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Social cost of CO_2 emissions in Tehran waste management scenarios and using life cycle assessment to select the scenario with the least impact on global warming

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ABSTRACT

Climate change includes global warming driven by human-induced emissions of greenhouse gases and the resulting large-scale shifts in weather patterns. Tehran, Iran, has a population of 13 million (2017) and produces about 13,000 tons of municipal solid waste per day and 4.7 million tons annually. This study used the life cycle assessment (LCA) method to calculate all the emissions in different scenarios for Tehran's waste management. The IWM model was used for Phase II of the LCA. The results of the proposed scenarios showed that the highest emission was from greenhouse gases (GHG), which were9.6, 3.2, and 2.7 million tons in the first, second, and third scenarios, respectively. The IPCC reports and the results from the life cycle inventories were used to calculate the social cost analysis for the scenarios based on the CO_2 equivalents. The third scenario caused a 71.8% and 17.2% reduction in terms of social costs compared to the first and second scenarios, respectively. Thus, according to the importance of greenhouse gases in global warming, employing a third scenario in the waste management system could effectively reduce greenhouse gases in Tehran.

1. Introduction

Developing technologies, together with increased consciousness, consider greenhouse gas emissions in waste management as an influential factor in climate change [1]. The impact of GHG can be significant and highly variable for waste management practices [2]. The existence of different types of materials and waste management systems presents a need for analytical frameworks and tools to assess GHG emissions. One of the most important urban problems and, in fact, one of the causes of urban pollution is the lack of integrated waste management systems [3]. According to all the

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mentioned cases, achieving a proper waste management system requires new tools and different techniques. [4]. One of the tools used worldwide to select and implement a waste management system is life cycle assessment [5]. Life cycle assessment is an analytical tool used to evaluate the effects of a product, process, service, or activity [2]. This method is a systematic test that recognizes the environmental effects of a product during its life cycle. In fact, it evaluates the product from the cradle to the grave. LCA waste management is used in the collection, transfer, treatment facilities, and treatment and burial. According to ISO 14040, the life cycle assessment process has four phases, shown in Figure 1. These phases include the following [6,7]: Phase 1) Definition of purpose and scope of application. The subject matter and application of the method create the boundaries of the system and the level of detail of an LCA study. The purpose of a particular LCA may make a significant difference in its depth and extent [8]; Phase 2) Inventory analysis. The database analysis step involves the set of data needed to meet the objectives of the defined study [9]; Phase 3) Life Cycle Impact Assessment (LCIA). It provides additional information to help evaluate the LCI results of a product system so that a better understanding of their environmental significance can be obtained. Different methodologies can be used to assess the impact. The reference substance for each impact (e.g., kg CO equivalents for global warming) can be used directly for the impact assessment results; it can also be used as a normalized unit in "Person Equivalents" (PE). Its value is the impact given for all the accumulated activities for an average person in a year [10]; and Phase 4) Interpretation. The last step is used as a basis for conclusions, recommendations, and decisions, in which the results of the LCI or LCIA or both are summarized. The last step of the LCA implementation method is called life cycle interpretation. They are discussed by defining the purpose and scope of the application [7].

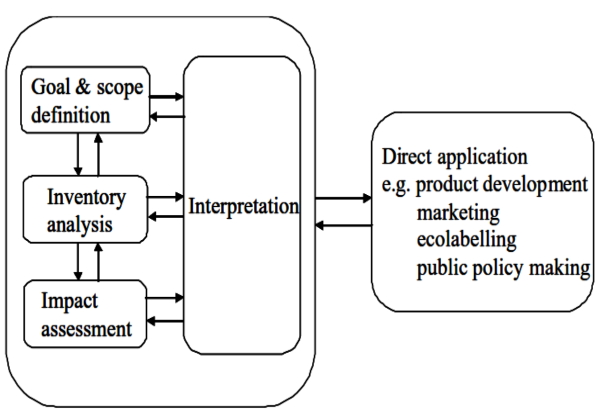

Fig. 1. The four phases of an LCA (8).

One of the environmental consequences of urban waste management, which is of particular importance among experts today, is global warming due to greenhouse gas emissions. There is general agreement among scientists that increasing the concentration of greenhouse gases in the atmosphere will lead to climate change. Tehran is one of the largest cities in Iran, with about 13 million people, and produces an average of 13,000 tons of waste daily. According to the analysis, there is 70 -75% of compostable organic matter (wet waste), 20% -25% of recyclable dry matter, and 10% -5% of other waste. The separation of these materials at the source greatly assists in recycling and sanitary disposal, which prevents environmental pollution and loss of national assets [11]. Considering the increase in waste and environmental pollution caused by population growth and industrial activities in Tehran, this study aimed to provide an optimal waste management system using life cycle assessment (LCA) and choose an optimal scenario considering the health and environmental consequences. In fact, the present study presents a waste management system for Tehran with the lowest environmental pollution, the lowest waste generation, the highest efficiency, and the lowest impact on global warming and climate change.

