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Life cycle assessment (LCA) of solid waste management strategies in Tehran: landfill and composting plus landfill

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Abstract As circumstances of operating and maintenance activities for landfilling and composting in Tehran metropolis differ from those of cities in developed countries, it was concluded to have an environmental impact comparison between the current solid waste management (MSW) strategies: (1) landfill, and (2) composting plus landfill. Life cycle assessment (LCA) was used to compare these scenarios for MSW in Tehran, Iran. The Eco-Indicator 99 is applied as an impact assessment method considering surplus energy, climate change, acidification, respiratory effect, carcinogenesis, ecotoxicity and ozone layer depletion points of aspects. One ton of municipal solid waste of Tehran was selected as the functional unit. According to the comparisons, the composting plus landfill scenario causes less damage to human health in comparison to landfill scenario. However, its damages to both mineral and fossil resources as well as ecosystem quality are higher than the landfill scenario. Thus, the composting plus landfill scenario had a higher environmental impact than landfill scenario. However, an integrated waste management will ultimately be the most efficient approach in terms of both environmental and economic benefits. In this paper, a cost evaluation shows that the unit cost per ton of waste for the scenarios is 15.28 and 26.40 US$, respectively. Results show landfill scenario as the preferable option both in environmental and economic aspects for Tehran in the current situation.

Keywords Life cycle assessment · Composting · Landfilling · Tehran

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Introduction

Low environmental impact waste management systems that are protective of human health and safety are currently gaining more attention globally. However, there is no optimal system for waste management because geographic locations, characteristics of waste, energy sources, availability of some disposal options, and size of markets for products derived from waste management differ widely (White et al. 1997; Mendes et al. 2004).

For a healthy environment, both municipal and industrial wastes should be managed according to the solid waste management hierarchy (prevention/minimization/recovery/incineration/landfilling; Banar et al. 2008). For this purpose, several composting sites have been opened near

Tehran (such as Aradkuh, Karko and biomechanical) in recent decades, but these sites have only been partially effective in addressing the situation (Abduli 1995). Currently, Tehran, with more than 8 million inhabitants, produces 7,435 tons/day of MSW. Eighty seven percent of this waste is disposed of in Aradkuh landfill and 8.3% is composted. The remaining waste (approximately 5%) is recycled. Currently, critical conditions are observed in Aradkuh Center (Kahrizak) which may have developed as a result of (1) lack of gas emission control systems, (2) incompatibility of the imported technology with the local waste composition (in the case of composting unit), and (3) seeping of leachate from landfilling and composing. Facing the situation and the 3.6% increase in compost production in recent years (Mahdavi Damghani et al. 2008) have made the authors to have an environmental assessment between two defective, current MSW strategies which is done through LCA. Although many studies have been done regarding solid waste management systems in Iran (Alavi Moghadam et al. 2009; Sadugh et al. 2009; Jalili Ghazi Zade and Noori 2008; Mahdavi Damghani et al. 2008; Abduli et al. 2008; Ghiasinejad and Abduli 2007), there is no reported study concerning the application of LCA in decision-making of solid waste management strategies in Iran.

LCA is a methodology for evaluating environmental impacts associated with a product, process or service, “from cradle to grave”—from extraction of raw materials to ultimate disposal of wastes (Goedkoop and Spriensma 2001).

LCA is currently being used in several countries to evaluate solid waste management strategies or treatment options for specific waste fractions (Mendes et al. 2004; Obersteiner et al. 2007; Buttol et al. 2007; Boer et al. 2007; Banar et al. 2008; Cherubini et al. 2009).

Cherubini et al. (2009) focused on a life cycle assessment of four waste management strategies in Rome (Italy): landfill without biogas utilization; landfill with biogas combustion to generate electricity; sorting plant, and direct incineration of waste. Results showed landfill systems as the worst waste management options and significant environmental savings at global scale were achieved from undertaking energy recycling. Hong et al. (2010) assessed four solid waste management scenarios through LCA in China to assess the influence of various technologies on environment: (1) landfill, (2) incineration, (3) composting plus landfill, and (4) composting plus incineration. They reported that the technologies play only a small role in the impact of carcinogens, respiratory inorganics, and terrestrial ecotoxicity. Also, potential impacts generated from transport, infrastructure and energy consumption were quite small. In the global warming (climate change) category, the highest potential impact was observed in landfill because of the direct methane gas emissions. Furthermore, electricity recovery from methane gas was the key factor for reducing the potential impact of global warming.

