Environmental assessment of different municipal waste management methods with approach to life cycle assessment (Case study: Yazd, Iran)

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Keywords

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Abstract

Today, the production of various types of solid waste and the occurrence of related social, economic and environmental inconsistencies have faced the management of municipal services and waste with many problems in the areas of collection, transportation, processing and disposal of such waste. The purpose of this study is to assess the life cycle of the current management system in Yazd, Iran from the environmental and economic point of view and to determine the priority in the decision-making to improve waste management. There are many tools for assessing the environmental impacts and determining the priority in the decision-making, but one of the widely used methods is life cycle assessment (LCA). In this study, three different scenarios of waste management were defined. The first scenario is the unsanitary separation and landfill (according to current situation in Yazd), the second scenario is the separation, composting and anaerobic digestion, waste incineration plant, disposal of residues and ash in sanitary landfill, and the third scenario is the separation, composting and anaerobic digestion, and sanitary landfill. Then, using the Integrated Waste Management (IWM-2) software, the inventory of the environmental and economic burden of each scenario was analyzed and presented. In general, the assessment of Yazd municipal waste life cycle was performed to achieve the optimal scenario that has less environmental and economic burden. The third scenario was selected as the best management option in this respect.

1. Introduction

Over the last decades, urban expansion and global population growth, particularly in developing countries, have caused several challenges for the environment and public health [1; 2]. The developing countries in Asia are facing the challenges of an annual growth of urban population (approximately 4%) [3]. The growth of urban population results in rising demands of food consumption, economic development, urban expansion and industrial development, which are the most important factors of increased municipal solid waste (MSW) production in the Asian countries [4]. Poor management system in solid waste leads unpleasant consequences on the standard of human life [5]. It is generally accepted that the municipal solid waste management (MSWM) is one of the significant environmental problems of sustainable development. Currently, uncontrolled landfills are the major option for disposal of wastes in developing countries [6]. Waste open dumping and landfilling are the main operation of MSWM in developing Asian countries, while incineration is the most common alternative in developed countries of Asia [7].

The foundation of MSWM system should have the potential to expand with growth of population and development of economic. Poor waste management systems need developments in their structures for collection, transportation, and disposal [8]. Non-scientific MSWM can make numerous environmental problems, such as climate change, human health risks, ecosystem destruction and natural resource depletion (soil, air and water) [9]. Hence, various decision support models have been designed to help decision makers in the planning of SWM approaches [10]. Life Cycle Assessment (LCA) strategies are one of the most widely used techniques to evaluate solid waste systems [11]. LCA is a method that has the potential to compare the environmental effects of various MSWM strategies to identify the most environmentally, economically and socially appropriate management option [12]. In general, LCA is carried out in connection

with material flow analysis, intending to analyze MSWM systems relying on actual MSW flows [2].

Effective MSWM requires new waste management strategies and procedures to deal with the problems of MSWM. LCA is used to assess, distinguish and recognize the potential adverse effects of various MSWM practices. The LCA approach is declared to be promising for solution of problems [13]. Over recent years, LCA method has been considered as a crucial tool to assist systematic and accurate decision-making on waste management systems [14]. LCA methods are able to draw a comparison among various scenarios of waste management systems performance from top to bottom to evaluate the environmental implications and consumption of resources. The LCA in MSW management system is strongly reliant on local conditions including the composition of waste and the energy system [9]. Furthermore, composition of MSW has a great impact on the waste-management system performance [15].

With regard to sustainability, LCA is addressed as the practical analysis of a product's life cycle. By applying LCA, impacts of the service or product on the environment from beginning to ending can be assessed [16]. LCA method is capable of aggregate environmental implications of all inputs and outputs of a system. The publicity of LCA for assessing the MSWM systems has been demonstrated in many published studies [17]. Besides, over the last decades, many organizations, including the International Organization of Standards (ISO) have assisted to the development of the LCA methodology. Referring to ISO 14040:2006 standard, this method includes four phases such as: (1) goal and scope definition (2) life cycle inventory (LCI) (3) life cycle impact assessment (LCIA) and (4) interpretation [18]. According to Hou et al [19], LCA is the most appropriate way for applying in MSW management in consideration of some parameters including geographic location, unwanted properties, energy sources and access of some discarding options.

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LCA can be exhibited as a manner of assessing the environmental implications from the raw material removing by applying some factors such as processing, production, distribution, use, preservation and disposal, or recycling of materials. Modelers apply this approach to assess their products [17]. This survey assesses the effects of various potential MSWM scenarios in Yazd city, applying the LCA methodology. Three MSWM scenarios will comprise the current MSWM system. The review of the literature shows that no study has yet been conducted to assess the life cycle of the waste management system in Yazd. Therefore, this study aims to compare the environmental impacts of waste processing and disposal systems in Yazd by the LCA method and also select the best scenario that has the least impacts. The results of this study can assist the decision-makers to assess approaches for the treatment of MSW with regard to an environmental effect.

