Proceedings of the

4th International Symposium on

Enhanced Landfill Mining

5 - 6 February 2018

Mechelen, Belgium

Editors

Peter Tom Jones

Lieven Machiels

TO MINE OR NOT TO MINE: A REVIEW OF THE EFFECTS OF WASTE COMPOSITION, TIME AND LONG-TERM IMPACTS OF LANDFILLS IN THE DECISION MAKING FOR ELFM

Giovanna SAUVE, Karel VAN ACKER

Department of Materials Engineering, KU Leuven, Kasteelpark Arenberg 44 - box 2450, 3001 Leuven, Belgium

giovanna.sauve@kuleuven.be, karel.vanacker@kuleuven.be

Introduction

The environmental impacts of municipal solid waste (MSW) landfills have been addressed in comparison with other waste management strategies, in relation to the variation of site-specific and time-dependent parameters, and in the framework of landfill mining.[1–13] Environmental and economic assessments have been performed to determine the profitability of Landfill Mining (LFM) and, more recently, on Enhanced Landfill Mining (ELFM).[13–20] The environmental assessment of landfill mining and the benefits of resource recovery compared to remediation are an important incentive for policy implementation in the different countries.[21] Therefore, it is of great importance to develop a methodology for the environmental impact assessment which takes into account all site-specific and time-dependent parameters that affect the environmental performance of landfills. The more comprehensive methodology could allow to better assess the impacts of landfills as final disposal solutions and their environmental potential for Enhanced Landfill Mining.

As landfills represent complex and highly heterogeneous systems, the analysis of their impacts cannot be carried out as for other waste management solutions. In fact, landfill impacts occur over a much more extended period, thousands of years, and at different rates.[22,23] The emission potential of landfills depends on the degradation of waste and on the chemical, biological and physical processes that occur in the landfill.[3,9,10,24,25] These processes depend on time-related variations in the landfill and in the environment, and on site-specific characteristics. Soil conditions, hydrological, geological, climatic conditions, landfill management strategies, landfill design, waste composition and age of the waste: they all affect the short- and long-term emission potential and the actual release of contaminants.[9,12,22,25–28] Therefore, the reliability of the results significantly depends on the system boundaries, time frame and data quality and availability.[22] When assessing the environmental impacts of different landfills it is therefore important to consider aspects such as time-dependency, site related parameters and multi-input processes. Landfill sites cannot be considered as black boxes. The mechanisms underlying the emission potential need to be addressed to estimate the impact of landfills on a longer time horizon. Time-related emission profiles from landfills could lead to more accurate and consistent estimations of the long-term impacts of disposal sites. In this framework, this paper will address the evaluation of long-term emissions of closed landfills by analysing the literature related to landfill gas (LFG) and landfill leachate emissions. In particular, the paper will address the remaining available content of substances within the landfill body and the mobilising substance potential linked to leachate generation.

Waste composition and time-dependency in the environmental impact assessment of landfills

Waste composition

Waste composition is an important factor influencing the rate of generation of leachate and landfill gas, but also the valorisation potential for materials and energy in the framework of Enhanced Landfill Mining (ELFM).[26] The different waste compositions depend on the landfill location, due to local regulations on waste management, but also on the time period when the waste was landfilled, and on the type of waste landfilled in the site.[26] The importance of a qualitative and quantitative evaluation of the landfilled waste in terms of composition and properties has been highlighted in several studies.[29–33]

An important factor to consider when defining the waste composition in landfills is the degradation rate of waste over time. For waste fractions such as metals, plastics, glass, ceramics, textiles, inert fractions, *etc.*, which are less-easily degradable and undergo slower changes over time, the amounts in the excavated waste are usually comparable with the amounts originally landfilled.[26] On the other hand, organic fractions degrade more easily into a soil-like material.[26] Indeed, landfilled waste undergoes different biological, chemical and physical transformation processes over time that result in different impacts and conditions, even within a landfill, depending on the location and waste characteristics. Waste age and composition, together with weather conditions and landfill design and management, affect the outcome of waste recovery strategies.[34]

