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Using life cycle assessment for municipal solid waste management in Tehran Municipality Region 20

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Abstract

Background: Due to the lack of a proper waste management system, Tehran Municipality Region 20 is facing economic and environmental problems such as the high costs of a disposal system and source pollution. Life cycle assessment (LCA) is a method for collecting and evaluating the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle. The current study purposed to provide a stable and optimized system of solid waste management in Tehran Municipality Region 20.

Methods: The LCA method was used to evaluate various scenarios and compare the effects on environmental aspects of management systems. Four scenarios were defined based on existing and possible future waste management systems for this region. These scenarios were considered with different percentages for source separation, composting, recycling, and energy recovery.

Results: Based on the results of this study, Scenario 4 (source separation [14%] + composting [30%] + municipal recycling facility [MRF] [20%] + energy recovery [10%] + landfilling [26%]) was found to be the option with the minimum environmental impact. In the absence of government support and sufficient funds for establishing energy recovery facilities, the third scenario (source separation [14%] + composting [30%] +MRF [20%] + landfilling [36%]) is recommended.

Conclusion: The results acquired from this investigation will confirm the belief that LCA as an environmental device may be successfully used in an integrated solid waste management system (ISWMS) as a support tool for decision-making.

Keywords: Municipal solid waste management, Life cycle assessment, Waste management, Tehran

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Introduction

Life cycle assessment (LCA) is a methodology for examining environmental impacts of a product, process, or service "from cradle to grave," i.e. from the production of raw materials to the ultimate disposal of wastes (1,2). The information obtained from an LCA study can be helpful in identifying solutions and optimizing the environmental impact of the product. The results will further be beneficial in terms of decision-making, organizing, and both governmental and nongovernmental planning (3,4). One of the most important capabilities of LCA is helping decision-makers choose the best option from among two or more options by comparing the environmental impacts of products, processes, and services (5,6). This feature is particularly important in studies employing the comparative view and choosing the best option from among solid waste disposal options (7,8). An LCA study includes four steps: goal, scope definition, life cycle inventory (LCI) impact assessment, and interpretation. These steps are continuously linked (9) (Figure 1). In some cases, the intended purpose of an LCA study is only to collect, analyze, and interpret data. This kind of LCA is the same as the method of LCA with the only difference being in the third phase of the study, which is the impact assessment.

LCA has been used as an effective environmental management tool in many studies to compare the environmental impacts of different automobiles (10), to compare the environmental impacts of using key detergent builder systems (11), to decrease the volatile organic compounds (VOCs) content of paint in the paint industry (12), to reduce the environmental burdens of
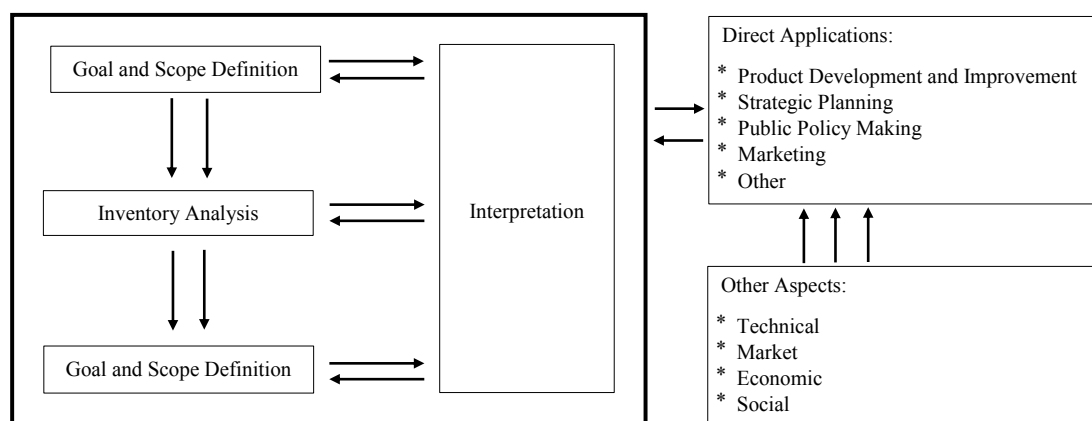
Figure 1. Life cycle assessment.

used automotive batteries (13), to compare 2 groundwater treatment schemes for removing hardness and color (14), to compare various forestry activities such as cutting and shelterwood cutting in forest management systems (15), to assess different possible scenarios for the treatment of municipal wastewater (16), to examine the potential environmental and human health implications of different contaminated site remediation options (17), and so on. Shahr-e-Rey Tehran Municipality Region 20 has 7 zones. At present 92 000 families live in this region. According to recent studies conducted by the Waste Management Organization of Tehran in 2012, 298 tons of waste is being generated on a daily basis in Shahr-e-Rey. Currently, 9% of the generated waste is separated at source and 15% of organic components are transferred to the composting plant. In recent years, the lack of a proper management system has presented the region with many problems. Although many studies have been conducted in the field of solid waste management systems in Iran (18-23), very few works have examined the application of LCA in decision-making about solid waste management strategies (7,18,24,25). In recent years this approach has been used in several countries to assess waste management strategies (16,26-37).