2. Material and Methods

2.1. Study area

Yazd is located in a dry and vast valley between Shirkuh and Khoranagh mountains at 15° 53' to 40° 54' east longitude and 46° 31' to 15° 32' north latitude. Located almost in the center of Iran, Yazd has an arid and desert climate with very limited rainfall, high evaporation and high daily temperature. This city is one of the important cities in Iran in terms of trade industry, antiquities and historical monuments that have well developed in recent decades. During this development, however, less attention has been paid to the environmental aspects. The growth of industries, increased number of vehicles, lack of improvement of traffic situation, immigrant acceptance and, on the other hand, existence of natural factors that aggravate air pollution and the special geographical and climate conditions are among the main reasons for the air pollution in this city. According to the general census of population and housing in 2016, the population of Yazd is totally 652474 who live in 168528 households, among which 51.01% are men and 48.99% are women. In the Yazd county, 93.14% of people are the urban population and 6.86% are the rural population, and the household size is 3.36 [20].

Figure. 1 Study area

2.2. Current waste status in Yazd

Yazd consists of five residential areas where the produced waste is transported to three facilities: landfill, recycling and composting plant (inactive). Also, according to the statistics obtained from the Yazd Waste Management Organization (WMO), the waste collected from the city is mostly sent to the landfill, and only 5% of the recycled waste is separated at the source and destination. The average waste production in Yazd is 393 tons per day and, on average, 6300 kg of recyclable dry waste is collected daily from the residential units, which includes only 2% of the total daily produced waste. Recently, the WMO has adopted various educational methods for the citizens, including going to the residential areas and face-to-face training, distribution of brochures, teaching in primary schools, holding

symbolic recycling ceremonies, etc., to increase the participation of citizens in the project of separation from the source, which has been somewhat successful. The landfill of Yazd is located in the northeast of the city with coordinates of 31° 55' north and 54° 25' east in the miscellaneous lands. This place has been used for a long time. Since the lack of methane and leachate collection and treatment system in this landfill and also the landfill construction and preparation phase has not been done based on engineering principles, this landfill can be considered a non-engineering unsanitary landfill. The composting plant is located on a 30-hectare plot of land, 7 km from the Yazd area near the current landfill for household and hospital waste. The nominal production tonnage of the plant is 250 tons per day, the number of required employees is 35, the amount of used electricity is 400 kW, and the amount of consumed fuel is 200 liters of gas oil per day. The types of products are large and soft fertilizers and it has a daily capacity of 250 tons of waste to prepare compost to the plant, which 25 to 35% of them can be turned into compost. This facility it is not currently active [21].

2.3. Method

In this study, the life cycle of Yazd waste management system was assessed according to the tonnage of waste which introduced into each system and also, the amount of output, energy and used fuel in each system. To compare the impacts of each of the waste management methods in Yazd, some scenarios were defined and then, the inventory of environmental and economic impacts of each of the scenarios was analyzed by the Integrated Waste Management (IWM-2) model. This software was used for the inventory phase of this study, which is the most difficult phase of life cycle assessment. In the life cycle impact assessment phase, the results of the life cycle inventory were converted into physical units so as to yield the management methods.

Figure. 2 Structure of research

Goals and scope: The purpose of this study is to environmentally assess the waste management method in Yazd and to provide the best management method for the waste disposal using the defined scenarios for improving the environmental and economic aspects of waste management. In this regard, in most of the presented scenarios, the phases of collection, transportation, separation from the source, processing and disposal of waste, such as recycling, waste incineration for energy recovery, anaerobic digestion, composting and engineering landfill with gas and leachate recovery were examined and assessed. The boundaries of the system begin from the residential areas where the waste is collected and transported to the landfill, then composting site for the production of organic fertilizers, and also transfer to the recycling companies for paper, cardboard, metals and plastics.

Figure 3. Interaction between life cycle assessment processes

2.4. Inventory analysis

In order to compare the impacts of each of the waste management methods in Yazd, three scenarios were defined and then, the inventory of the economic and environmental impacts of each scenario was analyzed by the IWM-2 model. To assess the life cycle impacts, the results obtained from the life cycle inventory are converted into physical units to obtain management methods. So far, no common standard methodology that is universally accepted has been proposed to assess the impacts of the life cycle. This phase includes the following steps:

1. Classify and characterize the environmental impacts obtained from the inventory phase
2. Weight each category according to the relevant formula and obtain the ecological indicator of each environmental impact

2.5. Life cycle impact assessment

In this study, the metabolic equivalent of task (MET) classification and weighting were used for the assessment of the impacts. In this method, the impact categories of environmental indicators are: global warming impacts (greenhouse gases), acidification and acid rain (acid gases), reduction of non-renewable resources, photochemical oxidation and formation of photochemical smog, and toxic impacts on humans (Table 1). In the classification phase, the stresses analyzed in the inventory phase were classified according to the impact categories defined in the MET method. Table 1 presents the categories and the equivalent unit in each category, and Table 2 presents the allocation of inventory values to each category in the present study.

Table 1. Impact categories considered in present study and equivalent unit in each category [22].

