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Using Life Cycle Assessment Method for Selecting Optimal Waste Management System in Tehran City

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ABSTRACT

Introduction: In Tehran with a population of 9 million currently, about 2.5 million tons municipal solid waste have been producing annually.

Materials and Models: In this study by using Life Cycle Assessment (LCA) model an optimal system of waste management of Tehran was recommended. Based on the quantity and quality of waste in Tehran in 2013 and facilities, three scenarios were selected. First, current status (15% compost, 5% recycling and 80% landfill), second, the maximum use of the capabilities of waste of Tehran (70% compost, 20% recycled and 10% landfill) and third, the optimal scenario according to conditions of Tehran (55% compost, 10% recycling, 5% energy recovery and 30% landfill). The IWM model and WRATE model was used for Phase II and Phase III, respectively.

Results: Results of the conducting second Phase showed in compared to the first scenario by the second and third scenario, the amount of emissions was decreased 64% and 72%, respectively. The third phase results showed the third scenario has the lowest environmental impact in chosen six impact groups.

Conclusion: Considering the quality and quantity of wastes in Tehran and also the current facilities, conducting the third scenario could be useful for reducing emissions, the external costs and environmental impacts.

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Introduction

Waste management in Iran is one of the main issues of municipalities across the country and imposes significant costs on urban management. Population growth and development of economic activities, especially industry, commerce, etc., cause waste and chemical-physical changes to increase, so existing waste collection and disposal programs will not meet the needs of cities. The city of Tehran was selected for the following reasons:

- Increasing the population of Tehran and consequently increasing the volume of waste
- Production of about 8000 tons daily and about 2.5 million tons of municipal waste (domestic and commercial) annually, which is twice the world standard, according to city officials.

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- According to available statistics, a small percentage of compostable and recyclable materials are converted into compost and recycled under the current Tehran waste management system.

- One of the most important urban problems and in fact one of the contaminants in Tehran is the lack of integrated waste management in Tehran.

Due to the increasing population and industrial activities in Tehran which increase the amount of waste and environmental pollution in the city, the overall objective of this study was to "present an optimal waste management system in Tehran using Life Cycle Assessment (LCA)". Using this technique can be a good solution to this problem.

In addition to the main objective, the present study will pursue the following sub-objectives:

1- Determine the status of the current waste management system in Tehran
2- Providing different scenarios for waste management in Tehran
3- Examine the types of existing LCA models in waste management and determine their capabilities and limitations
4- Selecting the right model for data analysis
5- Choosing the right model for life cycle outcome assessment
6- Analyze model results and compare selected scenarios
7- Economic analysis of selected scenarios
8- Optimal scenario selection considering health, environmental and economic consequences

In fact, using the present research, the waste management system of Tehran is presented with the following features:

- Minimize environmental pollution
- The system with the least waste generation
- The system with the least impact on global warming and climate change
- The system with the highest efficiency and lowest cost

In developing plans for Integrated Municipal Solid Waste (IMSW) management, planners can use a wide variety of available options to evaluate, such as source reduction programs, different collection, separation, treatment, and disposal processes. To investigate the complicated interrelationships of mass flows and related costs, resource consumption, and environmental releases of integrated MSW management strategies, and determine optimal management solutions, it is essential to calculate the costs and environmental aspects related with each unit process included in the strategy [1]. Technologies for waste management are ever-improving, and the number of different ways for treating waste increasing. It is therefore necessary to find ways to assess the most optimal forms of waste treatment. One of the assessment models that have arisen to help perform this task is LCA [2]. In evaluating the environmental aspects of a specific MSW management strategy, planners are required to consider the burdens occurring outside the activities' traditional framework from waste collection to final disposal. As shown in Figure1, these types of tradeoffs are determined by taking a life cycle approach [3]. To investigate the interrelationship and tradeoffs of integrated MSW management strategies, life cycle management concepts and tools should be applied to evaluate the integrated MSW management systems [3].

