110E+05	2,761E+01	1,371E+02	2,055E+05	1,381E+01
2050	4,882E+02	3,909E+05	2,627E+01	1,304E+02	1,955E+05	1,313E+01
2051	4,644E+02	3,719E+05	2,498E+01	1,240E+02	1,859E+05	1,249E+01
2052	4,417E+02	3,537E+05	2,377E+01	1,180E+02	1,769E+05	1,188E+01
2053	4,202E+02	3,365E+05	2,261E+01	1,122E+02	1,682E+05	1,130E+01
2054	3,997E+02	3,201E+05	2,150E+01	1,068E+02	1,600E+05	1,075E+01
2055	3,802E+02	3,044E+05	2,046E+01	1,016E+02	1,522E+05	1,023E+01
2056	3,617E+02	2,896E+05	1,946E+01	9,660E+01	1,448E+05	9,729E+00
2057	3,440E+02	2,755E+05	1,851E+01	9,189E+01	1,377E+05	9,255E+00
2058	3,272E+02	2,620E+05	1,761E+01	8,741E+01	1,310E+05	8,803E+00
2059	3,113E+02	2,493E+05	1,675E+01	8,315E+01	1,246E+05	8,374E+00
2060	2,961E+02	2,371E+05	1,593E+01	7,909E+01	1,186E+05	7,965E+00
2061	2,817E+02	2,255E+05	1,515E+01	7,523E+01	1,128E+05	7,577E+00
2062	2,679E+02	2,145E+05	1,441E+01	7,156E+01	1,073E+05	7,207E+00

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2063	2,549E+02	2,041E+05	1,371E+01	6,807E+01	1,020E+05	6,856E+00
2064	2,424E+02	1,941E+05	1,304E+01	6,475E+01	9,706E+04	6,522E+00
2065	2,306E+02	1,847E+05	1,241E+01	6,160E+01	9,233E+04	6,203E+00
2066	2,194E+02	1,756E+05	1,180E+01	5,859E+01	8,782E+04	5,901E+00
2067	2,087E+02	1,671E+05	1,123E+01	5,573E+01	8,354E+04	5,613E+00
2068	1,985E+02	1,589E+05	1,068E+01	5,302E+01	7,947E+04	5,339E+00
2069	1,888E+02	1,512E+05	1,016E+01	5,043E+01	7,559E+04	5,079E+00
2070	1,796E+02	1,438E+05	9,663E+00	4,797E+01	7,190E+04	4,831E+00
2071	1,708E+02	1,368E+05	9,191E+00	4,563E+01	6,840E+04	4,596E+00
2072	1,625E+02	1,301E+05	8,743E+00	4,341E+01	6,506E+04	4,372E+00
2073	1,546E+02	1,238E+05	8,317E+00	4,129E+01	6,189E+04	4,158E+00
2074	1,470E+02	1,177E+05	7,911E+00	3,928E+01	5,887E+04	3,956E+00
2075	1,399E+02	1,120E+05	7,525E+00	3,736E+01	5,600E+04	3,763E+00
2076	1,330E+02	1,065E+05	7,158E+00	3,554E+01	5,327E+04	3,579E+00
2077	1,266E+02	1,013E+05	6,809E+00	3,380E+01	5,067E+04	3,405E+00
2078	1,204E+02	9,640E+04	6,477E+00	3,216E+01	4,820E+04	3,239E+00
2079	1,145E+02	9,170E+04	6,161E+00	3,059E+01	4,585E+04	3,081E+00
2080	1,089E+02	8,723E+04	5,861E+00	2,910E+01	4,361E+04	2,930E+00
2081	1,036E+02	8,297E+04	5,575E+00	2,768E+01	4,149E+04	2,787E+00
2082	9,856E+01	7,892E+04	5,303E+00	2,633E+01	3,946E+04	2,651E+00
2083	9,376E+01	7,508E+04	5,044E+00	2,504E+01	3,754E+04	2,522E+00
2084	8,918E+01	7,141E+04	4,798E+00	2,382E+01	3,571E+04	2,399E+00
2085	8,483E+01	6,793E+04	4,564E+00	2,266E+01	3,397E+04	2,282E+00
2086	8,070E+01	6,462E+04	4,342E+00	2,155E+01	3,231E+04	2,171E+00
2087	7,676E+01	6,147E+04	4,130E+00	2,050E+01	3,073E+04	2,065E+00
2088	7,302E+01	5,847E+04	3,929E+00	1,950E+01	2,923E+04	1,964E+00
2089	6,946E+01	5,562E+04	3,737E+00	1,855E+01	2,781E+04	1,868E+00
2090	6,607E+01	5,290E+04	3,555E+00	1,765E+01	2,645E+04	1,777E+00
2091	6,285E+01	5,032E+04	3,381E+00	1,679E+01	2,516E+04	1,691E+00
2092	5,978E+01	4,787E+04	3,216E+00	1,597E+01	2,394E+04	1,608E+00
2093	5,687E+01	4,554E+04	3,060E+00	1,519E+01	2,277E+04	1,530E+00
2094	5,409E+01	4,331E+04	2,910E+00	1,445E+01	2,166E+04	1,455E+00
2095	5,145E+01	4,120E+04	2,768E+00	1,374E+01	2,060E+04	1,384E+00
2096	4,894E+01	3,919E+04	2,633E+00	1,307E+01	1,960E+04	1,317E+00
2097	4,656E+01	3,728E+04	2,505E+00	1,244E+01	1,864E+04	1,252E+00
2098	4,429E+01	3,546E+04	2,383E+00	1,183E+01	1,773E+04	1,191E+00
2099	4,213E+01	3,373E+04	2,267E+00	1,125E+01	1,687E+04	1,133E+00
2100	4,007E+01	3,209E+04	2,156E+00	1,070E+01	1,604E+04	1,078E+00
2101	3,812E+01	3,052E+04	2,051E+00	1,018E+01	1,526E+04	1,025E+00
2102	3,626E+01	2,903E+04	1,951E+00	9,685E+00	1,452E+04	9,754E-01

Appendix 2. Measured results from Lassabacka

Lassabacka 2010-10-01



(10*10)m

Methane flow (mg/m2/h) = (Dppm/Dtime)* ((P*V)/(R*T))* M/A

Dppm= Differance in concentration (ppm)
P= Atmospheric pressure (101325 Pa)
Dtime= Differanve in time (h)
V= Chamber volume (m3)
R= Gas konstant (8,3145 Pa*m3/mole/K)
T= Temperature (K)
M= Molar wight (kg/mole)
A= Area (m2)

M CH4 (g/mole)	0,016043
M CO2 (g/mole)	0,044
Volume (m3)	0,012
Area (m2)	0,04

L1 GV 1,6m, CO2:36.8%, CH4:66,6%, O2:9,2%
13 Celsius degrees, cloudy

C3 (L1)

Soilair: CO2: 3,72% CH4:4,24% O2: 18,5%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	246
0,1	0	248
1,1	8	304
2,1	37	445
3,1	52	551
4,1	71	653
5,1	89	773
Flow (g/m2/h)	0,218588	3,53641365

B4 (L1)

Soilair: CO2: 0,97% CH4:0,12% O2:20,1%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	245
0,1	0	247
1,1	1	341
2,1	1	463
3,1	2	593
4,1	2	719
5,1	3	829
Flow (g/m2/h)	0,007368	3,920367132

C5 (L1)

Soilair: CO2: 0,07% CH4:0,00% O2:20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	242
0,1	0	243
1,1	0	250
2,1	0	265
3,1	0	285
4,1	0	296
5,1	0	311
Flow (g/m2/h)	0	0,458049768

E4 (L1)

Soilair: CO2: 0,03% CH4:0,00% O2:20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	258
0,1	0	250
1,1	0	250
2,1	0	259
3,1	0	274
4,1	1	287
5,1	1	301
Flow (g/m2/h)	0,002456	0,343537326

D2 (L1)

Soilair: CO2: 0,00% CH4:0,00% O2:20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	255
0,1	0	297
1,1	1	318
2,1	2	337
3,1	2	355
4,1	2	378
5,1	2	401
Flow (g/m2/h)	0,004912	0,700546704

A3 (L1)

Soilair: CO2: 0,03% CH4:0,00% O2:20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	237
0,1	0	240
1,1	0	246
2,1	0	262
3,1	0	280
4,1	0	296
5,1	0	309
Flow (g/m2/h)	0	0,464785794

(L2) cloudy, 13 Celsius degrees, soil, soft, new?