In this paper, landfill (scenario 1), and composting plus landfill (scenario 2) are evaluated by LCA for Tehran case study. However, the final results can be considered reliable for other cities in developing countries, especially in the Middle East, which have similar MSW composition and similar solid waste management actions. Finally, since economical aspects have a unique role in management and decision-making, this paper is concluded by an economic evaluation of the two waste management scenarios used in Kahrizak, Tehran.

Methods

Life cycle assessment was used to make an environmental assessment for the solid waste management system in Tehran. According to TSE EN ISO14040 (1996), an LCA is comprised of four steps: goal and scope definition, life cycle inventory, life cycle impact assessment (LCIA) and interpretation of results. The most critical and controversial step in life cycle impact assessment is the weighting step. In this paper, the Eco-indicator 99 methodology is considered as the weighting method.

Goal and scope

The goal was to compare the environmental impacts of the existing MSW strategies to improve the current solid waste management system in Tehran. The municipal solid waste characteristic and composition of its leachate are shown in Tables 1 and 2, respectively (OWRC 2007; Jalili Ghazi Zadeh 2006). In this comparison, the functional unit was 1 ton of municipal solid wastes.

Besides the investigation of the two different waste management strategies, the transportation of wastes is investigated to assess its environmental impacts proportion to the whole environmental impacts for each scenario.

Transportation

Semi trailers (281 FH12) were employed to transport 7435 tons of waste from 15 mid-stations to Aradkuh Center every day. According to the municipality's reports, the fuel consumption ratio for one ton of wastes can be calculated as 1.34 l/ton. As there is no precise set of data regarding the emissions of the vehicles in Tehran, the emissions are estimated based on Euro2 standards. The emission factors are shown in Table 3. Since composting unit and landfill are located in Aradkuh Center, the same impacts are applied to both scenarios due to transportation.

Table 1 MSW components and characteristics in Aradkuh Center (Kahrizak) (OWRC 2007)

Waste type	Weight%
Wet waste	67.8
Bread	1
Soft plastic	2.2
Hard plastic	0.6
PET	0.7
Plastic bags	6.2
Paper	4.4
Cardboard	3.7
Ferrous metals	1.6
Non-ferrous metals	0.2
Textile	3.4
Glass	2.4
Wood	1.7
Tires	0.7
Leather	0.6
Dust and rubble	1.3
Special waste (health care waste)	1.6
Density[a]	450 kg/m^3
Moisture content[a]	40–44%
Waste temperature[a]	35°C
pH[a]	6.0~7.4

[a]Harati et al. (2007)

Table 2 Leachate composition of waste in Aradkuh Center (Kahrizak) (Jalili Ghazi Zadeh 2006)

Parameter	Average of samples content
COD (mg/l)	64,516
Nitrate (mg/l)	153
Phosphate (mg/l)	242
Sulfate (mg/l)	2,567
Chloride (mg/l)	5,973
Bicarbonate (as mg $CaCO_3$/l)	17,967
pH	6.218
TDS (g/l)	15.4

Scenario 1: landfill

Wastes are collected from mid-stations of collection systems and delivered to Aradkuh Landfill. Part of biogas naturally released by the landfill is collected and controlled to produce electricity by a system energy recovery. It is assumed that this system operates full time and with 50% and 80% efficiencies for collecting gas and generating electricity, respectively. So, 50% of pollutants are emitted into air and the rest are collected and controlled. The rate of methane generation was estimated using LandGem (EPA 1998). According to Harati et al. (2007); L_0, methane generation potential, is suggested to be about 103.2 m^3/Mg refuse in the model. Energy produced per year is estimated at 80,695,589 MJ, considering the extractable mass of methane produced per year and its thermal value, 50.1 MJ/kg (Obersteiner et al. 2007). The amount of 900 m^3 per day leachate is produced in Aradkuh Landfill. It is assumed that 80% of leachate is treated in municipal sewage treatment plant and the sludge formed