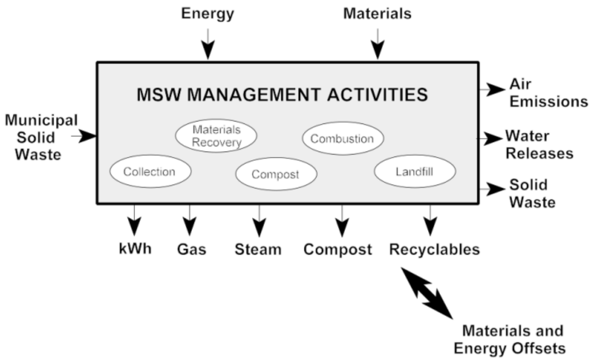

Figure 1: Illustration of the MSW management life cycle [4]

A number of new waste treatment technologies have come into use in the last decade, the arrival of which has begun to contest what can be considered the best treatment option in the waste hierarchy. These new treatment technologies have produced a need for ways to determine optimal treatment systems. Waste management systems cover a number of different activities that are grouped into three phases, each of which can have a number of sub-steps. A conceptual representation is shown in Figure 2 [5].

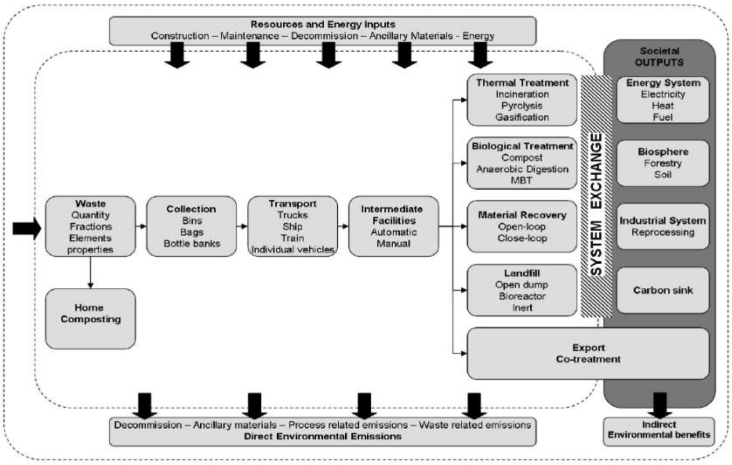

Figure 2: Generic waste management system [5]

The outer dotted line indicates the general society (earth system and technosphere). The inner dotted line illustrates the waste management systems, consisting of some waste management technologies (light shaded grey). The dark shaded grey shows the whole waste management system's inputs and outputs. The box showing the system exchange determines the relationships of materials and energy flows between the waste industry and wider society by substitution [5]. The point of origin in a waste management system is always at the site of the waste generation. From the waste producer, collection schemes are set up to handle the collection of the waste and transport it to the treatment facilities [2].

During each step in the system, a number of direct or indirect impacts are taking place. Emissions from the waste treatment process itself (e.g. methane released from a landfill) or from the use of auxiliary materials and energy are released into the environment [2].

LCA is an internationally standardized methodology for environmental assessment, [6, 7] which is used to evaluate the environmental impact of a product or system. According to the ISO standard, an LCA should cover four distinct phases, as illustrated in Figure 3.

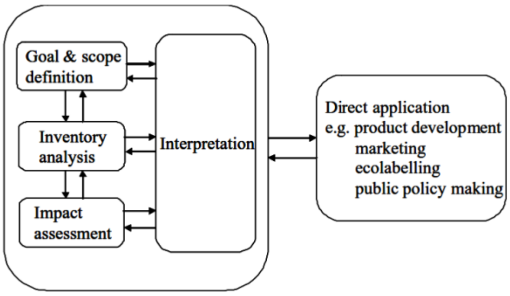

Figure 3: The four phases of an LCA [6]

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Goal and scope definition

In the goal and scope phase, we should specify the goal and scope of a study as related to an intended application. The functional unit should be specified, In the case of waste management, the unit could, for example, be the treatment of a tone of waste [6].

Inventory analysis

The inventory analysis is where all emissions into the environment, energy production and use and resource consumption are tallied [8].

Impact Assessment

The third phase is the impact assessment. Here, the data from the inventory analysis is applied characterization factors, which is a way to ask "how much" this impact really is. A number of different methodologies exist which can be used for assessing the impact. The results from the impact assessment can be given either directly in the form of the reference substance for each impact (e.g. kg CO equivalents for global warming) or as a normalized unit in 'person equivalents' (PE), which is the amount of that impact given for all the accumulated activities for an average person in one year [9].

Interpretation

The fourth and final step is interpretation. This is where the results from the inventory analysis and impact assessment are held up against the goal and scope for the study, so that conclusions and recommendations can be established [7].

