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The impact of municipal solid waste treatment methods on greenhouse gas emissions in Lahore, Pakistan

Syeda Adila Batool [a,*], Muhammad Nawaz Chuadhry [b,1]

[a] *Department of Space Science, Punjab University, Lahore 54600, Pakistan*
[b] *College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan*

Abstract

The contribution of existing municipal solid waste management to emission of greenhouse gases and the alternative scenarios to reduce emissions were analyzed for Data Ganj Bukhsh Town (DGBT) in Lahore, Pakistan using the life cycle assessment methodology. DGBT has a population of 1,624,169 people living in 232,024 dwellings. Total waste generated is 500,000 tons per year with an average per capita rate of 0.84 kg per day. Alternative scenarios were developed and evaluated according to the environmental, economic, and social atmosphere of the study area. Solid waste management options considered include the collection and transportation of waste, collection of recyclables with single and mixed material bank container systems (SMBCS, MMBCS), material recovery facilities (MRF), composting, biogasification and landfilling. A life cycle inventory (LCI) of the six scenarios along with the baseline scenario was completed; this helped to quantify the CO_2 equivalents, emitted and avoided, for energy consumption, production, fuel consumption, and methane (CH_4) emissions. LCI results showed that the contribution of the baseline scenario to the global warming potential as CO_2 equivalents was a maximum of 838,116 tons. The sixth scenario had a maximum reduction of GHG emissions in terms of CO_2 equivalents of –33,773 tons, but the most workable scenario for the current situation in the study area is scenario 5. It saves 25% in CO_2 equivalents compared to the baseline scenario.
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1. Introduction

The waste management process can help to conserve resources and protect the environment (Sandulescu, 2004). Municipal solid waste (MSW) management is a highly neglected factor of environmental management in all low and most middle-income countries (Murtaza and Rahman, 2000). Poorly managed waste streams are causing adverse environmental impacts and may result in health hazards (Misra and Pandey, 2005). Environmental concerns are assuming ever-increasing importance in the MSW decision-making process (Elizabeth, 1998). Appropriate waste management strategies can substantially reduce the burden placed on the environment. If the waste management system is based on sound data and is well executed with public awareness, it can reduce emissions and resource depletion (Jurczak, 2003; Woodard et al., 2004).

Rapid climate change is a most important contemporary concern. Policy measures and legal obligations, which include recycled content laws, producer responsibility, and landfill gas capture criteria, may increase the impact of solid waste management on greenhouse gas (GHG) emissions (Saft and Elsinga, 2006; Talyan et al., 2007). Various MSW management options have built-in options for varying degrees of GHG reductions and have links to other sectors (e.g., energy, industrial processes, forestry, and transportation, etc.) with further GHG reduction opportunities (Clemens and Cuhls, 2003; Eschenroeder, 2001; Abbadi and Abbadi, 2005).

GHG emissions trap heat in the atmosphere and lead to global warming and a subsequent change in weather

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* Corresponding author. Tel.: +92 42 9230370; mobile: 0300 4591316.
  E-mail addresses: aadila_batool@yahoo.com (S.A. Batool), muhammadnawazchaudhry@yahoo.com (M.N. Chuadhry).
[1] Tel.: +92 42 5900046, mobile: 0345 4005008; fax: +92 42 590038.

(Jicong et al., 2006). According to the US EPA, in the "inventory of GHG emissions, the waste management sector represents ~4% of total US anthropogenic GHG emissions (i.e., 260 out of 6750 teragrams of CO_2 equivalents). Landfills are the largest anthropogenic source of CH_4 in the United States and represented ~90% of GHGs from the waste sector in 1999" (Thorneloe et al., 2002).

Recycling may reduce GHG emissions, in many cases, by reducing the amount of virgin material being processed and thereby avoiding life cycle emission. Anaerobic digestion converts some of the organic matter in MSW to methane and carbon dioxide (Saft and Elsinga, 2006).

This study analyzed the effect of MSW management options on GHG emissions. The scope of the study included all activities that play a role in MSW management. These activities include MSW collection, transport, recycling, composting, combustion (with and without energy recovery), and landfilling (with and without gas collection and energy recovery). The life-cycle environmental aspects of fuel and electricity consumption were also included, as well as the displacement of virgin raw materials through recycling and the displacement of fossil fuel-based electrical energy through energy recovery from MSW. The GHG emissions studied in this analysis are CO_2 and CH_4.

