Evaluation of actual and future residual fluxes deriving from two Italian MSW landfills

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Leachate and biogas generated by a Municipal Solid Waste (MSW) landfill must be assessed and quantitatively defined, both in the active phase of cultivation and also in the final phase after the end of admissionof waste materials.In fact while operating costs and energy flows are mainly considered during the active phase, emissions deriving from leachate and biogas at a local and global level should be also taken into account in post-closure phase.Predictive models based on solid-liquid-gas mass transfer phenomena and biological kineticaspects have been largely defined in literature. A careful interpretation of the field data about the qualitative and quantitative features of the disposed waste and of generated leachate and biogas is mandatory for a reliable implementation of the models to specific real cases. These aspects have been evaluated for twoItalian case studies (one in the North and another in the South) of large practical interest, that may be suitable to define a general approach for the evaluation of the critical issues and best practice to adopt both in the active and in the post-closure phase of the management of a MSW landfill.

Keywords: residual fluxes, leachate, biogas, model, waste, landfill.

Introduction

The total amount of waste generated by economic activities and households in EU-27 increased from 211 Mt in 2004 up to 213 Mt in 2012 (Eurostat, 2015). In the last decades a policy of recycling and reusing of waste materials was developed in most EU Countries, determining an average decrease of landfill disposal of about 23%. However in 2013 about 30% w/w of the MSW generated in EU-27 was landfilled, therefore a careful landfill management policy is still mandatory in many Countries. Landfills technically evolved in recent years towards a modern role that has environmental aspects as a main priority (Cossu, 2010; Cossu, 2012).

A Municipal Solid Waste (MSW) landfill presents two fundamental aspects of impact from the point of view of residual fluxes that are potentially emitted in the surrounding environment: leachate, that is formed from the contact between the waste and the natural and released percolating water, and biogas which derives from the biological (anaerobic digestion) and physical (volatile components evaporation) phenomena operating in the mass of the landfill (Cossu and Christensen, 1989). The qualitative and quantitative prediction of generated outflows is a key factor to define consistently both operating cost and technological interventions concerning leachate (treatment, potential recycle solution, final disposal), while the evaluation of biogas flow-rate is important as a fundamental energetic vector in operating phase, and it should also be considered in account of local (atmospheric impact) and global (climate change) aspects of emission.

In order to evaluate the liquid and gaseous flow-rates deriving from a MSW landfill, predictive models based on solid/liquid/gas mass transfer phenomena and on biological kinetics were defined by many authors (among the others Manna et al., 1999; Rada et al., 2015; Alfieri et al., 2004). Although the specific parameters of these models should be outlined case-by-case through a careful interpretation of the field data, together with the records about the amounts and categories of disposed solid materials.The aim of the research is the evaluation of best practice and critical issues about the management of the active and passive phase of a MSW landfill, by means of the discussion of two significant Italian case studies: Turin (Northern Italy) and Potenza(Southern Italy)landfills, that differ about design and management aspects and about their period of activity. Several predictive models were implemented to the considered case studies: mass balance (hydrological balance) and Serial Water Balance for leachate production, and mass balance (stoichiometric equation) and LandGEM for biogas generation.

Landfill site	surface (ha)	volume (Mm^3)	cells	waste (Mt)	Active period
1 (Northern Italy)	79.9	18.63	9	17.38	1984–2009
2 (Southern Italy)	10	0.58	7	0.406	1989 – 2004

Table 1.General data about the considered case studies. Data about Landfill 2 were derived from Alfieri (Alfieri et al., 2004).

Material and Methods

Two Italian MSW landfills are here considered (Table 1): one in Northern Italy, in Turin area, and one in the South, in Potenza area. The two plants differ about design and management aspects, having Site 1 a volume that is more than 30 times the volume of Site 2, a surface that is almost 8 times higher than the one of Site 2, a disposed waste amount that is more than 40 times higher than Site 2, although the number of sub-cells is analogous. While Landfill 1 is completely in post-closure phase since 1/1/2010, Site 2 was mostly in post-closurein 2004; therefore Landfill 1 has a longer passive life. Both plants are equipped with systems pumping leachate and biogas and the sub-cells are individually impermeabilized.

Site 1 was the first Italian landfill equipped with an integrated environmental management system certified by UNI EN ISO 14001:2004. Landfill 1 was cultivated by "surface addition", starting from a level difference of 3 m below ground level up to a height of approximately 32 m above ground level. Below the bottom of the landfill there is an aquifer with a free surface located at depths of 6-10 m below ground level(Chiodoni, 2005;Melidoro, 2013). The area, located at a height of about 240 m above sea level, is currently involved in a transformation into a wildlife park. The managing Society provided detailed data about design aspects, quality and quantity of disposed waste, meteorological parameters, volumes of leachate and biogas generated since the beginning of the active phase, thatmade possible the present research.

