

DIFFUSED LANDFILL GAS EMISSION MONITORING IN NON-HAZARDOUS WASTE LANDFILLS: STUDY CASES

A. CORTI*, L. LOMBARDI**, I. PECORINI** AND L. FRASSINETTI°

* *Dipartimento di Ingegneria dell'Informazione – Università degli Studi di Siena – via Roma, 56, 53100 Siena*

***DE, Dipartimento di Energetica “Sergio Stecco” – Università degli Studi di Firenze – via Santa Marta, 3, 50139 Firenze*

° *CSAI, Centro Servizi Ambiente Impianti Spa - S.p. 7 di Piantravigne, 52028 Terranuova Bracciolini (AR)*

SUMMARY: With the aim of reducing Greenhouse gases emissions and in general environmental impact of landfills, scientific research has been concentrated, since several years, on monitoring and control of non-collected emissions of landfill gas, since these are the main responsible for the landfill environmental load. With reference to these issues, the proposed study is concerned with the management of two non-hazardous waste landfills, located in Tuscany Region (Italy). The study, which is part of a larger project aimed to manage and optimise the energy recovery potential carried by the landfill gas coming from waste biodegradation, is concerned, in this first phase, with the estimation of landfill gas emissions from landfill covers, the analysis of the collection system efficiency, and the research of a spatial correlation between emissive areas and the type of landfill covers in order to optimise the possible interventions on-site.

1. INTRODUCTION

An articulated monitoring plan was arranged in order to set up an adequate measure campaign of the possible landfill gas escape from landfill body, with the aim of assuring scientific significance and coherence for the evaluation of vertical landfill gas emissions (i.e. from landfill surfaces in contact with atmosphere) and of horizontal landfill gas emissions (i.e. landfill gas migration through soil and subsoil toward the outside of landfill cultivation area).

Such a monitoring plan came as the result of several analyses and experimental measures carried out, also taking into account the critical suggestions and the information requirements highlighted by the local environmental control authorities, and it is based on the composition of two investigation techniques suitable for accidental emissions monitoring:

- measures of landfill gas presence in fixed monitoring points, realised as wells or trenches, named “gas-spy”;
- measure campaigns with “static accumulation chamber” of landfill gas fluxes from the surfaces of closed landfill modules, landfill cultivation zones and landfill neighbouring areas.

Both the measuring techniques, which have been already applied in similar scientific sectors and also in this specific one, required accurate studies and checks both in the definition phase and the on-site application phase, in order to be optimised.

By means of composing the two measuring techniques it is possible to monitor both the vertical component of landfill gas fluxes to atmosphere, using the accumulation chamber, and the horizontal component of landfill gas fluxes through soil and subsoil, by means of gas-spy. Hence, the two measuring techniques are complementary and are able to supply a quite complete investigation and control tool. For these reasons the two monitoring techniques were proposed as suitable tools to optimise the possible interventions on the plant.

The composition of the two measuring techniques represents a monitoring model able to highlight plant malfunctions and to help in general with the management of the landfill gas collection system, with the aim of reducing local and global environmental impacts and risk conditions and of optimising the energy recovery, when present.

On-site measures were elaborated, by means of geo-statistic tools, in order to evaluate the volumetric amounts of Greenhouse gases emitted to atmosphere per surface and time units. Hence, this part of the work allows highlighting the environmental impact due to emission coefficients of different covers.

Further, with reference to a landfill gas production model, based on the evaluation of waste organic matter biodegradation, the landfill gas mass balance was carried out allowing a calibration of the model itself with respect to actual landfill conditions. In this way, it was possible to improve the capability of the model to predict the landfill thermodynamic potential, supplying a tool for the definition of optimised plant management conditions in order to maximise the energy recovery.