Table 3 Transport emission factors Solitic and Hausberger (2004)

Emission	g/km	g/day	g/ton of waste
CO_2	1,188	23,367,960	3,142.97
NO_x	9.4	184,898	24.87
CO	3.9	76,713	10.32
THC	0.72	14,162.4	1.90
SO_x	8.5	167,195	22.49

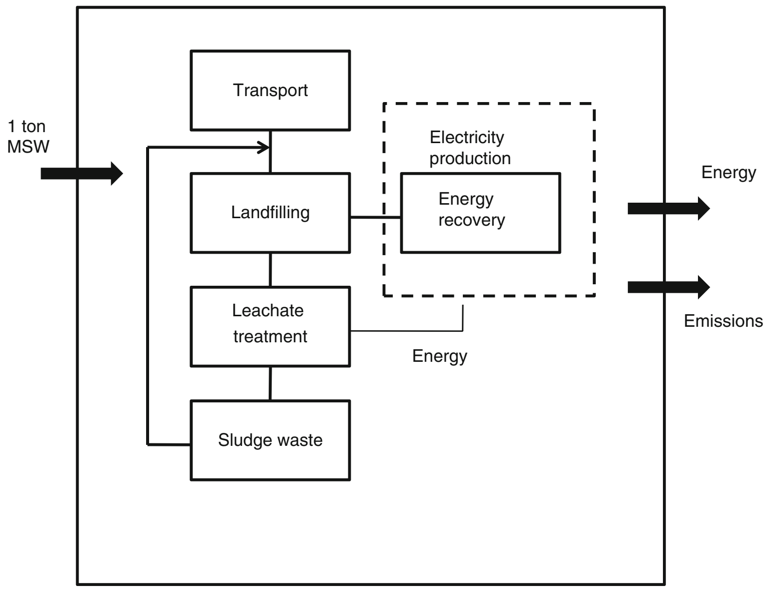


Fig. 1 Schematic diagram showing boundaries for scenario 1 (landfill)

in the plant is landfilled. The remaining 20% of leachate would enter aquatic environments in a critical condition which can pollute water resources (Nielsen and Hauschild 1998).

Energy usage of compactors is excluded and emissions produced during the construction are also neglected due to their small amounts compared to those released during the use of facility (Finnveden et al. 2005). System boundaries for scenario 1 are shown in Fig. 1.

Scenario 2: composting plus landfill

Boundaries for this scenario begin with the collection of MSW from mid-stations of collection systems and include not only the aerobic composting and landfilling processes, but also the complementary processes such as energy recovery and leachate treatment. Emissions for this scenario are calculated by means of a superposition in which contribution of composting and landfilling with energy recovery are considered 65% and 35%, respectively. The boundaries for this scenario are shown in Fig. 2. Having no emission control system in composting process, pollutants are emitted into air with no restrictions. Electricity use in composting process is approximated to be 54.4 MJ/ton of waste (Finnveden et al. 2005), which is assumed to be provided by a gas power plant. Emissions for such power plant are shown in Table 4. The fossil fuel energy utilized by loaders, mills and strainers in the composting process is estimated to be about 555.5 MJ/ton of waste (Bovea and Powell 2006).

Life cycle inventory

The data gathered from actual applications in Tehran, literature and the database of LandGem model are used for life cycle inventory. Emissions to air, water, and soil resources and also energy consumptions have been calculated and are expressed per functional unit. Diesel and electricity consumption, land-use (sand or clay), CO_2, CH_4, HCFCs, NH_3, NO_x, SO_x, SPM, VOCs, COD, T–N, T–P, Cu, Cr, Zn, Pb, Cd and Ni were entered into our calculations. The inventory results for the scenarios are shown in Table 5.