Site 2 is located at a 800 m height above sea level, and it is made of 9 sub-sites. In 2004 only one sub-cell was in active phase. Limited data concerning design aspects, quality and quantity of waste and produced leachate were derived from literature (Alfieri et al., 2004).

fraction	C % d.s.	H % d.s.	O % d.s.	N % d.s.	S % d.s.	moisture %
paper and cardboard	47	6.5	42	0.2	0.2	16
textiles and leather	52	6.3	35.8	3.2	0.2	20
wood	50	6	42.3	0.2	0.1	22
plastic	62	8.5	17.4	2.3	0.2	6
glass and inerts	3	0.4	0.4	0.2	0.05	2
metals	4,5	0.6	4.3	0.1	0.05	4
fines	26	5.5	30.5	2.5	0.15	30
sludge	35	5.2	52.6	3.7	0.6	70

Table 2. Elemental analysis and moisture content of waste materials (Panepinto and Genon, 2012)

The waste material disposed in both plants is made of MSW, wastes assimilated to MSW (i.e. that may be treated as MSW) and sludge deriving from municipal wastewater treatment.The composition of wastes disposed in Landfill 1 (Table 2 and Table 3) may be assumed as representative for Italy in a period that is congruent with the active phase of the two plants. The overall relative amounts of the different kind of wastes in the two sites are the following: 73% w/w of MSW, 14% w/w of assimilated MSW, 13% w/w sludge from wastewater treatment for Landfill 1; 90% w/w of MSW and 10% of sludge for Landfill 2.

fraction	amount (% w/w)
fines	9.2
organic	25.9
plastic	14.3
paper and cardboard	23.8
polylaminated	2.5
wood	1.8
textiles and leather	4.5
glass and inerts	10.3
metals	3.4
other	4.3

Table 3. Component analysis of MSW disposed in Landfill 1 (average data referred to 2000-2009)

Various mathematical models, based on quantitative, qualitative and kinetic parameters, may be applied to predict the amounts of leachate and biogas generated in a specific MSW landfill. The data concerning the considered case studies were analysed by means of the following models: Hydrological Mass Balance and Serial Water Balance for leachate evaluation, and Stoichiometric model and LandGEM for biogas estimate.

Hydrological Mass Balance (Cossu and Christensen, 1989) is based on the evaluation of water mass balance within the landfill, making a distinction between active and passive phase of the plant. Rainwater and waste field capacity account as inflows, while evaporation, evapotranspiration and runoff are among the outflows.

As previously mentioned, detailed data were available for all life of Landfill 1. The following data, derived from Regional Environment Protection Agency (ARPA) of Basilicata databases, were considered in modelling leachate production for Landfill 2: average temperature 12°C, average precipitation 653.1 mm*year^{-1}. These values were analogous to the ones taken into account by Alfieri (Alfieri et al., 2004). Field capacity valuesof 5-47% for MSW, 5-36% for assimilated MSW, 0.07-0.09 for sludgewere calculated for Landfill 1 and employed also about Landfill 2.

Serial Water Balance model (Orta De Velasquez et al., 2003)and it takes into account monthly precipitations, infiltration, runoff, evaporation and evapotranspiration. Field capacity, elemental composition and particle-size are involved as waste characteristics.

Apart of the data already employed for the implementation of Hydrologic Mass balance to the two case studies, the application of Serial Water Balance model involved also the data shown in Table 3, and the data in Table 1 as quantitative characteristics.Serial Water Balance model was implemented only to Landfill 1, and not to Lanfill 2 because of the scarcity of available field data. For the same reason, no modelling was implemented to evaluate biogas production in Landfill 2.

The Stoichiometric Model (Tchobanoglous, 1993), based on a mass balance deriving from the elemental composition of waste, was applied to evaluate the generated biogas and methane. ForLandfill 1 the data schematized in Tables 2 and 3 were considered as physic-chemical properties of the disposed waste, and the data in Table 1 as quantitative characteristics.

Gass Emission Model (LandGEM) is a biochemical model developed by US EPA (Thomeloe, 1999) on the grounds of local landfilling operations, that calculates the annual amount of produced methane and biogasconsidering the amount of waste, methane generation rate (a value equal to 0.05 was employed in this study) (ZishenMou et al., 2015), methane potential production capacity (a value equal to 0.2 m^3kg^{-1} was employed in this study).The number of years making both the active and the passive phases of the landfill plant are considered as well by the model. Version 3.02 of LandGEM was implemented in the research. Apart of the already specified data, contained in Tables 1-3, the above-cited values of methane generation rate and potential production capacity were employed in the study.

Results and discussions

Leachate generation

The annual leachate volume values generated in Landfill 1 (the available field data refer to the period 2000-2014) is compared with the trend calculated by means of Hydrological Mass Balance model in Figure 1. Hydrological Mass Balance approach largely underestimates field data, although reliably representing the overall trend, probably because of the following aspects: first of all approximated values of the required parameters were employed (i.e. average monthly meteorological data and simplified composition of waste), then some significant aspects of filtration were neglected (i.e. channelling in preferential paths), as well as the effect of the hydraulic load of leachate collected at the bottom of the landfill, and the heterogeneous features of waste as porous medium.