2. STUDY CASES

Two landfill sites located in Tuscany and managed by Centro Servizi Ambiente Impianti (C.S.A.I.) were studied. The two landfills deal with non-hazardous waste – mainly municipal solid waste (MSW). The sites have differing geometric and operational characteristics. All two sites are in active use. The information pertinent to the study is presented in the Table 2.1, with the indication of the period during which the measurements have been carried out and the number of measurement points in each considered landfill site. All two sites are located in hilly areas with low population density and high importance in terms of landscape. The sites were designed to have a limited active life. They are managed by the creation, in various phases, of independent, overlapping modules that are the operative units on which the management plans of the landfills in question are based. The capture systems involve as much as possible the areas of active banking and the extracted gas is sent to internal combustion engines for power generation. Emergency flaring torches are however still present.

Table 2.1. Characterization of the sites studied: Casa Rota and Podere il Pero landfills.

	Examined active area (m ²)	V (m ³)	V closure (m ³)	Modules	n° LFG wells	Period of measurement
Casa Rota	149,095	2,348,234	3,700,000	11	55	Aug-06
Podere il Pero	39,150	464,218	438,000	4	37	Aug-06

3. GAS-SPY METHOD

The monitoring system used to identify possible lateral gas leaks from the landfill was conceived as an innovative, experimental marker spie system. Its aim is to identify possible non-conformities of the entire capturing system of LFG produced by the landfill reactor in respect to methods that have already been developed (Christophersen et al., 2001).

3.1 Materials and methods

To that end, Gas-spy devices were employed, intended to intercept and therefore accumulate, in static conditions, fluxes of gas in the lands surrounding the area being managed. From an instrumental point of view it is an elementary solution that costs little and is easy to carry out and maintain. The components of the device are the following:

- Slotted PVC tube with a threaded seal, ($\Phi 40$, L=250 cm);
- Gravel drainage bed;
- Non-woven fabric covering;
- Clay cover layer.

Once an appropriate setting has been chosen, an excavation of the proper dimensions is created. The PVC (Polyvinyl chloride) tube is inserted into the excavation perpendicular to the ground. In the following phase, three quarters of the excavation are filled with gravel. Finally, the drainage bed is covered with a non-woven fabric and a waterproof clay layer that reduces to a minimum the surface emissions of gas and guarantees semi-static conditions.

If fluxes of LFG are present, fluid accumulates in the spaces in the gravel (0.31 vol/vol porosity), and through the fissures of the PVC, it enters into the sealed tube. During the measurement plan a specific procedure is followed in which the volumetric percentages of the components of LFG are surveyed inside the Gas-spy. The instrument used is a “Bacharach-Landfill Gas Analyzer,” with a 300 cc/min sampling pump. The measurement is taken by switching on the suction pump of the instrument for the time necessary to obtain the maximum reliability of data in respect to the inertia given by the conditions of the measuring instrument and its feeding tube. The percentages of carbon dioxide, oxygen, and methane allow for the confirmation of the possible presence of LFG inside the Gas-spy. They also allow for the qualitative evaluation of the importance of the source of nourishment.

