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Municipal Solid Waste Management Using Life Cycle Assessment Approach: Case Study of Maku City, Iran

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Abstract**—**This paper aims to determine the best environmental and economic scenario for Municipal Solid Waste (MSW) management of the Maku city by using Life Cycle Assessment (LCA) approach. The functional elements of this study are collection, transportation, and disposal of MSW in Maku city. Waste composition and density, as two key parameters of MSW, have been determined by field sampling, and then, the other important specifications of MSW like chemical formula, thermal energy and water content were calculated. These data beside other information related to collection and disposal facilities are used as a reliable source of data to assess the environmental impacts of different waste management options, including landfills, composting, recycling and energy recovery. The environmental impact of MSW management options has been investigated in 15 different scenarios by Integrated Waste Management (IWM) software. The photochemical smog, greenhouse gases, acid gases, toxic emissions, and energy consumption of each scenario are measured. Then, the environmental indices of each scenario are specified by weighting these parameters. Economic costs of scenarios have been also compared with each other based on literature. As final result, since the organic materials make more than 80% of the waste, compost can be a suitable method. Although the major part of the remaining 20% of waste can be recycled, due to the high cost of necessary equipment, the landfill option has been suggested. Therefore, the scenario with 80% composting and 20% landfilling is selected as superior environmental and economic scenario. This study shows that, to select a scenario with practical applications, simultaneously environmental and economic aspects of different scenarios must be considered.

Keywords**—**IWM software, life cycle assessment, Maku, municipal solid waste management.

I. Introduction

DUE to the increase of Municipal Solid Waste (MSW) generation, waste management has become an important social and environment problem [1]. The first step in waste management is to determine the quality and quantity of MSW [2], [3]. So, a lot of researches in different regions have been done to identifying waste [4], [5]. After studying the quality and quantity of the waste in each region, we can investigate the different waste disposal options [6], [7], and finally, we can determine a suitable method to dispose MSW in every region [8], [9].

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In some studies, Life Cycle Assessment (LCA) approach is used to assess the environmental effects of MSWM scenarios [10]. In these studies, a list of environmental effects of different scenarios has been compared, and then, the best scenario is selected [11], [12]. But, this scenario may not be suitable in economic aspects [13]. Therefore, environmental and economic aspects of scenarios should be considered simultaneously.

In different cities of Iran, MSW is often disposed in non-standard method, which causes water pollution, public health problems, explosions and land subsidence in landfill [12]. Since providing the data necessary to evaluate of waste and determine the waste management plans at national levels is difficult, this study is limited to the city of Maku. The results of this study can also be used for MSWM in the other cities with similar conditions.

The aim of this study is to use LCA in order to compare different MSWM scenarios and to select a scenario with the lowest environmental effect and economic costs for the city of Maku. For this purpose, qualitative and quantitative analysis of waste of Maku city has been done, and environmental aspects of 15 MSWM scenarios have been compared by using Integrated Waste Management (IWM) software. Then, the appropriate scenario is selected by consideration economic aspects of scenarios.

II. Materials and Methods

A. Study Area

Maku is located in Azerbaijan-e-Gharbi province in northwestern of Iran. Currently, MSW of Maku is managed by municipalities. Separation and recycling of waste is done informally, and in small scale, the remaining MSW goes to an unsanitary landfill by 10 km distance from the city center.

B. MSW Characterization

Quality and quantity of wastes is the most important principle of waste management. In this study, weighing trucks at landfill has been used to quantify the waste. Also, ASTM5231-9 is used as a guide for the sampling and determining waste composition. Density, chemical composition, heating value, and the moisture content of waste is calculated based on waste composition.

C. Life Cycle Assessment (LCA)

LCA is composed of four steps: (1) goal and scope of definition (2) life cycle inventory (3) assessment (4) interpretation.

Goal and scope of definition: The goal is to compare different MSWM scenarios from life cycle perspective. The functional unit of the study is the MSW produced in the city of Maku. The system boundary included transportation, recycling, composting, energy recovery, and landfill (Fig. 1).

The scenarios have been studied in five groups including landfills, landfills and composting, recycling and landfills, recycling and composting and landfills, energy recovery and composting and landfills. In each group, different scenarios have been used to find the optimum ratio between management options (Table I).