D3 (L2)

Soilair: CO2: 0,00% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	269
0,1	0	289
1,1	0	308
2,1	0	394
3,1	0	450
4,1	0	516
5,1	0	581
Flow (g/m2/h)	0	1,966919592

E1 (L2)

Soilair: CO2: 0,00% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	257
0,1	0	260
1,1	0	
2,1	0	324
3,1	0	351
4,1	0	371
5,1	0	391
Flow (g/m2/h)	0	0,882419406

C1 (L2)

Soilair: CO2: 0,18% CH4:0,00% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	257
0,1	0	263
1,1	0	334
2,1	1	449
3,1	1	568
4,1	2	690
5,1	3	808
Flow (g/m2/h)	0,007368	3,67113417

A2 (L2)

Soilair: CO2: 0,00% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	275
0,1	0	265
1,1	0	276
2,1	0	316
3,1	0	368
4,1	0	418
5,1	0	460
Flow (g/m2/h)	0	0,478929274

L3, cloudy, next to the path, gravels in the ground, apr. 13 celcius degrees
GW: 6m, CO2:0,62%, O2: 20,7%, CH4:0,00%

B2 (L3)

Soilair: CO2: 0,22% CH4:0,24% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	289
0,1	0	290
1,1	1	317
2,1	3	367
3,1	6	424
4,1	8	408
5,1	11	552
Flow (g/m2/h)	0,027017	1,764838812

D1 (L3)

Soilair: CO2: 3,28% CH4:6,03% O2: 17,0%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	318
0,1	0	417
1,1	3	478
2,1	5	518
3,1	8	557
4,1	12	602
5,1	14	619
Flow (g/m2/h)	0,034393	0,69453049

A4 (L3)

Soilair: CO2: 0,10% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	293
0,1	0	296
1,1	0	318
2,1	0	347
3,1	0	376
4,1	0	402
5,1	0	429
Flow (g/m2/h)	0	0,895891458

B5 (L3)

Soilair: CO2: 3,2% CH4:11,8% O2: 20,0%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	295
0,1	1	296
1,1	34	317
2,1	100	354
3,1	172	390
4,1	236	420
5,1	298	453
Flow (g/m2/h)	0,729446	1,057556082

D4 (L3)

Soilair: CO2: 0,73% CH4:0,50% O2: 19,3%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	264
0,1	0	265
1,1	1	281
2,1	3	299
3,1	6	322
4,1	8	341
5,1	11	358
Flow (g/m2/h)	0,027017	0,626450418

E2 (L3)

Soilair: CO2: 21,84% CH4:2,82% O2: 19,8%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	284
0,1	0	290
1,1	16	318
2,1	31	344
3,1	55	382
4,1	75	415
5,1	98	454
Flow (g/m2/h)	0,240693	1,104708264

L4, GW: 4,5m, cloudy, 13 celsius degrees, soft ground

C3 (L4)

Soilair: CO2: 2,05% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	255
0,1	0	255
1,1	0	269
2,1	0	294
3,1	0	317
4,1	0	335
5,1	0	353
Flow (g/m2/h)	0	0,660130548

A2 (L4)

Soilair: CO2: 0,06% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	213
0,1	0	289
1,1	0	294
2,1	0	314
3,1	0	332
4,1	0	349
5,1	0	365
Flow (g/m2/h)	0	0,511937976

A4 (L4)

Soilair: CO2: 0,04% CH4:0,00% O2: 20,8%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	1	263
0,1	1	263
1,1	2	275
2,1	2	291
3,1	2	301
4,1	2	314
5,1	2	325
Flow (g/m2/h)	0,002456	0,417633612

E4 (L4)

Soilair: CO2: 0,19% CH4:0,04% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	263
0,1	0	264
1,1	0	313
2,1	1	363
3,1	2	397
4,1	2	431
5,1	4	463
Flow (g/m2/h)	0,009824	1,340469174

E2 (L4)

Soilair: CO2: 0,06% CH4:0,01% O2: 20,6%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	262
0,1	0	264
1,1	1	287
2,1	1	319
3,1	2	336
4,1	2	362
5,1	2	376
Flow (g/m2/h)	0,004912	0,754434912

D1 (L4)

Soilair: CO2: 0,14% CH4:0,00% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	260
0,1	0	261
1,1	0	297
2,1	0	350
3,1	0	401
4,1	0	451
5,1	0	498
Flow (g/m2/h)	0	1,596438162

	CO2		CH4	
	conc. (%)	flow (g/m2/h)	conc. (%)	flow (g/m2/h)
C3 (L1)	3,72	3,53641	4,24	0,218588
B4 (L1)	0,97	3,920367	0,12	0,007368
C5 (L1)	0,07	0,45805	0	0
E4 (L1)	0,03	0,343537	0	0,002456
D2 (L1)	0	0,700547	0	0,004912
A3 (L1)	0,03	0,464786	0	0
D3 (L2)	0	1,96692	0	0
E1 (L2)	0	0,88242	0	0
C1 (L2)	0,18	3,671134	0	0,007368
A2 (L2)	0	0,478929	0	0
B2 (L3)	0,22	1,764839	0,24	0,027017
D1 (L3)	3,28	0,69453	6,03	0,034393
A4 (L3)	0,1	0,895891	0	0
B5 (L3)	3,2	1,057556	11,8	0,729446
D4 (L3)	0,73	0,62645	0,5	0,027017
E2 (L3)	21,84	1,104708	2,82	0,240693
C3 (L4)	2,05	0,660131	0	0
A2 (L4)	0,06	0,511938	0	0
A4 (L4)	0,04	0,417634	0	0,002456
E4 (L4)	0,19	1,340469	0,04	0,009824
E2 (L4)	0,06	0,754435	0,01	0,004912
D1 (L4)	0,14	1,596438	0	0
	Mean flow	1,265824	Mean flow	0,059839

Useful CH4	
%	g/m2/h
0	0
4,24	0,218588
0,12	0,007368
0,24	0,27017
6,03	0,034393
11,8	0,729446
0,5	0,027017
2,82	0,240693
0,04	0,009824
0,01	0,004912

