Int. J. Environ. Res., 7(1):155-164, Winter 2013
ISSN: 1735-6865

Investigation of Solid Waste Disposal Alternatives in Lavan Island Using Life Cycle Assessment Approach

Shams Fallah, F.[1], Vahidi, H.[2], Pazoki, M.[2*], Akhavan-Limudehi, F.[2], Aslemand, A.R.[2] and Samiee Zafarghandi, R.[2]

[1] Department of Environment, Pardiasan Park, Hakim Highway, Tehran, Iran

[2] Graduate Faculty of Environment, University of Tehran, P.O. Box 14155-6135, Tehran, Iran

Received 2 March 2012; Revised 12 July 2012; Accepted 19 July 2012

ABSTRACT: Escalating development of tourism and petroleum industries in small islands such as Lavan-Iran requires sound solid waste management. In the present investigation, three scenarios which consist of the combination of landfill, recycling, incineration and composting and their environmental impacts have been evaluated for 7514 Kg/day of waste generation in Lavan island. For this purpose, life cycle assessment was used. The environmental impact assessment was carried out by Eco-indicator 99. The impacts include health (organic substances, inorganic substances, climate change, ionizing radiation, and ozone layer depletion), ecosystem quality (ecotoxic emissions, acidification, eutrophication and double coating) and resources (extraction of minerals and the fossil fuels). Although all three scenarios have positive impacts on the environment, the third one causes the least damage. Introduced Scenario one has the most adverse effects on human health and ecosystem quality. However, introduced scenario Two has less than the others. In general, the effects of scenario three (landfilling plus recycling, incineration and composting) is less than the other two scenarios which makes it a better candidate for further investigations.

Key words: Life Cycle Assessment,Municipal Solid Waste, Landfilling,Composting, Recycling, Incineration

INTRODUCTION

All around the globe, various approaches to proper Solid Waste Management (SWM) systems has led to significant goals such as public health improvement, safety and environmental benefits. Recent studies show a great interest proposing several options for an integrative managing of the solid wastes worldwide (Cherubini et al. 2009, Thanh and Matsui 2011; Abdoli *et al.*, 2012; Nada *et al.*, 2012; Rashidi *et al.*, 2012). Integrated Solid Waste Management (ISWM)is generally regarded as the optimized waste management system, with individual consideration of both environment and economic to obtain the best solution (Hyun *et al.*, 2011; Nouri *et al.*, 2011; Safari *et al.*, 2011; Chen *et al.*, 2011; Arshad *et al.*, 2011; Maqbool *et al.*, 2011; Koroneos and Nanaki 2012).

A significant methodology with potential of diminishing the environmental impacts of ISWM is Life Cycle Assessment (LCA). However, LCA is considered-as an effective technique with the association of a product, process or activity by identifying, quantifying and assessing the impact of the utilized energy, material and waste released to the environment to evaluate the environmental capacities (Curran 2004). LCA was initially introduced by “net energy analysis” studies. Based on these studies in 1972, only the amount of energy assumption, over the life cycle of product or a process was considered (Boustead 1972; Hannon 1972). Succeeding that, waste and emissions were entered in the model but none of them went further than the application of materials and energy’s quantification (Lundolm and Sundstrom 1985; Boustead 1989). In addition, LCA methodology was improved significantly in 1990s by the works of Society of Environmental Toxicology and chemistry and International Organization for Standardization (ISO) and introduced as ISO 14040-3, and also the ISO 14040 got revised in 2006 (ISO-14040, 1997; ISO-14041, 1998; ISO-14042,2000a; ISO-14043, 2000b; ISO-14040, 2006; ISO-14044, 2006). Eventually, the final version of the LCA standard was presented in 2006 as ISO 14044 , in which the readability and accessibility of the