2. Materials and methods

According to Figure 2, the current Tehran waste management system includes waste generation, collection and transportation, transfer stations, and municipal waste disposal (recycling, compost, landfill) [12].

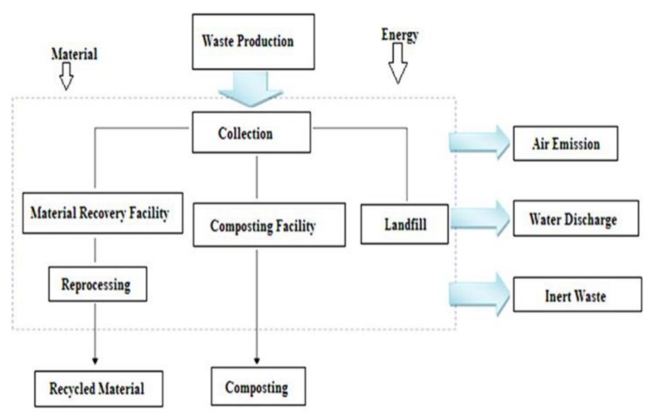

Fig. 2. Tehran Waste Management System.

In 2017, Tehran had 11 intermediate waste transfer stations for collecting and transporting more than 13,000 tons of solid waste to Kahrizak. Table 1 shows general information about Tehran's quality and quantity of waste in 2017 [12].

Table 1. The quality and quantity of waste in Tehran in 2017.

Waste	Weight (%)	Weight (Ton)
Wet waste	67.8	3,217,110
Bread	1	47,450
Soft plastics	2.2	104,390
Hard plastic	0.6	28,470
Pet	0.7	33,215
Plastic bags	6.2	294,190
Paper	4.4	208,780
Mixed paper	3.7	175,565
Metals	1.6	75,920
Aluminum	0.2	9,490
Cloth	3.4	161,330
Glass	2.4	113,880
Wood	1.7	80,665
Tire	0.7	33,215
Leather	0.6	28,470
Rubble	1.3	61,685
Special waste	1.6	75,920
Total	**100**	**4,749,745**

The analysis of three essential disintegration factors is used to assess the GHG emission rate of waste management: 1) GHG emissions during the life cycle of the material, 2) The scope to which carbon sinks are affected by making and disposing of the material; and 3) The extent to which the management option meliorate energy that can be consumed to extrude energy that would be generated at an electric utility, thus decreasing GHG emissions. The life cycle assessment method was used to investigate the Tehran waste management system and calculate GHG emissions. The LCA models were selected. Then, three scenarios were presented and reviewed according to the composition of the waste and the proposed processing methods based on the available capabilities, facilities, and quantity and quality of existing waste. The model was run for the selected scenario. According to the output of the models and effects, the option with the least environmental impact was selected as the optimal scenario. Table 2 offers the proposed scenarios in this paper for Tehran. Three scenarios were identified regarding the quality and quantity of waste and waste management system facilities in Tehran. The proposed processing methods for Tehran's waste management system were presented according to the available capabilities, features, and quality and quantity of the waste. The first Scenario is the Current Situation Scenario and is based on the waste management system used in Tehran in 2017. The second Scenario is the Maximum Scenario. According to this analysis, the second scenario was defined to make maximum use of the capabilities of the waste and assume the use of these capabilities. The third Scenario is the Optimal Scenario based on Tehran's circumstances. This scenario was selected due to the quality and quantity of waste, facilities available to the Tehran municipality, the experiences of successful Metropolises like Tehran, and Tehran's integrated solid waste management plan. Two criteria were used for selecting the models in this study. The first was the potency of the model in the environmental implementation of a full waste management system from waste collection to final disposal, including links between a potentially variable waste composition and emissions into the environment. And the second was the ability to model process emissions (formation of dioxin in an incinerator) and waste emissions (mercury in incoming wastes released through the stack). The IWM model was selected based on these criteria for calculating emissions from Tehran's waste management system. The IWM model was used to perform the second phase of the life cycle evaluation in this research. The model was introduced in 2000 and is in Excel format. The following hardware and software requirements are required to implement it: Microsoft Excel, a RAM of at least 16.0 Megabytes, and a 486 computer or higher. The aim of these models is to provide a wide-ranging environmental impact of waste management options, which can potentially increase the environmental performance of waste management systems. The model provides information on energy consumption and pollutant load for each waste management strategy or a combination of waste management options. Figure 3 shows the system boundary for the environmental analysis model. The assessment of the environmental burden associated with waste management from the point of entry of a substance into the municipal waste stream to the point where it becomes a useful substance or is eventually buried can be used in this model [13]. The IWM model can estimate the amount of energy consumed (or produced) and the amount of emissions to the air, water, and land associated with different waste management methods. Therefore, specific index parameters can be evaluated, and the related environmental effects identified. These parameters and their environmental effects are presented in Table 3 [13]. This research focused on climate change and emissions from a waste management system, which can influence climate change; other emissions were ignored.