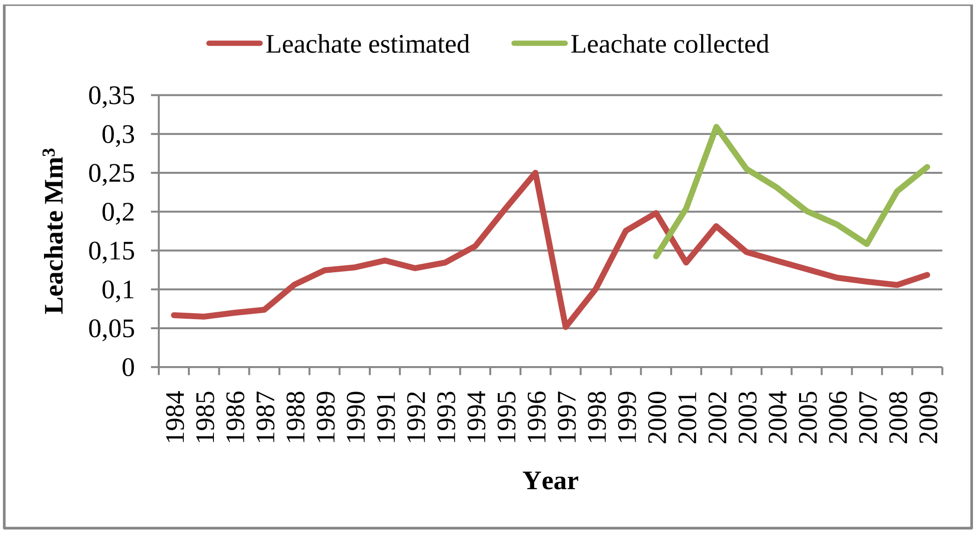

Fig. 1. Estimation of the amount of leachate for Landfill 1 by means of Hydrological Mass Balance Model and comparison with field data

The results of the prevision of leachate production by means of Serial Water Balance model about Landfill 1 (Figure 2) are in agreement with the ones obtained by means of the Hydrological Mass Balance model.

It can be observed that in 2002 the largest quantity of leachate was estimated(192.860 m^3).In 2007 a decrease in the production of leachate was prevised, reaching a quantity of 126.942 m^3. This fact is due to the decrease of the waste quantity stored in Landfill 1, but it is also the result of the increased extraction of biogas and leachate in the period of active management.Starting with 2010, when thecomplete closure of the landfill happened, the estimated leachate production reached a quantity of 178.870 m^3. It can be noticed that the entire leachate quantity exponentially decreased during the entire post-closure period. However the results of the application of Serial Water Balance model to Landfill 1 show a significant production of leachate for over 20 years after the beginning of the post-closure phase.

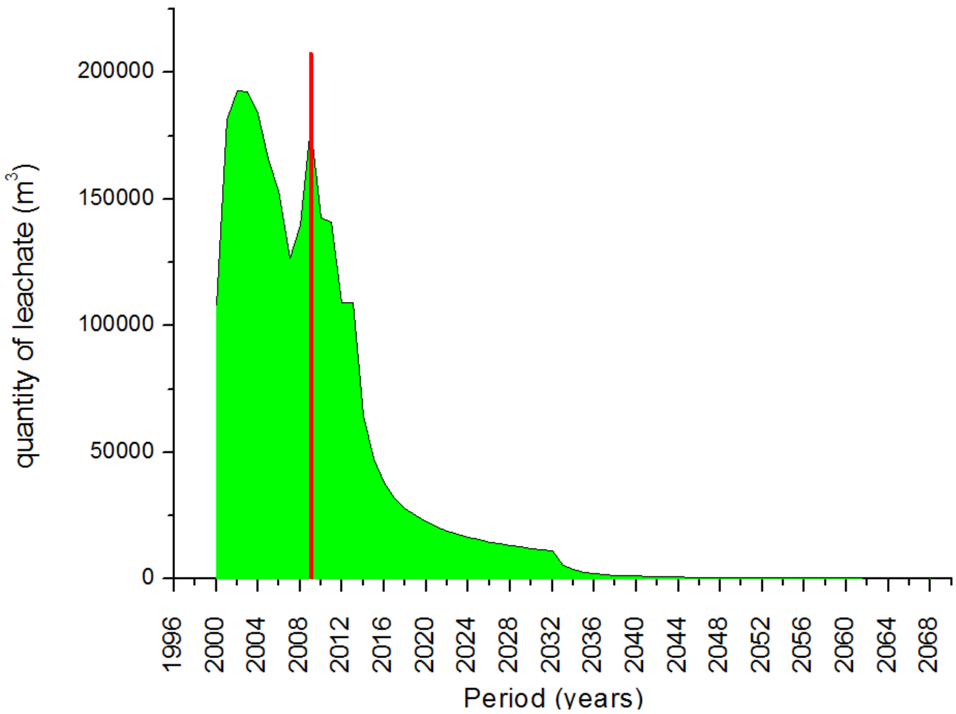

Fig.2 Estimation of amount of leachate for Landfill 1 using Serial Water Balance Model (the red line represents the beginning of post-closure phase)

Figure 3 represents the estimated quantity of leachate generated in Landfill 2 during the active phase of the plant by means of Hydrological Mass Balance model. The only available data for leachate about Landfill 2 were referred to 2003. The Hydrological Mass Balance model overestimated the experimental value, probably because it took into account values that were too approximated. In fact The accuracy of the results gathered through the implemented models depends on the correct estimation of chemical and physical parameters that describe the properties of the waste, the climatological data used and the superficial coverage that influence the amount of water going into the landfill body.