The boundaries for this study include unit processes associated with waste management, including production and consumption of energy, transport, collection, recycling/composting, combustion, and landfilling.

1.1. Description of study area

Data Ganj Bukhsh Town (DGBT) is one of the six towns within Lahore (City District of Lahore). The District Nazim (administrator) of the city District Government Lahore heads the Solid Waste Management Department. The individual towns are led by Assistant District Officers (ADOs). Data Ganj Bukhsh Town, a purely urban town of Lahore, was selected for this model LCI study. This town is inhabited by 1,624,169 people (one quarter of the population of the City District of Lahore) living in 232,024 dwellings. It comprises the entire Ex-metropolitan corporation Lahore area, which is the most densely populated area of the Punjab Province. All major administrative, recreational, institutional, office and commercial areas are located in this town.

The municipal solid waste generated in DGBT is 500,000 tons per year or 0.84 kg per capita per day (kg/c/day).

The solid waste management system for the city of Lahore was formalized when it became part of the Lahore Urban Development Project (LUDP), which was initiated in 1978. The main objective of the LUDP was to upgrade the solid waste management in the walled city, which is now a part of DGBT. In November 1980, a pre-appraisal mission of The World Bank addressed, for the first time, a solid waste management (SWM) project for Lahore.

Table 1
Composition and quantity of solid waste produced in Data Ganj Bakhsh Town

Series no.	Description	Tons per day	% Weight
1	Paper	69.1	5.04
2	Glass	30	2.19
3	Ferrous metal	0.3	.02
4	Non ferrous metal	6.5	0.47
5	Film plastic	177.3	12.94
6	Rigid plastic	76.0	5.55
7	Organics	917.9	67.02
8	Textiles	13.7	1.00
9	Other	79.0	5.77
Total		1369.8	100.00

Source: this study.

The Metropolitan Corporation of Lahore (MCL) was designated as the executing agency.

These studies measured MSW generation rates and identified potential dumpsites. The composition and quantity of the solid waste produced in Lahore is given in Table 1.

2. Methodology

Life cycle assessment (LCA) methodology was used for this study. The IWM-2 model (McDougall et al., 2003), basically an LCI model, was used for this research.

2.1. The functional unit and system boundaries

The functional unit used in the scenarios for the study has been defined as the amount of MSW generated in DGBT, Lahore. The system boundaries for the life cycle inventory of MSW was defined as the moment when used materials become waste, have no value, become emissions into the air or water, are used as inert landfill materials, or become useful products once again.

2.2. Greenhouse gases and the time frame

The global warming potential (GWP) of different gases were proposed by the International Panel on Climatic Change (IPCC, 1995, 1996). Because different GHGs have different efficiencies in heat adsorption and different half-lives in the atmosphere, the GWP for every gas depends on the chosen planned time horizon. The GWP of CH_4 for a time horizon of 20 years is 56 (compared with CO_2 over the same period of time) and 21 for 100 years (IPCC, 1995, 1996). This has significant importance for decision makers, because implementation of any policy to reduce methane would have an immediate impact on GHG emissions and the benefits from initiatives would be apparent in the short to medium-term.

CO_2 equivalents are used to compare the abilities of different greenhouse gases to trap heat in the atmosphere. It provides a construct for converting emissions of various gases into a common measure, which allows climate ana-

lysts to aggregate the radiative impacts of various greenhouse gases into a uniform measure.

The energy consumption, energy production, fuel consumption and CH_4 emissions have been expressed by CO_2 equivalents.

2.3. Data collection

To calculate GHG emissions from MSW management, primary and secondary data were collected during the years 2002–2005. The output method or direct waste sampling method (Shanklin et al., 2002), and continual random sampling (Guven, 2001) were used for working out the generation rate and physical composition of MSW. The methods focus on the sources of waste generation as well as disposal sites.

Before starting a detailed study, a preliminary survey of 1000 households was carried out by studying their generated waste. Questionnaires were also filled out (300 in English and 700 in Urdu) on the basis of interviews to get maximum information. Apart from other measurable parameters, this study gave insight into the generation rate, physical composition, and collection methods of the waste. It also provided a basis for detailed study.

For the detailed study, a sample of 360 houses (with 118 low-income families, 210 middle-income families, and 32 high-income families) were selected (Oregon DEQ, 1995; CIWMB, 1998; SENES, 1999; Beck, 2000; MFE, 2002; OWDO, 2002). The houses were selected randomly on the basis of socio-economic groupings (Parks and Brockman, 2000; MFE, 2002). These houses were in proportion to the actual distribution of income groups in the population. The low-income group households had a monthly income of up to Rs.6000 or £56, the middle-income households had a monthly income of Rs.6001–14,000, or £56–131, while the high-income group households had income more than Rs.14,000 or £131.