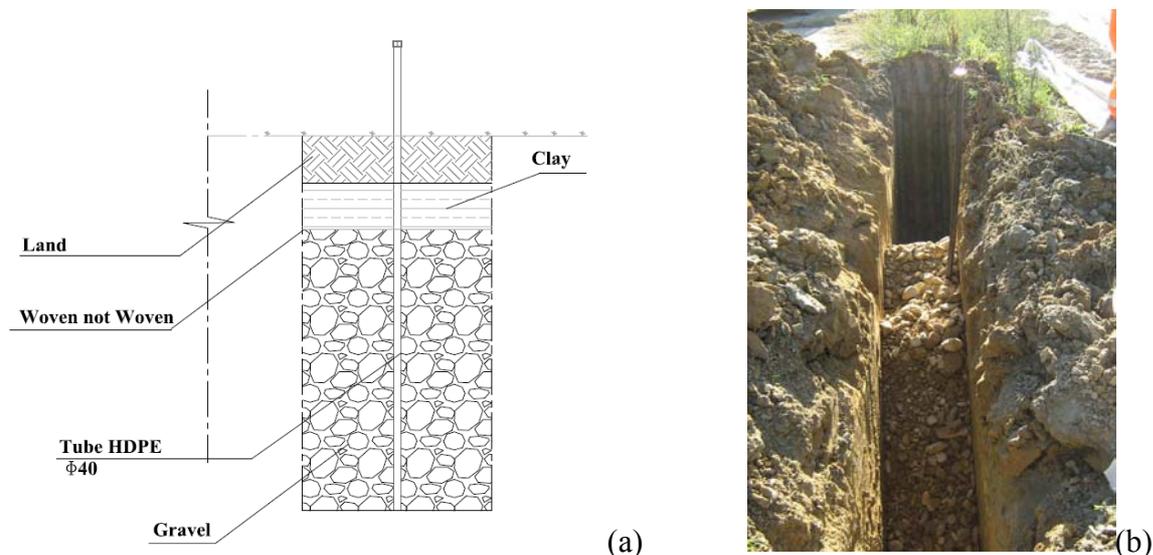


Figure 3.1. (a) Section of the Gas-spy device; (b) Excavations of the Linear Gas-spy.

Two different types of Gas-spy devices have been studied up to the present moment. An early version of the “Gas-spy” foresaw a relatively cubic excavation whose dimensions were 150x150x200 cm. This technique, called “point Gas-spy,” gives the product dimensions that allow for the proper functioning of the sentinel but limit its radius of interception.

The addition of a form able to monitor a larger section was made to the first version. As a result, “linear Gas-spies” with dimensions of 50x500x200 cm, similar to small trenches, were used. In comparison to the point devices, the linear devices are better able to survey the presence of fluxes of random or unknown origin. Figure 1 illustrates the creation of a linear Gas-spy.

3.2 Application to the case study and discussion

Gas-spy devices have been used in Casa Rota and Podere il Pero landfills and provided further information to the manager of the planning of the work done on the coverings. Especially in the case of landfill Podere il Pero, pursuant to the measurement of the composition of gas accumulated inside the device, it was possible to notice a lateral discharge and thus to carry out an intervention of lateral reinforcement of the capping by welding an additional membrane. Figure 3.2 illustrates the choice made in the positioning of the devices, with which the entire perimeter of the landfills is monitored, where possible.

It is evident that the measurements on the Gas-spy must be carried out at intervals (in the cases considered here they are monthly) in order to correlate various management schemes (for example a fastener implanted at the LFG collection plant) with the presence of LFG leaks. While taking measurements for various types of sentinels, the values noted were generally comparable to the conditions of atmospheric gas, with a coherent concentration of oxygen and a limited amount of carbon dioxide and methane and were within the error margin (1%) of the quantification device used. A few limited conditions in which the values of oxygen identified tend to decrease slightly are indicative of scarce metabolic activity in the land areas with no vegetation. Only in the case of the linear LSPY3 Gas-spy, situated in Casa Rota, at the top of the plant facing north, are there traces of LFG, even if the quantities lead one to suppose that they are fluxes of contamination of the interstitial gas even if they are not definitive.

The following are the values noted in one day, on both landfills.