Impact categories	Equivalent unit
Energy consumption	Gj
Greenhouse gases	CO ₂ (Kg)
Acid gases	SO ₂ (Kg)
Photochemical smog	C ₂ H ₄ (Kg)
Toxic outputs	1-4 DioxinCdBOD (Kg)

In the next step, the inventory stresses were calculated using the basic characterization formula and the category indicator of each work impact was obtained. The purpose of characterization in the LCA is to estimate the potential impact of different stresses on the impact and to summarize different values in a number in each category. According to ISO 14043, the characterization must be based on scientific analysis and clear environmental processes. For assessing the life cycle, the basic formula for characterizing and calculating the impact category indicators is expressed as follows:

$$I_i = \sum C_{ij} * X_j \quad \text{Eq (1)}$$

where I_i is the impact category indicator, C_{ij} is the characterization factor, and X_j is the amount of material j . In this way, at the end of the characterization for each impact category, the indicator is calculated, which indicates the set of environmental burden impacts created in the mentioned category. This study used the characterization factors developed by the Center for Environmental Sciences at the University of Leiden in the Netherlands for the whole world. The characterization factors of different materials in each of the impact categories are shown in Tables 3 to 6, where M_i is the amount of produced inventory material.

Table 2. Components allocated in present study and allocation of inventory values in each category [22].

Impact categories	Allocated components
Energy consumption	Energy consumption (GJ)
Greenhouse gases	CO ₂ - NO _x - CH ₄
Acid gases	NO _x - SO _x - HCL
Photochemical smog	PM- NO _x - VOCs
Toxic outputs	Pb _{Air} , Hg _{Air} , Cd _{Air} , Dioxin _{Air} Pb _{water} , Hg _{water} , Cd _{water} , Dioxin _{water} , BOD

Table 3. Characterization factors for impact category of greenhouse gases [23].

Substances	Characterization factors
CO ₂	1
CH ₄	21
N ₂ O	320
CFC ₁₁	4000
CO	2
TCA	110
IGGP = $\sum GGP_i * M_i$	

Table 4. Characterization factors for impact category of acid gases [24].

Substances	Characterization factors
SO _x	1
NO _x	1.07
HCL	0.88
IGGP = $\sum GGP_i * M_i$	

Table 5. Characterization factors for impact category of photochemical smog [25].

Substances	Characterization factors
VOC	0.6
CO	0.3
CH ₄	0.007
NO _x	0.028
PM	0.07
ISPP = $\sum SPPI_i * M_i$	

In the following, according to the Eq (1), the values were multiplied by the characterization factors (C_{ij}) so that in each of the impact categories, the inventory values were calculated based on the equivalent unit. As a result, the environmental burden of each category was calculated based on the equivalent unit (SO₂, CO₂, GL). In this way, at the end of the characterization phase for each impact category, the category indicator is calculated, which shows the set of environmental burden impacts created in the mentioned categories. In order to combine the data representing different environmental categories, these categories are identified by the relative importance. For example, the greenhouse gas impact category should be compared to the acid gas category, and based on the scientific modeling; the relative weight of each category should be determined [23]. In this study, the relative weights were calculated based on the MET modeling method presented in Table 7.

Table 6. Characterization factors for impact category of toxic output [23].

Substances	Characterization factors
Pb _{Air}	34.72
Hg _{Air}	120.5
Cd _{Air}	222.62
Dioxin _{Air}	7.6
Pb _{water}	3.26
Hg _{water}	28.12
Cd _{water}	6.25
Dioxin _{water}	2.93
BOD	11.82
ITEP = $\sum TEPI * Mi$	

Table 7. Relative weights of study impact categories in MET modeling method [25].

Impact categories	Weight
Energy consumption	0.88
Greenhouse gases	0.89
Acid gases	0.40
Photochemical smog	0.29
Toxic outputs	0.13

Equation (2) is also used to calculate the total impact value from a system. The obtained indicator is a quantitative criterion for comparing the two systems. The smaller the I (ecological) indicator, the lower the environmental burden of the system [26].

$$I = \sum Ni = 1WiIn \quad \text{Eq (2)}$$

Where I is a quantitative criterion for comparing the two systems, Wi is the relative weight of the impact categories, and In is the impact category indicator. Thus, an ecological indicator was obtained for each of the scenarios. The ecological indicator was considered as a quantitative criterion for comparing the environmental burden of each scenario, and finally, each scenario with a low score has less environmental burden. The following figure (4) summarizes the steps for assessing the life cycle impacts.

Figure 4. Phases of life cycle impact assessment [25]

In addition to the environmental assessment of scenarios by determining the indicators such as the price of each kilogram of recycled materials, price of each kilowatt of consumed electricity and also price of each kilowatt of produced electricity, selling price of each kilogram of produced compost and costs of operation and management of each of the waste treatment and management methods (due to the lack of information on the annual cost of each of the waste management methods in Iran, the contractual data of the model were used which calculates and shows the management and operation costs of each method by the tonnage of managed waste), the economic impacts of each scenario were calculated and estimated using the IWM-2 model.