Additionally, both waste composition and the related biodegradation potential have a significant influence on the environmental impacts of landfills and on the estimation of the ELFM potential from an environmental perspective. Different fractions determine different impacts to either water, air or soil.[22] Several studies have reported how the organic content highly affects the final results,[4,35] as waste with lower organic content can lead to lower environmental impacts.[4] Previous literature has highlighted that large amounts of pollutants, as heavy metals, ammonium, chemical oxygen demand (COD), are still available in closed landfills and can pose a threat to human health and the environment if released. The availability of these substances depends on the waste type and age. It has been shown that the concentrations of elements such as As, Cd, Cr, Cu, Ni, Zn, Pb, Hg increase with increasing storage time due to the different composition of landfilled MSW over the years.[26] Indeed, the presence of these elements in landfill bodies could be responsible, in the future, for significant emission potentials. In this context good data quality is important in order not to neglect impacts in different impact categories. Consistent methodological choices should then be made not to underestimate future emission potentials.

Time dependency

As mentioned, degradation of waste, landfill waste characteristics and long-term emission potentials of available substances are affected by time. On the other hand, time is also a challenging parameter in the environmental impact assessment of landfills. In fact, landfill gas and leachate production varies in time, the technologies used in the landfill have a limited lifespan and/or can deteriorate. However, in life cycle assessment (LCA), impacts are aggregated over time. Therefore, the effect of emissions on the environment, soil, air and water, are considered to be identical, regardless of whether emitted in one second or over a century.[36] This lack of site- and time-dependent information in the life cycle assessment (LCA) of landfill sites is a significant source of uncertainties and could lead to misinterpretation, underestimation or overestimation of the impacts.[11,24,37–41] Moreover, not every landfill-related impact or process can be foreseen if the long term horizon is taken into account (10^4-10^5 years).[39] These considerations lead to the necessity of interpreting the results as a function of time[39] and to identify the most adequate time period to comprehensively assess the environmental impacts of landfills. This issue has been addressed in many studies where temporal emission profiles have been included in the life cycle inventory (LCI) stage of the LCA.[42–45] Moreover, there is on-going research to try to include time- and site-dependent variations in the definition of characterisation factors also for the toxicological categories.[45–50] As a first step, the importance of time-related emission profiles from landfills could lead to more accurate and consistent results. In this framework, this paper will address the evaluation of long-term emissions of closed landfills by analysing the literature related to landfill gas (LFG) and landfill leachate emissions.

Long-term emissions from landfills

Landfill gas generation potential

Most studies aiming to assess the potential of ELFM compared to the reference landfill scenario take into account the waste composition and in particular the landfill gas potential to define the environmental impacts of the reference scenario.[12] However, LFG emission profiles decrease substantially after the methanogenic phase, the fourth identified stage of the LFG generation curve, reaching negligible values in a few decades.[11] When considering long-term impact, LFG does not represent the major concern for landfills. Therefore, considering landfill impacts as only dependent on LFG and on the amount of organic carbon would tend to underestimate the impacts of landfills. Nevertheless, in light of the need to define time-dependent emission profiles for more consistent impact assessments, different models can be adopted for the estimation of landfill gas (LFG) generation. The assessment of landfill gas production is usually carried out by adopting the first order decay model (FOD).[35,51,52] The FOD model relies on the amount of biodegradable organic content in the waste, as this is the main factor affecting the LFG generation potential.[52] One of the inputs to the model is the methane generation potential, L_0[m^3 CH_4/tonne waste], which is usually calculated based on the DOC present in the waste.[52] This highlights the dependency of LFG generation on the amount of degradable organic fraction and thus the dependency of landfill impacts on the waste composition.[4,35]