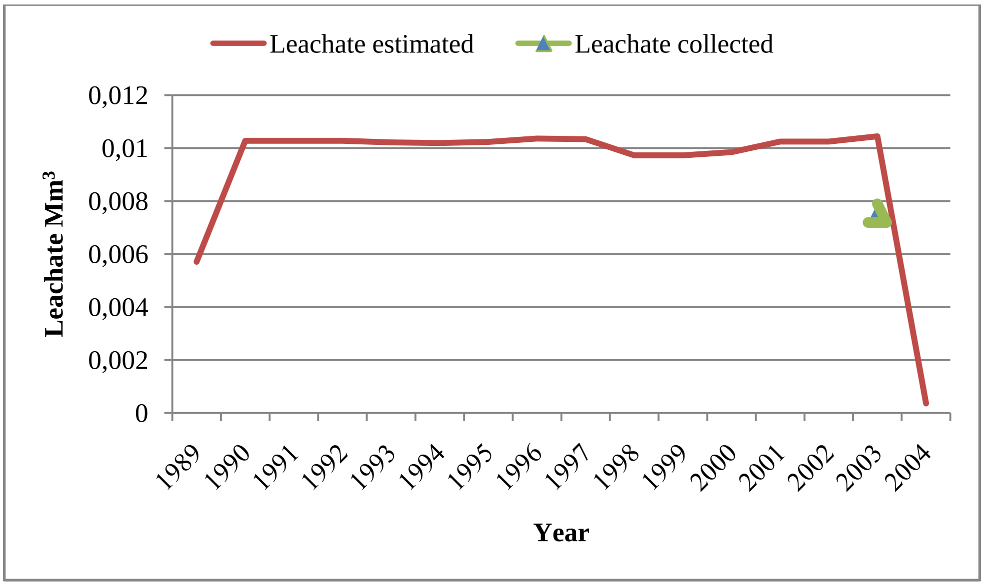

Fig. 3. Estimation of the amount of leachate for Landfill 2 using Hydrological Mass Balance Model

Biogas generation

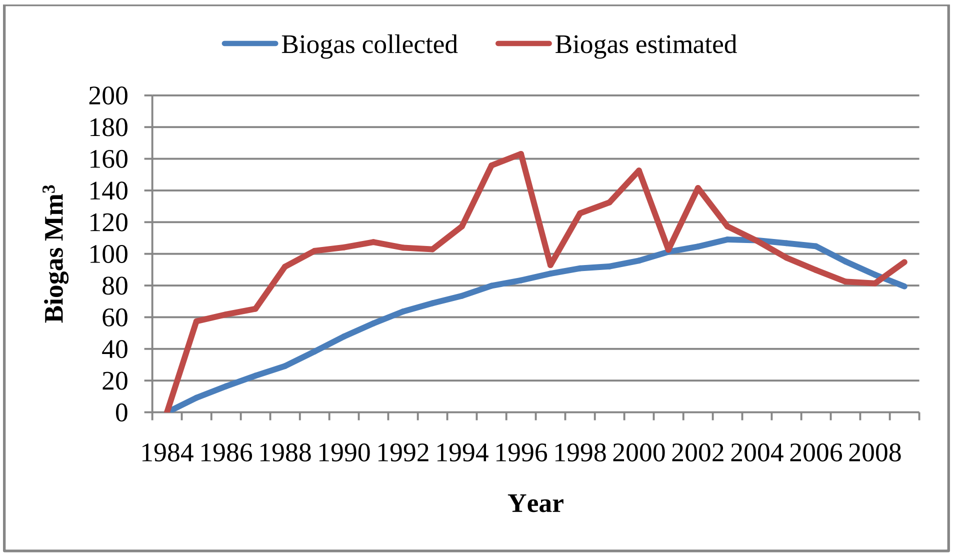

Fig. 4. Comparison between the real quantity of biogas generated in Landfill 1 and the volume estimated by means of Stoichiometric model

It can be observed (Fig. 4) that the volume of biogas estimated with Stoichiometric Model keep the curve of real biogas collected from the Landfill 1, with a higher overestimation in the first period of activity. Towards the end of the active period, the estimated curve keeps the tendency of the curve of real volume of biogas collected from Landfill 1.

Figure 5 shows the production of methane and biogas in Landfill 1 evaluated by means of Stoichiometric model.