Table 2. Proposed Scenarios for Tehran waste management system.

Scenario	Composting (%)	Recycling (%)	*EFW (%)	Landfill (%)	Rest of Composting (%)	Rest of Recycling (%)	Rest of (%) EFW	Disposal (%)
	a	b	c	d	a_1	b_1	c_1	-
First	15	5	-	80	5	1		86
Second	70	20	-	10	5	·	·	15
Third	55	10	5	30	10	·	·	40

* Energy From Waste

Table 3. Indicator parameter [13].

Indicator Parameter	Indicator of	Indicator parameter	Indicator of
Energy	Resource depletion		
Total Energy Consumed			
Emission to air		Emission to Water	
Greenhouse Gases	Climate change	Heavy Metals	Health risk
Carbon dioxide (CO2)		Lead (Pb)	environmental
Methane (CH4)		Cadmium (Cd)	degradation
		Mercury (Hg)	
Acid Gases	Acidification, health risk	Trace Organics	Health risk,
Nitrogen oxides (NOx)		Dioxins & Furans (TEQ)	
Sulphur dioxides (Sox)			
Hydrogen Chloride (HCl			
Smog Precursors	Urban smog formation,	Biochemical Oxygen	Water quality,
Volatile Organic	Health risk	Demand (BOD)	
Compounds			environmental
Nitrogen oxides (NOx)			degradation
Particulate Matter (<10			
microns) (PM-10)			
Heavy Metals	Health risk	Emission to Land	
Lead (Pb)		Residual Solid Waste	Land use disruption
Cadmium (Cd)			
Mercury (Hg)			
Trace Organics	Health risk		

3. Result and discussion

A model that can be useful and practical is the conceptual and computer model (IWM), which looks at all types of waste generated (recyclable and non-recyclable) locally and their disposal at the same time. In addition, this model can bring some economic, environmental, or social benefits. Other advantages of this model are the use of different sources of waste (commercial, household, industrial) and different technical methods of waste disposal. The second phase of the life cycle assessment inventories and outputs from waste management to the environment was calculated using the IWM model. Then according to these emissions, the social costs based on the CO2 equivalent were calculated for the three scenarios. By performing the second scenario, 3,261,092 tons of greenhouse gas emissions were produced. The residual waste was approximately 2,700,534 tons. In the second scenario, the amount of emissions decreased by 64%. With the implementation of the third scenario, greenhouse gas emissions compared to other emissions was lowest. But with the implementation of this scenario, the greenhouse gas emissions were reduced compared to the other scenarios. And 2,700,534 tons of greenhouse gas emissions were produced. The Residual Waste was approximately 1,171,058 tons. In comparison to the first scenario, the amount of emissions decreased 72%. Tables 4, 5, and 6 present the results of the IWM model for the three scenarios.

Table 4. Environmental inventory - MSW management system (Scenario 1).

	Recycling	Composting	EFW	Landfill	Total Waste Management System	Virgin Material Displacement Credit	Reprocessing of Recycled Materials	Net Life Cycle Inventory
Tons Managed	95,143	712,469	0	3,942,134	4,749,745		952,303	34,019,144
Energy Consumed (GJ)	28,350	2,122,402	0	33,778,698	35,929,450	-2,862,611		
Greenhouse Gases							62,651	3,293,481
- CO2 (tons)	3,586	216,275	0	3,187,391	3,407,252	-176,422	0	299,710
- CH4 (tons)	4.33	17.25	0.0	300,187	300,210	-499	62,651	9,587,389
- CO2 Equivalents (tons)	3,678	216,637	0	9,491,329	9,711,645	-186,907	10,946	3,978,031
Residual Waste (tons)	951.59913	35,623	0	3,942,142	3,978,717	-11,634	952,303	34,019,144

Table 5. Environmental inventory - MSW management system (Scenario 2).