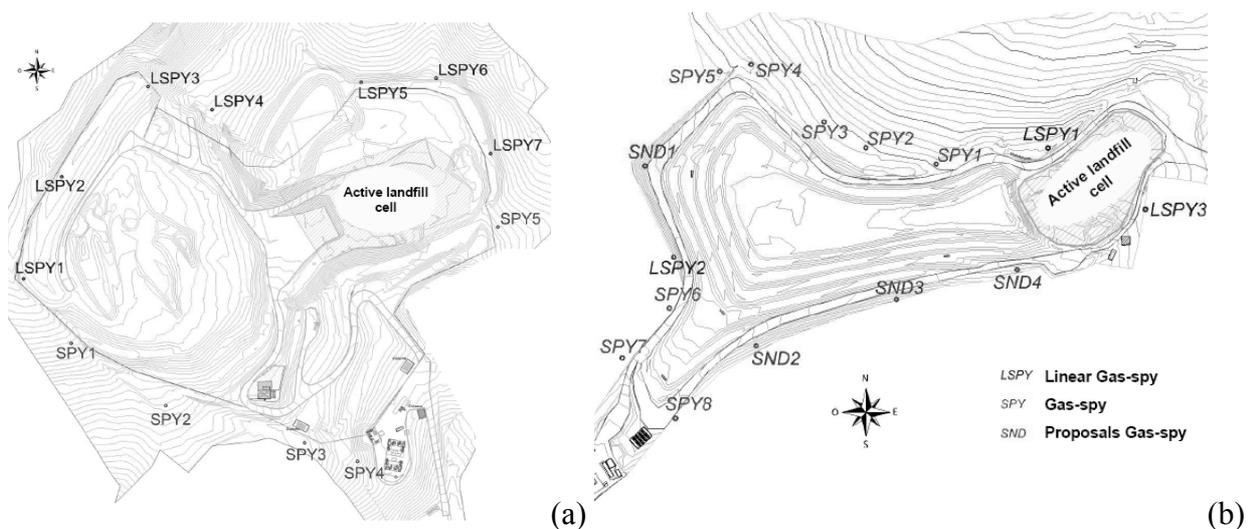


Figure 3.2. Location of “Gas-spy” in Casa Rota (a) and Podere il Pero (b) landfills

Table 3.1. Values of the volumetric concentrations measured on the Gas-spy: standard day.

	Casa Rota (Sept-06)			Podere il Pero (Sept-06)			
	CH ₄ (%)	CO ₂ (%)	O ₂ (%)	CH ₄ (%)	CO ₂ (%)	O ₂ (%)	
<i>SPY1</i>	0	0.5	19	<i>SPY1</i>	0	2.5	17.4
<i>SPY2</i>	0.1	0.5	18.9	<i>SPY2</i>	0	1.1	18.4
<i>SPY3</i>	0	0.4	18.7	<i>SPY3</i>	0	0.8	18.9
<i>SPY4</i>	0	0.3	19.1	<i>SPY4</i>	0	3.9	15.7
<i>SPY5</i>	0	0.2	19.3	<i>SPY5</i>	0	0.7	18.9
<i>LSPY1</i>	0.1	0.3	19	<i>SPY6</i>	1.3	12	7
<i>LSPY2</i>	0.5	1	17.6	<i>SPY7</i>	0	2.3	17.4
<i>LSPY3</i>	14.5	26	2.4	<i>SPY8</i>	0	0.3	19.2
<i>LSPY4</i>	0.1	2.4	17.1	<i>LSPY1</i>	0	2.5	17.4
<i>LSPY5</i>	0	0.2	19.2	<i>LSPY2</i>	0	2.3	14.1
<i>LSPY6</i>	0	0.1	19.3	<i>LSPY3</i>	0	0.9	17.7
<i>LSPY7</i>	0	0.2	19.1				

4. ACCUMULATION CHAMBER METHOD

The instruments used were designed and built in the laboratories of Dipartimento di Energetica "Sergio Stecco" University of Florence. The constructive and dimensional criteria were determined through critical review of scientific literature as no standardized guidelines or relevant technical regulations have been set out yet (Cardellini et al., 2003). The instruments used are: i) accumulation chamber; ii) infrared (IR) concentration level detector; iii) portable computer with data acquisition software.

The cylindrical chamber (radius= 100 mm; volume: 0.006 m³) is constructed from various materials: the main body is in HDPE (High Density Polyethylene), while the cover is made from transparent Plexiglas. The Plexiglas was chosen because of the need to visually verify the constant functioning of the mixer placed inside the accumulation chamber. The mixer, powered by a photovoltaic panel, guarantees a homogenous distribution of the concentration of gas within the chamber. The EGM-4 (Environmental Gas Monitor for CO₂) was produced and calibrated by PPSystems in England (Hitchin, Hertfordshire). The instrument has a guaranteed range of measurement of 0 - 2000 ppm, with an accuracy of 1%. It is fitted with gas pressure, temperature and humidity gauges and has an external hydrophobic filter. The instrument is suitable for application in larger measurement fields provided it is recalibrated. The analyzer can be connected to a portable computer, equipped with "Transfer PPSystems" data acquisition software. This software allows the measured data to be recorded with a minimum interval of less than 1.6 seconds. By placing the instrument correctly on the ground, in such a way that the rim is in full contact with the soil, continuous measurements of the levels of CO₂ concentration within the chamber are obtained. By means of a small pump, the gas from the chamber is passed through a filter to eliminate humidity and is then sent to the spectrophotometric cells. It is then sent back to the accumulation chamber. In this way, the conditions of a closed system are guaranteed within the interval of time referred to by the validity of the measurement. The concentration values measured by the spectrophotometers are passed through a serial interface analog-digital converter and exported to a computer which creates a graphic representation of the concentration of CO₂ as a function of time. The output software provides raw data with which, through suitable elaboration, it is possible to calculate the derivative before the function in its initial tract, that is to say the flux (Cardellini et al., 2003).