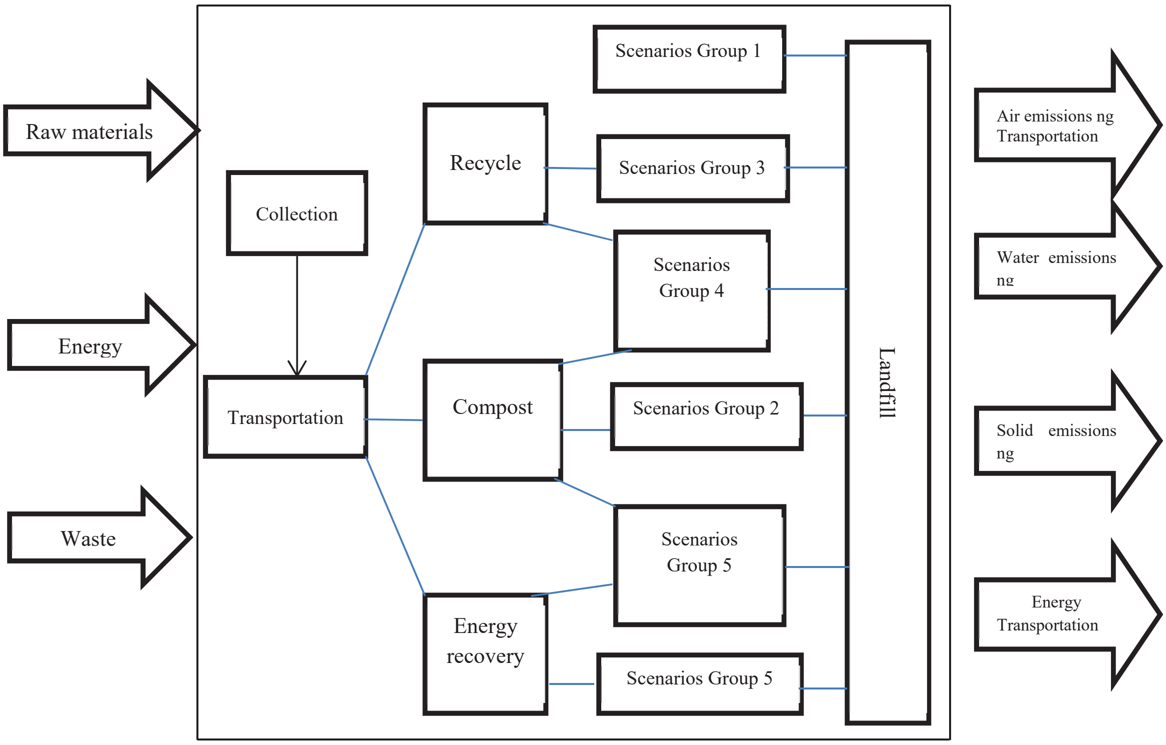

Fig. 1 System boundaries

Landfill: The landfill biogas is released directly into the atmosphere. So, there is no energy recovery at this landfill. Annual rainfall of this city is 303 mm. It was assumed that 80% of leachate from the landfill is collected and transported for off-site treatment and the remaining 20% leaks to aquatic recipients [16]. The energy required for the landfill process is 0.22 liters of diesel fuel, 0.028 m^3 of natural gas, and 0.29 kWh electricity for every tonne. Recycling: After separating paper, glass, plastic and metal, this waste is transferred to recycling factories that are located at landfills site. Electricity consumption for waste separation and bale compression is 0.059 kWh/t [17]. Paper, plastic, and

Life cycle inventory: Required data to assess the life cycle collected from the study of waste characteristics of Maku and the current situation in Maku.

Transportation: In this study, it is assumed that all processes of waste disposal are located in landfill site.

In all scenarios, total distance traveled for the transport of waste to the landfill site is 412 kilometers, so the amount of pollution caused by transport is similar in all scenarios.

Compost: Compost process is considered in string type. The energy required for the composting process is 61 kWh /t [1].

Incineration: The energy recovered is used to electricity generation at the rate of 17% [14]. A typical incinerator consumes 70 kWh energy and generates 200 kg/t ash during the burning process [15]. Metal is recycled with a rate of 17%, 28%, and 5% loss, respectively.

LCA: IWM release 2.0.6 model is used to evaluate the effects of waste management. This software includes several windows about compound and quantity of waste, Transportation, fuel consumption, materials recovery facility, composting, energy, landfill. By this software, the environmental effects of waste management have been evaluated in five classes which include energy consumption, greenhouse gases, acid gases, photochemical smog, toxic emissions.