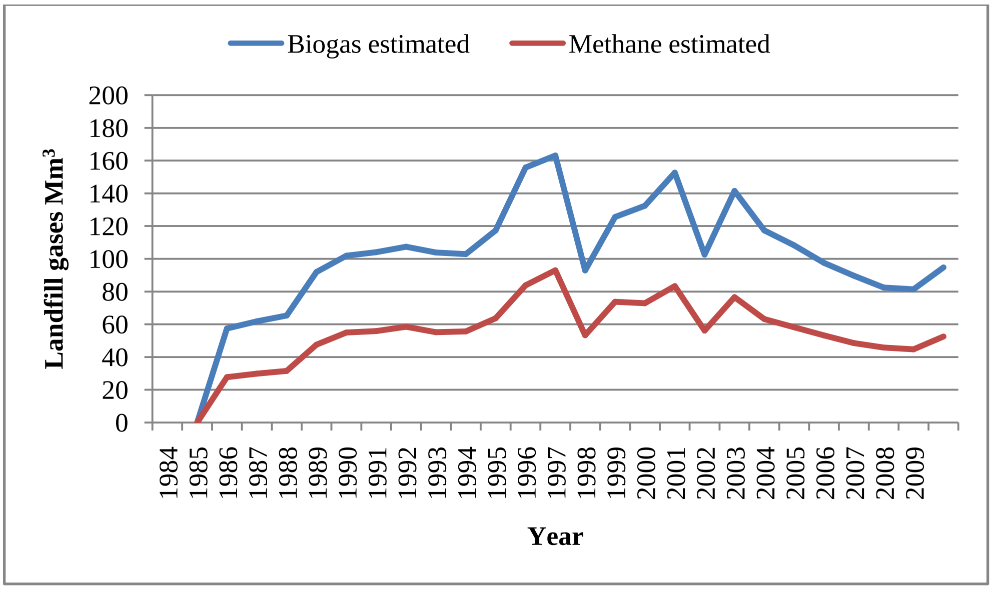

Fig. 5. Estimated amount of biogas and methane for Landfill 1 by means of Stoichiometric model

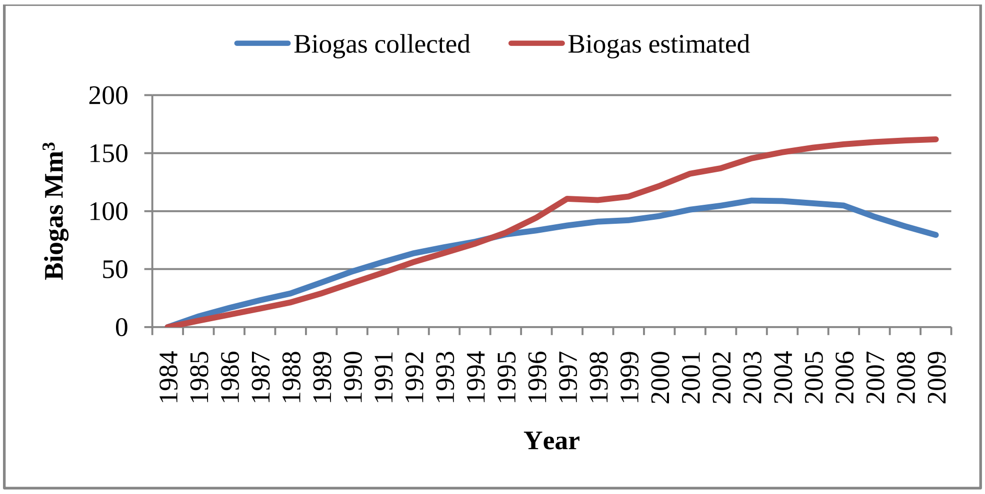

Fig. 6. Comparison between the real quantity of biogas generated in Landfill 1 and the volume estimated by means of LandGEM model

It can be observed (Fig. 6) that the trend of biogas estimated for Landfill 1 with LandGEM model, after a good agreement with field data for the first decade, shows the tendency to overestimate real volumes of biogas generated in the plant.

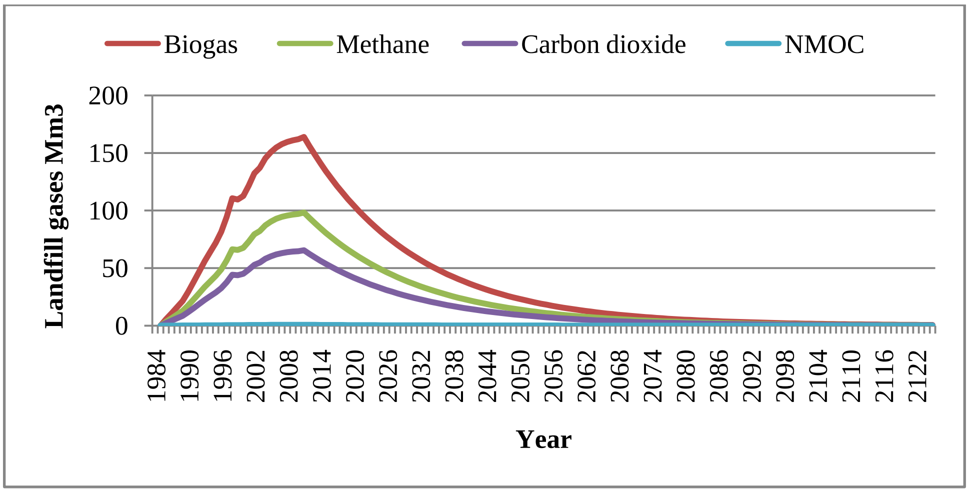

Fig. 7.Estimated biogas production of Landfill 1 by means of LandGEM model

According to the results of the application of LandGEM model to Landfill 1 (Fig. 7), a peak of the volume of biogas formed is noticeable after twenty years of activity, and biogas production will be relevant until more than 60 years after the beginning of the passive phase of the plant.