Appendix 3. Theoretical result with Land GEM at Härlövsängar

Results

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
1950	0	0	0	0	0	0
1951	8,432E+02	6,752E+05	4,536E+01	2,252E+02	3,376E+05	2,268E+01
1952	1,645E+03	1,317E+06	8,852E+01	4,394E+02	6,587E+05	4,426E+01
1953	2,408E+03	1,928E+06	1,296E+02	6,432E+02	9,642E+05	6,478E+01
1954	3,134E+03	2,509E+06	1,686E+02	8,371E+02	1,255E+06	8,430E+01
1955	3,824E+03	3,062E+06	2,057E+02	1,021E+03	1,531E+06	1,029E+02
1956	4,481E+03	3,588E+06	2,411E+02	1,197E+03	1,794E+06	1,205E+02
1957	5,105E+03	4,088E+06	2,747E+02	1,364E+03	2,044E+06	1,373E+02
1958	5,700E+03	4,564E+06	3,067E+02	1,522E+03	2,282E+06	1,533E+02
1959	6,265E+03	5,017E+06	3,371E+02	1,673E+03	2,508E+06	1,685E+02
1960	6,802E+03	5,447E+06	3,660E+02	1,817E+03	2,724E+06	1,830E+02
1961	7,314E+03	5,857E+06	3,935E+02	1,954E+03	2,928E+06	1,968E+02
1962	7,800E+03	6,246E+06	4,197E+02	2,084E+03	3,123E+06	2,098E+02
1963	8,263E+03	6,617E+06	4,446E+02	2,207E+03	3,308E+06	2,223E+02
1964	8,703E+03	6,969E+06	4,683E+02	2,325E+03	3,485E+06	2,341E+02
1965	9,122E+03	7,304E+06	4,908E+02	2,437E+03	3,652E+06	2,454E+02
1966	9,520E+03	7,623E+06	5,122E+02	2,543E+03	3,812E+06	2,561E+02
1967	9,899E+03	7,927E+06	5,326E+02	2,644E+03	3,963E+06	2,663E+02
1968	1,026E+04	8,215E+06	5,520E+02	2,740E+03	4,108E+06	2,760E+02
1969	1,060E+04	8,490E+06	5,704E+02	2,832E+03	4,245E+06	2,852E+02
1970	1,093E+04	8,751E+06	5,880E+02	2,919E+03	4,375E+06	2,940E+02
1971	1,124E+04	8,999E+06	6,047E+02	3,002E+03	4,500E+06	3,023E+02
1972	1,153E+04	9,236E+06	6,205E+02	3,081E+03	4,618E+06	3,103E+02
1973	1,181E+04	9,460E+06	6,356E+02	3,156E+03	4,730E+06	3,178E+02
1974	1,208E+04	9,674E+06	6,500E+02	3,227E+03	4,837E+06	3,250E+02
1975	1,234E+04	9,877E+06	6,637E+02	3,295E+03	4,939E+06	3,318E+02
1976	1,258E+04	1,007E+07	6,767E+02	3,359E+03	5,035E+06	3,383E+02
1977	1,196E+04	9,580E+06	6,437E+02	3,196E+03	4,790E+06	3,218E+02
1978	1,138E+04	9,112E+06	6,123E+02	3,040E+03	4,556E+06	3,061E+02
1979	1,082E+04	8,668E+06	5,824E+02	2,891E+03	4,334E+06	2,912E+02
1980	1,030E+04	8,245E+06	5,540E+02	2,750E+03	4,123E+06	2,770E+02
1981	9,795E+03	7,843E+06	5,270E+02	2,616E+03	3,922E+06	2,635E+02
1982	9,317E+03	7,461E+06	5,013E+02	2,489E+03	3,730E+06	2,506E+02
1983	8,863E+03	7,097E+06	4,768E+02	2,367E+03	3,548E+06	2,384E+02
1984	8,430E+03	6,751E+06	4,536E+02	2,252E+03	3,375E+06	2,268E+02
1985	8,019E+03	6,421E+06	4,315E+02	2,142E+03	3,211E+06	2,157E+02
1986	7,628E+03	6,108E+06	4,104E+02	2,038E+03	3,054E+06	2,052E+02
1987	7,256E+03	5,810E+06	3,904E+02	1,938E+03	2,905E+06	1,952E+02
1988	6,902E+03	5,527E+06	3,714E+02	1,844E+03	2,763E+06	1,857E+02
1989	6,566E+03	5,257E+06	3,532E+02	1,754E+03	2,629E+06	1,766E+02
1990	6,245E+03	5,001E+06	3,360E+02	1,668E+03	2,501E+06	1,680E+02
1991	5,941E+03	4,757E+06	3,196E+02	1,587E+03	2,379E+06	1,598E+02
1992	5,651E+03	4,525E+06	3,040E+02	1,509E+03	2,263E+06	1,520E+02
1993	5,375E+03	4,304E+06	2,892E+02	1,436E+03	2,152E+06	1,446E+02
1994	5,113E+03	4,094E+06	2,751E+02	1,366E+03	2,047E+06	1,376E+02
1995	4,864E+03	3,895E+06	2,617E+02	1,299E+03	1,947E+06	1,308E+02
1996	4,627E+03	3,705E+06	2,489E+02	1,236E+03	1,852E+06	1,245E+02
1997	4,401E+03	3,524E+06	2,368E+02	1,176E+03	1,762E+06	1,184E+02
1998	4,186E+03	3,352E+06	2,252E+02	1,118E+03	1,676E+06	1,126E+02
1999	3,982E+03	3,189E+06	2,143E+02	1,064E+03	1,594E+06	1,071E+02

