Environment International 35 (2009) 1256–1266

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Review article

# Life cycle assessments of municipal solid waste management systems: A comparative analysis of selected peer-reviewed literature

Julian Cleary

*Department of Geography, University of Toronto, Sidney Smith Hall, 100 Saint-George Street, Rm. 5047, Toronto (Ontario), Canada M5S 3G3*

ARTICLE INFO

*Article history:*
Received 11 September 2008
Accepted 14 July 2009
Available online 13 August 2009

*Keywords:*
Acidification potential
Comparative analysis
Global warming potential
LCA
Life cycle assessment
Life cycle costing
Municipal solid waste
MSW
Net energy use
Scope
System boundaries
Waste hierarchy

ABSTRACT

Life cycle assessment (LCA) is a popular tool used to evaluate the environmental performance of municipal solid waste (MSW) management systems. Although reviews of LCAs of MSW have been undertaken to assess the validity of the 'waste hierarchy,' a recent review of the goal, scope and results of LCAs of mixed-material MSW management systems has yet to be performed. This paper is a comparative analysis of 20 process-based LCAs of MSW published between 2002 and 2008 in a total of 11 English-language peer-reviewed journals. It quantifies the methodological transparency of the studies and the frequency of use of particular system boundaries, types of data sources, environmental impact categories, impact weightings, economic valuations, sensitivity analyses, and LCA computer models. Net energy use (NEU), global warming potential (GWP), and acidification potential (AP) values for various types of MSW management systems are also compared using statistical indicators.

The reviewed LCAs differ substantially in their system boundaries. Half or more of the LCAs either do not mention or are unclear in whether or not life cycle emissions from energy inputs or capital equipment are included in the calculation of results. Only four impact categories are common to more than half of the reviewed LCAs. The human and ecological toxicity impact categories are much less common than global warming potential, acidification, and eutrophication.

A financial life cycle costing is present in eight of the reviewed LCAs, while an economic valuation of the environmental impacts is observed in five. Explicit sensitivity analyses are present in 4/20 of the studies, although many more LCAs evaluate the effects of varying model parameters by increasing the number of waste management scenarios. There is no consensus on whether or not to use the marginal or average source of electricity in calculating environmental impacts. Eight out of the 20 do not mention this source while the remaining LCAs are evenly split between the marginal and average electricity source. One quarter of the reviewed LCAs supply weighted results for the overall environmental performance of MSW management scenarios. All but one of these concurred with the 'hierarchy of waste' that the environmental performance of landfilling is lower than that of all the other treatment methods, and that thermal treatments are inferior to recycling.

The comparative analyses of the NEU, GWP and AP results are based on 37, 45, and 42 MSW management scenarios, respectively. As measures of statistical dispersion, the interquartile ranges of the NEU, GWP and AP values are lowest for the landfilling (AP, NEU) and thermal treatment (GWP) scenarios. The results of the statistical analysis of the NEU, AP and GWP values appear to indicate that thermal treatment scenarios have a better environmental performance than landfilling, while the results for mixed treatment scenarios are less obvious. A comparison of the relative environmental performances of MSW treatment scenario types within each study did not provide a clear confirmation or repudiation of the waste hierarchy.

This paper concludes that many recently published LCAs do not ensure that the methodological assumptions are made clear to the reader. Lack of transparency makes the results difficult to interpret, and hampers meaningful comparisons between the LCA results. A convergence in the adoption of particular assumptions that are more representative of MSW management systems would facilitate the comparison of the results.



**Contents**



*E-mail address:* julian.cleary@utoronto.ca.

0160-4120/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.envint.2009.07.009

## 1. Introduction

The popularity of life cycle assessments (LCAs) in analyzing municipal solid waste (MSW) management systems is illustrated by the numerous published studies of the life cycle emissions of these systems, as well as by the substantial number of LCA computer models addressing MSW management. Over the past few decades, many academics, as well as organizations such as the *International Organization of Standardization* (ISO) and the *Society of Environmental Toxicology and Chemistry* (SETAC) have contributed to the development of the methodology used to undertake LCAs. Of recent importance is the revision of the requirements and guidelines for LCAs by the ISO in 2006. Comparisons of the results of different LCAs of MSW management systems have been published, with most tending to focus on results from a material-specific basis (Björklund and Finnveden, 2005; Finnveden and Ekvall, 1998; WRAP, 2006). However, comparative studies focused on the methodological transparency of published LCAs of MSW are not undertaken because transparency is perceived as a criterion to filter out studies from review (e.g., WRAP, 2006; Björklund and Finnveden, 2005), instead of a subject area for review.

The results from Winkler and Bilitewski (2007) and Winkler (2005) underline the necessity of clearly identifying both the scope and methodological assumptions of LCAs in order to have confidence in the results. In their comparative analyses of six prominent LCA models, both Winkler (2005) and Winkler and Bilitewski (2007) use identical input data for landfilling, incineration and material recovery scenarios for the waste management system of Dresden, Germany. They find very high variations in the predicted emissions, especially for those associated with toxicity, such as heavy metals. The authors suggest that the transparency of the LCA models needs much improvement, although the identification of the specific differences between each model is not part of the research objectives of their important papers.

A number of published comparisons of the results of LCAs of MSW management systems have been undertaken from a material-specific perspective. The Waste & Resources Action Programme (WRAP) (2006), in its international review of 55 'state-of-the-art' LCAs designed to evaluate the environmental benefits of recycling, observes a high level of agreement concerning the life cycle environmental emissions from the treatment of recyclable materials. WRAP (2006) indicates that recycling generates greater net environmental benefits than landfilling and thermal treatment in most of the reviewed LCAs, for most of the examined materials.

Björklund and Finnveden (2005), Denison (1996), and Finnveden and Ekvall (1998) also review LCA results for MSW management systems and produce results similar to WRAP (2006), while using much smaller sample sizes. Björklund and Finnveden (2005) focus on the material-specific global warming impact and total energy use of MSW management scenarios from 10 LCAs. Denison (1996) examines four North American LCAs of MSW from both a mixed-waste and material-specific perspective. In contrast to the other papers, Finnveden and Ekvall (1998) compare seven sets of LCA results that pertain only to the treatment of waste paper. A comprehensive comparative study of LCAs of MSW that provides the relative frequencies of applying the particular guidelines and requirements associated the goal and scope of LCA, as detailed in ISO 14044 (2006) has not yet been undertaken, although WRAP (2006) and Björklund and Finnveden (2005) address some system boundary issues. In addition, no one has used statistical indicators to compare the results of published LCAs of MSW management systems.

## 2. Research objectives

This study touches upon many of the issues addressed by the aforementioned comparative studies, and is the most comprehensive comparative study of LCAs of mixed-waste MSW management systems yet published in a peer-reviewed journal. It provides an indication of the frequency of use of particular methodological assumptions made during the goal and scope definition phase of LCA, as well as the relative clarity of LCA practitioners in revealing