Impact assessment

Emissions are weighted based on the weighted damage factors introduced by Eco-indicator 99 method. The model evaluates damages to human health, ecosystem quality and mineral and fossil as endpoints which are explained as follows. Here, hierarchist perspective that balances time perspective and consensus among scientists for the

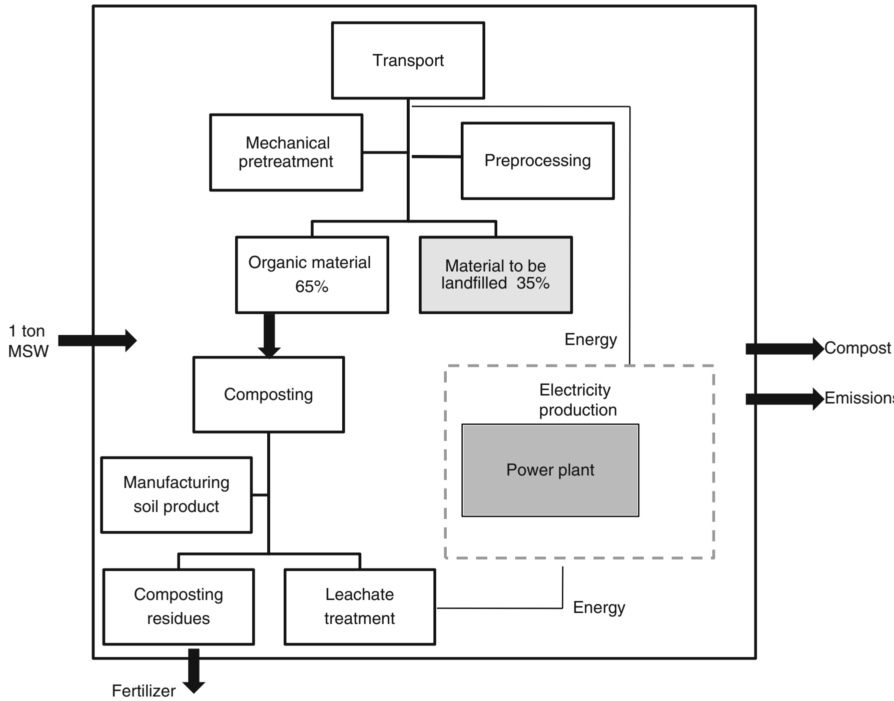


Fig. 2 Schematic diagram showing boundaries for scenario 2 (composting plus landfill)

inclusion of effects has been used (Goedkoop and Spriensma 2001).

Human health: the basic assumption is that all humans, presently or in the future, should be free of environmentally transmitted illnesses, disabilities caused by pollution or premature deaths. Climate change, ozone layer depletion, ionizing radiation, respiratory effects, and carcinogenesis are categorized under this damage category (Goedkoop and Spriensma 2001).

Ecosystem quality: this damage contains the idea that non-human species should not suffer from disruptive changes of their populations and geographical distribution. Acidification/ euthrophication, ecotoxicity, regional effect on vascular plant species, and local effect on vascular plant species are categorized under this damage category. (Goedkoop and Spriensma 2001).

Damage to mineral and fossil resources: this category measures the additional energy requirement to compensate the lower future ore grade (Goedkoop and Spriensma 2001).

Seven impact categories are considered to be representative of the potential environmental impact of solid waste management in Tehran: climate change, acidification, respiratory effect, carcinogenesis, ecotoxicity, ozone layer depletion and surplus energy for future extraction.

Results and discussion

The results of inventory analysis per functional unit for both scenarios are presented in Table 6. Here is a brief description and also comparison between the two proposed scenarios in

Table 4 Emission factors for the gas power plant (MOE 2005)

Emissions (g/Kw h)	NOx	SO_2	CO_2	SO_3	CO	CH	SPM	C
Gas power plant	1.236	1.001	787.056	0.015	0.002	0.037	0.133	214.652

Table 5 The inventory results of each scenario (per functional unit)