Samples were collected from each household, in all seasons, to account for variations due to changing seasons and to special occasions (holidays) (OWDO, 2002). This continual random stratified sampling was carried out over a period of 1 year (2004–2005).

Total waste generated in DGBT was calculated on the basis of surveys. The data from surveys was cross-checked against the total waste collected, and then uncollected waste was added to the total; the amount of uncollected waste was determined by the surveys. Therefore, the data obtained matched the estimates of SWMD very well.

2.4. Description of alternative scenarios

The following aspects were considered to develop the other scenarios:

- Energy consumption and production, which was associated with storage, collection and different treatment and disposal methods of waste.

- Air emissions that were not related to the energy consumption e.g., in aluminum and steel manufacturing. CO_2 is emitted due to the conversion of limestone to lime.
- Emissions of methane by the decomposition of organic matter at dumpsites or landfill sites.

These three aspects add GHGs to the atmosphere and may contribute to global warming.

Scenario 1 assumed separate collection of 70% of biowaste for composting. In this scenario, the Kerbside Collection System (KSCS) is used for the collection of household waste. This is due to 67% organic waste in the waste stream. The KSCS system was assumed because it is the most suitable system for the collection of organic waste in the study area. The process of composting was assumed here because it is low technology and is considered suitable for developing countries.

Scenario 2 assumed separate collection of 70% of biowaste for biogasification. The biogasification process was assumed because during an energy crisis it can provide organic compost. In addition, energy can be recovered from this process.

Scenario 3 In this scenario, a method of a "bring system" was introduced. According to ERRA (1993), bring collection systems are those where householders are required to take recyclable material to one of a number of communal collection points. Communal bring systems are used for collection of mixed recyclables and single materials. This scenario includes the impacts of mixed recyclables banks. In the study area, this practice is common in the informal sector. This scenario explored the recycling potential (environmental pollution, economic) in the study area.

Scenario 4 In this scenario, the amount of recyclables collected was the same as in Scenario 3, but the method of collection was changed. It was assumed here that recyclables from households were collected in single material banks that collected a single material per container. This represents one of the best-known forms of material collection. A high level of material collection has been achieved using this method.

Scenario 5 This scenario was developed using two treatment methods: (1) recycling through single material bank containers from household waste, and 2) biowaste collection through the KSCS.

Scenario 6 A combination of biogasification and recycling (SMBCS) with energy recovery at the landfill site comprised this scenario.

3. Results and discussion

The IWM-2 model was used for each scenario. The results of the inventory data gives detailed information on the emission of each greenhouse gas, CO_2, CH_4, and their GWP as shown in Fig. 1, and the contribution of fuel and energy consumption in the gaseous emission at every
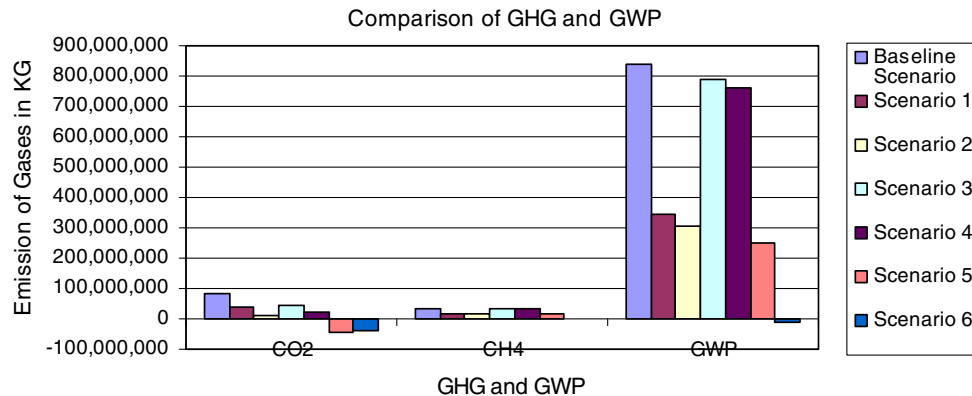
Fig. 1. Comparison of GHG and GWP for baseline and alternating scenarios (Source: This study).

step of each scenario. This paper focuses on the comparison of the CO_2 equivalents emitted or avoided as a result of all scenarios as shown in Table 2.

