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Life cycle assessment of solid waste management options: A Review

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Abstract

Evaluating the environmental performance of municipal solid waste management options is a complex job. LCA is an analytical tool (software) for assessing the environmental acceptability of municipal solid waste management (MSWM) options. LCA is currently being used in several countries to evaluate different strategies for integrated solid waste management and to evaluate treatment options for waste fractions. According to the characteristics of solid wastes, and availability of disposal options, LCA helps in supporting the identification of opportunities for pollution prevention and reductions in resource consumption while taking the entire solid waste life cycle. The primary elements of solid waste management are generation, collection, transportation, treatment, and disposal. Different scenarios were developed and reported as alternatives to the current waste management systems. The most prominent is material recovery facility (MRF) and other methods involve source reduction, reuse, recycling, composting, incineration, energy recovery, on-site burial, open burning and bioremediation. The goal of this review is to determine the most environmentally friendly option of MSWM system with the help of LCA.

Keywords: Energy recovery; Landfilling; Life cycle assessment; Material recovery facility; and Municipal solid waste management.

INTRODUCTION

Generation of solid waste is a natural consequence of human life (Shekdar 2009). Solid wastes are all the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted. Solid waste management is a complex and multidisciplinary environmental problem that should be considered from technical, economic, environmental and social aspects on a sustainability basis. For a healthy and a good environment, both municipal and industrial wastes should be managed according to the solid waste management hierarchy (prevention/ minimization/ recovery/ incineration/ landfilling). For this objective, different techniques can be used. Environmental life cycle assessment (LCA) is a systems analysis tool. The use of LCA had started in 1960s to evaluate the limitations of raw material and energy use in the USA, focusing primarily on energy and resource requirements of waste (Wenzel et al. 1997). LCA studies the environmental aspects and potential impacts throughout a 'waste' life cradle (when an item become valueless and usually is placed in the dustbin)-to-grave (when value is restored by creating usable material or energy) from raw material acquisition through production, use and disposal (Finnveden 1999). The main areas of the application of LCA within public environmental politics are waste treatment options, means of transport, energy sources, and product's choice (Frankl and Rubik 2000). Now LCA is a valuable tool for evaluating the total environmental impacts of solid waste management options within a boundary (Zhao et al. 2009). LCA process is a systematic approach and consists of the following four major components: (a) goal definition and scoping that defines and describes the product, process or activity, (b) inventory analysis in which data are collected, (c) impact assessment that includes classification, characterization, normalization, grouping, weighting, and valuation, and (d) interpretation of the results (Barton et al. 1996). The major components of LCA are depicted in Fig 1.

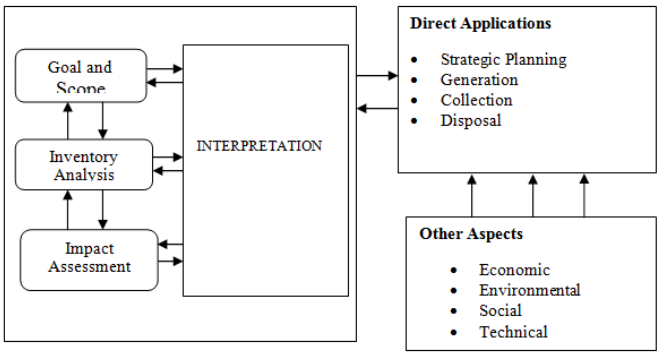

Fig 1. Components of Life Cycle Assessment for Solid Waste

Methodology of Life Cycle Assessment

The methodologies of LCA of municipal solid waste describe solid waste composition, the presence situation of solid waste management and practices in India, and determine the most environmentally friendly option (recycling/MRF, incineration, landfilling and composting) of MSWM system with the help of LCA.

The composition of solid waste

The composition of MSW depends on a wide range of factors

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such as food habits, cultural traditions, lifestyles, climate and income, etc. There are many different sources of solid waste in municipal areas. Waste comes from the residential population, commercial establishments and public and private institutions (Shekdar 2009). Depending on the sources, solid wastes can be broadly classified into municipal solid waste (MSW), bio-medical solid waste (BSW), industrial solid waste (ISW) and agriculture waste. MSW is heterogeneous in nature and consists of a number of different materials derived from various types of activities. The major constituent are paper and prescribes organic matter; Metal, glass, ceramics, plastics, textiles, dirt and wood are generally present although not always so, the relative proportions depending on local factors; The average proportion of constituents reaching a disposal site.