Conclusions

The characterization of the products arising from landfills is important from different points of view. In fact it is necessary to know the quantities of leachate and of biogas which can be formed during all the phases of landfill cultivation in account of their influence on receiving environment. If the good quantities of products are extracted, we can prevent disasters (explosions done by accumulations of biogas), and we can reduce the operating costs (reuse of products, recirculation of leachate); chiefly we can protect our environment.

The post-closure activity of landfill sites is one of the most important phases in the lifespan of a landfill.

On the basis of the implemented monitoring activities and of the elaborated stabilization reports, the obtained leachate and biogas in the landfill can be maintained within normal parameters.

This post-closure period contributes to the generation of biogas and leachate quantities that are estimated, in account of need of their correct treatment, in accordance with the mathematical models – Hydrological Mass Balance and Serial Water Balance (leachate) and Stoichiometric and LandGem Models (biogas).

After the landfills are closed, it can be observed that both leachate and biogas preserve their quantitative and qualitative properties, while their flow rate decreases gradually in time.

The Northern Italy landfill is one of the oldest sites in Italy. It is the beneficiary of specific treatment for the post-closure phase for the extraction of leach and biogas in optimal conditions.

The estimation of biogas quantity with the assistance of the LandGEM mathematical model enabled the characterization of the Northern Italy landfill from the viewpoint of the production/generation of products obtained from waste.

According to the estimations that were made with the assistance of the mathematical model for leachate (Serial Water Balance), it can be observed that the extraction of leachate from the landfill continues even after the closure of the landfill and that the obtained total quantity decreases exponentially in time.

A landfill located in South of Italy, with similar operating conditions but with different technological control measures, has been considered for the sake of comparison.

Acknowledgements

The authors gratefully acknowledge AMIAT SpA, the Society managing the landfill plant located in Turin area (Landfill 1), for supplying the field data that were necessary for the research.

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paper and cardboard	47	6.5	42	0.2	0.2	16
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organic	25.9
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Table 3. Component analysis of MSW disposed in Landfill 1 (average data referred to 2000-2009)

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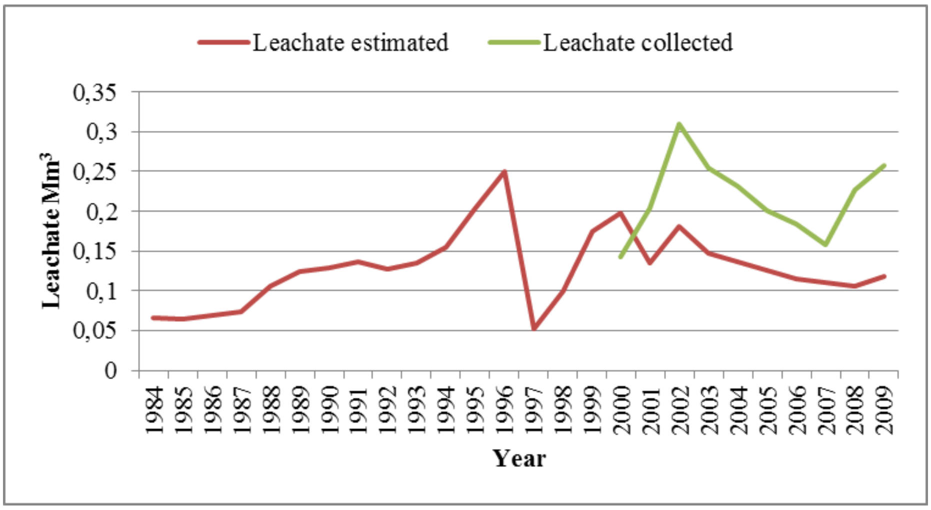