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2000	3,788E+03	3,033E+06	2,038E+02	1,012E+03	1,517E+06	1,019E+02
2001	3,603E+03	2,885E+06	1,939E+02	9,625E+02	1,443E+06	9,693E+01
2002	3,428E+03	2,745E+06	1,844E+02	9,155E+02	1,372E+06	9,221E+01
2003	3,260E+03	2,611E+06	1,754E+02	8,709E+02	1,305E+06	8,771E+01
2004	3,101E+03	2,483E+06	1,669E+02	8,284E+02	1,242E+06	8,343E+01
2005	2,950E+03	2,362E+06	1,587E+02	7,880E+02	1,181E+06	7,936E+01
2006	2,806E+03	2,247E+06	1,510E+02	7,496E+02	1,124E+06	7,549E+01
2007	2,669E+03	2,138E+06	1,436E+02	7,130E+02	1,069E+06	7,181E+01
2008	2,539E+03	2,033E+06	1,366E+02	6,782E+02	1,017E+06	6,831E+01
2009	2,415E+03	1,934E+06	1,300E+02	6,452E+02	9,670E+05	6,498E+01
2010	2,298E+03	1,840E+06	1,236E+02	6,137E+02	9,199E+05	6,181E+01
2011	2,185E+03	1,750E+06	1,176E+02	5,838E+02	8,750E+05	5,879E+01
2012	2,079E+03	1,665E+06	1,119E+02	5,553E+02	8,323E+05	5,593E+01
2013	1,978E+03	1,584E+06	1,064E+02	5,282E+02	7,918E+05	5,320E+01
2014	1,881E+03	1,506E+06	1,012E+02	5,025E+02	7,531E+05	5,060E+01
2015	1,789E+03	1,433E+06	9,627E+01	4,780E+02	7,164E+05	4,814E+01
2016	1,702E+03	1,363E+06	9,158E+01	4,546E+02	6,815E+05	4,579E+01
2017	1,619E+03	1,296E+06	8,711E+01	4,325E+02	6,482E+05	4,355E+01
2018	1,540E+03	1,233E+06	8,286E+01	4,114E+02	6,166E+05	4,143E+01
2019	1,465E+03	1,173E+06	7,882E+01	3,913E+02	5,865E+05	3,941E+01
2020	1,394E+03	1,116E+06	7,498E+01	3,722E+02	5,579E+05	3,749E+01
2021	1,326E+03	1,061E+06	7,132E+01	3,541E+02	5,307E+05	3,566E+01
2022	1,261E+03	1,010E+06	6,784E+01	3,368E+02	5,048E+05	3,392E+01
2023	1,199E+03	9,604E+05	6,453E+01	3,204E+02	4,802E+05	3,227E+01
2024	1,141E+03	9,136E+05	6,138E+01	3,048E+02	4,568E+05	3,069E+01
2025	1,085E+03	8,690E+05	5,839E+01	2,899E+02	4,345E+05	2,920E+01
2026	1,032E+03	8,267E+05	5,554E+01	2,758E+02	4,133E+05	2,777E+01
2027	9,820E+02	7,863E+05	5,283E+01	2,623E+02	3,932E+05	2,642E+01
2028	9,341E+02	7,480E+05	5,026E+01	2,495E+02	3,740E+05	2,513E+01
2029	8,886E+02	7,115E+05	4,781E+01	2,373E+02	3,558E+05	2,390E+01
2030	8,452E+02	6,768E+05	4,548E+01	2,258E+02	3,384E+05	2,274E+01
2031	8,040E+02	6,438E+05	4,326E+01	2,148E+02	3,219E+05	2,163E+01
2032	7,648E+02	6,124E+05	4,115E+01	2,043E+02	3,062E+05	2,057E+01
2033	7,275E+02	5,825E+05	3,914E+01	1,943E+02	2,913E+05	1,957E+01
2034	6,920E+02	5,541E+05	3,723E+01	1,848E+02	2,771E+05	1,862E+01
2035	6,583E+02	5,271E+05	3,542E+01	1,758E+02	2,636E+05	1,771E+01
2036	6,262E+02	5,014E+05	3,369E+01	1,673E+02	2,507E+05	1,684E+01
2037	5,956E+02	4,769E+05	3,205E+01	1,591E+02	2,385E+05	1,602E+01
2038	5,666E+02	4,537E+05	3,048E+01	1,513E+02	2,268E+05	1,524E+01
2039	5,389E+02	4,316E+05	2,900E+01	1,440E+02	2,158E+05	1,450E+01
2040	5,127E+02	4,105E+05	2,758E+01	1,369E+02	2,053E+05	1,379E+01
2041	4,877E+02	3,905E+05	2,624E+01	1,303E+02	1,952E+05	1,312E+01
2042	4,639E+02	3,714E+05	2,496E+01	1,239E+02	1,857E+05	1,248E+01
2043	4,412E+02	3,533E+05	2,374E+01	1,179E+02	1,767E+05	1,187E+01
2044	4,197E+02	3,361E+05	2,258E+01	1,121E+02	1,680E+05	1,129E+01
2045	3,993E+02	3,197E+05	2,148E+01	1,066E+02	1,599E+05	1,074E+01
2046	3,798E+02	3,041E+05	2,043E+01	1,014E+02	1,521E+05	1,022E+01
2047	3,613E+02	2,893E+05	1,944E+01	9,650E+01	1,446E+05	9,718E+00
2048	3,436E+02	2,752E+05	1,849E+01	9,179E+01	1,376E+05	9,244E+00
2049	3,269E+02	2,618E+05	1,759E+01	8,731E+01	1,309E+05	8,794E+00
2050	3,109E+02	2,490E+05	1,673E+01	8,306E+01	1,245E+05	8,365E+00

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2051	2,958E+02	2,368E+05	1,591E+01	7,900E+01	1,184E+05	7,957E+00
2052	2,813E+02	2,253E+05	1,514E+01	7,515E+01	1,126E+05	7,569E+00
2053	2,676E+02	2,143E+05	1,440E+01	7,149E+01	1,072E+05	7,200E+00
2054	2,546E+02	2,039E+05	1,370E+01	6,800E+01	1,019E+05	6,848E+00
2055	2,422E+02	1,939E+05	1,303E+01	6,468E+01	9,696E+04	6,514E+00
2056	2,303E+02	1,845E+05	1,239E+01	6,153E+01	9,223E+04	6,197E+00
2057	2,191E+02	1,755E+05	1,179E+01	5,853E+01	8,773E+04	5,894E+00
2058	2,084E+02	1,669E+05	1,121E+01	5,567E+01	8,345E+04	5,607E+00
2059	1,983E+02	1,588E+05	1,067E+01	5,296E+01	7,938E+04	5,334E+00
2060	1,886E+02	1,510E+05	1,015E+01	5,038E+01	7,551E+04	5,073E+00
2061	1,794E+02	1,437E+05	9,652E+00	4,792E+01	7,183E+04	4,826E+00
2062	1,706E+02	1,366E+05	9,181E+00	4,558E+01	6,832E+04	4,591E+00
2063	1,623E+02	1,300E+05	8,733E+00	4,336E+01	6,499E+04	4,367E+00
2064	1,544E+02	1,236E+05	8,308E+00	4,124E+01	6,182E+04	4,154E+00
2065	1,469E+02	1,176E+05	7,902E+00	3,923E+01	5,881E+04	3,951E+00
2066	1,397E+02	1,119E+05	7,517E+00	3,732E+01	5,594E+04	3,758E+00
2067	1,329E+02	1,064E+05	7,150E+00	3,550E+01	5,321E+04	3,575E+00
2068	1,264E+02	1,012E+05	6,802E+00	3,377E+01	5,062E+04	3,401E+00
2069	1,203E+02	9,629E+04	6,470E+00	3,212E+01	4,815E+04	3,235E+00
2070	1,144E+02	9,160E+04	6,154E+00	3,055E+01	4,580E+04	3,077E+00
2071	1,088E+02	8,713E+04	5,854E+00	2,906E+01	4,356E+04	2,927E+00
2072	1,035E+02	8,288E+04	5,569E+00	2,765E+01	4,144E+04	2,784E+00
2073	9,845E+01	7,884E+04	5,297E+00	2,630E+01	3,942E+04	2,649E+00
2074	9,365E+01	7,499E+04	5,039E+00	2,502E+01	3,750E+04	2,519E+00
2075	8,909E+01	7,134E+04	4,793E+00	2,380E+01	3,567E+04	2,397E+00
2076	8,474E+01	6,786E+04	4,559E+00	2,264E+01	3,393E+04	2,280E+00
2077	8,061E+01	6,455E+04	4,337E+00	2,153E+01	3,227E+04	2,168E+00
2078	7,668E+01	6,140E+04	4,125E+00	2,048E+01	3,070E+04	2,063E+00
2079	7,294E+01	5,840E+04	3,924E+00	1,948E+01	2,920E+04	1,962E+00
2080	6,938E+01	5,556E+04	3,733E+00	1,853E+01	2,778E+04	1,866E+00
2081	6,600E+01	5,285E+04	3,551E+00	1,763E+01	2,642E+04	1,775E+00
2082	6,278E+01	5,027E+04	3,378E+00	1,677E+01	2,513E+04	1,689E+00
2083	5,972E+01	4,782E+04	3,213E+00	1,595E+01	2,391E+04	1,606E+00
2084	5,680E+01	4,549E+04	3,056E+00	1,517E+01	2,274E+04	1,528E+00
2085	5,403E+01	4,327E+04	2,907E+00	1,443E+01	2,163E+04	1,454E+00
2086	5,140E+01	4,116E+04	2,765E+00	1,373E+01	2,058E+04	1,383E+00
2087	4,889E+01	3,915E+04	2,630E+00	1,306E+01	1,957E+04	1,315E+00
2088	4,651E+01	3,724E+04	2,502E+00	1,242E+01	1,862E+04	1,251E+00
2089	4,424E+01	3,542E+04	2,380E+00	1,182E+01	1,771E+04	1,190E+00
2090	4,208E+01	3,370E+04	2,264E+00	1,124E+01	1,685E+04	1,132E+00