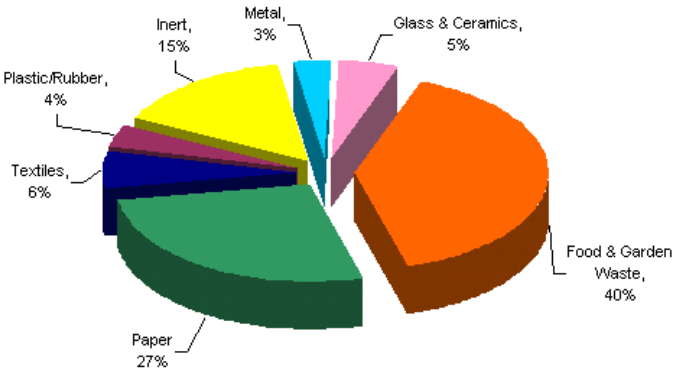

Fig 2. The composition of municipal solid waste (Source: CPHEEO Manual on MSW, 2005)

Municipal solid quantity and solid waste management practices in India

The term municipal solid waste refers to solid waste from houses, streets and public places, shops, offices, and hospitals. Management of these types of waste is most often the responsibility of Municipal or other Governmental authorities. A study conducted by the CPCB on management of MSW in the country estimates that waste generation at present about 48 million tons (MT) per year is expected to increase to 300 MT per year, by the year 2047 (490 g per capita to 945 g per capita). The estimated requirement of land for disposal would be 169.6 square kilometer (km^2) in 2047 as against 20.2 km^2 in 1997 (CPCB 2000a). The Urban population is rising between 3 – 3.5 % per annum and hence per capita waste generation in India is increasing by 1.3 % per annum resulting in 5 % increase in waste generation annually. In a low or middle-income country like India includes the following MSWM strategy: (a) waste generation and storage (b) segregation, reuse, and recycling at the household level (c) primary waste collection and transport to a transfer station or community bin (d) street sweeping and cleansing of public places (e) management of the transfer station or community bin (f) secondary collection and transport to the waste disposal site (g) waste disposal in landfills (CPCB 2000).

Elements of MSW Management

The activities associated with the management of MSW from the start of waste generation to final disposal can be grouped into the six functional elements: waste generation, waste storage at source, waste segregation, collection (primary and secondary), transportation, processing and recycling, disposal of reject material, rehabilitation of the existing dump sites to mitigate the pollution potential.

System boundaries of LCA for municipal solid waste management

The system of the study starts with collection of MSW from residential areas and includes waste transport, waste treatment (recycling, composting and incineration and landfilling) of solid waste. The system was limited at the landfilling of residual materials after treatment processes. Life cycle analyses of the secondary materials obtained from the recycling and composting processes (Banar et al. 2008). Fig. 2 shows the system boundaries for LCA of MSW. The figure describe the input in system (energy, raw material and waste source) of solid waste and outputs (Atmospheric emission, water born emission, solid emissions, and residuals) after treatment (MRF, composting, incineration and landfilling) of solid waste.

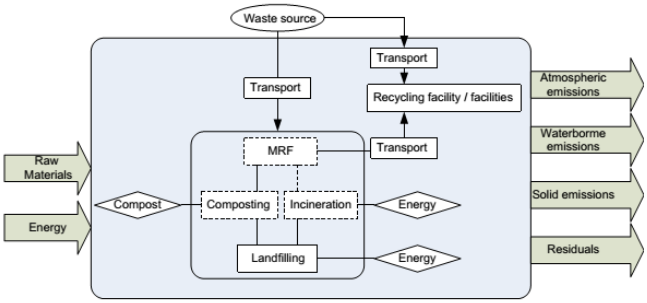

Fig 3. LCA System boundaries of municipal solid waste (Banar et al. 2009)

Solid waste management options

The LCA studies with no comparison between scenarios are not of interest for the review, because they cannot help to illuminate the benefits and drawbacks of the different handling options, as defined in the review's objective (Villanueva and Wenzel 2007).