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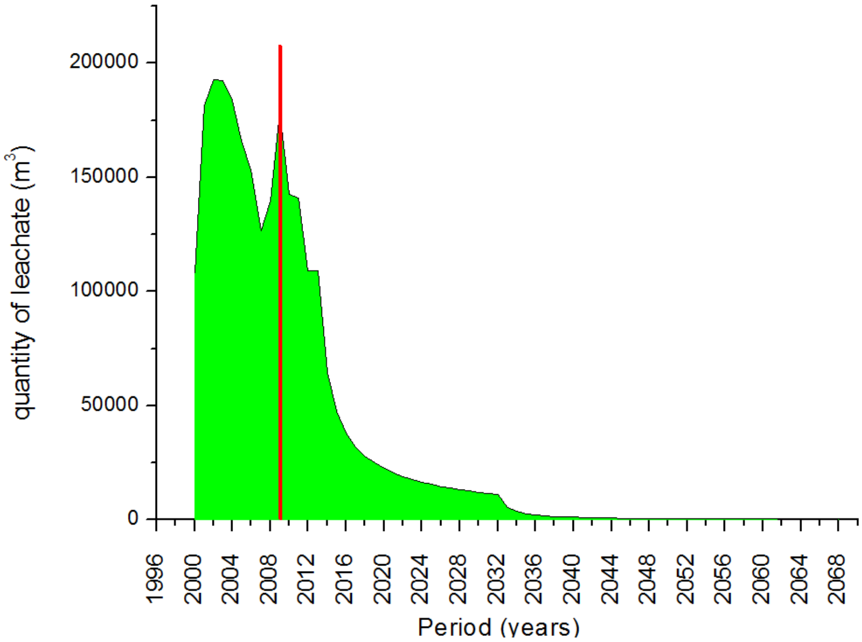

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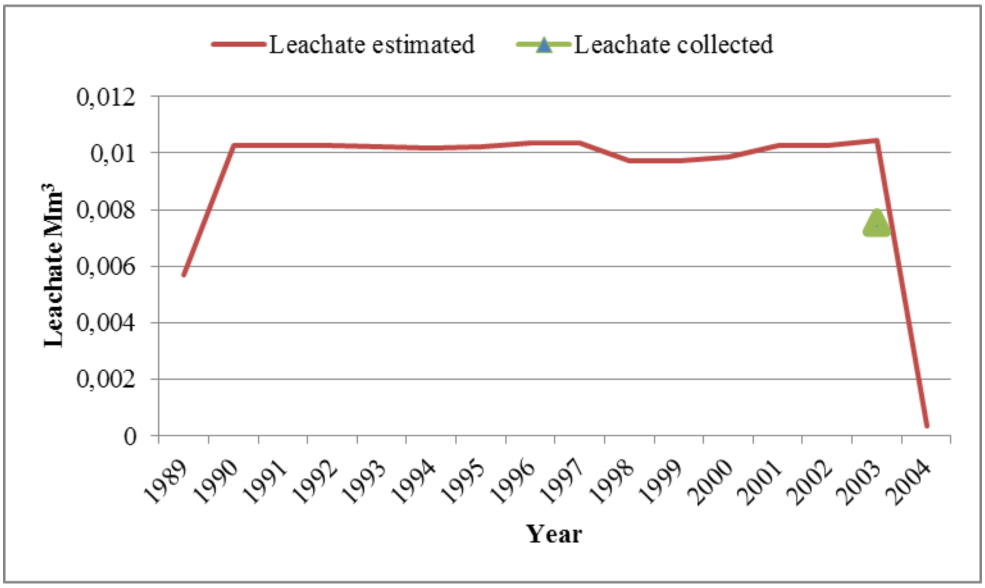
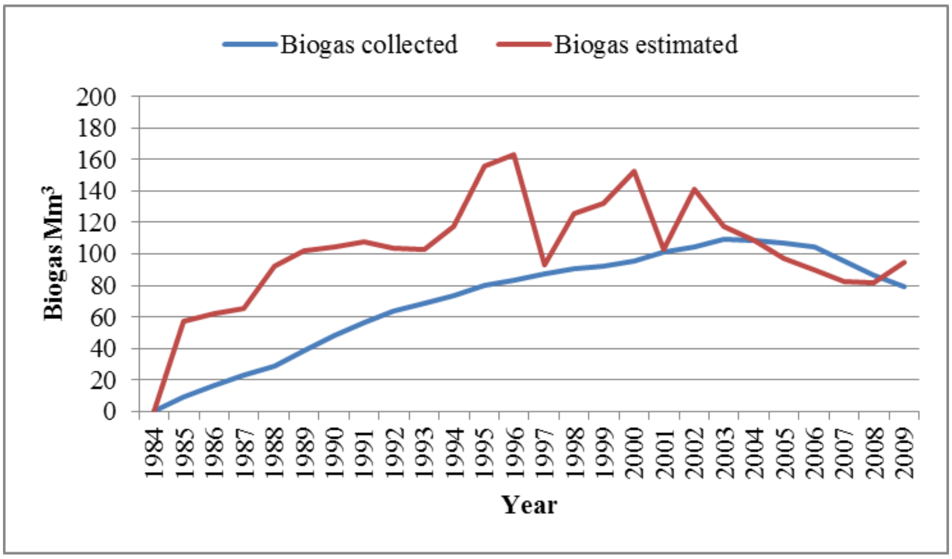


Fig. 3. Estimation of the amount of leachate for Landfill 2 using Hydrological Mass Balance Model