Appendix 4. Measured results at Härlövsängar

Härlövsängar 2010-09-24 & 29

	1	2	3	4	5
A					
B					
C					
D					
E					

Methane flow (mg/m2/h) = (Dppm /Dtime)* ((P*V)/(R*T))* M/A

Dppm= Differance in concentration (ppm)
P= Atmospheric pressure (101325 Pa)
Dtime= Differanve in time (h)
V= Chamber volume (m3)
R= Gas konstant (8,3145 Pa*m3/mole/K)
T= Temperature (K)
M= Molar wight (kg/mole)
A= Area (m2)

dCH4 (kg/mole)	0,016043	Volume (m	0,012
dCO2 (kg/mole)	0,044	Area (m2)	0,04

(H4) sun, 19 Celsius degrees, 2010-09-24

E4 (H4)

Soilair: CO2: 1,02% CH4:0,00% O2: 20,3%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	368
0,1	0	376
1,1	0	527
2,1	0	745
3,1	0	961
4,1	0	1182
5,1	0	1407
Flow (g/m2/h)	0	6,944842806

C1 (H4)

Soilair: CO2: 0,18% CH4:0,02% O2:20,8%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	328
0,1	0	352
1,1	0	385
2,1	1	404
3,1	2	435
4,1	2	467
5,1	3	500
6,1	3	528
7,1	4	554
8,1	4	584
9,1	5	611
Flow (g/m2/h)	0,006822	0,968239297

A5 (H4)

Soilair: CO2: 0,62% CH4:0,00% O2:20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	383
0,1	0	391
1,1	0	422
2,1	0	477
3,1	0	557
4,1	0	652
5,1	0	757
Flow (g/m2/h)	0	2,465385516

A2 (H4)

Soilair: CO2: 0,15% CH4:0,00% O2:20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	355
0,1	0	363
1,1	0	382
2,1	0	408
3,1	0	435
4,1	0	464
5,1	0	489
6,1	0	514
Flow (g/m2/h)	0	0,847616605

C5 (H4)

Soilair: CO2: 0,26% CH4:0,00% O2:20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	382
0,1	0	401
1,1	0	453
2,1	0	505
3,1	0	588
4,1	0	684
5,1	0	779
Flow (g/m2/h)	0	2,546217828

A4 (H4)

Soilair: CO2: 0,32% CH4:0,00% O2:20,6%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	314
0,1	0	317
1,1	0	359
2,1	0	436
3,1	0	498
4,1	0	559
5,1	0	628

Flow (g/m2/h) 0 2,094904086

(H3) sun, 19 Celsius degrees, 2010-09-24, sand, plastic waste, soft

C5 (H3)

Soilair: CO2: 2,15% CH4:0,00% O2: 19,2%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	367
0,1	0	376
1,1	0	489
2,1	0	799
3,1	0	1076
4,1	0	1321
5,1	0	1599

Flow (g/m2/h) 0 8,238159798

E4 (H3)

Soilair: CO2: 3,1% CH4:0,00% O2: 19,3%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	329
0,1	0	370
1,1	0	533
2,1	0	869
3,1	0	1344
4,1	0	1825
5,1	0	2329

Flow (g/m2/h) 0 13,19587493

D3 (H3)

Soilair: CO2: 1,11% CH4:0,09% O2: 12,0%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	449
0,1	0	482
1,1	0	617
2,1	1	943
3,1	2	1327
4,1	2	1709
5,1	2	2055
6,1	2	2394

Flow (g/m2/h) 0,004093 10,73273476

A1 (H3)

Soilair: CO2: 0,46% CH4:0,00% O2: 20,2%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	397
0,1	0	403
1,1	0	469
2,1	0	578
3,1	0	703
4,1	0	839
5,1	0	969

Flow (g/m2/h) 0 1,390122919

C1 (H3)

Soilair: CO2: 0,54% CH4:0,00% O2: 20,5%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	384
0,1	0	464
1,1	0	531
2,1	0	728
3,1	0	958
4,1	0	1189
5,1	0	1423

Flow (g/m2/h) 0 6,459848934

A4 (H3)

Soilair: CO2: 0,01% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	395
0,1	0	401
1,1	0	428
2,1	0	475
3,1	0	541
4,1	0	605
5,1	0	668

Flow (g/m2/h) 0 0,918018024

(H2) cloudy, 15 Celsius degrees, 2010-09-29

A1 (H2)

Soilair: CO2: 0,03% CH4:0,00% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	312
0,1	0	321
1,1	0	344
2,1	0	406
3,1	0	472
4,1	0	533
5,1	0	596

Flow (g/m2/h) 0 1,85240715

D2 (H2)

Soilair: CO2: 0,38% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	314
0,1	0	310
1,1	0	411
2,1	0	528
3,1	0	645
4,1	0	791
5,1	0	915

Flow (g/m2/h) 0 4,07529573

D3 (H2)

Soilair: CO2: 0,76% CH4:0,00% O2: 20,4%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	293
0,1	0	302
1,1	0	386
2,1	0	532
3,1	0	667
4,1	0	828
5,1	0	939

Flow (g/m2/h) 0 4,290848562

C5 (H2)

Soilair: CO2: 0,77% CH4:0,00% O2: 20,3%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	208
0,1	0	295
1,1	0	383
2,1	0	551
3,1	0	702
4,1	0	855
5,1	0	1064

Flow (g/m2/h) 0 5,180003994

A4 (H2)

Soilair: CO2: 0,00% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	292
0,1	0	303
1,1	0	320
2,1	0	344
3,1	0	376
4,1	0	404
5,1	0	428

Flow (g/m2/h) 0 0,84200325

A3 (H2)

Soilair: CO2: 0,50% CH4:0,00% O2: 20,3%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	290
0,1	0	298
1,1	0	347
2,1	0	426
3,1	0	512
4,1	0	596
5,1	0	676
Flow (g/m2/h)	0	2,546217828

C3 (H1)

Soilair: CO2: 0,46% CH4:0,00% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	277
0,1	0	291
1,1	0	440
2,1	0	660
3,1	0	778
4,1	0	928
5,1	0	1074
Flow (g/m2/h)	0	5,274308358

B4 (H1)

Soilair: CO2: 0,32% CH4:0,00% O2: 20,6%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	277
0,1	0	284
1,1	0	470
2,1	0	645
3,1	0	854
4,1	0	1032
5,1	0	1208
Flow (g/m2/h)	0	6,224088024

B2 (H1)

Soilair: CO2: 0,40% CH4:0,00% O2: 20,6%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	275
0,1	0	281
1,1	0	337
2,1	0	415
3,1	0	480
4,1	0	572
5,1	0	650
Flow (g/m2/h)	0	2,485593594

E4 (H1)

Soilair: CO2: 0,38% CH4:0,00% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	278
0,1	0	301
1,1	0	520
2,1	0	786
3,1	0	981
4,1	0	1214
5,1	0	1419
Flow (g/m2/h)	0	7,530877068

D5 (H1)

Soilair: CO2: 0,62% CH4:0,00% O2: 20,6%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	282
0,1	0	297
1,1	0	501
2,1	0	771
3,1	0	1028
4,1	0	1247
5,1	0	1487
Flow (g/m2/h)	0	8,01587094

E1 (H1)

Sollair: CO2: 0,15% CH4:0,00% O2: 20,9%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	281
0,1	0	318
1,1	0	394
2,1	0	449
3,1	0	530
4,1	0	544
5,1	0	547
Flow (g/m2/h)	0	1,542549854