2.6. Scenarios

First scenario

The total waste introduced into this scenario is 143666 tons (work unit), which about 5% is separated and recycled, and the rest of the waste, which is 95%, is disposed of in a non-engineering and unsanitary manner to the Yazd landfill and is covered with soil on a daily basis.

Second scenario

In the second scenario, based on the potential of the current waste in Yazd, it is modeled. The total waste introduced into this scenario is 143666 tons, which 25% is recyclable, 60% can be turned into compost fertilizer, 10% is used for feeding the waste incineration plants for the electricity generation in Yazd, and about 5% is the residual waste rejected from the composting and waste incineration plant which can be considered for the disposal in the sanitary landfill.

In this scenario, the waste incineration system was selected to examine the environmental and economic impacts before any investment and to compare with other scenarios. In addition to using the waste incineration system, this scenario also used an anaerobic digestion system (biogas) to treat organic waste and generate electricity. It was assumed that anaerobic digestion and waste incineration are present in Yazd's management system, and that the produced ash from incineration plants and the non-degradable and unsuitable waste for the incineration plants in the Yazd landfill, which has a methane and leachate collection and control system with 90% efficiency, are transported and disposed to the sanitary landfill. In this scenario, the waste is delivered to the MRF center after the collection. After the separation and recycling of the recyclable materials from the waste flow, the residual waste is introduced into the composting plant. In this scenario, the composting phase involves the both aerobic and anaerobic (gas production) decomposition of waste, and the energy is recycled from the waste at the plant. The rest of the waste, plus the rejects of the composting plant is introduced into the incineration plant. In this scenario, it was assumed that more than 90% of the leachate and methane gas are collected and used to generate electricity.

Third scenario

The third scenario was modeled on the 15-year horizon considered by the Yazd Waste Management Organization (WMO). The WMO believed that there is an 1% increase in the recycling rate per year with the education and culture building in the field of the separation from the source, reaching the 20% recycling rate, and the rest 60% of the waste, including organic waste, are turned into compost, and about 20% of other non-recyclable and rejected waste from the composting plant is disposed to the sanitary landfill (with gas and leachate control and collection system).

3. Results and discussion

Assessment of life cycle impacts of modeled scenarios of Yazd waste management system

The significance and the potential environmental consequences of a product system throughout its life cycle are understood and evaluated. In order to use the IWM-2 results to make decisions about different waste systems, in addition to the results of the inventory phase, we need the results of the next two steps of life cycle assessment. In the life cycle assessment phase, we examine the results obtained in the inventory analysis phase. For this purpose, we need to define a list of impact categories and the impact characterization factors. Different models are used to calculate the characterization factor of the categories, and in each of the methods, a different weight is given to the analyzed stresses of the inventory phase. Finally, the results of the characterization factors are grouped and weighted.

In the life cycle assessment phase, the results of the life cycle inventory were converted into physical units to yield management methods. To assess the impacts of the life cycle for different modeled scenarios of Yazd waste management, we classified, characterized and weighted the results obtained from the life cycle inventory according to the 5 impact categories, and finally the ecological indicators of the scenario were obtained. The results are as follows:

Assessment of life cycle impacts in first scenario

The amount of waste produced in Yazd is about 143666 tons per year, and by dividing this amount by the Yazd population, the per capita waste production per year was obtained as 220 kg. The total waste introduced into this scenario is 143666 tons, which was considered as a work unit, which 5% is separated and recycled, and the rest of the waste is disposed to the unsanitary landfill. The results in Tables 8 to 11 show the costs, total amount of consumed energy, amount of pollutants emitted to air, and level of entering contaminants to water in the first scenario, respectively. As shown in Table 8, the costs and revenues are shown separately for each sector. The total cost of managing the first scenario was \$1406954, and if we deduct the revenues derived from the sale of recycled materials, which is about -\$1930234, the total annual cost of the first scenario is obtained about -\$523280. Also, the total annual cost of the first scenario was -\$3 per household and -\$1 per person. The negative sign is due to the higher revenues than costs.

The amount of consumed energy, including the electricity, gasoline, petrol and natural gas, is shown separately in each step along with the amount of recycled electricity in each step in Table 9. The total energy consumption was about -5486551 GJ. By subtracting amount of stored energy derived from recycling and from consumed energy in all steps, total amount of consumed energy in this scenario is obtained as negative. Recycling one kilogram of recycled materials retains significant energy compared to the production of same material from raw materials. Table 12 shows the results of normalizing the inventory values of the first scenario.

The environmental burden of each category was calculated based on the equivalent unit (SO₂, CO₂, GJ). Thus, at the end of the characterization phase for each impact category, the impact category indicator was calculated, which indicates the total environmental burden impacts created in the mentioned categories.

Finally, the obtained indicators in each categories (Table 13) were multiplied according to Equation (2) by the relative weight of the category (Table 6) so that the indicators could be added together.