Landfill leachate

On the other hand, leachate generation and composition is a long-term and more concerning issue. The quantity of leachate production within a landfill depends on the water balances at the site, the moisture content of waste and the water flow within the landfill body.[11,25] Consequently, the amount of leachate produced is also dependent on the efficiency and the type of the top cover and on the climatic conditions of the location.[11] The quality of the leachate is then highly dependent on site-specific factors such as waste composition, chemical, physical and biological processes that occur within the landfill body, the water flow distribution, or different landfill design and management systems.[11,24,28,47,53–56] As a general trend, decreased concentrations of leachate constituents can be observed with landfill age[11]. According to Laner,[11] organic leachate pollutants usually decrease around an order of magnitude in 20 years after closure. Similar trends can be observed for other pollutants such as iron, chloride and ammonium. On the other hand, xenobiotic organic compounds may persist for longer time frames. MSW is also characterised by amounts of heavy metals, which are usually found in low concentrations in leachate due to their low solubility. However, metal solubility and thus bioavailability in leachate, is influenced by site-specific conditions such as *pH*, redox potential, *L/S* ratio, heterogeneous water flow, *etc.*[11,24,25,27,54,57] Therefore, the concentrations of heavy metals in leachate could vary between landfills or according to the landfill phase, or depending on the occurrence of events that could lead to the alteration of these mentioned parameters. An example could be the failure or gradual deterioration of the containment system. In fact, together with the *pH* and the amount of oxygen present, the liquid to solid ratio (*L/S*) within the landfill body highly affects the mobilisation of substances. The failure of the top cover, for example, could result in an increase of the *L/S* ratio, the infiltration of oxygen, and a variation of the *pH* within the landfill. Such an event could lead to the flushing of substances to the environment. Generally, the quantity of leachate is meant to decrease with the installation of top covers, with a consequent reduction in the total substance loads, meaning the amount of substance contained in the leachate over the year.[11] However, that does not mean that the available amount of substance remaining in the landfill decreases too. On the contrary, the installation of the top cover with a decrease in leachate generation could lead to substantial substance potential remaining in the landfill body. Therefore, the important aspect for the estimation of future emission potential is the understanding of the actual fractions that can be mobilised of the total amount of substances present. These and the related long-term emission potential of landfills can be estimated with different models. Geochemical modelling is gaining relevance for the modelling of long-term emissions due to the possibility of including different parameters in the scenario analysis.[25,57] Another model was developed by Belevi and Baccini in 1989 and reported by Laner.[11] The model follows first order kinetics and is based on the assumptions of a constant release mechanisms, homogeneous water flow, and a negligible biodegradation process after the reactor phase. Of course, these assumptions lead to increased uncertainties on the actual behaviour of leachate and its pollutants. Nevertheless, the model gives an estimate of the emission potential for certain substances that could remain in the landfill body in significant quantities for a long term.

Discussion and conclusions

The review was carried out to stress the importance of considering long term emissions of landfills and the necessity of understanding the mechanisms underlying them. A deeper analysis is crucial for the environmental impact assessment of landfills as final disposal sites and as reference scenario for the comparison with ELFM. In fact, based on the above considerations, the assessment of landfill impacts on a long time frame could lead to building a more consistent reference scenario for the evaluation of the environmental profitability of ELFM. The consideration of site- and time-dependent parameters is then important for both the resource recovery potential and for the environmental impacts of the landfill site. It is therefore crucial to validate all models with site-specific data, as site-specific conditions could significantly alter the results and lead to different conclusions.

The models mentioned for the estimation of long-term emission potentials have limitations due to the assumptions made and can lead to the overestimation of the generation trends of, for example, LFG.[11,58] However, based on the review and on the results of other studies reported by Laner,[11] the analysis of the stored available substances would lead to a better estimation of the long term emission potential of landfills. Different scenarios could then be built to account for the variation in environmental conditions in the long time frame. The *L/S* ratio would be the major parameter to consider, as unforeseen events could lead to the variation of this parameter. Different models can then be adopted, with the inclusion of more parameters for a more realistic inventory. The obtained time-dependent emission profiles could then be integrated in LCA to model the impacts of landfills on a long term perspective and as a function of time.

Acknowledgement

This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No 721185 (EU MSCA-ETN NEW-MINE).