The main objective of the present study was to apply LCA to compare different solid waste management scenarios produced in Shahr-e-Rey in terms of environmental aspects. The results of this study can be used for other cities in developing countries that have similar municipal waste compounds.

Methods
Study area
Region 20 (Shahr-e-Rey) is in southern Tehran. It has an area of 22 km² in the metropolitan area, 178 km² limits at 35 degrees 36 minutes' north latitude and 51 degrees 26 minutes' east longitude, and a municipal population of 453 740. The amount of waste generated differs greatly among seasons, but reaches its maximum value in summer because of the presence of pilgrims. It is estimated that 6% of materials are disposed of in the landfill, 54% is paper and cardboard, 10% is plastic, 11% is metal, 10% is glass,

and textiles make up 9% (Table 1).

In the current study, LCA was applied to consider different waste management scenarios from an environmental point of view in order to present an optimal solid waste management system used to research information related to life cycle. The life cycle evaluation steps are described under the Integrated Waste Management (IWM) model advanced by Doughall (38). The model was designed as a choice-guide tool for waste managers in each industry and related authorities who want to decide between numerous options for waste management. This model is utilized in Europe, South America, and Asia to assist the design or optimization of both local and neighborhood waste management systems (38). The IWM model shows the environmental interventions associated with a waste disposal system. To carry out the LCA inventory of the landfill, all environmental masses were taken into consideration as well as those corresponding to the effluents from the plant itself. This input information must be transmitted to the following process in the landfill and to the by-products obtained there (gas, electrical energy, etc). This is done by means of a vector that contains all the information about all the possible types of pollution. Each product or process flow has an associated vector with all the information on the pollution generated during the entire life cycle. This eco-vector is a multidimensional vector in which each dimension corresponds to a selected pollutant (1).

Scope and goal definition
Three exceptional situations for municipal solid waste management systems (MSWMSs) that consist of special

Table 1. Municipal solid waste composition in Shahr-e-Ray (kg/y)

Waste	Mean (SD)
Plastic	33711.23 ± 393.7
Paper and Cardboard	182040.62 ± 747.5
Metals	37082.35 ± 252.8
Textiles	30340.10 ± 253.0
Glass	33711.23 ± 222.3
Residuals	20226.74 ± 132.4
Total	337112.27 ± 825.1

MSW processing and/or disposal methods were developed and then compared in terms of their environmental burdens and total fuel consumption. In order to achieve environmental sustainability the MSWMSs were compared in an LCA context which considered the following components source separation recycling composting material recovery and energy recovery.

Functional unit and system boundaries

The functional unit used in the scenarios was defined as the amount of municipal solid waste generated in Region 20 of Tehran in one year. The system boundaries selected for the life cycle of solid waste were defined as the moment materials ceased to have value and became waste and when waste became inert landfill material, was converted into air and/or water emissions, or regained some value (Figure 2).

Scenarios

In order to achieve the optimal system of waste management in Shahr-e-Rey, four management scenarios were proposed. The first scenario was considered the basic method of waste management, and future scenarios were developed based on the current situation of the solid waste management of Shahr-e-Rey, plans of the waste management organization to improve the management system, and international standards of solid waste management.

Scenario 1: In this scenario, all generated wastes collected either manually or automatically were sent to the transfer station and then to the landfill site; sometimes, they were transferred directly to the landfill.

Scenario 2: The second scenario was defined based on the current situation of waste management in the studied area. Nine percent of the waste was separated at the source by citizens, 15% was organic waste and was sent to a composting facility to produce compost, 16% was transferred to the material recovery facility (MRF) to separate recyclable materials, and the remaining 60% was

transferred to the landfill site for final disposal.

Scenario 3: Based on the organization's future plans to improve management methods, the third scenario was determined to be 14% source separation, 30% composting, 20% recycling, and 36% landfilling.

Scenario 4: Scenario 4 differs from Scenario 3 in that 10% energy recovery through an energy recovery facility was added to other management options. Only 26% of the remaining wastes were landfilled. Figure 3 illustrates the mentioned scenarios.