In operation, to gather measurements in the field, the following procedure is repeated:

- Location of sampling point by means of a GPS (Global Position System) instrument;
- Preparation of the sampling surface in order to ensure optimal adhesion of the chamber to the soil, thereby preventing gas from escaping during measurement;
- Survey and acquisition for 2-3 minutes of the concentration (ppm) of CO₂ inside the chamber.
- In order to reconstruct the regular grid (50x50m) in the field, a Leica SR20 GPS (Global Position System) receiver was used to georeference the sampling points.

4.1 Data elaboration and results

In order to estimate the flux of LFG emitted from the surface of the two landfill sites analysed in the study, statistical elaboration of the measured data is necessary.

Once data measured in several points over the landfill surface are available, the next step is the determination of optimal probability distribution. In the two cases, from the histogram it can be deduced that the log-normal distribution is the best function of probability density for the real data if compared to the normal distribution.

There is a wide variability in the emissions generated by the landfills: in the case of Casa Rota, values for CO₂ flux range from a precise minimum of 0.05 mol m⁻²d⁻¹, to a precise maximum of 36.58 mol m⁻²d⁻¹, determined in the cultivated area. This variability is also confirmed by the value of variance, a parameter that is particularly interesting as it gives an idea of the dispersion of the set of measurements in question. In this study the value of variance was quite high as reported in Table 4.1. The standard error is a value that describes the uncertainty in the estimate of the mean. It correlates directly to the variation of the obtained measure: the smaller the standard error, the smaller the variability of the measure and, therefore, the more reliable the statistics. For estimate of mean CO₂ flux diffusion, the procedure proposed by Sinclair (1991) is used. In order to continue with the calculation of the average CO₂ emission of the landfill, it is necessary to have an estimate of the average fluxes relative to the single populations.

For the evaluation of the CH₄/CO₂ relationship, samples were taken of the gases found in the gas capture wells dispersed in the landfill sites and carried away through tubes to the local stations.

Table 4.1. Statistical characterization of the series of experimental data

Statistical parameters		N° mes.	Mean	Conf. int 95%		Min	Max	Var.	S.D.	S.E.
				inf	sup					
Casa Rota	Flux CO ₂	58	3.44	1.52	5.36	0.05	36.58	53.26	7.3	0.96
	Ln Flux CO ₂	58	-0.31	-0.73	0.11	-2.98	3.6	2.7	1.64	0.21
Podere il Pero	Flux CO ₂	40	2.43	1.13	3.73	0.04	20.57	16.88	4.11	0.65
	Ln Flux CO ₂	40	-0.17	-0.63	0.39	-3.29	3.02	2.26	1.5	0.23

N° Mes. = number of measurements; *Conf. int. 95%* = confidence interval of 95%; *Var.* = variance; *S.D.* = Deviation; *S.E.* = Standard Error (the data are expressed in mol/m²day)