References

1. A. Niskanen, S. Manfredi, T. H. Christensen and R. Anderson, “Environmental assessment of Ammässuo Landfill (Finland) by means of LCA-modelling (EASEWASTE)”, *Waste Manage Res,* **27** 542-550 (2009).
2. S. Manfredi and T. H. Christensen, “Environmental assessment of solid waste landfilling technologies by means of LCA-modeling”, *Waste Manage,* **29** 32-43 (2009).
3. S. Manfredi, D. Tonini and T. H. Christensen, “Landfilling of waste: accounting of greenhouse gases and global warming contributions”, *Waste Manag Res,* **27** 789-799 (2009).
4. S. Manfredi, T. H. Christensen, H. Scharff and J. Jacobs, “Environmental assessment of low-organic waste landfill scenarios by means of life-cycle assessment modelling (EASEWASTE)”, *Waste Manag Res,* **28** (2) 130-40 (2010).
5. E. Chalvatzaki and M. Lazaridis, “Estimation of greenhouse gas emissions from landfills: application to the akrotiri landfill site “, *Global NEST Journal*, **12** 108-116 (2010).
6. S. Hellweg, U. Fischer, T. B. Hofstetter and K. Hungerbühler, “Site-dependent fate assessment in LCA: Transport of heavy metals in soil”, *J Clean Prod,* **13** 341-361 (2005).
7. U. Arena, M. L. Mastellone and F. Perugini, “The environmental performance of alternative solid waste management options: A life cycle assessment study”, *Chem Eng J,* **96** 207-222 (2003).
8. Å. Moberg, G. Finnveden, J. Johansson and P. Lind, “Life cycle assessment of energy from solid waste - part 2 : landfilling compared to other treatment methods”, *J Clean Prod,* **13** 231-240 (2005).
9. A. Damgaard, S. Manfredi, H. Merrild, S. Stensøe and T. H. Christensen, “LCA and economic evaluation of landfill leachate and gas technologies”, *Waste Manage,* **31** 1532-1541 (2011).
10. J. T. Kirkeby, H. Birgisdottir, G. S. Bhander, M. Hauschild and T.H. Christensen, “Modelling of environmental impacts of solid waste landfilling within the life-cycle analysis program EASEWASTE”, *Waste Manage,* **27** (7) 961-970 (2007).