LCA on waste has been performed since the early 1990s[10], and there are today more than 50 LCA models available in Europe [11]. These models have all been developed with different scopes with regards to applicability, functionality, user friendliness and costs.

In Tehran, the capital of Iran, with more than eight million inhabitants, most wastes (80%) are disposed in the Aradkuh landfill and the rest is composted (15%) or recycled (5%) [12]. Furthermore, some other waste disposal facilities exist near Tehran, such as biomechanical composting plant, which could not solve the problems appropriately [13]. By 1993, industrial wastes were disposed in the Kahrizak landfill [14].

Unfortunately, significant problems exist in Aradkuh disposal site: [15,16,17] (1) lack of gas emission control systems, (2) incompatibility of the imported technology with the local waste composition (in the case of composting units), and (3) seeping of leachate from landfilling and composting sites. These problems have caused critical environmental situation in this site. The present solid waste management system in Tehran consists of:

• Collection and transport;
• Intermediate facilities;
• Material recycling;
• Composting
• Landfill

Figure 4 represents the municipal solid waste system [12]. In this comparison, the functional unit was 1 ton of municipal solid wastes.

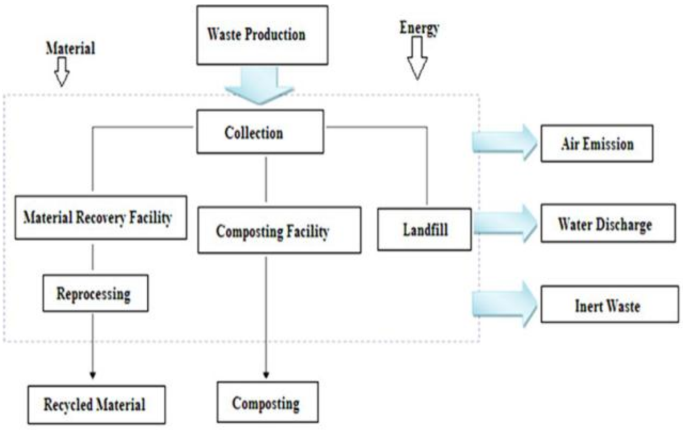

Figure 4: Tehran waste management system [12]

Tehran in 2013 has 11 intermediate waste transfer stations which is used for collecting and transporting more than 8,000 tons of solid waste to Kahrizak [12]. Table 1 shows general information about quality and quantity of waste in Tehran in 2013.

Table 1: Quality and quantity of waste in Tehran in 2013

WASTE	Weight (%)	Weight (Ton)
Wet waste	67.8	1,856,025
Bread	1	27,375
Soft plastics	2.2	60,225
Hard plastic	0.6	16,425
Pet	0.7	19,162.5
Plastic bags	6.2	169,725
Paper	4.4	120,450
Mixed paper	3.7	101,287.5
Metals	1.6	43,800
Aluminum	0.2	5,475
Cloth	3.4	93,075
Glass	2.4	65,700
Wood	1.7	46,537.5
Tire	0.7	19,162.5
Leather	0.6	16,425
Rubber	1.3	35,587.5
Special waste	1.6	43,800
Total	100	2,740,238

Due to the increasing population and industrial activities in Tehran, which increases the amount of waste and environmental pollution in this city, the aim of this study is provide optimal waste management system in Tehran, by using LCA.

Materials and Models

To investigate the waste management system in Tehran and providing optimum system, life cycle assessment model was used. LCA models were selected. Then 3 scenarios were identified. The model was run for the selected scenario. According to the output of models and effects, an option that has the least environmental impact, was selected as the optimal scenario for the city of Tehran.

Model Selection

In order to perform a study of these models and their applicability for the LCA of waste, two criteria were set up to choose the models for comparison. These criteria were:

- The ability to model the environmental performance of a complete waste management system from waste collection to final disposal, including links between a potentially variable

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waste composition and emissions into the environment.

• The ability to model process-related emissions (dioxin formation in an incinerator) and waste-related emissions (mercury in the input waste released through the stack).

Based on these criteria, nine models were selected: EASEWASTE, EPIC/CSR, IWM2, LCA-IWM, MSW-DST, ORWARE, SSWMSS, WISARD and WRATE.

A number of other models fulfilled the criteria, but were not supported or information was too scarce. Finally IWM and WRATE were selected for this study.

