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Evaluation of the Life Cycle of Household Waste Management Scenarios in Moderate Iranian Cities; Case Study Sirjan City

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Abstract
Solid waste is one of the unavoidable products of every society that necessitates the establishment of municipal solid waste management system. Because of variability in quantity and composition of municipal solid wastes, several management scenarios are considered. Assessing the environmental impacts of the life cycle of these scenarios will have a significant role in reducing and resolving urban service management problems. The aim of this study was to compare different scenarios of municipal solid waste management using life cycle assessment (LCA) approach in a typical medium cities in Iran which Sirjan city is assessed as a sample. For this purpose, four scenarios were considered and the life cycle inventory (LCI) was accomplished using integrated waste management model (IWM-2) in each scenario and the results of the model were entered to OpenLCA software and environmental impact assessment of scenarios was carried out Based on the TRACI2014 method. The results showed that the fourth scenario, in the impact categories of acidification, eutrophication, ozone layer depletion, photochemical ozone formation and respiratory effects, third scenario in the impact categories of ecosystem toxicity, human health (carcinogenicity and non-carcinogenicity) and second scenario in the impact categories of global warming and resource depletion (fossil fuels) has the least environmental burden among other scenarios.

Keywords: LCA, Municipal Waste Management, OpenLCA, Medium Iranian City.

Introduction

Sustainable development encompasses the reduction of polluting emissions and the establishment of sustainable waste management practices (Belboom et al., 2013). Particularly, waste management is a method directing managements to acting for sustainability by displaying their ability to use and protect current resources (Cucchiella et al., 2014). For a sustainable society should not generate wastes exceeding its capacity of manage them. an important factor for sustainable development is an affordable, effective and truly sustainable waste management. Thus, on the one hand solid waste management (SWM) is crucial to achieve sustainability. On the other hand, increases in population, urbanization and economic development have led to the growth of concerns in this field (Tulokhonova and Ulanova,

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2013; Levis et al., 2013). As a result, solid waste management has emerged as one of the most challenging service sectors in the 21st century for municipal authorities (Puig et al., 2013; Zaman, 2014). in developing countries the health and environmental implications related to solid waste management are mounting in urgency. Indeed, municipal solid waste (MSW) becomes an important issue for cities in emerging economies due to the high costs associated and to the lack of understanding over the factors that affect the different stages of SWM (Guerrero et al., 2013).
Thus, several decision support models have been developed to aid decision makers in the planning of solid waste management strategies (Karmperis et al., 2013). Life Cycle Assessment (LCA) approaches are one of the most largely used methodologies to assess solid waste systems (Panahandeh et al., 2013; Allesch and Brunner, 2014). The Life Cycle Assessment (LCA) methodology is nowadays considered to be the focus of attention of environmentalists as an international standard method that can analyze inputs and outputs from a waste management system to suit the life cycle of products or processes (Cherubini et al., 2009; Laurent et al., 2014). LCA was completed in the 1990s by the works of Society of Environmental Toxicology and Chemistry and International Organization for Standardization as ISO 14040-3, after that ISO 14040 was revised in 2006 (ISO-14040 1997; ISO14041 1998; ISO-14041 1998; ISO-14042 2000a; ISO-14043 2000b; ISO-14040 2006; ISO-14044 2006).The application of this method to assess the urban waste management system, especially in the field of decision making, designing strategies and examining different methods of disposal, is increasing. Various studies have been done on urban waste management with the LCA approach.

Abdoli et al (2011) compared and evaluated the effects of the life cycle of two different waste management scenarios in Tehran. The scope of this study included 2 scenarios: 1- Landfill 2 - Compost, plus Landfill. The main results showed that in this study, scenario 2 for Tehran has a higher environmental burden than the Landfill scenario.

Shams Fallah et al (2013) reviewed three combined waste disposal scenarios and their environmental impact assessment with the Life Cycle Assessment Approach in Lavan Island. Eco indicator99 was applied for their environmental impacts and the best environmental scenario was determined.

Bueno et al (2015) compared two energy recovery scenarios from Remains of mixed residues in a incineration plant and recovered materials collected by the Life Cycle Assessment Approach in the province of Gipuzkoa in northern Spain. The results showed that recycling provides better environmental results that are highly related to fossil fuels.

Parks et al (2015) evaluated the Life Cycle of Integrated solid Waste Management Systems (ISWMS) at 3 sites designed for the London Olympic Village. The results showed that ISWMS combined with advanced thermal processing technology and energy recovery waste has the lowest global warming effect compared to traditional waste disposal systems.