The baseline scenario resulted in 838,116 tons of CO_2 equivalents, and this scenario was the largest contributor compared to other scenarios considered, as shown in Table 2. The organic portion of the waste was responsible for this high value because of the uncontrolled anaerobic and aerobic degradation of the biowaste. The organic fraction of MSW contributed 67.02% to the total waste amount, and this level may threaten the health of residents as the indiscriminate waste dumps attract rodents and other disease vectors (Gupta et al., 1998). The total waste generated in DGBT is 500,000 tons per year. In this scenario, the waste is collected from streets as well as communal storage centers and is disposed of by the drivers of CDGL (City District Government, Lahore) into nearby vacant plots, depressions, ponds, excavations, flood plains, oxbow lakes, and back swamps of the River Ravi that flows through the city of Lahore.

During the modeling of this scenario, dumpsites were defined as landfill sites without landfill gas collection and leachate control. This is an accurate picture of the current situation in DGBT.

All the waste in this scenario, including paper, glass, metal, plastic, textiles, and organics, was sent to the landfill.

Total fuel consumption calculations were based on 3 L of diesel per ton of waste. It was assumed that 2.5 L of diesel is consumed during the collection of waste and 0.5 L of diesel is consumed on the landfill site while dumping the waste. These values are based on actual annual fuel consumption data and were collected from the original records of the Solid Waste Management Department (SWMD). They were also double-checked and verified.

The amount of landfill gas and leachate produced per year is 91,250,000 m^3 and 75,000 m^3, respectively. There is no treatment of waste involved in this system. This enormous amount of landfill gas and leachate is polluting both the water and air.

In this scenario, air emissions are associated only with collection and landfilling. The air emissions produced with the collection of waste were calculated on the basis of diesel consumption during transportation. In DGBT 908,850 L of diesel per year are used by the drivers of collection vehicles.

Scenario 1 (the composting scenario) was considered because biowaste comprises 67.02% of the total MSW. Furthermore, LCI results show that CO_2 equivalents may be avoided by the production of compost. The amount of CO_2 equivalents avoided through compost production is 6015 tons. The market for compost for nurseries and home gardens is about 30% of the total production of compost in this scenario. The demand for compost is already mostly

Table 2
CO_2 equivalents (emitted and avoided) under different scenarios (tons)

Scenario	CO_2 – equivalent for electricity consumed	CO_2 – equivalent for electricity generated	CO_2 – equivalent for fuel consumption	CO_2 – equivalent for CH_4	CO_2 – equivalent emission in the process	CO_2 – equivalent emission in landfilling	CO_2 – equivalent avoided by recycling	Total
Baseline	Nil	Nil	45,234	752,934	Nil	80,659	Nil	838,116
1	4633	Nil	5039	315,638	7	33,787	−6,015	353,089
2	9380	−33,206	4958	269,912	10	29,005	−10,694	269,365
3	1129	Nil	5080	746,012	Nil	79,902	−42,386	789,737
4	148	Nil	5005	737,351	Nil	78,975	−60,218	761,261
5	7566	−26,250	−4826	267,374	10	28,696	−62,592	209,978
6	7565	−33,141	−5064	25,394	10	34,055	−62,592	−33,773

Source: this study – sign shows the CO_2 equivalent that was avoided.

met by private nursery owners. Farmers are unaware of the advantages of compost. In addition, farmers are not convinced of the reliability and consistency of the quality of the product. This uncertainty is further reinforced by the fact that proposals on composting are based on conventional low-tech methods used at compost plants. Odor problems are another issue that devalues the option for solid waste management.

There is no doubt that composting is an excellent way to turn waste products into a soil conditioner commodity, simply and economically (Diaz et al., 2002). One disadvantage of composting is that some of the nutrients in raw waste, particularly nitrogen, can be lost by volatilization. Phosphorus and potassium may be lost by leaching through the soil (Hansen, 2004; Wilshusen et al., 2004; Komilis and Ham, 2004). Although composting reduces the CO_2 equivalents, it is not a very suitable treatment process for solid waste management considering the adverse impacts discussed above.

Scenario 2 is a biogasification scenario where all the biowaste is feedstock to biogasification. This produces not only energy but also compost, which is actually a suitable soil conditioner with more consistent quality and has appreciable economic benefits (Diaz, 1976; De Baere, 2000). This scenario avoids 33,206 tons and 10,694 tons of CO_2 equivalents by the production of electricity and liquid compost, respectively.