	CO2 conc. (%)	CO2 flow (g/m2/h)	CH4 conc. (%)	CH4 flow (g/m2/h)
E4 ( )	1,02	6,9448	0	0
C1 [ ]	0,18	0,969239	0,02	0,006822
A5 ( )	0,62	2,465386	0	0
A2 ( )	0,15	0,847617	0	0
C5 [ ]	0,26	2,546218	0	0
A4 ( )	0,32	2,0949	0	0
C5 (H4)	2,15	8,238159	0	0
E4 (H4)	3,1	13,19587	0	0
D3 (H4)	1,11	10,73273	0,09	0,004053
A1 (H4)	0,46	1,390123	0	0
C1 (H4)	0,54	6,459849	0	0
A4 (H4)	0,01	0,918018	0	0
A1 (H3)	0,03	1,852407	0	0
D3 (H3)	0,76	4,290848	0	0
D2 (H3)	0,76	4,290848	0	0
C5 (H3)	0,77	5,180004	0	0
A4 (H3)	0	0,842003	0	0
A3 (H3)	0,5	2,546218	0	0
C3 (H2)	0,46	5,274306	0	0
B4 (H2)	0,32	6,224088	0	0
B2 (H2)	0,4	2,48559	0	0
E4 (H2)	0,38	7,530877	0	0
D5 (H2)	0,62	8,015871	0	0
E1 (H2)	0,15	1,54255	0	0
Mean flow		4,453272	Mean flow	0,000453

Useful CH4 %	g/m2/h
0	0
0,02	0,006822
0,09	0,004053

Appendix 5. Theoretical result with Land GEM at Onsjöparken

Results

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
1955	0	0	0	0	0	0
1956	3,449E+02	2,762E+05	1,856E+01	9,213E+01	1,381E+05	9,279E+00
1957	6,730E+02	5,389E+05	3,621E+01	1,798E+02	2,695E+05	1,811E+01
1958	9,851E+02	7,888E+05	5,300E+01	2,631E+02	3,944E+05	2,650E+01
1959	1,282E+03	1,027E+06	6,898E+01	3,424E+02	5,133E+05	3,449E+01
1960	1,564E+03	1,253E+06	8,417E+01	4,179E+02	6,264E+05	4,208E+01
1961	1,833E+03	1,468E+06	9,862E+01	4,896E+02	7,339E+05	4,931E+01
1962	2,089E+03	1,672E+06	1,124E+02	5,579E+02	8,362E+05	5,618E+01
1963	2,332E+03	1,867E+06	1,254E+02	6,228E+02	9,335E+05	6,272E+01
1964	2,563E+03	2,052E+06	1,379E+02	6,846E+02	1,026E+06	6,894E+01
1965	2,783E+03	2,228E+06	1,497E+02	7,433E+02	1,114E+06	7,486E+01
1966	2,992E+03	2,396E+06	1,610E+02	7,992E+02	1,198E+06	8,049E+01
1967	3,191E+03	2,555E+06	1,717E+02	8,523E+02	1,278E+06	8,584E+01
1968	3,380E+03	2,707E+06	1,819E+02	9,029E+02	1,353E+06	9,093E+01
1969	3,215E+03	2,575E+06	1,730E+02	8,589E+02	1,287E+06	8,650E+01
1970	3,059E+03	2,449E+06	1,646E+02	8,170E+02	1,225E+06	8,228E+01
1971	2,909E+03	2,330E+06	1,565E+02	7,771E+02	1,165E+06	7,827E+01
1972	2,768E+03	2,216E+06	1,489E+02	7,392E+02	1,108E+06	7,445E+01
1973	2,633E+03	2,108E+06	1,416E+02	7,032E+02	1,054E+06	7,082E+01
1974	2,504E+03	2,005E+06	1,347E+02	6,689E+02	1,003E+06	6,737E+01
1975	2,382E+03	1,907E+06	1,282E+02	6,363E+02	9,537E+05	6,408E+01
1976	2,266E+03	1,814E+06	1,219E+02	6,052E+02	9,072E+05	6,095E+01
1977	2,155E+03	1,726E+06	1,160E+02	5,757E+02	8,630E+05	5,798E+01
1978	2,050E+03	1,642E+06	1,103E+02	5,476E+02	8,209E+05	5,515E+01
1979	1,950E+03	1,562E+06	1,049E+02	5,209E+02	7,808E+05	5,246E+01
1980	1,855E+03	1,486E+06	9,981E+01	4,955E+02	7,428E+05	4,991E+01
1981	1,765E+03	1,413E+06	9,494E+01	4,714E+02	7,065E+05	4,747E+01
1982	1,679E+03	1,344E+06	9,031E+01	4,484E+02	6,721E+05	4,516E+01
1983	1,597E+03	1,279E+06	8,591E+01	4,265E+02	6,393E+05	4,295E+01
1984	1,519E+03	1,216E+06	8,172E+01	4,057E+02	6,081E+05	4,086E+01
1985	1,445E+03	1,157E+06	7,773E+01	3,859E+02	5,785E+05	3,887E+01
1986	1,374E+03	1,100E+06	7,394E+01	3,671E+02	5,502E+05	3,697E+01
1987	1,307E+03	1,047E+06	7,034E+01	3,492E+02	5,234E+05	3,517E+01
1988	1,244E+03	9,958E+05	6,691E+01	3,322E+02	4,979E+05	3,345E+01
1989	1,183E+03	9,472E+05	6,364E+01	3,160E+02	4,736E+05	3,182E+01
1990	1,125E+03	9,010E+05	6,054E+01	3,006E+02	4,505E+05	3,027E+01
1991	1,070E+03	8,571E+05	5,759E+01	2,859E+02	4,285E+05	2,879E+01
1992	1,018E+03	8,153E+05	5,478E+01	2,720E+02	4,076E+05	2,739E+01
1993	9,685E+02	7,755E+05	5,211E+01	2,587E+02	3,878E+05	2,605E+01
1994	9,212E+02	7,377E+05	4,956E+01	2,461E+02	3,688E+05	2,478E+01
1995	8,763E+02	7,017E+05	4,715E+01	2,341E+02	3,509E+05	2,357E+01
1996	8,336E+02	6,675E+05	4,485E+01	2,227E+02	3,337E+05	2,242E+01
1997	7,929E+02	6,349E+05	4,266E+01	2,118E+02	3,175E+05	2,133E+01
1998	7,542E+02	6,040E+05	4,058E+01	2,015E+02	3,020E+05	2,029E+01
1999	7,175E+02	5,745E+05	3,860E+01	1,916E+02	2,873E+05	1,930E+01
2000	6,825E+02	5,465E+05	3,672E+01	1,823E+02	2,732E+05	1,836E+01
2001	6,492E+02	5,198E+05	3,493E+01	1,734E+02	2,599E+05	1,746E+01
2002	6,175E+02	4,945E+05	3,322E+01	1,649E+02	2,472E+05	1,661E+01
2003	5,874E+02	4,704E+05	3,160E+01	1,569E+02	2,352E+05	1,580E+01
2004	5,588E+02	4,474E+05	3,006E+01	1,492E+02	2,237E+05	1,503E+01

Results (Continued)