Life cycle inventory

The data in this study was obtained mainly from the information available from the Waste Management Organization of Shahr-e-Rey, related literature, and field studies and included waste characteristics and composition by weight waste flow, waste collection transfer and transportation, amount of recycling and composting, and operational data from the transfer station and landfill site. The data was collected to calculate the level of emissions to air and water as well as energy consumption.

The IWM model was run for each scenario. The outcomes defined the environmental elements of those eventualities. The significance of every effect in inventoried values was normalized based on the rate of controlled waste in each scenario and opportunity. These values were then expanded using the characterizing factors to calculate the inventoried values in every significant executed effect in line with the unit. The next stage, achieved indicators in each class, were multiplied by the proportional weight of that class to put the additive indictors together. Based on the equivalent unit or ecological indicator, environmental load of each class was calculated. At the time of the study, 337 112.3 kg of waste were being generated annually in Shahr-e-Rey. Approximately 9% of the generated waste was collected separately, not sent to landfills, but sold to various companies and factories as raw materials. In the second scenario, 3% of source separation was added to the waste management system. In the last scenario, an energy
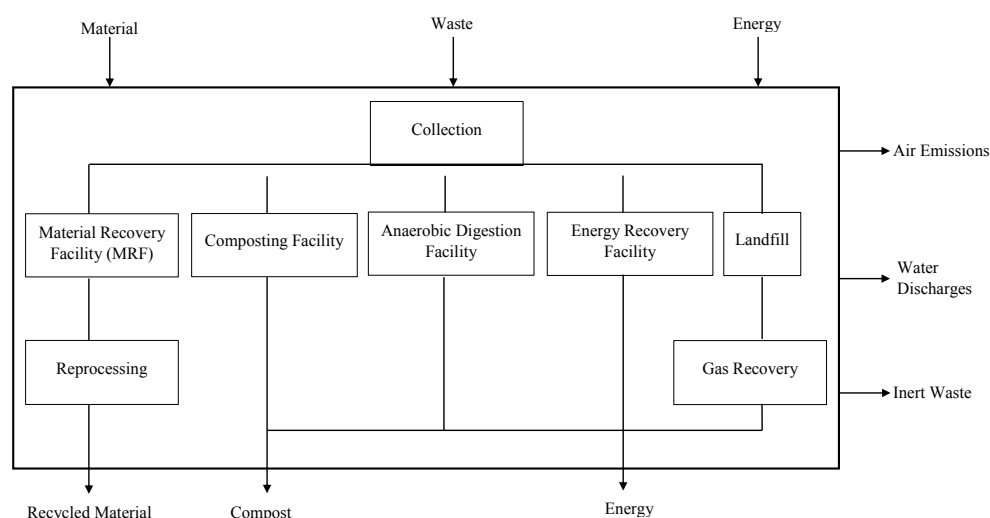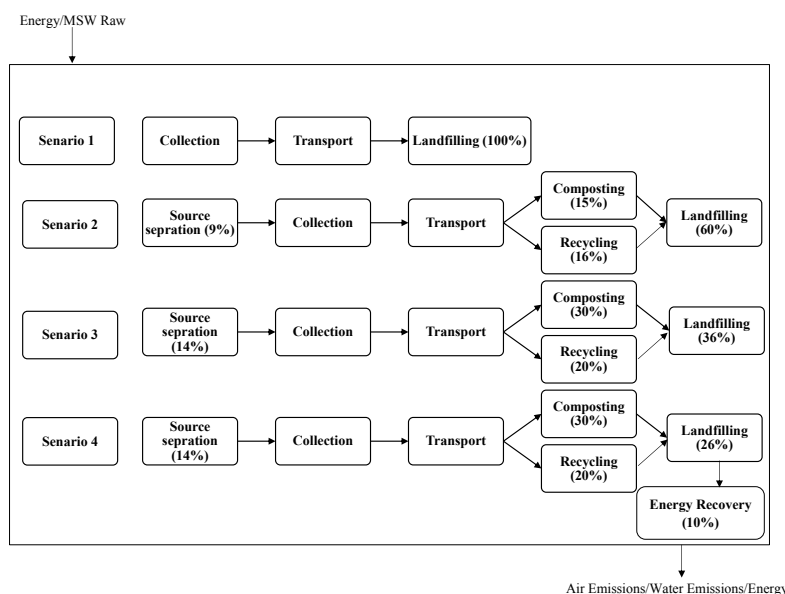

Figure 2. Boundary definition.