The biogasification process requires additional investment in capital, materials, and labor. A biogas digester yields both a fuel gas and a good soil conditioner and fertilizer (Mbuligwe and Kassenga, 2004). Unlike composting, the digestion process retains and even improves the nutrient value of the original feedstock (Hansen et al., 2006; Borglin et al., 2004). During biogasification, raw wastes can be digested, and returned to the environment in the form of fertilizer and fuel, without degrading the environment (Borglin et al., 2004). It has been shown that the use of a mixture of liquid compost from biogas plants in agriculture can increase yields of rice, corn, wheat, and cotton by 5.6%, 8.9%, 15.2% and 15.7%, respectively (Mughal, 2006).

Scenarios 3 and 4 are recycling scenarios with mixed and single material bank container systems (MMBCS, SMBCS). The results of these scenarios show that the recycling process saves more energy than the composting and biogasification processes by avoiding the use of virgin materials. The MMBC system shows that the amount of CO_2 equivalents avoided through recycling was 42,386 tons whereas 60,218 tons were avoided by using the SMBC system. The difference in CO_2 equivalents between these two scenarios was mainly because aerobic conditions are most prevalent in the MMBC system, which stimulates CO_2 emissions. In Scenario 3, less material can be segregated because of the MMBC system, so more virgin material is used to fulfill the requirement and therefore, more CO_2 emissions are expected. The contribution of Scenarios 3 and 4 to CO_2 equivalents is therefore high (789,737 tonnes

and 761,261 tonnes, respectively) as shown in Table 2. The LCI results showed that Scenarios 3 and 4 are the second and third biggest contributors to GWP. The GHG emissions may be controlled by the avoidance of using virgin material (Hettiaratchi et al., 2006).

Properly planned and executed recycling programs have proven to be quite successful at reducing both waste and costs, and their effects on the environment (Hong and Adams, 1999; Koli and Mahamuni, 2005; Bhattarai, 2005; Kinnamann and Fullerton, 1999; Tanskanen, 2000). The LCI results showed that recycling is important because a long-term nationwide recycling effort extends and conserves scarce resources and ultimately reduces GHG emissions and GWP. Recycling, in general, conserves natural resources; recaptures inherent energy introduced during manufacturing and GHG emissions are reduced (Braunegg et al., 2004; Hettiaratchi et al., 2006; Beukering et al., 1999).

The LCI results showed that the recyclable portion (26.21%) of the waste is much less than the organic waste proportion (67%), so not only can recycling appreciably reduce the need for expensive land by reducing landfill area, but it also reduces the costs of landfilling. However, recycling alone, in Pakistan, cannot improve the situation of GHG emissions from the solid waste sector. The rapid increase in the population of Pakistan is increasing the amount of waste, so the situation can only be improved by a combination of recycling and biogasification programs. This scenario was second best in terms of savings of CO_2 equivalents (i.e., 209,978 tons). This combination was most effective with respect to our social and economic conditions and this scenario also has a significant employment potential.

Thus, Scenario 6 was very environmentally appealing as it avoided a maximum amount of CO_2 equivalents of – 33,773 tons.

4. Conclusion

This study was conducted to evaluate the most appropriate municipal solid waste management scenario with respect to greenhouse gas emissions. This was completed by using the LCA tool for the comparison of different management options. The results of the study draw some conclusions as follows:

- The baseline scenario (collection + landfilling) was the major contributor of GHG emissions.
- Scenario 6 (biogasification + recycling with single material bank container systems + energy recovery from landfill gas) seemed to be very environmentally appealing as it avoided the maximum amount of CO_2 equivalents.
- Given the present state of the political, industrial, scientific, technological and human resource development of Pakistan, however, this option may not work very well. Under the given conditions, scenario 5 (biogasification + recycling with single material bank container

systems) may be the best and most workable option both from the environmental and economic viewpoints. Pakistan enjoys a very good relationship with Western democracies, and at present, a substantial amount of money is available to the government from the developed world for technical assistance, as well as grants and soft loans to deal with solid waste management. Therefore, money and technical expertise could be organized to implement Scenario 5 in the shortest possible time. However, this can only happen if the relevant authorities are aware of the need to implement waste management on the basis of the versatile IWM-2 model, using Scenario 5. The present study based on IWM-2 will be made available to the government for implementation and for leveraging technical expertise and funds from developed countries to improve the solid waste situation, and subsequent GHG emissions in Pakistan.

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