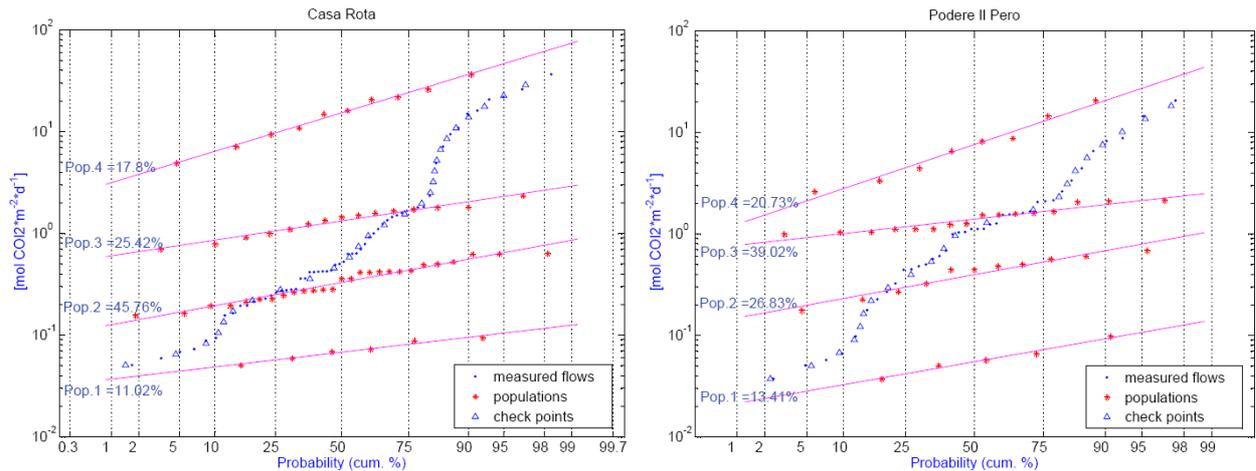


Figure 4.1. Adaptation of validation points (triangles) to the combination of the fluxes, (Sinclair 1991). Casa Rota (left) and Pero (right) Sinclair's analysis.

The analysis was completed with the use of “Gas Analyzer 2000”. With the aim of analyzing the flux of biogas emitted from the sites under examination, it is assumed that the methane emitted does not oxidize into CO₂ and that the relationship between the two principal components of the tapped LFG remains the same even when they come into contact with air. Carrying out a static analysis of the distribution of the measurements of the CH₄/CO₂ relationship for the gas capture wells, and considering only samples with an oxygen content of less than 10%, it can be inferred that the molar relationship in the case of Casa Rota is 1.26 and that of Podere il Pero is 1.20. The flux of CH₄ was thus calculated with the equation:

$$\varphi(CH_4)_{Estimated} = k_{CH_4/CO_2} \varphi(CO_2)_{Measured} \quad (1)$$

It must be remembered that the flux of CH₄ that has been assessed is only an indication and is an overestimated quantity since it was evaluated independently of the oxidation process of the methane located in the surface layer of the cap. Looking at Table 4.3, a hypothetical dependence can be drawn of the specific flux of emitted LFG on the extension of the landfill by hypothesizing a dependence on the reduced capacity to control per unit of volume of landfill used in the case of larger plants.

Table 4.2. Maximum quantity of LFG emitted from the landfills in question

		Flux [Nm ³ /h]	95% confidence interval	
			Inf.[Nm ³ /h]	Sup.[Nm ³ /h]
Casa Rota	Measured CO ₂ flux	343	204	432
	Estimated CH ₄ flux	412	237	564
	<i>Total LFG flux</i>	<i>755</i>	<i>441</i>	<i>997</i>
Podere il Pero	Measured CO ₂ flux	62	34	93
	Estimated CO ₂ flux	74	40	112
	<i>Total LFG flux</i>	<i>137</i>	<i>76</i>	<i>203</i>

Table 4.3. Comparison of specific fluxes of LFG

	Specific LFG flux [Nlh ⁻¹ m ²]	Surface [m ²]
Amiat (2001) (Raco et al., 2005)	8.05	500,000
Legoli (2005) (Raco et al., 2005)	4.7	130,000
Landfill 2 (2005) (Raco et al., 2005)	5.66	19,650
Landfill 3 (2005) (Raco et al., 2005)	3.2	13,000
Casa Rota (2006)	5.3	149,095
Podere il Pero (2006)	3.6	39,150

Table 4.4. Comparison of specific fluxes for different cover types at Casa Rota landfill

Cover type	Specific LFG flux [Nl ⁻¹ *h ⁻² *m ²]	S [m ²]
LDPE and Clay	0,45	9517
Clay	2,32	72168
LDPE	6,27	10537
Daily cover	15,55	19068

As a results of its cultivation evolution and of different subsequent management requirements, Casa Rota lanfill counts four several types of cover (see figure 4.2).