Interpretation: The extensive data were obtained from model IWM classified according to indices of each class of environmental effects.

TABLE I
MSWM SCENARIO

Scenario code	Different scenario groups				
	1 Landfill	2 Compost and landfill	3 Recycling and landfill	4 Recycling and compost and landfill	5 Energy recovery and compost and landfills
A	Landfill without liner	40% compost, 60% landfill	10% recycling, 90% landfill	25% Recycling, 65% compost, 10% Landfill	30% energy recovery, 70% landfill
B	Landfill with liners	60% compost, 40% landfill	25% recycling, 75% landfills	10% Recycling, 80% compost, 10% Landfill	15% energy recovery, 35% compost, 50% landfill
C	-	80% compost, 20% landfill	-	25% Recycling, 10% compost, 65% Landfill	-
D	-	20% compost, 80% landfill	-	10% Recycling, 10% compost, 80% Landfill	-
E	-	-	-	25% Recycling, 35% compost, 40% landfill	-

TABLE II
SPECIFICATIONS REQUIRED FOR ENVIRONMENTAL ASSESSMENT SCENARIOS

effect class	relative weight of each class	effect class index	parameters listed	characteristics factor
energy consumption	0.88	-	-	-
greenhouse gases	0.89	CO2	CO2	1
			CH4	2
			N2O	320
			CFC11	4000
			CO	2
			TCA	110
acid gases	0.40	SO_2	SOX	1
			NOX	1.07
			HCL	0.88
photochemical smog	0.29	C2H4	VOC	0.6
			CO	0.3
			CH4	0.007
			NOX	0.028
			PM	0.07
toxic emissions	0.13	CO2	Lead in the air	0.047
			Mercury in the air	0.06
			Cadmium in the air	0.000015
			Dioxins in the air	0.0105
			Lead in water	0.12
			Mercury in water	0.0014
			Cadmium in water	0.23
			Dioxins in water	0.108
			Biological oxygen demand	0.0106

For this purpose, the characteristics equation is used for the calculation of indices classes:

$$Ii = \sum Cij * Xj \quad (1)$$

In this equation Ii, Cij, Xj are the effect class index, characteristics factor, the amount of material, respectively. In this way, total environmental impact of each class will be calculated by their equivalent units. In Table II, the effect classes, index of each class, parameters listed of each class and characteristics factors are presented. Also, the relative weight of each class is indicated to determine the relative importance of each class.

By this way environmental index of each scenario has identified. The scenario with smaller environmental index has less environmental effect. But, for choosing the best scenario, it is necessary to consider economic aspects of each scenario. The cost of each option is calculated by studying other research. According to this, the approximate cost to landfills, composting, recycling and energy recovery are 22, 24, 33, 71 dollars per kg waste, respectively. So, the economic cost of each scenario can be calculated. Finally, the best environmental and economic scenario is selected by using the eco-efficiency.

III. Results and Discussion

A. Waste Specification

The average amount of waste is 40 t/day in Maku. Fig. 2 shows the components of the waste of Maku. According to this figure, putrescible wastes are 68%, Dry waste are about 25% and non-perishable and non-recyclable waste are 7% that mostly dumped in landfills. Chemical composition of waste is $C_{531} H_{823} O_{285} N_{16}$ S. heating value of waste is 4167 kJ/kg and its moisture content is 42%. The density of waste is 138 kg /m^3.

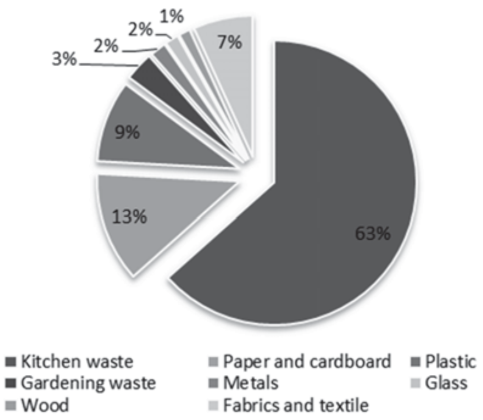

Fig. 2 Maku MSW composition

B. Environmental Impact

Fig. 3 shows the energy consumption of the scenario. The 5A and 5B scenarios, because of incineration of waste to energy recovery, show the lowest energy consumption. The 2C and 4B scenarios with 80% compost have the highest energy consumption.