Scenario 1: Landfill	Material consumption	Diesel	1.09	kg
		Electricity consumption for leachate treatment[a]	0.139	MJ
		Electricity recovery	−560.4	MJ
		Land-used	0.186	M^2
	Direct gas emissions	CH_4	31.1	kg
		NO_x	0.0588	kg
		VOC	2.89	g
		SO_x	5	g
		Metal (air)	8.80E–05	g
		Mercury (air)	8.80E–05	g
		CO_2	69.8	kg
		HCFC	0.337	g
		SPM	2.17	g
	Direct water emissions	COD[b,c]	1.615	kg
		T–N[b,c]	4.256	g
		T–P[b,c]	6.72	g
		Cu[d]	0.06	g
		Cr[d]	0.14	g
		Zn[d]	0.34	g
		Pb[d]	0.041	g
		Cd[d]	0.012	g
		Ni[d]	0.148	g
Scenario 2: composting plus landfill	Material consumption	Diesel[e]	8.331	kg
		Electricity consumption[f]	35.425	MJ
		Electricity recovery	−196.14	MJ
		Electricity consumption for leachate treatment[a]	0.2436	MJ
		Land-used	0.1283	M^2
	Direct gas emissions	CH_4	13.49	kg
		NO_x	0.228	kg
		VOC	1.000111	g
		SO_x	0.012	kg
		NH_3	0.182	kg
		Metal (air)	3.00E–05	g
		Mercury (air)	3.00E–05	g
		CO_2	35.749	kg
		HCFC	0.118	g
		SPM	2.1	g
	Direct water emissions	COD[b,c]	0.56525	kg
		T–N[b,c]	1.4896	g
		T–P[b,c]	2.352	g
		Cu[g,d]	0.0621	g
		Cr[g,d]	0.05683	g
		Zn[g,d]	0.19193	g
		Pb[g,d]	0.03697	g
		Cd[g,d]	0.005799	g
		Ni[g,d]	0.06779	g

[a]Finnveden et al. (2005)
[b]Based on assumption made by Nielsen and Hauschild (1998) in critical condition
[c]Jalili Ghazi Zadeh (2006)
[d]Safari (2003)
[e]Bovea and Powell (2006)
[f]Assumed to be provided by gas power plant
[g]Hosseinzadeh (2007)

Table 6 Emissions and damages for the scenarios

Emissions	Damages	Scenario 1	Scenario 2
Extraction of minerals &fossil fuels (MJ/ton)	Surplus energy	−2.00E+00	7.16E−01
Fossil fuels	Fossil fuels	1.57E−01	5.49E−02
Land-use (m^2/ton)	Reg. effect on vascular plant species	3.65E−01	1.32E−01
Land-use (m^2/ton)	Loc. effect on vascular plant species	0.00E+00	0.00E+00
NO_x (kg/ton)	Acidification/eutrophication	2.62E−02	1.01E−01
NO_x (kg/ton)	Respiratory effects	1.35E−01	5.24E−01
SO_x (kg/ton)	Acidification/eutrophication	4.09E−04	9.56E−04
SOx (kg/ton)	Respiratory effects	7.16E−03	1.67E−02
NH_3 (kg/ton)	Acidification/eutrophication	0.00E+00	2.20E−01
Mercury (kg/ton) air	Ecotoxicity (PAF)	5.68E−06	1.99E−06
Metals (kg/ton)air	Carcinogenesis (cancer)	1.19E−05	4.16E−06
CO2 (kg/ton)	Climate change	3.80E−01	1.95E−01
HCFC (kg/ton)	Climate change	7.54E−03	2.64E−03
HCFC (kg/ton)	Ozone lay depletion	4.06E−03	1.42E−03
SPM (kg/ton)	Respiratory effects	2.12E−02	2.01E−02
VOCs (kg/ton)	Respiratory effects	4.86E−05	1.70E−05
CH_4 (kg/ton)	Respiratory effects	1.03E−02	4.48E−03
CH_4 (kg/ton)	Climate change	3.55E+00	1.54E+00
Cu (kg/ton) water emission	Ecotoxicity (PAF)	6.90E−04	7.26E−04
Cr (kg/ton) water emission	Ecotoxicity (PAF)	7.50E−04	2.99E−04
Cr (kg/ton) water emission	Carcinogenesis (cancer)	1.25E+00	4.97E−01
Zn (kg/ton) water emission	Ecotoxicity (PAF)	4.32E−04	2.44E−04
Pb (kg/ton) water emission	Ecotoxicity (PAF)	2.36E−05	2.13E−05
Cd (kg/ton) water emission	Ecotoxicity (PAF)	4.49E−04	2.17E−04
Cd (kg/ton) water emission	Carcinogenesis (cancer)	2.22E−02	1.07E−02
Ni (kg/ton) water emission	Ecotoxicity (PAF)	1.66E−03	7.59E−04
Ni (kg/ton) water emission	Carcinogenesis (cancer)	1.20E−01	5.48E−02

each selected impact category based on Eco-Indicator 99:

Climate change

In both scenarios, methane has the dominant effect on climate change impact category. Also, hydrochlorofluorocarbon (HCFC) compounds have the less effective role for both cases. Methane's characteristics make landfill the case with comparatively more undesirable impacts on the environment. Previous research indicates that landfill make a greater contribution to global warming than aerobic composting (Hong et al. 2010; Banar et al. 2008; Finnveden et al. 2005; Lee et al. 2007; Lundie and Peters 2005).