Scenario 2: 70% Composting, 20% Recycling,10% Landfilling								
	Recycling	Composting	EFW	Landfill	Total Waste Management System	Virgin Material Displacement Credit	Reprocessing of Recycled Materials	Net Life Cycle Inventory
Tons Managed	118,179	3,324,825	0	1,306,741	4,749,745			
Energy Consumed (GJ)	35,209	9,898,283	0	11,224,698	21,158,190	-3,212,593	1,330,755	19,276,351
Greenhouse Gases								
- CO2 (tons)	4,453	976,329	0	973,689	1,954,472	-212,543	87,696	1,829,625
- CH4 (tons)	5.55	80.48	0.0	68,597	68,682	-517	0	68,165
- CO2 Equivalents (tons)	4,569	978,019	0	2,414,205	3,396,793	-223,397	87,696	3,261,092
Residual Waste (tons)	0	232,738	0	1,306,748	1,539,486	-13,915	14,387	1,539,958

To compare the social costs of the proposed scenarios based on the information provided by the IPCC (Table 7), the social costs of the scenarios for the CO2-equivalent emissions in the second phase of the lifecycle assessment were calculated, and the results are presented in Table 8.

Table 6. Environmental inventory - MSW management system (Scenario 3).

Scenario3 Optimum:55% Composting, 10% Recycling, 5% EFW,30% Landfilling								
	Recycling	**Composting**	**EFW**	**Landfill**	**Total Waste Management System**	**Virgin Material Displacement Credit**	**Reprocessing of Recycled Materials**	**Net Life Cycle Inventory**
Tons Managed	95,143	2,612,356	291,754	1,750,492	4,749,745			
Energy Consumed (GJ)	28,421	7,777,222	1,319,809	12,891,936	22,017,390	-2,891,527	961,923	20,087,786
Greenhouse Gases								
- CO2 (tons)	3,591	383,468	160,054	1,049,291	1,596,405	-247,537	118,751	1,467,619
- CH4 (tons)	4	46	-75	82,085	82,061	-504.22621	0	116,260
- CO2 Equivalents (tons)	3,683	402,129	188,352	2,231,932	2,826,045	-188,794	63,284	2,700,534
Residual Waste (tons)	0	235,113	52,808	883,831	1,171,751	-11,750	11,057	1,171,058

Table 7. Social cost of CO2, 2015-2050a (in 2011 Dollars).

Year	5% Ave.	3% Ave.	2.5% Ave.	3% 95th percentile
2015	$12	$39	$61	$116
2020	$13	$46	$68	$137
2025	$15	$50	$74	$153
2030	$17	$55	$80	$170
2035	$20	$60	$85	$187
2040	$22	$65	$92	$204
2045	$26	$70	$98	$220
2050	$28	$76	$104	$235

Table 8. Social cost of CO_2 for proposed scenarios.

Scenario	CO_2 equivalent (ton)	Social Cost of CO_2, (12 Dollars)[1]	Social Cost of CO_2, (10^9 Rials)[2]
Scenario 1	9,587,389	115,048,668	5,459
Scenario 2	3,261,092	39,133,104	1,857
Scenario 3	2,700,534	32,406,408	1,538

1. The SCC values are dollar-year and emissions-year specific.
2. Central Bank of the Islamic Republic of Iran (2017.02.18, 1$=47,452 Rial).

The analysis of the social costs using the second scenario compared to the first scenario caused a 66% reduction in terms of social costs. Conducting the third scenario caused a 71.8% and 17.2% reduction in terms of social costs in comparison to the first and second scenarios, respectively. Considering the quality and quantity of wastes in Tehran and the current facilities, conducting a third scenario could be useful for reducing emissions, social costs, and environmental impacts.

4. Conclusions

There are various methods used in solid waste management, one of which is life cycle assessment. In this approach, the environmental impacts of the whole waste disposal process are investigated and allowed some analysis and optimization. One of the practical and applicable methods of LCA is the IWM method, which has all the required principles of this phase. Other advantages of this model are the separation of a specific option or the evaluation of different waste management systems; it also describes the functional units and the boundaries of the waste management system are investigated. Based on the results and outputs of this research in the evaluation of alternative scenarios for waste management in Tehran, the third scenario had the lowest emissions in the second phase of the life cycle assessment via the IWM model. The third scenario of this study is a proposed option for waste management in Tehran, according to current facilities and the quality and quantity of waste. By performing this scenario, greenhouse gas emission will be significantly reduced compared to the other scenarios. By implementing the third scenario, the waste management system has the following characteristics:

- Cause the least environmental impact
- Systems with minimum waste production

- Systems with the lowest impact on global warming and climate change

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