Thus, for the first scenario, an ecological indicator was obtained. It was considered as a quantitative criterion for comparing the biological burden of each scenario, and ultimately, the scenario with a lower score has a lower environmental burden. Table 14 shows the ecological indicator calculated for the first scenario.

Assessment of life cycle impacts in second scenario

The total waste introduced into this scenario is equivalent to 143666 tons (work unit), which 25% is recyclable and 60% can be turned into the compost, 10% is used for feeding the waste incineration plants for the generation of electricity in Yazd, and about 5% of rejected waste from the composting and waste incineration plant can be considered for disposal in the sanitary landfill. The total cost of waste management in the second scenario was \$6470268. If we deduct the revenues derived from sale of recycled materials, methane gas, and generated electricity by the incineration plant, which is about -\$8319754, the total annual cost of the second scenario is about -\$1849486. The total annual cost of the second scenario was -\$10 per household and -\$3 per person. The negative sign is because the revenues are higher than costs. The reason for high revenue in this scenario is that almost all wastes were used properly in different management systems. About 25% of the recycled waste (-\$5021236) comes from sale of recycled materials, and 60% is transferred to the composting plant, which generates about -\$932795 revenue from the sale of compost. The remaining 10% is due to the removal of significant amounts of organic matter, glass and metals in biological sector, and removal of significant amounts of glass and metals. The removal of these materials caused waste entering the incineration plant system to have high thermal value and, therefore, it produces more electricity, and the revenue about -\$2365723 was obtained by selling the electricity generated from the plant.

The amount of consumed energy, including electricity, gasoline, petrol and natural gas, in the whole waste management processes of the second scenario was about -953124 GJ. The negative sign is due to the amount of stored energy from the recycling and electricity generation phase in the incineration plant. If amount of stored energy from recycling of materials and generated electricity by the incineration plant is deducted from consumed energy in the whole process, then the total amount of consumed energy in this scenario is obtained as negative. In the biological phase, by allocating 60% of the plant's capacity to anaerobic digestion, the generated electricity by the biogas of the digesters provides some of the consumed energy by the composting plant. Also, in a waste incineration plant, in addition to supplying the electricity to the plant, the surplus generated electricity can be sold to the national power grid. Tables 15 to 17 show the results of normalizing the inventory values and ecological indicators of the second scenario, respectively.

Table 8. Results from inventory of total costs and revenues in first scenario by each sector per year

	Unit	Collection	Segregation	Compost	Therma	Landfill	Recycle	TOTAL
Costs	\$	1052750	130700	0	0	145288	78216	1406954
Revenues	\$	0	0	0	0	0	-1930234	-1930234
Total	\$	1052750	130700	0	0	145288	-1852018	-523280
Cost per household	\$	6	1	0		1	-10	-3
Cost per person	\$	2	0	0		0	-3	-1

Table 9. Results from inventory of total energy consumed in first scenario by each sector per year

	Unit	Collection	Segregation	Compost	Thermal	Landfill	Recycle	Total
Consumed electricity	kwh	0	113535	0	0	0	0	113535
Produced electricity	kwh	0	0	0	0	0	0	0
Recycled electricity	kwh	0	0	0	0	0	-56238205	-56238205
Petrol	liters	654746		0	0	0	0	654746
Gasoline	liters	440300	1265	0	0	150681	12165	604411
Natural gas	M ³	0	0	0	0		0	0
Total	Gj	441700	114800	0	0	150681	-56226040	-54865513

Table 10. Results from inventory of total air pollutants in first scenario by each sector

Indicator parameter	Unit	Collection	Segregation	Compost	Thermal	Landfill	Recycle	TOTAL
Particulates	g	1.13E+06	6.9004	0	0	1.99 E+05	-9.50E+06	-8.10E+06
CO	g	2.56E+05	5.50E+06	0	0	2.44E+06	-1.27E+07	-4.50E+07
CO ₂	g	3.70E+04	2.61E+05	0	0	4.62E+06	-2.30E+08	-2.25E+08
CH ₄	g	5.73E+05	5.89E+05	0	0	9.59E+08	-2.86E+06	9.57E+07
NOx	g	8.46E+06	8.98E+05	0	0	3.22E+06	-5.58E+07	-4.35E+07
GWP	g	3.82E+08	3.64E+07	0	0	2.25E+10	-1.30E+09	2.16E+10
N ₂ O	g	1.10E+01	2.38E+03	0	0	4.00E+01	-1.53E+06	-1.29E+06
SOx	g	7.07E+05	1.31E+06	0	0	2.70E+05	-6.28E+05	1.65E+06
HCl	g	7.61E+02	3.38E+04	0	0	2.59E+05	-6.88E+04	2.24E+05
HF	g	0	3.31E+04	0	0	2.17E+04	1.17E+04	6.65E+04
H ₂ S	g	0	0	0	0	2.11E+04	1.57E+02	2.12E+04
TotalHC	g	0	0	0	0	3.02E+01	0	3.02E+01
Chlorinated HC	g	0	0	0	0	1.21E+03	0	01.21E+03
Dioxins/Furans	g	0	0	0	0	0	0	0
Ammonia	g	0	4.00E+02	0	0	2.02E+02	-5.02E+04	-4.95E+04
Arsenic	g	0	0	0	0	0	-5.13E+01	-5.13E+01
Cadmium	g	0	3.01E+01	0	0	1.22E+01	-6.22E+03	6.17E+03
Chromium	g	0	0	0	0	1.01E+01	1.21E+02	1.31E+02
Copper	g	0	0	0	0	0	8.05E+01	8.05E+01
Lead	g	0	5.30E+02	0	0	1.06E+01	4.25E+04	4.30E+04
Manganese	g	0	2.31E+01	0	0	0	0	2.31E+01
Mercury	g	0	5.00E+00	0	0	0	3.01E+01	3.51E+01
Nickel	g	0	3.03E+02	0	0	0	-5.13E+01	2.51E+02
Zinc	g	0	1.86E+02	0	0	9.46E+01	0	9.01E+01