Figure 3. Four scenarios of MSWMSs used in this study.

recovery facility was considered near the landfill site. The incineration method was not included in the waste management system because of the resulting high levels of pollution generated and high costs.

Results

Comparison of scenarios in terms of energy consumption

The results of the current study demonstrate that energy consumption in Scenario 1 was not compensated for in any way due to the lack of waste processing and byproduct production (Tables 1 and 2). Therefore, gross and net energy consumption values were equal. In the second scenario, source separation recycling and composting were included in the management plan and resulted in a reduction in the amount of waste disposal as well as energy consumption in landfilling. This is in contrast with energy consumption in recycling and composting which was increased. In this scenario, more energy was compensated for through the production of new materials by recycling, replacing the produced material with raw material consumed in the life cycle, and also by composting and producing other byproducts. However, this replacement rate was not sufficient to cover the total energy consumption; therefore, this scenario had a positive net energy consumption value and could not compensate for part of the energy consumed in reprocessing the recycled materials. In the third scenario, the amounts of source separation, MRF, and composting were increased. Although the amount of energy consumed in recycling and composting was higher compared with the second scenario, less energy was consumed for reprocessing the recycled materials; therefore, most of the energy was compensated for in this scenario, and net energy consumption was decreased. This means that the increase in the amount of recycling and composting solid waste had a positive effect on the life cycle. Energy recovery

was added to the waste management plan in the fourth scenario. Facilities for energy recovery from waste require energy; however, the production of energy resulted in a reduction in net energy consumption.

Discussion

Comparison of scenarios in terms of greenhouse gases

Table 3 shows the comparison of net emissions of the four studied scenarios. As indicated in the table, greenhouse gas emissions were decreased from the first scenario to the last one. This reduction in the amount of emissions confirmed that the scenarios were being optimized. Negative numbers indicated the emissions decreased because of facilities recycling metals and reprocessing other materials.

Comparison of scenarios in terms of acid gases

Like greenhouse gases, acid gases followed the declining trend; however, the reduction in the emission of this group was greater than that of greenhouse gas emissions. Recycling, composting, and energy recovery facilities had significant effects on reducing emissions, particularly HCl.

Comparison of scenarios in terms of smog precursors

The analysis of smog precursors in the different scenarios demonstrated that Scenario 2 had the greatest impacts on reducing smog emissions; this further indicated that the establishment of MRF and composting facilities were significant in decreasing such gas emissions. Conversely, the increase in recycling and composting in Scenario 3 caused an increase in smog emissions; thus, a certain amount of recycling and composting reduced smog emissions. In Scenario 4, the addition of an energy recovery option to the management system led to a reduction in NO_x and PM.

Comparison of scenarios in terms of heavy metals and organics

As Table 2 indicates, the establishment of MRF and energy from waste (EFW) facilities had no positive effect on reducing the emission of heavy metals or organics, while the emission of heavy metals and organics was decreased, like the previous group of gases. All in all, the fourth scenario was more optimized than the first one. Although Scenario 4 resulted in the release of larger amounts of heavy metals and organics into the air, this could be controlled by proper management.

Abduli et al (18) examined the operation and preservation activities for landfilling and composting in Tehran. They concluded that there were contrasting environmental impacts between the cutting-edge MSW strategies of landfill and composting-plus-landfill. LCA was used to compare these scenarios for MSW, and the results confirmed that the composting-plus-landfill scenario caused less damage to human health than the landfill scenario. Municipal waste management scenarios, such as open dumping, composting, anaerobic digestion, and pyrolysis–gasification, were compared using the Center for Environmental Studies method. The impact assessment categories that were considered were emission of greenhouse gases, ozone layer depletion, acidification, eutrophication, ecotoxicity, human toxicity, and summer smog. Mali and Patill revealed that open dumping had the greatest environmental impact. Pyrolysis–gasification with energy recovery potential and composting is an environmentally favorable MSW management option (39). Fernández-Nava et al reported that their results suggested that biomethanization of the supply-separated natural fraction, sorting of the combined fraction, and incineration of the rejected fraction had the least effect on the analyzed harm categories. At the same time, eventualities together with landfilling produced the finest effect in all of the categories analyzed. Concerning the methods involved in the studied eventualities, delivery produced a big effect within the environment, biomethanization contributed to lowering the impact of all damage categories, and incineration adversely impacted human health and weather exchange, but allowed harm to be reduced inside the assets category (40). Yay explained that, while landfilling and incineration have been confirmed as the worst waste final disposal options, composting and fabric restoration had better performances. The device (MRF, composting, incineration, and landfilling) was taken into consideration as an answer towards advanced sustainability to overcome the existing waste management

Table 2. Comparison of scenarios in terms of energy consumption

	Recycling	Composting	EFW	Landfill	Total waste management system	Virgin material displacement system	Reprocessing of recycled materials	Net life cycle inventory
Scenario 1	0	0	0	6853	6853	0	0	6853
Scenario 2	6844	4861	0	4737	16443	-42241	29844	4046
Scenario 3	4111	9722	0	4286	18119	-31945	11545	-2281
Scenario 4	4111	9722	50937	3300	33804	-64959	11545	-19610

Abbreviation: EFW, energy from waste.