Proposed scenarios

Table 2 offers the proposed scenarios in this paper for Tehran city. Three Scenarios were identified regarding the quality and quantity of waste and waste management system facilities in Tehran. The proposed processing models for Tehran waste management system were presented according to available capabilities, features, quality and quantity of waste.

- First Scenario: current situation scenario

This scenario is based on the current system of waste management in Tehran in 2013. The percentage assigned to each of the processing processes in this scenario is shown in Table 2.

- Second Scenario: maximum scenario

Based on the analysis carried out Tehran's wastes had about 70% -75% organic materials that can be composted (wet waste), the 20% - 25% dry matter that can be recycled and 5% - 10% other waste.[12] According to this analysis the second scenario was defined in order to make maximum use of the capabilities of waste in Tehran and assuming the use of these capabilities. Percentage assigned to each of the processing processes in this scenario is shown in Table 2.

- Third Scenario: optimal scenario according to Tehran circumstance

This scenario was selected due to the quality and quantity of waste, available facilities to the Tehran municipality and the experience of successful Metropolis like Tehran and Tehran integrated solid waste management plan. Percentage assigned to each of the processing processes in this scenario is shown in Table 2.

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 scenario	15	5	-	80	5	1		86
Second scenario	70	20	-	10	5	٠	٠	15
Third scenario	55	10	5	30	10	٠	٠	40

***** Energy from Waste

Model Selection

- IWM, as an environmental life cycle inventory, models an Excel 5.0™ model and uses a Visual Basic Graphical interface.

The environmental analysis model gives municipalities a broad view over the environmental effects of waste management decisions and indicates strategies that can potentially improve the environmental performance of the waste management system.

The system boundary for the environmental analysis model is represented in Figure 5. The model studies the environmental burdens related to the waste management from the point at which a material is discarded into the waste stream to the point at which it is either converted into a useful material or disposed.

This model calculates the consumed or produced energy as well as emissions to air, water, and land caused by different waste management strategies. Table 3 shows the specific indicator parameters estimated and the environmental effects related to these parameters.

The model consists of 10 main input screens (Input Screens A to J), as follows: [18]

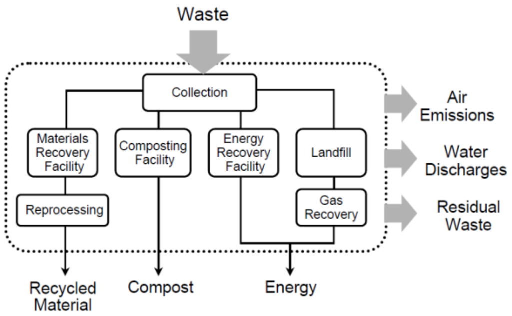

Figure 5: System boundary [18]

Table 3: Indicator parameter

Energy	Resource depletetion		
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 Compounds	Health risk	**Demand (BOD)**	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		

Input Screen A: Quantity and Composition of Waste

Input Screen B: Waste Flow

Input Screen C: Waste Collection, Transfer and Transportation

Input Screen D: Electric Grid Selection

Input Screen E: Recycling

Input Screen F: Materials Recovery Facility

Input Screen G: Composting

Input Screen H: Land Application

Input Screen I: Energy from Waste

Input Screen J: Landfilling

Waste and Resource Assessment Tool for the Environment (WRATE)

WRATE is a tool for evaluating the environmental aspects of waste management activities during their whole life. In developing WRATE, the goal was to develop a scientifically and technically valid life cycle tool to assess, as accurately as possible, the environmental costs and benefits of integrated waste management systems for MSW.

The aim was to produce a decision-support tool that could be used by non-LCA experts to compare options (scenarios) for integrated waste

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management systems. The tool was developed in conjunction with ISO standards on LCA. The scope of WRATE is to provide a tool to calculate a life cycle inventory and life cycle impacts for alternative integrated waste management systems for the management of MSW. WRATE manages information from different databases (Figure 6). Table 4 showed the summaries the system boundaries of WRATE.