11. D. Laner, *Understanding and evaluating long-term environmental risks from landfills* [online]. 1-225 (2011).
12. D. Laner, O. Cencic, N. Svensson and J. Krook, "Quantitative Analysis of Critical Factors for the Climate Impact of Landfill Mining", *Environ Sci Technol,* **50** 6882-6891 (2016).
13. M. Danthurebandara, *Environmental and economic performance of enhanced landfill* (2015).
14. D. J. Van Der Zee, M. C. Achterkamp and B. J. De Visser, "Assessing the market opportunities of landfill mining", *Waste Manage,* **24** 795-804 (2004).
15. R. Hermann, R. J. Baumgartner, S. Vorbach, T. Wolfsberger, A. Ragossnig, R. Pomberger, "Holistic assessment of a landfill mining pilot project in Austria: Methodology and application", *Waste Manage Res,* **34** 646-657 (2016).
16. P. Frändegård, J. Krook, N. Svensson and M. Eklund, "A novel approach for environmental evaluation of landfill mining", *J Clean Prod,* **55** 24-34 (2013).
17. S. Van Passel, S. De Gheldere and M. Dubois, "Exploring the socio-economics of Enhanced Landfill Mining" 247-264 (2010).
18. J. Gusca, M. Fainzilbergs and I. Muizniece, "Life cycle assessment of landfill mining project", *Energy Procedia,* **72** 322-328 (2015).
19. P. Frändegård, J. Krook, N. Svensson and M. Eklund, "Resource and Climate Implications of Landfill Mining", *J Ind Ecol,* **17** 742-755 (2013).
20. Danthurebandara, M., Passel, S. V. A. N. & Van Acker, K. Life Cycle Analysis of Enhanced Landfill Mining : Case Study for the Remo Landfill. 1-23 (2013).
21. N. Johansson, J. Krook, & Eklund, M. The institutional capacity for a resource transition—A critical review of Swedish governmental commissions on landfill mining. *Environ Sci Policy,* **70** 46-53 (2017).
22. G. Obersteiner, E. Binner, P. Mostbauer and S. Salhofer, "Landfill modelling in LCA - A contribution based on empirical data", *Waste Manage,* **27** (8) S58-S74 (2007).
23. J. Cleary, "Life cycle assessments of municipal solid waste management systems : A comparative analysis of selected peer-reviewed literature", *Environ Int,* **35** 1256-1266 (2009).
24. D. Laner, "The consideration of long-term emissions from landfills within life-cycle assessment", *Waste Manage Res,* **27** 463-470 (2009).
25. H. A. Van Der Sloot and D. S. Kosson, "An Overview of Leaching Assessment for Waste Disposal and Materials Use Session 1 Assessment Framework and Leaching Fundamentals Current Application of Leaching Tests", Environ Eng, (2003).
26. M. Quaghebeur, B. Laenen, D. Geysen, P. Nielsen, Y. Pontikes, T. Van Gerven and J. Spooren, "Characterization of landfilled materials: screening of the enhanced landfill mining potential", J Clean Prod, 55 72-83 (2013).
27. J. Fellner and P. H. Brunner, "Modeling of leachate generation from MSW landfills by a 2-dimensional 2-domain approach", *Waste Manage,* **30** 2084-2095 (2010).
28. O. Hjelmar, L. Andersen and J. Hansen, "Leachate emissions from landfills", *AFR Rapp.* (2000).
29. M. Quaghebeur, B. Laenen, D. Geysen, P. Nielsen, Y. Pontikes, T. Van Gerven and J. Spooren, "Characterization of landfilled materials: screening of the enhanced landfill mining potential", *J Clean Prod*, **55** 72-83 (2012).
30. P. T. Jones, D. Geysen, Y. Tielemans, S. Van Passel, Y. Pontikes, B. Blanpain, M. Quaghebeur and N. Hoekstra, "Enhanced Landfill Mining in view of multiple resource recovery: a critical review", *J Clean Prod,* **55** 45-55 (2013).
31. M. Quaghebeur, B. Laenen and P. Nielsen, "Valorisation of materials within Enhanced Landfill Mining: what is feasible?", in *International Academic Symposium on Enhanced Landfill Mining*, Belgium, 2010.
32. T. Prechthai, M. Padmasria and C. Visvanathan, "Quality assessment of mined MSW from an open dumpsite for recycling potential", *Resour Conserv Recy,* **53** 70-78 (2008).