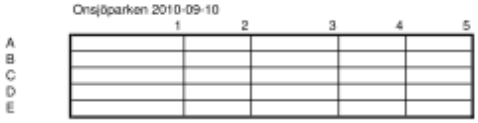
Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2005	5,315E+02	4,256E+05	2,860E+01	1,420E+02	2,128E+05	1,430E+01
2006	5,056E+02	4,048E+05	2,720E+01	1,350E+02	2,024E+05	1,360E+01
2007	4,809E+02	3,851E+05	2,588E+01	1,285E+02	1,926E+05	1,294E+01
2008	4,575E+02	3,663E+05	2,461E+01	1,222E+02	1,832E+05	1,231E+01
2009	4,352E+02	3,485E+05	2,341E+01	1,162E+02	1,742E+05	1,171E+01
2010	4,139E+02	3,315E+05	2,227E+01	1,106E+02	1,657E+05	1,114E+01
2011	3,937E+02	3,153E+05	2,118E+01	1,052E+02	1,576E+05	1,059E+01
2012	3,745E+02	2,999E+05	2,015E+01	1,000E+02	1,500E+05	1,008E+01
2013	3,563E+02	2,853E+05	1,917E+01	9,517E+01	1,426E+05	9,584E+00
2014	3,389E+02	2,714E+05	1,823E+01	9,052E+01	1,357E+05	9,117E+00
2015	3,224E+02	2,581E+05	1,734E+01	8,611E+01	1,291E+05	8,672E+00
2016	3,067E+02	2,456E+05	1,650E+01	8,191E+01	1,228E+05	8,249E+00
2017	2,917E+02	2,336E+05	1,569E+01	7,792E+01	1,168E+05	7,847E+00
2018	2,775E+02	2,222E+05	1,493E+01	7,412E+01	1,111E+05	7,464E+00
2019	2,639E+02	2,113E+05	1,420E+01	7,050E+01	1,057E+05	7,100E+00
2020	2,511E+02	2,010E+05	1,351E+01	6,706E+01	1,005E+05	6,754E+00
2021	2,388E+02	1,912E+05	1,285E+01	6,379E+01	9,562E+04	6,425E+00
2022	2,272E+02	1,819E+05	1,222E+01	6,068E+01	9,095E+04	6,111E+00
2023	2,161E+02	1,730E+05	1,163E+01	5,772E+01	8,652E+04	5,813E+00
2024	2,056E+02	1,646E+05	1,106E+01	5,491E+01	8,230E+04	5,530E+00
2025	1,955E+02	1,566E+05	1,052E+01	5,223E+01	7,829E+04	5,260E+00
2026	1,860E+02	1,489E+05	1,001E+01	4,968E+01	7,447E+04	5,003E+00
2027	1,769E+02	1,417E+05	9,519E+00	4,726E+01	7,084E+04	4,759E+00
2028	1,683E+02	1,348E+05	9,055E+00	4,495E+01	6,738E+04	4,527E+00
2029	1,601E+02	1,282E+05	8,613E+00	4,276E+01	6,409E+04	4,307E+00
2030	1,523E+02	1,219E+05	8,193E+00	4,068E+01	6,097E+04	4,096E+00
2031	1,449E+02	1,160E+05	7,793E+00	3,869E+01	5,800E+04	3,897E+00
2032	1,378E+02	1,103E+05	7,413E+00	3,680E+01	5,517E+04	3,707E+00
2033	1,311E+02	1,050E+05	7,052E+00	3,501E+01	5,248E+04	3,526E+00
2034	1,247E+02	9,983E+04	6,708E+00	3,330E+01	4,992E+04	3,354E+00
2035	1,186E+02	9,497E+04	6,381E+00	3,168E+01	4,748E+04	3,190E+00
2036	1,128E+02	9,033E+04	6,070E+00	3,013E+01	4,517E+04	3,035E+00
2037	1,073E+02	8,593E+04	5,773E+00	2,866E+01	4,296E+04	2,887E+00
2038	1,021E+02	8,174E+04	5,492E+00	2,727E+01	4,087E+04	2,746E+00
2039	9,710E+01	7,775E+04	5,224E+00	2,594E+01	3,888E+04	2,612E+00
2040	9,236E+01	7,396E+04	4,969E+00	2,467E+01	3,698E+04	2,485E+00
2041	8,786E+01	7,035E+04	4,727E+00	2,347E+01	3,518E+04	2,363E+00
2042	8,357E+01	6,692E+04	4,496E+00	2,232E+01	3,346E+04	2,248E+00
2043	7,950E+01	6,366E+04	4,277E+00	2,123E+01	3,183E+04	2,139E+00
2044	7,562E+01	6,055E+04	4,069E+00	2,020E+01	3,028E+04	2,034E+00
2045	7,193E+01	5,760E+04	3,870E+00	1,921E+01	2,880E+04	1,935E+00
2046	6,842E+01	5,479E+04	3,681E+00	1,828E+01	2,740E+04	1,841E+00
2047	6,509E+01	5,212E+04	3,502E+00	1,739E+01	2,606E+04	1,751E+00
2048	6,191E+01	4,958E+04	3,331E+00	1,654E+01	2,479E+04	1,666E+00
2049	5,889E+01	4,716E+04	3,169E+00	1,573E+01	2,358E+04	1,584E+00
2050	5,602E+01	4,486E+04	3,014E+00	1,496E+01	2,243E+04	1,507E+00
2051	5,329E+01	4,267E+04	2,867E+00	1,423E+01	2,134E+04	1,434E+00
2052	5,069E+01	4,059E+04	2,727E+00	1,354E+01	2,029E+04	1,364E+00
2053	4,822E+01	3,861E+04	2,594E+00	1,288E+01	1,930E+04	1,297E+00
2054	4,587E+01	3,673E+04	2,468E+00	1,225E+01	1,836E+04	1,234E+00
2055	4,363E+01	3,494E+04	2,347E+00	1,165E+01	1,747E+04	1,174E+00

Results (Continued)