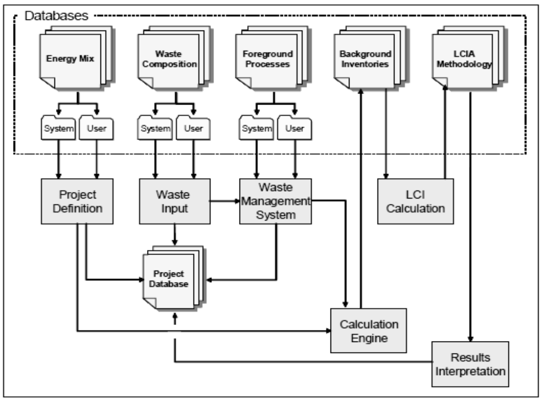

Figure 6: WRATE conceptual model [19]

Table 4: WRATE's system boundaries [19]

NO.	DESCRIBTION
1	Inputs (waste): the point where the waste leaves the household.
2	Inputs: the extraction of fuel resources for operating the processes.
3	Inputs (Materials): the extraction of virgin and secondary materials for use in waste management facilities, waste containers and transport.
4	Outputs (Energy): the electric power or heat leaving and energy-from-waste (EFW) facility, or resulting from gas recovery from landfills and anaerobic digestion facilities, etc.
5	Outputs (Recovered Materials): exiting from all processes.
6	Outputs (Compost): exiting from biological treatment plant.
7	Output (Air Emissions): transport exhaust emissions, stacks of thermal treatment plant (i.e. after emissions controls), landfill gas flares and recovery, stacks of power stations (for electricity generation), landfill lining/cap, biological treatment (post-abatement if appropriate) and recycling facilities.
8	Outputs (Water Emissions): outlet of biological treatment plant, thermal treatment plant or power stations (electricity), recycling facilities.
9	Outputs (Residual Solid Waste): content of landfill at end of biologically active period.

WRATE contains a number of default Impact Assessment Models databases including:

- Problem oriented approach (CML 1999);
- Damage Approach EPS (Steen 1999);
- Ecoindicator 99
- Impact 2002+ (Midpoint)
- Impact 2002+ (Endpoint)

Results

In the second phase of the LCA inventories and outputs from waste management to the environment was calculated. In the third phase of it the impact of the emissions on the environment in 6 groups (global warming potential, acidification potential, potential of Eutrophication, Eco toxicity, the potential for human toxicity, Resource depletion) were identified.

Implementation IWM model for proposed scenarios

With the implementation of the first scenario greenhouse gas emissions with 5,500,000 tones will be higher than other scenario. Due to the fact that global warming is already important, the amount of greenhouse gas emissions is an important factor in the selection of waste management system. Then, smog emission with 21,000 tons has the highest effect on environment. Acid gases by 3,136 tons are in the next. Residual waste is approximately 2,300,000 tons, which require much space for disposal.

By performing the second scenario produced 1,959,690 tons greenhouse gas emissions, 1,400 tons of acid gases and 7,479 tons smog. Residual Waste was approximately 888,166 tons. In compared to the first scenario by conducting the second scenario, the amount of emissions was decreased 64%. With the implementation of the third scenario greenhouse gas emissions compared to other emissions was high. But with the implementation of this scenario greenhouse gas emissions reduced than other scenarios. 1,560,000 tons of greenhouse gas emissions, 1,400 tons acid gases and 7,179 tons smog was produced. Residual waste was approximately 675,611 tons. In compared to the first scenario, the amount of emissions was decreased 72%.

Implementation WRATE model for proposed scenarios (The third Phase of LCA)

The life cycle assessment third phase was calculated by WRATE model for proposed scenarios. In the third phase of the life cycle assessment the impact of the emissions on the environment in 6 groups (global warming potential, acidification potential, potential of Eutrophication, Eco toxicity, the potential for human toxicity, Resource depletion) were identified with normalize data. Normalization helps to provide a better understanding and context for the relative magnitude between different environmental impacts by converting them to a common unit. Typically this common unit is the number of 'average' people that would cause the same impact over the course of a year. WRATE uses Figures for the average European person for this normalization.

Based on the Table 5 with the implementation of the first scenario resource depletion and eco toxicity were the highest. Perhaps the most important cause of this effect is the composition and materials in Tehran's waste. By increasing the volume of material going into landfill, the volume of leachate was increased that due to the toxicity of the ecosystem.

The life cycle assessment third phase results were obtained by using WRATE model showed that by conducted the second scenario compared to first scenario rate of resource depletion, toxicity in ecosystem, acid rain, global Warming, health and eutrophication potential was reduced 32%, 29.6%, 25.4%, 44.7%, 27.4% and 28.8%, respectively (Table 5).