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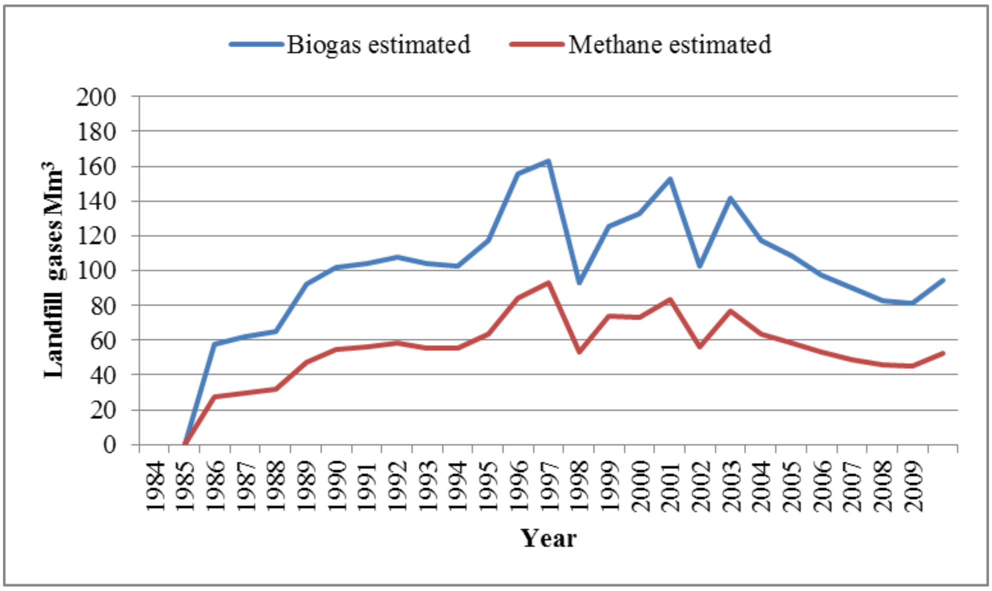

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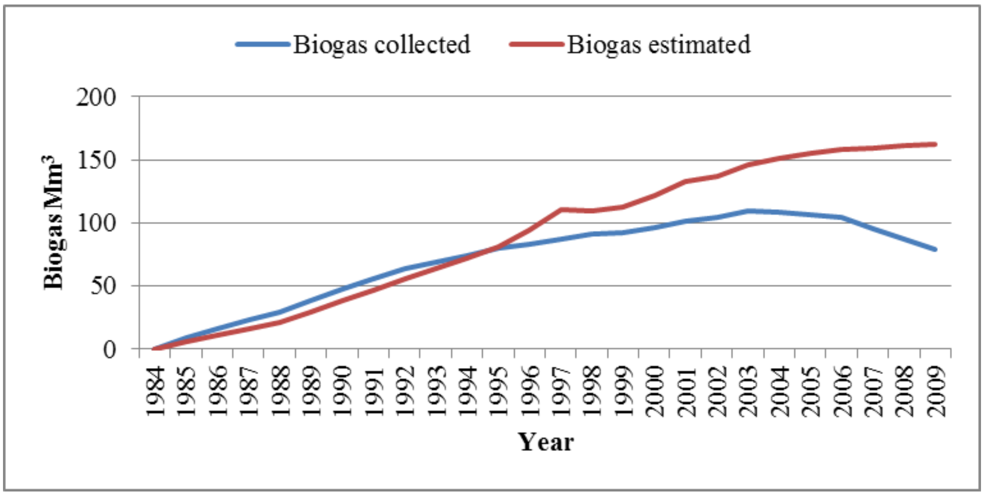

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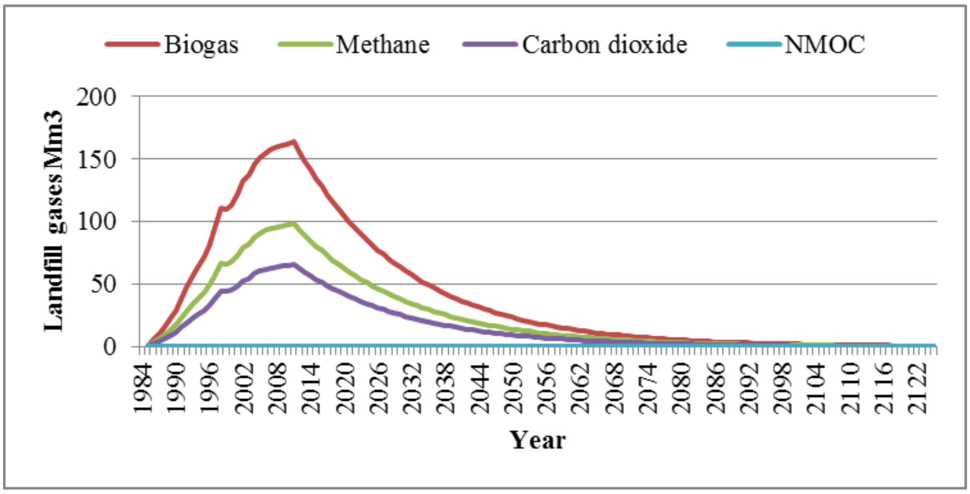

Fig. 7. Estimated biogas production of Landfill 1 by means of LandGEM model