Acidification

Acidification in landfill and composting plus landfill scenarios is primarily due to NO_x and NH_3 emissions, respectively. In both cases, SO_x contributes the least to acidification. Since more NO_x and NH_3 are produced during composting process, the first scenario would be the preferable scenario in terms of acidification. Lee et al. (2007) argues that composting has a much more undesirable acidification impact than landfill. However, landfill has been shown to have severe acidification impact (Banar et al. 2008).

Respiratory effects

Nitrogen oxides have the most adverse respiratory effects in landfill and composting plus landfill scenarios, while volatile organic compounds (VOCs) have the least significant effect on respiration in the both cases. Due to larger volume of NO_x released during composting, the second scenario has the more undesirable effect in this impact category.

Table 7 Impact assessment results for the scenarios

Impact categories	Acidification	Respiratory effects	Carcinogenesis	Climate change	Ozone lay depletion	Resource	Ecotoxicity
Scenario 1	0.0266	0.174	1.39	3.93	4.06	−1.84	0.00401
Scenario 2	0.323	0.565	0.563	1.73	0.00142	0.771	0.00227

Resources

Although securing reliable energy sources is the biggest global challenge today, in Iran, due to the presence of large fossil resources, policy makers usually have ignored this crucial parameter in their decisions. To minimize mineral and fossil fuel depletion, the first scenario is preferred. The supposed scenario for landfilling has the potential for energy production as much as 80,695,589 MJ/year which is equal to 0.0125% of total annual generated electricity in Iran. Contrary to the first scenario, the second is an energy consuming process with about 200.6 MJ per ton of inlet waste.

Although generating energy is beneficial, Mendes et al. (2004) concluded that landfilling with energy recovery slightly reduces the environmental impacts in comparison to landfilling without energy recovery. However, Hong et al. (2010) reported that electricity recovery from methane gas is the key factor for reducing the potential impact of global warming.

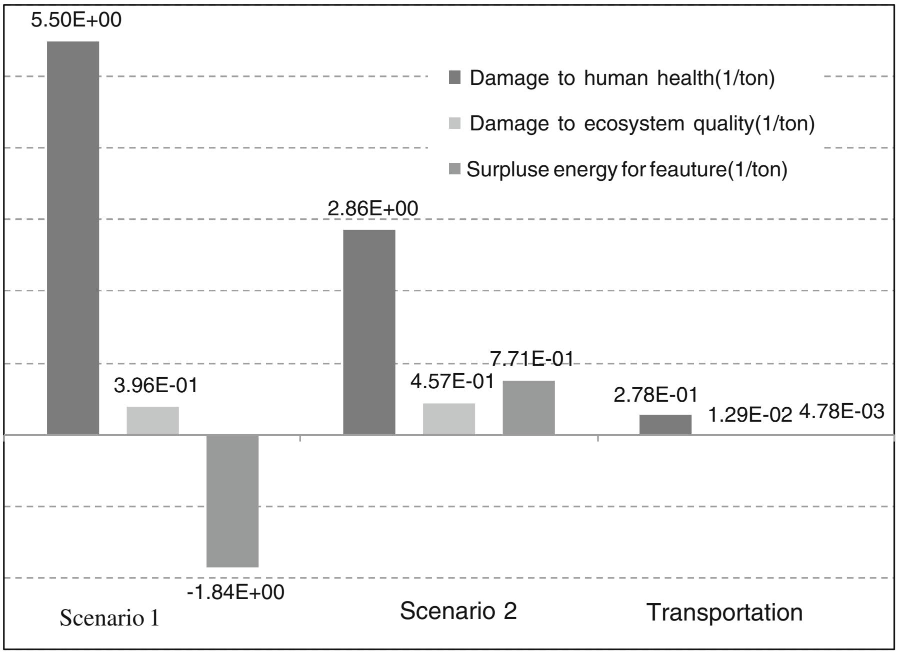
Carcinogenesis

Heavy metals are mainly responsible for carcinogenesis. And among them, chromium and metals emitted into the air are the most and the least effective emissions in the both scenarios. Having heavy metals with high concentrations, the first scenario has the worse environmental impact in terms of carcinogenesis.