By conducted the third scenario compared to first scenario rate of resource depletion, toxicity in ecosystem, acid rain, global Warming, health and Eutrophication Potential was reduced 89.1%, 54%, 88.9%, 85.9%, 64.5% and 89.3%, respectively (Table 5).

In compared to second scenario by conducted the third scenario rate of resource depletion, toxicity in ecosystem, acid rain, global Warming, health and eutrophication potential was decreased 84%, 34.6%, 85.1%, 74.5%, 51% and 84.9%, respectively. Thus, the third scenario has the lowest environmental impact in chosen six impact groups by the WRATE model in the third phase of LCA.

Table 5: Impact Assessment for Scenarios

Impact	Normalized data for scenario 1 (Eur. Person. Eq)	Normalized data for scenario 2 (Eur. Person. Eq)	Normalized data for scenario 3 (Eur. Person. Eq)
Glob warm	500	276.3	70.32
Acid rain	528.9	393.6	58.6
Eutroph'n	211.6	150.6	22.6
Aqua ecotoxcity	976.6	687	449.1
Health	251	182.2	89.1
Resources	1838.6	1250.8	200.1

In compared to first scenario by conducted the second and third scenarios, the amount of emissions was decreased 64% and 72%, respectively.

The results of the third phase of the implementation of 3 scenarios showed, 50 to 89 percent reduction in the effect will be decided (Figure 7).

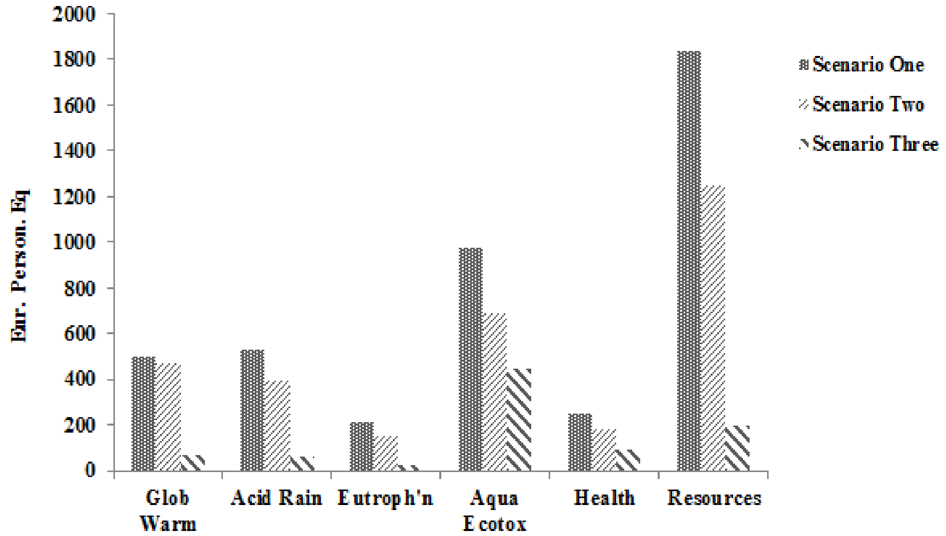

Figure 7: Normalize impact assessment of the implementation of the proposed scenarios by WRATE

According to the results and outputs of selected models in the evaluation of alternative scenarios for waste management in Tehran, the third scenario has the lowest emissions in the second phase of the LCA by IWM model and the lowest environmental impact in six groups selected by WRATE model in third phase of the LCA. The third scenario based on the study is a proposed option for waste management in Tehran, according to current facilities and the quality and quantity of waste was selected. By performing this scenario will significantly reduce the effects of degradation compared to other sources. Due to the increasing population in Tehran, the need for resources to survive is necessary. So, by using of resources, regardless of the population growth trend, the future certainly will be faced with a reduction in resource consumption.[12]

Discussion

Waste management in Iran is one of the main issues of municipalities across the country and imposes significant costs on urban management. Population growth and development of economic activities, especially industry, commerce, etc., cause waste and chemical-physical changes to increase, so existing waste collection and disposal programs will not meet the needs of cities. The current waste management system in Tehran has not been responsive and has created many problems for the citizens. The current waste management system fails for the following reasons:

- System malfunction
- Not paying attention to the elements required and supporting the municipal waste management system
- Non-separation of waste from the source
- No reduction of waste at production stage

Therefore, a system should be chosen that use the most of the available waste facilities and has the least impact on the environment.