Table 11 Results from inventory of total water contaminants in first scenario by each sector

Indicator parameter	Unit	Collection	Segregation	Compost	Thermal	Landfill	Recycle	TOTAL
BOD	g	1.00E+02	3.01E+03	0	0	4.85E+05	3.21E+04	5.17E+05
COD	g	3.01E+03	1.15E+03	0	0	5.03E+01	-1.36E+06	-1.35E+06
Suspended Solids	g	3.56E+03	4.45E+02	0	0	4.98E+08	1.85E+06	4.99E+08
TOC	g	4.32E+01	1.08E+04	0	0	3.69E+02	6.21E+01	1.12E+04
AOX	g	0	5.56E+03	0	0	9.87E+01	-1.12E+08	-1.11E+08
Chlorinated HC	g	0	1.00E+00	0	0	8.03E+01	5.54E+02	6.35E+02
Dioxins/Furans	g	0	0	0	0	0	0	0
Phenols	g	0	2.03E+01	0	0	1.81E+01	-1.01E+04	1.00E+04
Aluminum	g	5.80E+01	6.38E+02	0	0	9.89E+01	-3.23E+03	-2.43E+03
Ammonium	g	1.63E+03	2.49E+04	0	0	3.71E+06	-5.35E+04	3.68E+06
Arsenic	g	0	-5.31E+01	0	0	8.45E+02	-1.72E+03	-9.28E+02
Barium	g	3.48E+05	9.83E+03	0	0	1.01E+04	-4.36E+04	3.24E+05
Cadmium	g	0	8.52E+01	0	0	9.78E+02	2.89E+03	3.95E+03
Chloride	g	0	3.15E+01	0	0	5.90E+03	2.42E+05	2.47E+05
Chromium	g	0	-1.45E+06	0	0	9.46E+03	8.01E+01	-1.44E+06
Copper	g	0	1.09E+05	0	0	1.18E+04	1.99E+08	1.99E+08
Cyanide	g	0	3.00E+01	0	0	9.89E+01	1.31E+02	2.59E+02
Fluoride	g	0	0	0	0	8.37E+03	-1.45E+04	-6.13E+03
Iron	g	4.86E+02	8.79E+01	0	0	6.45E+03	-1.89E+08	-1.88E+08
Lead	g	0	5.34E+03	0	0	5.89E+02	1.41E+05	1.46E+05
Mercury	g	0	0	0	0	7.47E+02	1.01E+01	7.57E+02
Nickel	g	0	5.40E+05	0	0	9.45E+06	1.09E+01	9.99E+06
Nitrate	g	5.00E+01	1.78E+02	0	0	5.12E+06	1.87E+04	5.13E+06
Phosphate	g	0	7.59E+04	0	0	7.37E+07	1.43E+06	7.52E+07
Sulphate	g	1.78E+01	2.99E+01	0	0	6.85E+04	2.68E+02	6.88E+04
Sulphide	g	0	1.32E+01	0	0	9.03E+01	1.48E+01	1.18E+02
Zinc	g	0	4.04E+01	0	0	2.49E+02	1.00E+02	3.89E+02

Assessment of life cycle impacts in third scenario

In the third scenario, instead of spending a large amount of money and high technology for different methods of treatment and disposal, a percentage of this cost is spent on the education and awareness citizens about the separation and reduction in the source, which leads to an increase in the waste recycling rate from 5% to 20% in 15 years.

Also, 60% of the organic waste is transferred to the composting plant for the production of fertilizer and after separating the compostable part, the rest of the waste is transferred to the landfill site and disposed to the sanitary landfill together with the gas collection for the energy exploitation.