Fig. 4 shows the greenhouse gases of the scenarios. The largest amount of greenhouse gases is produced in the 1A and 3A and 3B scenarios because, in these scenarios, more than 75% of waste has dumped in a landfill without any liner. The 2C and 4B scenarios with 80% compost produced least amount of greenhouse gases.

Fig. 5 shows the acid gases of the scenarios. The 5A and 5B scenarios, due to the waste burning process, released the greatest amount of acid gases. However, in the other scenarios, there are not major differences for this parameter. The 1A and 1B and 3A scenarios released the least amount of acid gases because, in these scenarios, more than 90% of waste has dumped in landfill and landfill option released the least amount of acid gases.

Fig. 6 shows the photochemical smog of the scenarios. The 1A and 1B and 3A and 3B scenarios show that more than 75% of the waste dumped in landfill produced the maximum amount of photochemical smog. The 4B and 2C scenarios indicate that 80% compost produced least amount of photochemical smog.

Fig. 7 shows the photochemical smog of the scenarios. The 1A and 3A scenarios demonstrate that more than 90% of the waste dumped into landfill without liner produced the maximum amount of toxic emissions. The 1B scenario, due to the use of landfill with liner, has reduced the toxic emissions significantly. The 4B and 2C scenarios imply that 80% in composting process produced the least amount of toxic emissions.

Environmental index of each scenario has been identified by weighting the five parameters (Fig. 8). Scenarios 1B, 2C, 3B, 2B, 5B have been selected as the best environmental scenarios in each group. Their environmental index is 275, 168, 658, 168 and 354, respectively. So, 2C and 4B scenarios have the least amount of environmental effect.