After analyzing the waste management system in Tehran, data collection and information on the quantity and quality of waste in Tehran were determined. Currently Tehran waste management system consists of waste production, collection and transportation, transfer stations, municipal waste disposal (recycling, compost, landfill). Considering

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the quantity and quality of Tehran waste and available facilities, three scenarios were identified.

BAU Scenario: Continuation of existing status (15% Compost, 5% Recycling, 80% Sanitation)

Second Scenario: 70% compost, 20% recycling, 10% sanitation

Optimal scenario: 55% compost, 10% recycling, 5% energy recycling, 30% sanitation

Life cycle assessment tools were used to compare scenarios and select the optimal system. Input data were prepared for the selected models and each model was run for three scenarios. Finally, the amount of impacts on the environment was compared in the following six groups and the scenario with the least impact on the environment was identified.

- Global warming potential
- Acidification potential
- Potential of eutrophication
- Eco toxicity
- Potential for human toxicity
- Resource depletion

Based on the results obtained from the models used, which are discussed in more detail in results, the effect of environmental optimization was reduced in the six mentioned groups by implementing the optimal scenario.

The model results show that by implementing the optimal scenario the effects are reduced by one quarter. Execution of this scenario will reduce the amount of resource degradation compared to other effects. Given the increasing population in Tehran, resources are needed to sustain survival. If the use of resources is increasing regardless of population growth, the next generation will inevitably face a decline in consumption.

Applying the optimum scenario to Tehran Waste Management System with recycling of materials and energy can help save it for the next generation.

In addition, by reducing greenhouse gas emissions, global warming can be reduced. Since global warming is now considered one of the major environmental challenges, efforts to reduce greenhouse gas emissions can be an effective step in this challenge. Increasing the population of Tehran has led to increased use of fossil fuels and greenhouse gas emissions, so it is important to pay attention to this factor.

Reducing input waste for landfill requires less land for landfill. Therefore, it reduces both surface and groundwater contamination and the rest of the land can be used for other purposes. The increasing population and the need for material and energy supply as well as the need for housing highlights the importance of the land.

In addition, by increasing the recycling of material and energy and using less energy, economically less costs will be paid which can be used elsewhere.

Regarding the outputs of the models, the optimal scenario is introduced as the best option for Tehran's waste management system. In fact, with the implementation of the optimal waste management system scenario it will have the following features:

- Minimize environmental pollution
- The system with the least waste production
- The system with the least impact on global warming and climate change
- The system with the highest efficiency and lowest cost

The main difference between the present study is that the life cycle tool was used to investigate the whole waste management system in Tehran and all the processing processes in it, which required more time and study.

According to the present research, the following are suggested.

1- Application of optimum scenario as a suitable. Option for waste management in Tehran

In order to achieve the desired results for Tehran waste management system, using the above scenario, the following is suggested.

- Reduction of waste in the source of production

Due to increasing population, decreasing resources and environmental problems, reducing the amount of waste produced at the source of production can be the most effective step in the waste management system. Reducing waste generation while reducing resource depletion also reduces energy waste and reduces costs.

- Cultivation and training of wet and dry waste separation

- Providing facilities for the separation of wet and dry waste by the municipality of Tehran

2- Application of LCA model for other metropolises of Iran (Shiraz, Isfahan, Tabriz ......) and comparing the results with the results of Tehran

This can investigate the impact of environmental, cultural, waste quality and available options on choosing the appropriate model for the waste management system.

3. Given the availability of several LCA models for waste management (MSWDST, EASEWASTE …) that could not be implemented due to the lack of information needed in this study, it is recommended to create the necessary data base to implement these models.

4- Considering the fact that the amount of impact on the environment caused by the waste management system has not been practiced, it is recommended to perform it practically for the waste management system in Tehran and compare its results with the present study.

Conclusion

A life cycle assessment tool was used to obtain the appropriate waste management system in Tehran City.

According to the outputs of the models, the optimal scenario was introduced as the best option for Tehran's waste management system. Model results showed that by applying the optimal scenario the effects are reduced by one quarter.

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Conflict of Interest

No conflict of interest has been stated by the authors.

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