Table 12 Normalized values of Yazd municipal waste life cycle inventory in terms of waste managed in first scenario

Indicator parameter	Unit	Normalized values
Consumed energy	Waste (GJ/ton)	5.48E+06
GWP	Waste (g/ton)	2.16E+10
CO ₂	Waste (g/ton)	-2.2E+08
CO	Waste (g/ton)	-4.50E+07
CH ₄	Waste (g/ton)	9.57E+07
NO _x	Waste (g/ton)	-4.35E+07
SO _x	Waste (g/ton)	1.65E+06
HCl	Waste (g/ton)	2.24E+05
N ₂ O	Waste (g/ton)	-1.29E+06
PM	Waste (g/ton)	-8.10E+06
VOC _s	Waste (g/ton)	2.12E+04
Pb	Waste (g/ton)	4.30E+04
Hg	Waste (g/ton)	3.5E+01
Cd	Waste (g/ton)	6.17E+03
Dioxins/Furans	Waste (g/ton)	0
Pb _{water}	Waste (g/ton)	1.46E+05
Hg _{water}	Waste (g/ton)	7.57E+02
Cd _{water}	Waste (g/ton)	3.95E+03
BOD	Waste (g/ton)	5.17E+05
COD	Waste (g/ton)	-1.25E+06
Dioxins/Furans _{water}	Waste (g/ton)	0

Table 13 Impact category indicator obtained in first scenario

Impact category	Normal index
Energy consumption	5.48E+06
Greenhouse gases	2.16E+10
Acid gases	-4.46E+07
Photochemical smog	-8.61E+06
Toxic outputs	9.49E+06

Table 14. Ecological indicator of first scenario

Impact category	Normal index	Multiply by weight
Energy consumption	5.48E+06	4.82E+06
Greenhouse gases	2.16E+10	1.92E+10
Acid gases	-4.46E+07	-1.78E+07
Photochemical smog	-8.61E+06	-2.49E+06
Toxic outputs	9.49E+06	1.23E+06

Table 15. Normalized values of Yazd municipal waste life cycle inventory in terms of waste managed in second scenario

Indicator parameter	Unit	Normalized values
Consumed energy	Waste (GJ/ton)	-9.53E+05
GWP	Waste (g/ton)	-1.01E+10
CO ₂	Waste (g/ton)	2.65E+07
CO	Waste (g/ton)	-1.36E+01
CH ₄	Waste (g/ton)	7.07E+07
NO _x	Waste (g/ton)	2.35E+07
SO _x	Waste (g/ton)	-8.75E+08
HCl	Waste (g/ton)	2.24E+05
N ₂ O	Waste (g/ton)	-1.29E+06
PM	Waste (g/ton)	5.40E+05
VOC _s	Waste (g/ton)	3.21E+06
Pb	Waste (g/ton)	3.40E+04
Hg	Waste (g/ton)	1.05E+03
Cd	Waste (g/ton)	1.17E+01
Dioxins/Furans	Waste (g/ton)	0
Pb _{water}	Waste (g/ton)	-3.59E+01
Hg _{water}	Waste (g/ton)	1.07E+02
Cd _{water}	Waste (g/ton)	-3.62E+02
BOD	Waste (g/ton)	1.15E+04
COD	Waste (g/ton)	-2.45E+01
Dioxins/Furans _{water}	Waste (g/ton)	0

The total cost of waste management in the third scenario was \$3210368. If we deduct the revenues from the sale of produced compost and recycled materials (which is about -\$4087304), the total cost of the third scenario is obtained which is about -\$876936. One of the main reasons for using landfill in waste management is need for expertise and the low cost of the landfill method. Also, the environmental impact of the landfill method is higher than the economic impact of this method. The total annual cost of waste management in Yazd for each household in this scenario was -\$5. Finally, the total annual cost of waste management in Yazd was -\$1 per person. The total amount of consumed energy in this scenario was -9272356. The negative sign is due to the amount of stored energy from the recycling and electricity generation from the landfill gas. Tables 18 to 20 show the results of the normalization of the inventory values and ecological indicators in the third scenario, respectively.

Table 16. Impact category indicator obtained in second scenario

Impact category	Normal index
Energy consumption	-9.53E+05
Greenhouse gases	-1.01E+10
Acid gases	-8.49E+08
Photochemical smog	3.11E+07
Toxic outputs	1.44E+06

Table 17. Ecological indicator in second scenario

Impact category	Normal index	Multiply by weight
Energy consumption	-9.35E+05	-8.35E+05
Greenhouse gases	-1.01E+10	-8.98E+09
Acid gases	-8.49E+08	-3.39E+08
Photochemical smog	3.11E+07	9.01E+06
Toxic outputs	1.44E+06	1.87E+05

Table 18. Normalized inventory values of Yazd municipal waste life cycle in terms of waste managed in third scenario

Indicator parameter	Unit	Normalized values
Consumed energy	Waste (GJ/ton)	-9.27E+06
GWP	Waste (g/ton)	-1.38E+11
CO ₂	Waste (g/ton)	-2.80E+05
CO	Waste (g/ton)	-3.75E+06
CH ₄	Waste (g/ton)	7.87E+07
NO _x	Waste (g/ton)	-1.75E+01
SO _x	Waste (g/ton)	1.00E+01
HCl	Waste (g/ton)	6.24E+02
N ₂ O	Waste (g/ton)	-1.49E+07
PM	Waste (g/ton)	8.19E+03
VOC _s	Waste (g/ton)	7.10E+06
Pb	Waste (g/ton)	2.10E+02
Hg	Waste (g/ton)	9.50E+01
Cd	Waste (g/ton)	8.17E+03
Dioxins/Furans	Waste (g/ton)	1.08E+03
Pb _{water}	Waste (g/ton)	-2.47E+02
Hg _{water}	Waste (g/ton)	7.37E+01
Cd _{water}	Waste (g/ton)	7.85E+01
BOD	Waste (g/ton)	8.12E+02
COD	Waste (g/ton)	-1.25E+06
Dioxins/Furans _{water}	Waste (g/ton)	1.31E+01