Recycling/ Material Recovery Facility (MRF)

Recycling is the recovery of useful materials, such as paper, glass, plastic, and metals, from the trash to use to make new products, reducing the amount of virgin raw materials needed. A positive effect of recycling is seen in all relevant scenarios, especially in the acidification category, where the net effect is an ecological benefit. The most likely explanation is that the production of materials from virgin material resources requires considerable amounts of energy based on 'dirty' fuels such as coal and crude oil (Miliute *et al.* 2010).

Incineration

Incineration involves the combustion of typically unprepared (raw or residual) MSW. To allow the combustion to take place a sufficient quantity of oxygen is required to fully oxidize the fuel. Incineration plant combustion temperatures are in excess of 850oC and the waste is mostly converted into carbon dioxide and water and any noncombustible materials (e.g. metals, glass, stones) remain as a solid, known as Incinerator Bottom Ash (IBA) that always contains

a small amount of residual carbon. The direct combustion of a waste usually releases more of the available energy compared to pyrolysis and gasification .specific emission limits for the release to atmosphere are: sulphur dioxide (SO_2), nitrogen oxides (NOx), hydrogen chloride (HCl), volatile organic compounds (VOCs), carbon monoxide (CO), particulate (fly ash), heavy metals.

Composting

Composting is a microbial (Bacteria, fungi and actinomyceties) based aerobic process which is now consider as an environmentally sound way to reduce organic waste and produce organic fertilizer or soil conditioner (Gautam et al. 2010). A key advantage of the composting process is that its high temperature essentially kills all pathogens and weed seeds that might be found in wastes. The emissions of gases due to composting are CO_2, CH_4, NH_3 and N_2O.

Landfilling

Landfills are generally located in urban areas where a large amount of waste is generated and has to be dumped in a common place. Unlike an open dump, it is a pit that is dug in the ground. LCA software helps in determining that landfilling of untreated waste releases a significant amount of greenhouse gases. The technosphere/ biosphere boundary of the model is limited to 100 years, which covers the main period of the impact. In practice, the time horizon is very long (longer than 100 years), but for practical reasons the observable time horizon is commonly limited to consensus-based periods, like 100 years (Banar et al. 2008). The result of the characterization analysis per functional unit for each impact category for each scenario as per the study done in Eskisehir, Turkey which is mentioned in Table 1.

Table 1. Describe characterization result, of solid waste landfilling, composting, Incineration. (Sb - Antimony), (1,4 DB- 1,4 dichlorobenzene). Functional unit (1 ton of MSW managed) (Banar et al.2009).

Scenarios	Landfilling	Composting	Incineration
Abiotic depletion (kg Sb eq/ton waste managed)	-0.437	-1.08	-0.16
Global warming (GWP100) (kg CO_2 eq/ton waste managed)	6990	1360	1570
Human toxicity (kg 1,4-DB eq/ton waste managed)	-135	-269	91.9
Acidification (kg SO_2 eq/ton waste managed)	43.6	41.4	38.3
Eutrophication (kg PO_4^{-3} eq/ton waste managed)	37.9	9.13	9.98
Photochemical oxidation (kg C_2H_4 eq/ton waste managed)	1.63	-0.0857	2.14

Impact assessment categories

The LCA studies analyzed included different environmental impact categories, belonging to different stages in the causality chain that goes from an emission to an endpoint impact. The categories included in at least more than one study were the following (Villanueva and Wenzel 2007): abiotic depilation, global warming potential, human toxicity (HTPs human toxicity potential are expressed as 1,4-dichlorobenzene equivalents/kg emission) (Goedkoop et al. 2004), acidification, eutrophication and photochemical oxidation are describe in Table.1

CONCLUSION

Life cycle assessment (LCA) is a tool to compare different (recycling, landfilling, composing and incineration) solid waste management options. It is apparent that the incineration (100%) has the highest human toxicity effect due to nitrogen oxide. The CO_2 emissions from landfills tend to have a high significance in the overall contribution to global warming. The release of methane in other disposal routes (composting, incineration, recycling) is normally less than landfilling. The results show that the composting scenario is the more environmentally preferable has other results for landfilling, composting and incineration. In this study, waste management alternatives were investigated from only an environmental point of view. It might be supported with other decision-making tools that consider the economic and social effects of solid waste management.

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