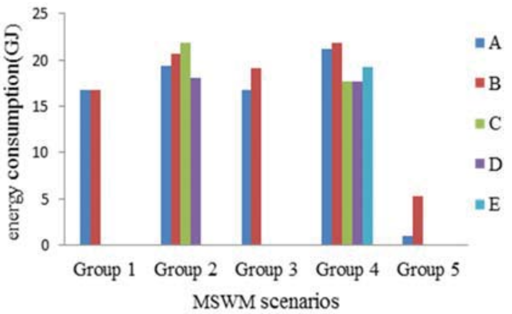

Fig. 3 Energy consumption of MSWM scenarios

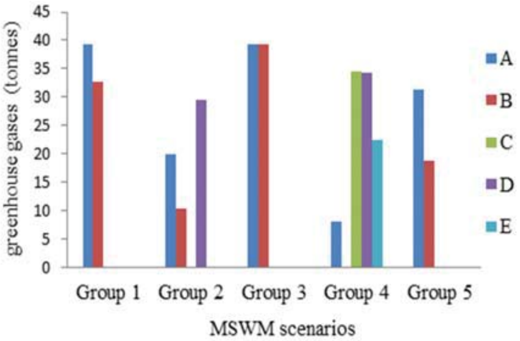

Fig. 4 Greenhouse gases of MSWM scenarios

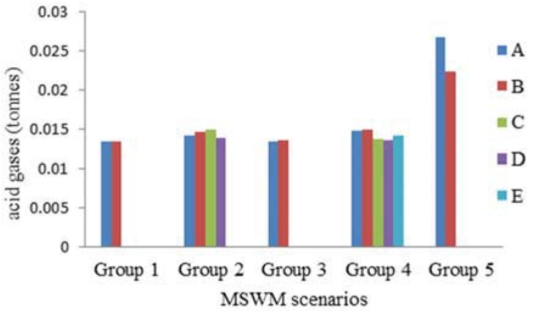

Fig. 5 Acid gases of MSWM scenarios

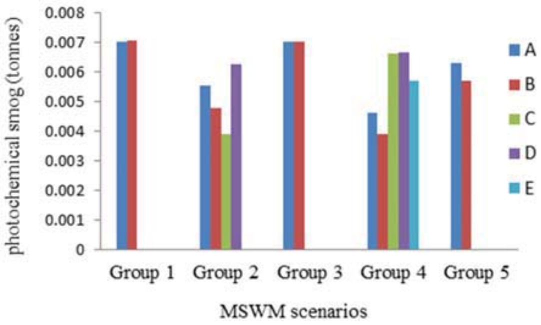

Fig. 6 Photochemical smog of MSWM scenarios

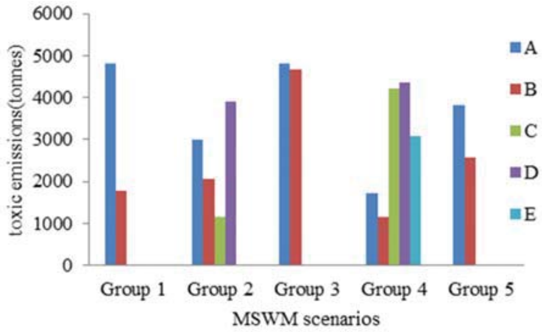

Fig. 7 Toxic emissions of MSWM scenarios

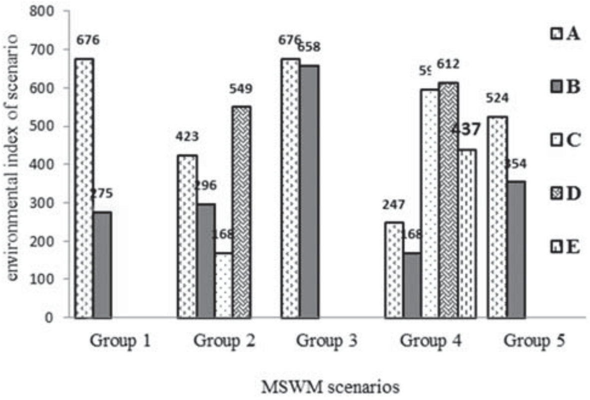

Fig. 8 Environmental index of MSWM scenarios

C. Economic Effects

To choose the best waste management scenario, the environmental and the economic aspects of each scenario must be evaluated together. Therefore, the economic cost of the five scenarios that have been identified in the previous step is calculated. Cost of 1B, 2C, 3B, 4B, 5B scenarios are 880000, 944000, 990000, 988000, 962000 dollars, respectively. The 1B and 5B scenarios are the cheapest and most expensive scenario, respectively.

We compare the economic and environmental effects of the scenarios simultaneously: the 2C and 4B scenarios have been selected as the best environmental scenario, while 1B scenario has been selected as the best economic. As seen in eco-efficiency diagram (Fig. 9), the 2C scenario is the best scenario in economic and environmental aspect.

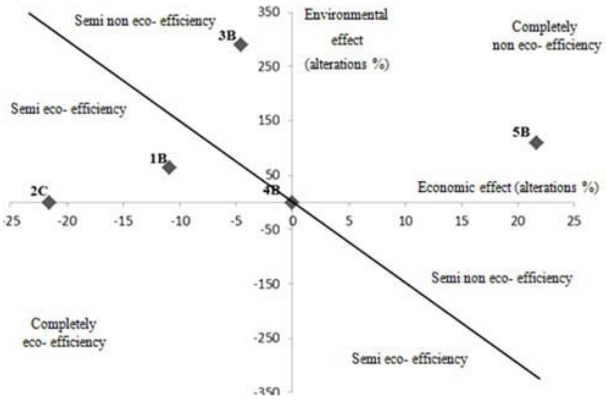

Fig. 9 Eco-efficiency diagram of environmental top scenarios

IV. Discussion

The aim of this research is finding the best scenario to MSWM in Maku by using the LCA. Investigation of the environmental effects of scenarios by using the IWM has shown that 2C and 4B scenarios have produced the least amount of greenhouse gases and photochemical smog and toxic emissions. Also, these scenarios have not shown a significant difference with the other scenarios (except landfills) in acid gas emissions and energy consumption. Totally, the 2C and 4B scenario are the best environmental scenarios to MSWM in Maku. The 5A scenario, due to energy recovery, has the lowest energy consumption, but the greatest amount of acid gases has produced in this scenario. In this study, the environmental effect of scenarios is considered [12], and the economic aspects of scenarios have also been investigated too. As observed, energy recovery is the most expensive, and landfill is the cheapest management options. Therefore, the 2C scenario in economic aspect is a suitable scenario to this city. 80% of solid waste of Maku is organic material and it has more than 40% moisture. Composting and landfills together have been chosen as the best disposal. Thus, it is necessary to implement this scenario by teaching people to separate perishable waste at the source. As has been shown in similar studies, LCA is a powerful tool to improve MSWM. City authorities can use this method to compare waste management scenarios each other [1], [12]. This method enables to investigate more scenarios, or doing economic analysis in more details. It can even investigate social aspects of scenarios in additional studies.

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