Table 19. Impact category indicator obtained in third scenario

Impact category	Normal index
Energy consumption	-9.27E+06
Greenhouse gases	-1.38E+11
Acid gases	5.40E+02
Photochemical smog	8.64E+07
Toxic outputs	1.90E+06

Table 20. Ecological indicator in third scenario

Impact category	Normal index	Multiply by weight
Energy consumption	-9.27E+06	-8.15E+06
Greenhouse gases	-1.38E+11	-1.22E+11
Acid gases	5.40E+02	2.16E+02
Photochemical smog	8.64E+07	2.50E+07
Toxic outputs	1.90E+06	2.47E+05

Interpretation of life cycle impacts of different waste management scenarios

Figures 5 and 6 compare the costs of each scenario with and without considering the revenue by each sector. According to the results of Figure 5, it can be stated that the second scenario has the highest cost in all waste management phases. As mentioned earlier, the operation and establishment of the waste incineration system, which is one of the most expensive waste disposal methods, is the most important reason for the increase of costs in the second scenario. As shown in Figure 6, the most expensive and least expensive costs are related to the second scenario. If the revenue from the sale of recycled materials, compost and recycled energy is deducted from the total cost of each scenario, the second scenario is selected as the most expensive and the third scenarios as the least expensive scenario.

Generally, the results of similar studies show that if the waste management system recycles a higher percentage of recyclable materials and if the residual waste in the form of organic matter is converted to compost, it is more suitable in an economic and environmental manner.

Figure 5. Comparison of total cost and cost by each phase of all scenarios without revenue considered

Figure 6. Comparison of total cost and cost by each phase of all scenarios with revenue considered

In another study, Shafiee et al. [27] assessed the municipal waste management system. This study aimed to compare four scenarios involving different methods of waste disposal in Shahinshahr, Iran. The scenarios were: (1) All waste to be transferred to the landfill without processing, (2) All organic materials in the waste to be used for compost and the rest to be transferred to the landfill, (3) The materials to be recyclable and the organic materials to be used for composting and the residue to be transferred to the landfill, (4) The recyclable materials to be recycled and the organic materials to be used for composting and the residual materials to be utilized for the energy production. The results showed that the highest and lowest impacts were related to the first and fourth scenarios, respectively.

Hasani et al. [28] compared and assessed five different waste management scenarios in Isfahan, Iran using the life cycle impact assessment. The life cycle inventory was analyzed using the IWM-2 model. From the environmental and economic point of view, the results of this study showed that recycling, composting and disposal of waste in the sanitary landfill as a suitable management option, in addition to making economic savings, plays an important role in reducing the burden of pollutants and energy consumption from the waste management system.

4. Conclusion

In this study, different management methods such as landfill, waste incineration plant, separation and recycling, and composting were modeled in three scenarios using IWM-2 model to compare the methods from the environmental and economic point of view. The results were obtained as five impact categories (energy consumption, global warming potential, acid gases, photochemical smog, and toxic outputs) and the results of estimating the costs and revenues to ultimately determine the most appropriate scenario from the environmental and economic viewpoint. In this study, the life cycle impact method was employed to investigate the environmental and economic impacts of different waste management options in Yazd, Iran. For this purpose, after reviewing the current management practice and waste disposal method in Yazd and knowing the quantity and quality of the produced waste, and also taking the new waste disposal methods into account, three scenarios were defined and modeled. Then, the scenarios defined using the IWM-2 model to achieve the ecological indicator. Finally, in the last step, the most appropriate scenario in terms of environment and economy was identified and proposed.

According to the results from the life cycle assessment of three scenarios of Yazd waste management system, the third scenario was selected as the best scenario in terms of environmental burden (assuming that about 20% of the total waste introduced into this scenario is separated and recycled, 60% is transferred to the composting plant for the production of fertilizer and 20% of waste produced by the rejects of MRF unit and energy exploitation is disposed of to the sanitary landfill). The third scenario also ranked second in terms of economy. Therefore, it can be concluded that the third scenario is the most suitable for Yazd waste management system than other scenarios. In the third scenario, increasing the recycling rate reduces the pollution production and also makes significant economic savings.

The results of this study can be communicated to the Environmental Protection Organization of Yazd Province, Municipality of Yazd, or urban decision-makers and legislators, and any government agencies related to the municipal waste management. In addition, this research can be made available to those interested and the researchers in the field of waste management and life cycle assessment and provide their needs in this field to some extent.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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