Di Gianfilippo et al (2016) studied the environmental impact assessment associated with two different management options (landfilling and recycling) for ash produced by thermal treatment (incineration, gasification), with life cycle assessment and the EASETECK model. LCA results showed that for both types of ash, landfill has the most environmental impacts associated with non-toxicity impact categories. For toxicity impact categories, Gasification ash released less pollutants than incineration ash.

Jensen et al (2016) compared the organic waste management systems in the Danish-German border region using the Life Cycle Assessment and the EASETECK model. In this study, organic waste disposal from households is very different on each side of the border. Denmark uses only incineration for waste disposal, while waste management methods in Germany include biomass and compost composition, mechanical and biological treatment and burning. The results showed that two different regions in Denmark work better in 10 of the 14 impact categories.

Akhavan limoodehi et al (2017) reviewed three suggested waste disposal scenarios and their environmental impact assessment with the Life Cycle Assessment Approach in Tehran city. Eco indicator99 was applied for their environmental impacts and the best environmental scenario was determined.

Ayodele et al (2017) evaluated the life cycles of waste conversion plants to energy with the goal of generating electricity in 12 Nigerian cities. Conversion technologies to energy include: converting landfill gas into energy, combining burning and anaerobic digestion, mixing incineration and converting landfill gas into energy. The results showed that the technology of converting landfill gas into energy is the best in terms of the potential for reducing carcinogenesis. Also, the greatest reduction in the global warming potential was due to the combination of burning and anaerobic digestion.

Ripa et al (2017) examined waste management strategies at the naple (Italy) metropolitan area with a lifecycle assessment approach after confronting the production and waste disposal crisis. The LCA results showed that the main loads are due to the management of municipal solid waste (such as biological treatment, landfill, waste-to-energy conversion). The study also confirms that LCA, if done carefully, has the potential to improve new management strategies and allow for identifying crises.

Other studies have also done with this approach in Iran and elsewhere in the world. The use of such studies provides an opportunity for urban planners and decision-makers, to be aware of the current state of waste management, they will make the necessary plans for achieving a sustainable environment by using the best pattern of processing and disposal (the lowest emission of biological pollutants).

The purpose of this study was to assess the environmental of urban waste management system in Sirjan city In the year of 2018 using a life cycle assessment approach by OPENLCA software.

Material and Methods

Study area

Sirjan is one of the oldest cities in Kerman province with an area of 17481 square kilometers, equivalent to 7.16 percent of the total area of the province. According to the questionnaire completed by the Sirjan municipality, the population of the city of Sirjan has been declared 267697 of which 137,304 are male and 130,393 are women. The total number of households in Sirjan has been announced at 73560 households. Sirjan weather is cold in the winter, hot and dry in the summer and moderate in spring. The average humidity is 36% and the average annual rainfall is 142 mm. Sirjan is one of the major agricultural centers in Kerman Province, which plays a major role in agricultural production, especially pistachio production. The Sirjan region, due to the special geological situation, which is more volcanic and igneous rock, is rich in minerals, including golgohar iron mines. In recent years, the Sirjan city industry has made some progress, including exploitation of the industrial complex (Gol Gohar) and industrial park, which includes gypsum manufacturing, plastics, ceramic and bolt industry.

Waste composition

The physical quality of the waste from the city of Sirjan is shown in Table 1. As you can see, organic materials with 68.4 percent are the largest amount of urban waste from Sirjan. The amount of waste produced in Sirjan is on average 150.511 tons per day and the waste generated per person is 685 grams per day.

Table 1. MSW components and characteristics in Sirjan city

Type of waste	Mass of waste(kg/day)	Waste weight percent
metals	3656	2.4
glasses	3056	2
other	13545	9
textiles	2040	1.4
Plastic and PET	12708	8.4
Paper and cardboard	12616	8.4
Organic materials	102890	68.4
total	150511	100

Life cycle assessment model

After identifying the quantitative and qualitative characteristics of the produced wastes within the scope of the study, the quadratic steps of the LCA method are followed in relation to each of the scenarios. The stages of life cycle assessment in this study are as follows:

1-Determining goals and scope: Our goal in this study is to compare environmental impacts of scenarios that include different methods of disposal. The boundaries of the study originate from the collection of municipal solid wastes from the transfer station and ends with the final disposal of waste. Four scenarios have been investigated and evaluated in the environmental field. The difference in these scenarios was greater in the final disposal section and it is assumed that all of these scenarios are deployed in one place. It should be noted that, the collection and transportation of the waste from the producer to the disposal site due to the common participation in all the scenarios are not considered. The amount of waste generated within one year (2017) is considered as Functional unit for the generated pollutants and the amount of energy consumed.