Ecotoxicity

In both landfill and composting plus landfill scenarios, nickel (Ni) has the most ecotoxic effects. Mercury (Hg) is more hazardous than nickel but

Fig. 3 Final results



because of its low concentration, it is less ecotoxic in both scenarios. The first scenario has a more undesirable impact on ecotoxicity damage to ecosystem.

It should be noted that the first scenario is responsible for ozone layer depletion impact to a limited extent. Table 7 summarizes the above mentioned comparison between the two solid waste management strategies.

Final results are summarized in Fig. 3. The ultimate damage from transport is considerably less than the other sections for both cases. However, according to the Finnveden et al. (2005) transport has a significant effect on these scenarios.

The second scenario causes more damages to ecosystem in comparison to the first scenario; in terms of mineral and fossil resources, landfill is again the preferred option. Despite advantages in the first scenario, it is a practice that causes higher levels of damage to human health. The overall eco-indicator introduces the first scenario as the preferred option from an environmental point of view for this case study. That landfill is the better environmental scenario, results from its having a system for collecting and controlling gasses which is used to generate electricity, whereas the composting process is the worse environmental scenario due to lack of such a system.

Costs evaluation

Despite considering the environmental impacts, economic aspects have a significant role in planning and decision-making. Capital, operation and maintenance costs were included in the evaluation.

In the case of the first scenario, cost evaluation is done for a 600,000-ton cell which is faced with 1087 ton of wastes for disposal per day. Costs are shown in Table 8. It is assumed that this cell will be closed in 1.5 years after the initial placement of waste and methane extraction is due to start in

Table 8 Landfill construction and operation costs

Item	Thickness	Cost per unit	Unit	Cost (US$)	Remark
Construction costs					
Land cost		5	$/m^2	250,000	
Construction of buildings				250,000	
Survey of LF		16,000	$/ha	80,000	–[a]
Excavation		5	$/m^3	2,000,000	
Intermediate covers	0.3	58,500	$/ha	292,500	–[b]
Clay layer	0.5	164,060	$/ha	820,300	–[b]
HDP sheet	0.0015	36,010	$/ha	180,050	–[b]
Geotextile	0.0015	25,480	$/ha	127,400	–[b]
Gravel layer	0.5	166,600	$/ha	833,000	–[b]
Gas and leachate collection system				400,000	
Construction of roads		150	$/m	525,000	
Leachate treatment		0.061	$/liter	4,069,920	–[a]
Energy production from methane		0.05	$/kw h	−2,632,681	–[a]
Other utilities				550,000	
Closure costs					
Final grades survey		12,400	$/ha	62,000	–[a]
Compacted clay cap		98,800	$/ha	494,000	–[a]
Cover and vegetative soil		49,400	$/ha	247,000	–[a]
Geomembrane cap		49,400	$/ha	247,000	–[a]
Gas and leachate collection maintenance		5%	capital cost/year	281,878.9	–[a]
Costs				9,077,367.7	
Engineering cost		1%	costs	90,773.677	–[a]
Total costs		15.28	$/ton	9,168,141.38	

[a]Berge et al. (2009)
[b]Baldasano et al. (2003)

6 years after the closure of the landfill. An average value for methane gas which is gathered through a gas collection system in 25 years was calculated as 1,006,280 m^3 per year by LandGem software and profits from energy production (13,449,264.8 MJ yearly) are computed based on 5% interest rate per year in the horizon of 25 years. The first scenario costs 15.28 US$ per ton.

The cost analysis for the second scenario was estimated by means of a superposition in which the contribution of composting and landfilling with energy recovery are considered 65 and 35 percent, respectively.