With the aim of characterizing the different types of cover in terms of their effectiveness, the LFG specific emission from the different types of cover were estimated. The estimation was carried out dividing the LFG flow values in four families, according the belonging zones, and considering an average CH₄/CO₂ rate for the deep gas. Values calculated for the LFG specific flux from the four different cover types are reported in table 4.4.

The results showed how the LDPE and Clay cover emits a very low flux, which is comparable to the flux values due to the natural respiration of the ground. (Capaccioni et al., 2005).

4.2 Isoflux map

Given the fact that it is impossible to continuously take measurements because of both the costs that they incur and the various technical difficulties associated with continual monitoring, we must have correct information at our disposal in order to give us a wider understanding of the natural phenomenon being studied.

For the study of the spatial variability of the emission of LFG from a landfill, an aerial flux map was created that provides a clearer picture of the areas with the highest emissions (Börjesson et al., 2000).

Since the function of optimal distribution proved to be the log-normal distribution according to the statistic interpretation of the series of flux data, the isoflux map was obtained by processing the measurements of the fluxes with the equation $\ln(\phi\text{CO}_2)$ using the program *Surfer 7.0*, which uses the interpolation process of *Kriging*. A phenomenon that was revealed during the monitoring phase was the effect of dryness in the summer that caused large fractures in the soil. This condition favors an increase in LFG leaks and explains the small, isolated leaks far from the area of cultivation visible on the isoflux maps (Figure 4.2).

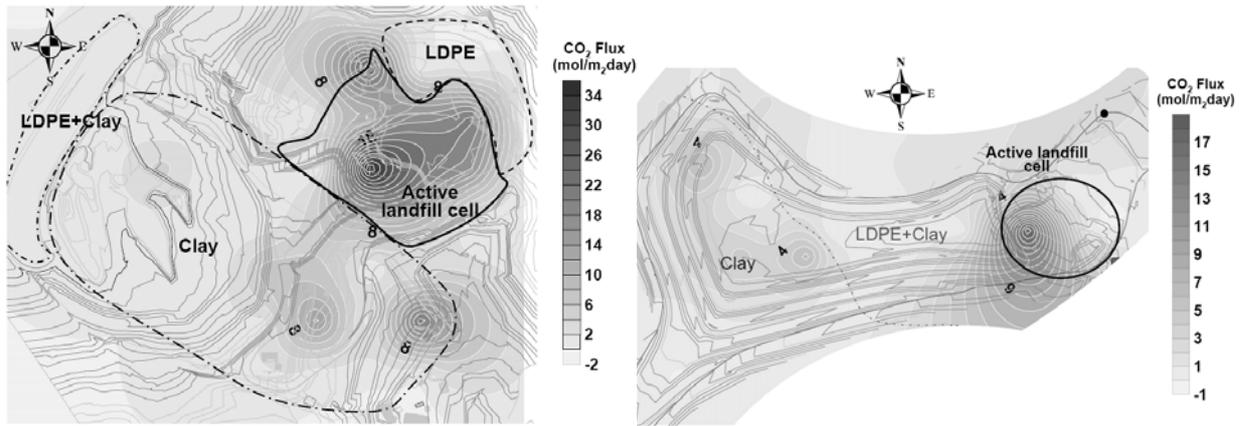


Figure 4.2. Emissions of CO₂ and types of covers in Casa Rota (left) and Podere il Pero (right).

4.3 Balance of mass and estimate of the capture coefficient

In order to complete the analysis of the case studies a validation must be done by means of the Scholl-Canyon theoretical model (Jones, 1995) used to calculate the LFG theoretically produced in landfills. In addition, the capture efficiency of the current LFG collection system must be assessed. The simplified balance of mass, is provided in: (Spokas et al., 2006)

$$LfG_{Model} = LfG_{engine} + LfG_{emes.Air} + LfG_{spy} \quad (2)$$

Where:

LfG_{Model} = annually produced LFG estimated according to Scholl-Canyon model [Nm³];

LfG_{engine} = annual amount of LFG combusted in the engines, measured upon entry into the energy recovery plant [Nm³];

LfG_{spy} = annual amount of LFG possibly dispersed in the ground (horizontal flux component) that is assumed to be zero [Nm³];

$LfG_{emes.Air}$ = annual amount of LFG possibly emitted to atmosphere through the cap, which has been evaluated by mean of static accumulation chamber [Nm³].