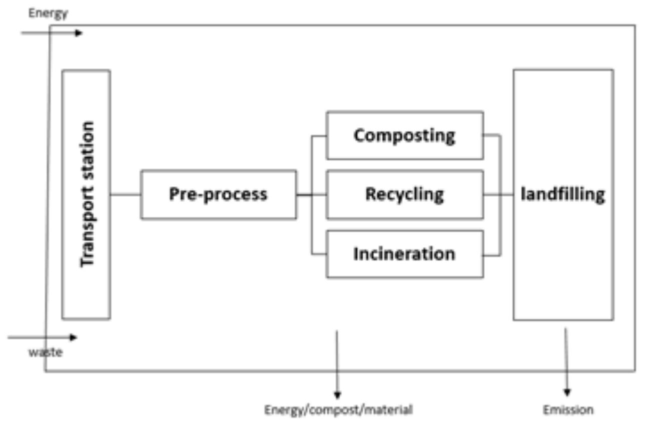

Figure1. System boundary

Table 2. Disposal solid waste scenarios

Residue Incineration (%)	Residue Recycle (%)	Residue Compost (%)	Landfill (%)	Incineration (%)	Recycle (%)	Compost (%)	scenario
0	0	0	100	0	0	0	1
0	30	14	12.4	0	19.2	68.4	2
14	30	14	12	55.9	15	17.1	3
14	30	0	11	69.8	19.2	0	4

Assumptions intended for scenarios are selected according to the Sirjan Waste Management comprehensive Plan and IWM-2 software defaults, which are in accordance with USEPA regulations. It is assumed that 50% of landfill gas and leachate are collected and recovery of energy from these gases is 50%, the efficiency of electricity generation from gases, leachate treatment, and the collection are assumed 30%,50%,25% respectively. Our method of composting is windrow. The mass loss in this process is considered to be 50%. The waste incineration technology for use in Sirjan city is a burnout method and the recovery efficiency of the waste incineration is assumed to be 30%.

2-Collecting data and life cycle inventory (LCI): Various tools have been developed for LCI, one of which is the IWM model. The IWM model is one of the lifecycle assessment models that can be used to define different scenarios and then compare the environmental impacts of each scenario .This model was designed and presented in 1996 by the Environmental and Plastic Industries Council and the University of Waterloo in Canada based on the assessment of the urban waste management life cycle and it contains various windows for data entry that the answer to the questions asked determines the status of the management system under investigation .By using standardized data in the IWM model, you can obtain the amount of contamination caused by each of the scenarios and the energy used in them. The components evaluated in the estimation of environmental load included water pollution, air pollution and energy consumption. at this stage, the data from physical analysis, the amount of waste produced, the stages of separation at source, collection, transportation and final disposal, were collected and analyzed and the amount of contamination caused by each of the Scenarios and energy consumption were determined.

3- Life cycle impacts assessment (LCIA): Assessing the impacts of the life cycle is a step of life cycle assessment, aimed at understanding and assessing the magnitude and significance of the potential environmental impacts of a product or service. At this step, the various information and data obtained at the LCI stage are reduced to less indicators and impact categories in order to facilitate the interpretation of this information and provide clearer outcomes to decision makers and managers (Clavreul et al., 2012). At the stage of LCIA, the values obtained during the LCI process, are entered into the OpenLCA software. This software has been developed by Greendelta since 2006 and has valid databases and various methods for assessing life cycle, sustainability assessment, social life cycle assessment, life cycle cost, water and carbon footprints, etc (Winter et al.,2015). Our method in this research is TRACI2014. This method, developed by the US Environmental Protection Agency, has been designed to assess the environmental impacts of various scenarios. In this method, Input data is allocated to the 10-impact categories of acidification, ecosystem toxicity, eutrophication, global warming, human health (carcinogens), human health (non-carcinogenicity), ozone depletion, photochemical ozone formation, resource depletion (fossil fuels), and respiratory effects.