Year	Total landfill gas			Methane		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2056	4,150E+01	3,323E+04	2,233E+00	1,109E+01	1,662E+04	1,116E+00
2057	3,948E+01	3,161E+04	2,124E+00	1,054E+01	1,581E+04	1,062E+00
2058	3,755E+01	3,007E+04	2,020E+00	1,003E+01	1,503E+04	1,010E+00
2059	3,572E+01	2,860E+04	1,922E+00	9,541E+00	1,430E+04	9,609E-01
2060	3,398E+01	2,721E+04	1,828E+00	9,076E+00	1,360E+04	9,141E-01
2061	3,232E+01	2,588E+04	1,739E+00	8,633E+00	1,294E+04	8,695E-01
2062	3,074E+01	2,462E+04	1,654E+00	8,212E+00	1,231E+04	8,271E-01
2063	2,925E+01	2,342E+04	1,573E+00	7,812E+00	1,171E+04	7,867E-01
2064	2,782E+01	2,228E+04	1,497E+00	7,431E+00	1,114E+04	7,484E-01
2065	2,646E+01	2,119E+04	1,424E+00	7,068E+00	1,059E+04	7,119E-01
2066	2,517E+01	2,016E+04	1,354E+00	6,724E+00	1,008E+04	6,771E-01
2067	2,394E+01	1,917E+04	1,288E+00	6,396E+00	9,587E+03	6,441E-01
2068	2,278E+01	1,824E+04	1,225E+00	6,084E+00	9,119E+03	6,127E-01
2069	2,167E+01	1,735E+04	1,166E+00	5,787E+00	8,674E+03	5,828E-01
2070	2,061E+01	1,650E+04	1,109E+00	5,505E+00	8,251E+03	5,544E-01
2071	1,960E+01	1,570E+04	1,055E+00	5,236E+00	7,849E+03	5,274E-01
2072	1,865E+01	1,493E+04	1,003E+00	4,981E+00	7,466E+03	5,016E-01
2073	1,774E+01	1,420E+04	9,544E-01	4,738E+00	7,102E+03	4,772E-01
2074	1,687E+01	1,351E+04	9,078E-01	4,507E+00	6,756E+03	4,539E-01
2075	1,605E+01	1,285E+04	8,635E-01	4,287E+00	6,426E+03	4,318E-01
2076	1,527E+01	1,223E+04	8,214E-01	4,078E+00	6,113E+03	4,107E-01
2077	1,452E+01	1,163E+04	7,814E-01	3,879E+00	5,815E+03	3,907E-01
2078	1,381E+01	1,106E+04	7,433E-01	3,690E+00	5,531E+03	3,716E-01
2079	1,314E+01	1,052E+04	7,070E-01	3,510E+00	5,261E+03	3,535E-01
2080	1,250E+01	1,001E+04	6,725E-01	3,339E+00	5,005E+03	3,363E-01
2081	1,189E+01	9,521E+03	6,397E-01	3,176E+00	4,761E+03	3,199E-01
2082	1,131E+01	9,057E+03	6,085E-01	3,021E+00	4,528E+03	3,043E-01
2083	1,076E+01	8,615E+03	5,788E-01	2,874E+00	4,308E+03	2,894E-01
2084	1,023E+01	8,195E+03	5,506E-01	2,734E+00	4,097E+03	2,753E-01
2085	9,735E+00	7,795E+03	5,238E-01	2,600E+00	3,898E+03	2,619E-01
2086	9,260E+00	7,415E+03	4,982E-01	2,473E+00	3,708E+03	2,491E-01
2087	8,808E+00	7,053E+03	4,739E-01	2,353E+00	3,527E+03	2,370E-01
2088	8,379E+00	6,709E+03	4,508E-01	2,238E+00	3,355E+03	2,254E-01
2089	7,970E+00	6,382E+03	4,288E-01	2,129E+00	3,191E+03	2,144E-01
2090	7,582E+00	6,071E+03	4,079E-01	2,025E+00	3,035E+03	2,040E-01
2091	7,212E+00	5,775E+03	3,880E-01	1,926E+00	2,887E+03	1,940E-01
2092	6,860E+00	5,493E+03	3,691E-01	1,832E+00	2,747E+03	1,845E-01
2093	6,525E+00	5,225E+03	3,511E-01	1,743E+00	2,613E+03	1,755E-01
2094	6,207E+00	4,970E+03	3,340E-01	1,658E+00	2,485E+03	1,670E-01
2095	5,904E+00	4,728E+03	3,177E-01	1,577E+00	2,364E+03	1,588E-01

Appendix 6. Measured result at Onsjöparken

Onsjöparken 2010-09-10



Methane flow (mg/m2/h) = (Dppm /Dtime)* ((P*V)/(R*T))* M/A

Dppm= Differance in concentration (ppm)
P= Atmospheric pressure (101325 Pa)
Dtime= Differanve in time (h)
V= Chamber volume (m3)
R= Gas konstant (8,3145 Pa*m3/mole/K)
T= Temperature (K)
M= Molar wight (kg/mole)
A= Area (m2)

dCH4 (kg/mole)	0,016043
dCO2 (kg/mole)	0,044
Volume (m3)	0,012
Area (m2)	0,04

D4 (O2)

Soilair: CO2: 0,14% CH4:0,01% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	381
0,1	0	379
1,1	0	465
2,1	0	601
3,1	0	741
4,1	0	880
5,1	0	1007
Flow (g/m2/h)	0	4,230224328

C3 (O2)

Soilair: CO2: 0,25% CH4:0,03% O2:20,8%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	456
0,1	0	375
1,1	0	472
2,1	0	641
3,1	0	810
4,1	0	985
5,1	0	1155
6,1	0	1298
Flow (g/m2/h)	0	5,181126665

B2 (O2)

Soilair: CO2: 0,30% CH4:0,00% O2:20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	373
0,1	0	375
1,1	0	428
2,1	0	529
3,1	0	659
4,1	0	777
5,1	0	883
6,1	0	974
7,1	0	1071
8,1	0	1155
Flow (g/m2/h)	0	3,283812675

E1 (O2)

Soilair: CO2: 0,18% CH4:0,03% O2:20,8%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	384
0,1	0	384
1,1	0	424
2,1	0	482
3,1	0	542
4,1	0	601
5,1	0	651
Flow (g/m2/h)	0	1,798518942

E5 (O2)

Soilair: CO2: 0,10% CH4:0,00% O2:20,8%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	370
0,1	0	372
1,1	0	408
2,1	0	512
3,1	0	645
4,1	0	737
5,1	0	840
6,1	0	949
Flow (g/m2/h)	0	3,238905835

A4 (O2)

Sollair: CO2: 0,08% CH4:0,03% O2:20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	1	300
0,1	2	384
1,1	2	431
2,1	3	510
3,1	2	589
4,1	2	663
5,1	2	729
Flow (g/m2/h)	0,002408	2,32392897

C4 (O1)

Sollair: CO2: 0,27% CH4:0,01% O2: 20,7%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	2	328
0,1	2	335
1,1	2	415
2,1	2	515
3,1	2	609
4,1	2	692
5,1	2	773
Flow (g/m2/h)	0	2,950379388

E2 (O1)

Sollair: CO2: 0,65% CH4:0,00% O2: 20,4%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	2	382
0,1	3	390
1,1	3	540
2,1	3	656
3,1	3	798
4,1	4	914
5,1	4	1038
6,1	4	1147
7,1	4	1243
8,1	3	1336
Flow (g/m2/h)	0,001754	3,982675373

D3 (O1)

Sollair: CO2: 0,69% CH4:0,00% O2: 20,6%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	0	382
0,1	0	488
1,1	0	590
2,1	0	727
3,1	0	857
4,1	0	974
5,1	0	1077
Flow (g/m2/h)	0	3,967519314

A2 (O1)

Sollair: CO2: 0,30% CH4:0,00% O2: 20,5%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	2	340
0,1	1	371
1,1	4	403
2,1	4	470
3,1	4	543
4,1	5	610
5,1	6	671
6,1	6	723
7,1	7	772
8,1	8	811
9,1	8	865
10,1	7	906
Flow (g/m2/h)	0,007368	0,656992722

A4 (O1)

Sollair: CO2: 0,42% CH4:0,00% O2: 20,0%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	2	382
0,1	2	452
1,1	2	486
2,1	2	563
3,1	2	643
4,1	3	724
5,1	3	810
6,1	3	900
7,1	3	989
Flow (g/m2/h)	0,001754	2,583747116

C5 (O1)

Sollair: CO2: 0,30% CH4:0,30% O2: 20,2%

time (min,sec)	CH4 (ppm)	CO2 (ppm)
0	2	376
0,1	2	384
1,1	3	427
2,1	4	503
3,1	4	577
4,1	5	640
5,1	2	710
6,1	6	766
7,1	6	828
8,1	6	883
9,1	6	935
10,1	6	992
Flow (g/m2/h)	0,004913	1,045234004

	CO2 conc. (%)	CO2 flow (g/m2/h)	CH4 conc. (%)	CH4 flow (g/m2/h)
D4	0,14	4,23	0	0
C4	0,27	2,95	0	0
C3	0,25	5,18	0,03	0
E2	0,65	3,98	0	0,00175
B2	0,3	3,28	0	0
D3	0,69	3,967	0	0
E1	0,18	1,7985	0,03	0
A2	0,3	0,6569	0	0,007368
E5	0,1	3,238	0	0
A4(1)	0,42	2,5837	0	0,001754
A4(2)	0,08	2,3239	0,03	0,002408
C5	0,3	1,045234	0,3	0,004913
	Mean flow	2,936103	Mean flow	0,001516

Useful CH4

%	g/m2/h
0	0
0,03	0,002408
0,3	0,004913