Windrow composting is employed by Tehran municipality in Aradkuh Center (Kahrizak). The current composting system accepts approximately 617 tons of wastes per day. Costs are represented in Table 9. It is assumed that equipments have a useful life of 10,000 h. Working 6.5 h/days/year, the costs are computed for 4.2 years. The amount of 610.3 MJ per ton as energy consumption, leachate treatment procedure for 200 l per ton of waste, and maintenance costs including 5% of the capital costs for buildings and equipments are considered in a horizon of 4.2 years with 5% interest rate. Mean price of 0.01$ per kilogram for compost, was included in our calculation. The total cost of composting is about 32.39 US$ per ton of waste. Thus, the second scenario costs 26.40 US$ per ton of waste.

Table 9 Compost construction, operation and maintenance costs

Item	Cost per unit	Unit	Cost (US$)	Remark
Construction costs				
Land cost	5	\$/m^2	2,000,000	–[a]
Factory building	200	\$/m^2	1,600,000	
Management building	400	\$/m^2	320,000	
Fencing	8	$/m	98,400	
Field preparation and landscaping	30	\$/m^2	600,000	
Security and service			200,000	–[a]
Electricity services			450,000	–[a]
Water supply			100,000	–[a]
Heating and cooling equipments			200,000	
Roads	150	$/m	900,000	
Equipment costs				
Facility movement(reassembling and cleaning)		400,000		
Conveyor plus repair costs	250,000	$/unit	1,000,000	
Separators	75,000	$/unit	300,000	
Magnet separators			180,000	
Balers and bag splitters			1,000,000	
Chipper	25,000	$/unit	100,000	
Trucks	120,000	$/one	960,000	
Tractors	15,000	$/one	120,000	
Loaders	150,000	$/one	600,000	
Operating costs				
Mixing	53,561.3	$/month	2,699,489.52	
Turning	9,564	$/month	482,025.6	
Screening	16,737	$/month	843,544.8	
Leachate treatment	0.061	$/liter	12,217,792.4	–[b]
Energy consumption	0.05	$/kw h	7,073,959.3	–[b]
Maintenance cost	259,000	$/year	959,783.7	–[b]
Total cost	37.39	$/ton	35,368,995.3	
Compost revenue	10	$/ton of compost	4,729,305	
Net cost	32.39	s/ton		

[a]Development up to acceptance rate of 2,500 ton waste per day is considered
[b]Berge et al. (2009)

Conclusion

The comparison between environmental impacts of the two solid waste management strategies in Tehran has been conducted according to the guideline of Eco-Indicator 99 which is a damage oriented method for life cycle assessment.

This paper shows that despite its nature, a defective waste management strategy (composting plus landfill) can have higher environmental impacts in comparison to landfilling which is suggested to be excluded from waste management decision-making. Since landfill has a gas collection and control system with 50% collection efficiency rather than compost which emits pollutants into the air with no filtration, the second scenario has higher environmental impacts in Tehran. Apparently, the second scenario would be the preferable option if a gas control system was installed in the composting process. Transportation does not have significant environmental impacts in either scenario.

In the both scenarios, methane and NO_x have the main effect on the climate change and respiratory effects, respectively. Chromium and Nickel emissions have the highest impact on carcinogenesis and ecotoxicity, respectively. In the acidification impact category, NO_x is the most effective emission for the first scenario, but NH_3 has the largest impact for the second scenario. Finally, the landfilling process is accountable for the ozone layer depletion impact to a limited extent.

The landfilling with energy recovery generates approximately 0.0125% of total electricity generation per annum in Iran which terminates in less air emissions specifically in terms of acidification/eutrophication and respiratory effects rather than composting which provides its energy from power plants by consuming fossil and mineral resources.

The cost evaluation shows that the first and the second scenarios cost $15.28 and $26.40 U.S. per ton of waste, respectively.

Although Tehran municipality desires to have high capacity composting facilities because of the high portion of organic waste in MSW, it must be considered that a defective alternative for recovering waste may have higher undesirable environmental impacts rather than landfilling. Therefore, we recommend that a superfund should be established by the government to apply an appropriate composting system with the latest technology to avoid landfilling which has high environmental impacts especially on human health.

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