4- Interpretation of results: At this stage, the results of the LCI and LCIA will be evaluated so that the stages or points which have the greatest and least harmful impacts on the environment in the production and consumption of the product have been determined. Finally, conclusions and solutions are discussed.

Results and discussion

In order to life cycle assessment of municipal solid wastes, based on the available data in the area and the standard data, four scenarios were considered using the IWM-2 model. The amount of pollutants caused by each scenario and energy consumption was calculated and shown in Table 3-4-5. Then the data was entered into OPENLCA software and environmental impact assessment was carried out based on the TRACI2014 method. Finally, the results from the scenarios were compared and analyzed. The results are shown in Table 6.

Table 3. Energy consumed in different scenarios per functional unit (annual waste tonnage)

Energy and fuels	unit	Scenario1	Scenario2	Scenario3	Scenario4
Electricity-consumed	Kwh	153815	1614749	2400023	2566513
Electricity-produced	Kwh	-4030571	-1334153	-10187565	-11307842
Diesel fuel	Lit	52517	15009	10227	10052
Natural gas	M^3	0	2109	7664	9641

Table 4. air Emissions in different scenarios per functional unit (annual waste tonnage)

Pollutants	unit	Scenario 1	Scenario 2	Scenario 3	Scenario4
PM10	G	-1892063	-2675068	-7561488	-7291053
CO	G	4998484	-13900722	-15110475	-15227806
CO_2	G	13790132185	52289951	11182904577	13314061515
CH_4	G	2105836223	692048964	42646872	343714357
NO_X	G	-180400	-21140153	-29278694	-29765252
N_2O	G	-16044	88606	72421	85805
SO_X	G	-8380401	-10179447	-25499057	-30578027
HCL	G	118676	172621	-510170	-578956
H_2S	G	1075732	356858	218030	179592
HF	G	40920	26149	11097	9567
NH_3	G	-4689	235344	116436	234525
As	G	0	0	1	1
Cd	G	-5	-80	-119	-116
Cr	G	4	38	100	119
Cu	G	0	196	227	238
Pb	G	-328	3536	3081	3102
Mn	G	-153	11	-10	-16
Hg	G	-47	7	720	944
Ni	G	-2216	-1310	-5855	-6165
Zn	G	-108	81	-624	-533

In the impact category of acidification, the fourth, third, second, and first scenarios have lower environmental loads, respectively. The fourth scenario with the lowest environmental impact, is Selected as the first priority in this impact category Because NO_X, SO_X, HCL, HF, HF, SO_2, H_2S emissions are lower than other scenarios.

In the impact category of ecosystem toxicity, the third, fourth, second and first scenarios are selected as the first, second, third and last priority, respectively. The reason for choosing a third scenario as a top priority, is Reduction in production and emission of toxic and dangerous pollutants such as cadmium, nickel and zinc to air and heavy metals such as arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc to the aquatic environment.

In the impact category of eutrophication, the fourth scenario is chosen as the best scenario Because NOx and ammonium released in the environment are less than other scenarios also, the phosphate released in this scenario after the third scenario had the lowest amount of emission rate.

Table 5. Water Emissions in different scenarios per functional unit (annual waste tonnage)

Pollutants	unit	Scenario1	Scenario2	Scenario3	Scenario4
BOD	G	15305148	9193732	6607252	6334251
COD	G	15297790	-106966445	-50452673	-111626122
NH_4	G	116832	517335	156999	62332
As	G	-1318	-2549	-2876	-2808
Ba	G	-70365	-101729	-123856	-114009
Cd	G	41	12	-3	2
Cr	G	-6622	-13061	-14717	-14372
Cu	G	-3123	-3378	-4198	-4040
Pb	G	-3859	-6199	-7307	-6967
Hg	G	2	7	7	7
Ni	G	-2465	-5822	-6786	-6662
NO_3^-	G	-20608	2086504	1030655	2082908
PO_4^{3-}	G	-41370	-21951	-58848	-29170
SO_4^{2-}	G	-7887087	15375668	3980755	13987058
SO_3^{2-}	G	-208	94	-29	58
Zn	G	-2855	-10560	-12608	-12372
Suspended-solids	G	-397176	7164756	3258638	7055577

Table 6. Results of environmental impact assessment of scenarios in each impact categories based on TRACI2014 method