Table 3. Comparison of scenarios in terms of environmental emissions

Environmental emissions		Scenario1	Scenario 2	Scenario 3	Scenario 4
Greenhouse Gases	CO_2 (tones)	511	-23240	-18581	-6434
	$CH_4 + NO_x$ (tones)	7161	4822	4656	3367
	CO2 Equivalents (tones)	151549	56591	64931	56595
Acid Gases	NO_x (tones)	2.3	-74.1	-49.3	-26.6
	SO_x (tones)	1.7	-11.4	-103.8	-97
	HCl (tones)	0.6	-677.2	-919.4	-916.2
Smog Precursors	NO_x (tones)	2.3	-74.1	-49.3	-26.6
	PM (tones)	39.1	10.6	29.4	23.7
	VOCs (tones)	22.8	-13.5	16.4	14.4
Heavy Metals & Organics					
Air	Pb (kg)	0.1	-4.6	-4.8	12.5
	Hg (kg)	0	0	0	6.58
	Cd (kg)	0.07	0.02	0	1.71
	Dioxins (TEQ) (g)	0.003	0.002	0.002	0.019
Water	Pb (kg)	6.72	-10.75	-17.05	-18.38
	Hg (kg)	0.092	0.067	0.059	0.036
	Cd (kg)	9.311	6.293	5.224	3.589
	BOD (kg)	123727	93615	77713	56986
	Dioxins (TEQ) (g)	0.00124	0.00090	0.00078	0.00056
Residual Waste (tones)		143451	101701	90113	64925

trouble. The paper showed LCA to be a treasured tool that can assist governors and managers in planning an IWM approach that provides more preferable environmental outcomes than the strategy suggested (8). To protect the plant environment and conserve natural resources, there is an obligation for the network to decrease waste output and recycle as much waste as possible. The restoration of solid waste is economically and environmentally worthwhile. In preference to landfilling substances such as glass, plastic, metal, ceramic, and paper, they can be assessed as secondary uncooked substances. Hence, it is viable to properly decrease the need for uncooked fabric and lower the energy intake for raw material production of an enterprise. The recuperation of stable waste will even reduce the amount of landfilling. Mixing the life cycle analysis and multicriteria decision-making can assist environmental designers in making better decisions regarding one-of-a-kind waste scenarios. In this investigation, waste management alternatives were examined from environmental and economic points of view. The results might be supported with other decision-making tools that consider the social effects of solid waste management. In accordance with the results of this study, Scenario 4 (source separation [14%] + composting [30%] + municipal recycling facility [MRF] (20%) + energy recovery [10%] + landfilling [26%]) was found to be the option with the minimum environmental impact. In the absence of governmental support and sufficient funds for establishing energy recovery facilities, Scenario 3 (source separation [14%] + composting [30%] +MRF [20%] + landfilling [36%]) is recommended.

Conclusion

This study assessed the life cycle of the current system of waste management in Tehran Municipality Region 20. Social and economic factors were not considered; therefore, the results can be considered in decision-making only from an environmental point of view. Economic (fuel costs), social (increased respiratory diseases, etc), and psychological (abnormal noises from the collection and transportation of waste) factors must be combined with environmental factors in evaluation and decision-making. The results of this study showed that a complete picture can be a LCA of a MSWMS in terms of the environment and also serve as a valuable tool in the hands of decision-makers. The results of the current study indicated recycling is one of the best alternatives for waste control. Furthermore, composting has a crucial position in alleviating the burden of pollutants and electricity usage in a waste control system. The results regarding the current status of the waste management system in Tehran Municipality Region 20 are accurate. Therefore, likely the results of this study due to the different characteristics of the waste, technology factors, times and places differ whit previous studies.

Ethical issues
The authors declare that all the data collected during the present study is published in this work, and there are no ethical issues in this work.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
SO, ZD, ZG and MM performed data collection, carried out statistical and technical analysis of data, participated in design of study and drafted manuscript. MM and ZD participated in the final version of manuscript and intellectual helping for analyzing of data. All authors read and approved the final manuscript.

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