In order to determine the collection coefficient, the relationship between collected LFG and the estimation of LFG produced by the landfill was calculated. The following are the collection coefficients that were obtained.

Table 4.3. Components of the balance of mass and capture coefficients (2006)

	LfG_{Model} Nm ³ /year	LDG_{engine} Nm ³ /year	$LfG_{emes.air}$ Nm ³ /year	Collection coefficient
Casa Rota	21,994,318	13,259,497	8,286,019	60%
Podere il Pero	3,089,779	2,599,177	1,509,840	84%

The calculation above results to be quite interesting as an operational tool of control, in order to optimize the management of LFG in the landfills.

4 CONCLUSIONS

The accumulation chamber method has proven to be the simplest method for measuring the flux of LFG. Nevertheless, many sampling points were needed in order to elaborate the data in a meaningful way, as was a great deal of manpower.

To summarize the results of the monitoring campaign the following synthesis can be made:

- the least emissions are those on the old modules, whereas a critical point that is difficult to manage is the cultivation area, where it is difficult to take in the LFG and the daily capping is not guaranteed to be waterproof;
- comparing the specific flux of the studied landfills with that of other landfills, present in literature on the subject, it can be confirmed that the estimated emission is in line with the other values;
- the emissions measured on the area in cultivation (case of daily cover) are of two orders of magnitude higher than the emissions found on the capping realized with LDPE and clay;
- from the calculation of the capture coefficient, the efficiency of the coverings is confirmed and useful feedback necessary for the management of the plant is provided.

Some aspects of these initial analyses could be studied in further detail. Measurement plans could be organized (in the winter as well) to study variations in the emission factor due to physical characteristics of the covering terrain (humidity levels, the depths to which grass and other herbage have taken root, etc). It would be ideal to carry out the measurements while meteorological parameters are simultaneously measured. Field tests aimed at determining the optimal dimensions of the regular grids on which to gather measurements with the accumulation chamber could also be carried out.

REFERENCES

- Christophersen M., Kjeldsen P., Holst Helle, Chanton J., (2001) Lateral gas transport in soil adjacent to an old landfill: factors governing emissions and methane oxidation". *Waste Management & Research*, vol. 19, pp. 595-612.
- Cardellini C., Chiodini G., Frondini F., Granirei D., Lewicki J. and Peruzzi L. (2003) Accumulation chamber measurements of methane fluxes: application to volcanic-geothermal areas and landfills. *Applied Geochemistry*, 18, 45-54.
- Sinclair A. J. (1991) Selection of threshold estimation in exploration geochemistry: probability plots revisited. *Journal of Geochemical Exploration*, vol. 3, pp. 129-149
- Raco B., Scozzari A., Guidi M., Lelli M. and Lippo G., (2005). Comparison of two non invasive methodologies to monitor diffuse biogas emissions from MSW landfills soil: a case study. *Proceedings Sardinia 2005, Tenth International Waste Management and Landfill Symposium*.
- Börjesson G., Danielsson A., Svensson B. H., (2000), "Methane Fluxes from a Swedish Landfill Determined by Geostatistical Treatment of Static Chamber Measurements", in *Environmental Science Technology*, vol. 34, pp. 4044-4050.
- Department of the Army U.S. Army Corps of Engineers Washington (1995)./Engineering and Design - Landfill Off-Gas Collection and Treatment Systems/, Environmental Technical Letter, ETL 1110-1-160 17 April 1995 by Cary Jones.
- Spokas K., Bogner J., Chanton J.P., Morcet M., Aran, C., Graff C., Moreau-Le Golvan Y., Hebe, I. (2006), "Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems?", in *Waste Management*, vol. 26, pp. 516-525.