Impact category	unit	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Acidification	Kg SO_2 eq	2.82533E+2	-8.31570E+2	-1.28623E+3	-3.28462E+3
Eco toxicity	CTUe	-1.21244E+4	-3.94749E+4	-4.66905E+4	-4.57523E+4
Eutrophication	Kg N eq	1.11516E+2	-3.16985E+2	-2.07863E+2	-3.91548E+2
Global warming	Kg CO_2 eq	4.32539E+6	1.13212E+6	1.42094E+6	1.42518E+6
Human health-carcinogenic	CTUh	-2.58903E-5	-7.20430E-5	-8.33248E-5	-8.14297E-5
Human health-non carcinogenic	CTUh	-2.26179E-3	-5.30360E-3	-6.08147E-3	-5.94231E-3
Ozone depletion	Kg CFC-11 eq	6.13146E-5	1.75233E-5	1.19402E-5	1.17359E-5
Photochemical ozone formation	Kg O_3 eq	2.53168E+3	-3.31220E+4	-4.65286E+4	-4.73904E+4
Resource depletion-fossil fuels	MJ Surplus	3.09106E+5	9.92504E+4	9.98403E+4	1.0907E+5
Respiratory effects	Kg PM2.5 eq	-2.06947+1	-4.65726E+1	-1.23718E+2	-2.40561E+2

In the impact category of global warming, the second scenario, where 100% of the corrosive materials is converted into compost, has the lowest environmental impact. This reflects the decisive role of compost in reducing CO_2 emissions and global warming. In this impact category, the third scenario (with converting 25% of the corrosive materials into compost), the fourth and first, respectively, are selected as the second, third and last priority. The first scenario, where all wastes are shipped directly to landfill, has been selected as the worst scenario by releasing the highest CO_2 and methane and NO_X emissions into the environment.

In the impact category of human health (carcinogenicity), the third, fourth, second and first scenarios are selected as the first, second, third and last priority, respectively. The reason for choosing a third scenario as a higher priority, is the less distribution of elements such as cadmium, nickel, zinc in gas and liquid forms, as well as elements such as lead and arsenic in liquid forms.

In the impact category of human health (non-carcinogenicity), the third, fourth, second and first scenarios are selected as the first, second, third and last priority respectively. Prioritizing this impact category with the prioritization of the ecosystem toxicity and human health (carcinogenicity) impact categories is the same because of similar reasons.

In the impact category of ozone layer depletion, the fourth, third, second and first scenarios are selected as the first, second, third and last priority, respectively. The reason for choosing the fourth scenario as a top priority is lower distribution of halogenated compounds than other scenarios that due to decomposition, cause ozone depletion.

In the impact category of photochemical ozone formation, the fourth scenario is chosen as the first priority. the reason for this, is reduction of pollutants such as hydrocarbons and methane and saving pollutants such as NO_x and CO in comparison to other scenarios. Also, this scenario, after the third scenario selected as the second priority that releases the smallest particles in the air. The second and first scenarios are selected as the next priority in this impact category.

In the impact category of resources depletion (fossil fuels), the best scenario is the second scenario in which compost plays a decisive role and 100% of the corrosive materials that make up 68.4 percent of our total waste compounds enter the composting plant. Also, this scenario does not use incinerations, which consume a lot of energy and natural gas that cause depletion of fossil fuels and resources. In this impact category the third, fourth, and first scenarios are chosen as the next options.

In the impact category of respiratory effects, the fourth scenario is chosen as the first priority due to the reduction and saving of NO_X and SO_X pollutants in comparison with other scenarios. Also, this scenario after the third scenario has the smallest airborne particles, which is due to the use of gas cleaning technology in incinerations, which eliminates metals such as cadmium, chromium, arsenic, copper, mercury, nickel, lead, zinc. The third scenario,is chosen as the second priority, has the lowest environmental impact on suspended particles released in the air and also after the fourth scenario, has the lowest emissions of SO_X and NO_X pollutants. The second and first scenarios will be next choices in this impact category. Fig. 2, derived from the OpenLCA software, shows the relative index of the variables of the corresponding project. For each scenario, the maximum value is 100 and the results of other variables are measured against it.

Conclusion

The goal of integrated waste management is to pursue sustainable development goals. To assess sustainable development, tools that can predict the environmental burden of each system are needed. Therefore, in this study, the life cycle assessment approach was used as a decision tool for choosing the appropriate waste disposal scenario in Sirjan city. For this purpose, four scenarios have been considered and IWM-2 software has been used to calculate the environmental burden of different scenarios. The results of this evaluation showed that the fourth scenario had the least environmental effects in the impact categories of acidification, eutrophication, ozone layer depletion, photochemical ozone formation and respiration effects among other scenarios. The third scenario, in the impact categories of ecosystem toxicity, human health (carcinogens and non-carcinogenesis) had the best environmental performance among other scenarios.