33. J. Spooren, M. Quaghebeur, P. Nielsen, B. Blanpain and Y. Pontikes, "Material recovery and upcycling within the elfm concept of the remo case", *2nd Int Acad Symp Enhanc Landfill Min,* Houthalen-Helchteren, Belgium, 2013.
34. K. Sormunen, M. Ettala and J. Rintala, "Detailed internal characterisation of two Finnish landfills by waste sampling", *Waste Manage,* **28** 151-163 (2008).
35. S. Manfredi, D. Tonini and T. H. Christensen, "Contribution of individual waste fractions to the environmental impacts from landfilling of municipal solid waste", *Waste Manage,* **30** 433-440 (2010).
36. M. Hauschild, S. I. Olsen, E. Hansen and A. Schmidt, Gone...but not away--addressing the problem of long-term impacts from landfills in LCA.pdf. (2008).
37. J. Potting, S. Gheewala, S. Bonnet and J. Van Buuren, *How to Approach the Assessment?,* Life Cycle Assessment Handbook, A Guide for Environmentally Sustainable Products, Scrivener Publishing LLC, 391-412 (2012).
38. J. J. Potting and M. Z. Hauschild, "Spatial Differentiation in Life Cycle Impact Assessment", *Int J Life Cycle Ass,* **11** 11-13 (2006).
39. G. Doka, Doka Life Cycle Assessments, *Assessing Long-term Effects of Municipal Solid Waste*, Zürich, Switzerland, 2005.
40. A. Levasseur, P. Lesage and M. Margni, "Considering Time in LCA: Dynamic LCA and its application to global warming impact assessment", *Time,* **44** 3169-3174 (2010).
41. L. Tiruta-Barna, Y. Pigné, T. Navarrete Gutiérrez and E. Benetto, "Framework and computational tool for the consideration of time dependency in Life Cycle Inventory: Proof of concept", *J Clean Prod,* **116** 198-206 (2015).
42. A. Pinsonnault, P. Lesage, A. Levasseur and R. Samson, "Temporal differentiation of background systems in LCA: relevance of adding temporal information in LCI databases", *Int J Life Cycle Ass,* **19** 1843-1853 (2014).
43. I. Bakas, M. Z. Hauschild, T. F. Astrup and R. K. Rosenbaum, "Preparing the ground for an operational handling of long-term emissions in LCA", *Int J Life Cycle Ass,* **20** 1444-1455 (2015).
44. W. O. Collinge, A. E. Landis, A. K. Jones, L. A. Schaefer and M. M. Bilec, "Dynamic life cycle assessment: Framework and application to an institutional building", *Int J Life Cycle Ass,* **18** 538-552 (2013).
45. A. H. Shimako, L. Tiruta-Barna and A.Ahmadi, "Operational integration of time dependent toxicity impact category in dynamic LCA", *Sci Total Environ,* **599-600** 806-819 (2017).
46. Y. Dong, N .Gandhi and M.Z. Hauschild, "Development of Comparative Toxicity Potentials of 14 cationic metals in freshwater", *Chemosphere* **112** 26-33 (2014).
47. A. Gupta and R. Paulraj, *Leachate composition and toxicity assessment : an integrated approach correlating physicochemical parameters and toxicity of leachates from MSW landfill in Delhi*, **3330** 0-7 (2016).
48. Diamond, M. L. *et al., "*The clearwater consensus: The estimation of metal hazard in fresh water", *Int J Life Cycle Ass,* **15** 143-147 (2010).
49. S. R. Samadder, R. Prabhakar, D. Khan, D. Kishan and M. S. Chauhan, "Analysis of the contaminants released from municipal solid waste landfill site: A case study", *Sci Total Environ*, **580** 593-601 (2017).
50. A. Kounina, M. Margni, S. Shaked, C. Bulle and O. Jolliet, "Spatial analysis of toxic emissions in LCA: A sub-continental nested USEtox model with freshwater archetypes", *Environ Int,* **69** 67-89 (2014).
51. H. R. Amini, D. R. Reinhart and K. R. Mackie, "Determination of first-order landfill gas modeling parameters and uncertainties", *Waste Manage,* **32** 305-316 (2012).
52. R. Pipatti *et al.*, 2006 IPCC Guidelines for National Greenhouse Gas Inventories- Volume 5- Chapter 3: Waste, pp 1-40, 2006.

53. P. Kjeldsen, I. M. A. Barlaz, A. P. Rooker, A. Ledin and T. H. Christensen, "Present and Long-Term Composition of MSW Landfill Leachate: A Review", *Crit Rev Env Sci Tec*, **32** 297-336 (2002).
54. H. A. Van Der Sloot, A. van Zomeren, J. J. Dijkstra, D. Hoede, J. Jacobs and H. Scharff, "Prediction of long term leachate quality and chemical speciation for a predominantly inorganic waste landfill", 9Th Int Waste Manag. Landfill Symp, Sardinia, 2003.
55. T. E. Butt, H. M. Gouda, M. I. Baloch, P. Paul, A. A. Javadi and A. Alam, "Literature review of baseline study for risk analysis — The land fi ll leachate case", *Environ Int*, **63** 149-162 (2014).
56. T. E. Butt, A. Alam, H. M. Gouda, P. Paul and N. Mair, "Science of the Total Environment Baseline study and risk analysis of landfill leachate – Current state-of-the-science of computer aided approaches", *Sci Total Environ,* **580** 130-135 (2017).
57. H.A Van der Sloot, D. S. Kosson and A. van Zomeren, "Leaching, geochemical modelling and field verification of a municipal solid waste and a predominantly non-degradable waste landfill", *Waste Manage,* **63** 74-95 (2017).
58. EPA USA. Landfill Gas Emissions Model (LandGEM). (2005).