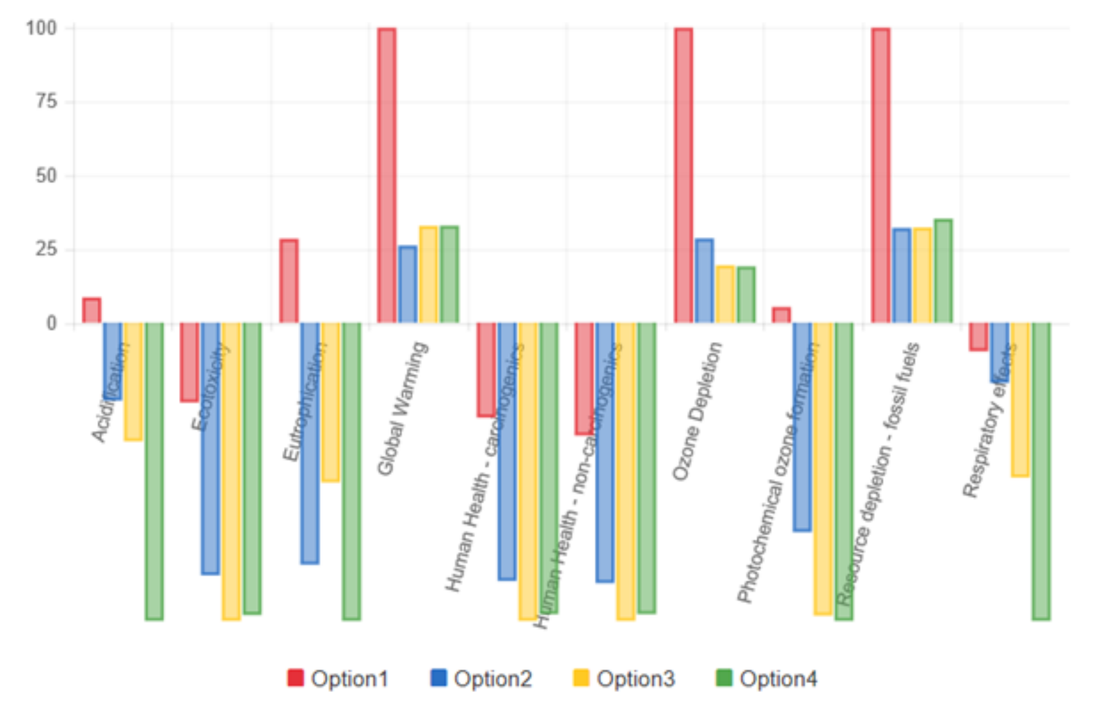

Figure 2. Relative index of project variables

The second scenario, in the impact categories of global warming and resource depletion (fossil fuels), had the least environmental burden among other scenarios. Finally, the first scenario in all impact categories is selected as the worst scenario. In all scenarios CH4, CO2, H2S, HF and Hydrocarbons have the main effects on air pollution. Scenario1 emits the maximum CO2 among the others which is undoubtedly caused by the burial of all the waste in landfill. Moreover, heavy metals including Cd and Hg show an extreme role in water pollution. In addition scenario4 recovers significant amounts of energy based on the IWM model whereas scenario1 has the least. In general, the results of this study can be deduced that in an integrated waste management system, the higher the rate of separation and recycling, due to the increase in the amount of materials for recycling and re-use and prevention of emissions caused by the production of raw materials, the emission rate of environmental pollutants will also be significantly reduced. As a result, the separation and recycling of materials, the use of existing potentials (biogas production, electricity, compost, etc.) and traditional options like landfill are our priorities in this study, respectively. In the present study, the economic and social factors are not investigated and the results obtained can be presented only to the decision makers from an environmental point of view. The results of this study are relevant to the current state of waste management in Sirjan city, so it may be different from similar studies in other locations due to different characteristics of waste, technology and spatial factors. The results of this study indicate that life cycle assessment can provide a complete picture of the urban waste management system from an environmental point of view and be given as a valuable tool for decision makers. It is also suggested that in other studies, the economic and social assessment of the urban waste management system of Sirjan city be considered.

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