*Corresponding author E-mail: maryam_pzk@yahoo.com

standards were improved (ISO-14040 2006; ISO-14044 2006). Previous studies have investigated the usefulness of LCA methodology in SWM (Denison 1996; Finnveden and Ekvall 1998; Björklund and Finnveden 2005; Cleary 2009). In 2003, the combination of Refuse-Derived Fuel (RDF), biological treatment, thermal treatment and landfilling was appraised using LCA methodology for the solid waste management in Italy (Arena *et al.,* 2003). Moreover, LCA and an integrated environmental monitoring system for the incinerators were evaluated together to assess the incineration process and its environmental impact (Morselli, *et al.,* 2005). However, using the residue of the incinerators based on the leaching of trace element to air and water were studied in 2009 (Toller, *et al.,* 2009). Various disposal methods are also compared with each other according to their environmental impacts achieved by LCA methodology, such as comparing the landfill impacts to the incinerator impacts (Mendes *et al.,* 2004). Two years later, Hong utilized LCA for the municipal waste management in China, based on the biological and mechanical treatment (Hong *et al.,* 2006). Moreover, several similar studies have determined various combinations of disposal methods such as recycling, RDF, composting, incineration and landfilling (Abduli *et al.,* 2010; Hong *et al.,* 2010; Koci and Trecakova 2011; Tunesi 2011; Koroneos and Nanaki 2012). LCA methodology is not only used to assess the disposal scenarios, but is also applied in other waste management categories such as waste collection systems (Iriarte *et al.,* 2009), products' fate in the landfill (Mersiowsky 2002) and evaluating the costs of emissions (Consonni *et al.,* 2005a; Consonni *et al.,* 2005b). Also, there are some studies in Iran on SWM such as Nouri's work who studied legal criteria and executive standards of solid waste disposal subjected to solid waste management act (Nouri *et al.,* 2011), studying the source reduction potential and strategies in Tehran (Abduli and Azimi 2010) or predicting the generation of municipal solid waste by usage of artificial neural network (Jalili Ghazi Zade and Noori 2008).

Lavan Island is considered as one of the main petroleum regions in the Persian Gulf. The approximate length and width of the island is about 24 and 4 km with the approximate area of 76.8 square kilometers, respectively. Lavan oil field consists of four fields, namely Salman, Resalat, Reshadat and Balal with a production capacity of 105 thousand barrels per day. Boosting investment and also population growth are leading to rapid industrial blooming in this area. However, municipal solid waste management in the island is not kept up with accelerating industrial advancement and population growth which causes detrimental environmental impacts. Consequently, larger amounts of solid waste are generated in this small island. At present, Lavan Island has more than 3100 inhabitants, generating up to 7514 kg waste per day. In general, the solid waste generators in Lavan Island are the Iranian Offshore Oil Company (IOOC), Lavan Oil Refining Company, Lez village, military facilities and other sources including domestics. The types of waste can be divided in two categories, including municipal solid wastes and oil sludge. Besides, the rate of municipal waste generation is about 2.42 kg/day per person and the moisture content of the wastes is 49.5%. In Lavan Island, generally the volume of the oil sludge is more than 12400 m^3 (about 14200 tons) per year.

It should be mentioned that, islands are extremely fragile integrated systems where any future development needs to be focused on sustainable and integrated options capable of reconciling the economy, human development and environmental conservation (WTO 1998).

MATERIALS & METHODS

LCA methodology was applied to evaluate the environmental performance of the generated waste management of Lavan island for different scenarios, according to the ISO standards 14040 series (2006). The aim of assessing LCA methodology for the generated municipal waste of Lavan island is to investigate the possible environmental impacts of various solid waste management scenarios which finally lead to select the finest disposal system. The level of awareness of the decision makers would be increased according to the results of this research. Thus, the possibility of the future environmental undesirable effects would be lessened. 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. ISO 14040 standard defines the functional unit as ''the quantified performance of a product system for use as a reference unit in a life cycle assessment study'' (ISO-14040 2006). Therefore, for this study the functional unit was chosen as the average amount of municipal generated waste of Lavan Island per day. The daily waste generation of Lavan Island in 2011 is more than 7514 kg/day which is considered as the input of the system. In addition, the amount and composition of Lavan island waste is shown in Table 1.

The unit processes and its inputs and outputs define the system boundaries. Fig. 1 and Table 2 reveal the system boundaries in this study and the percentage of the waste in each disposal facility, respectively. Various combinations by using four processes

Table 1. MSW components and characteristics in Lavan Island [IOOC, 2010]

Waste type	Mass (kg/day)	Mass (%)
Municipal wet waste	4930	65.61
bread	200	2.66
plastic	916	12.19
paper	694	9.24
metals	225	2.99
glass	373	4.96
wood	49	0.65
other waste	127	1.69
Total	**7514**	**100.00**

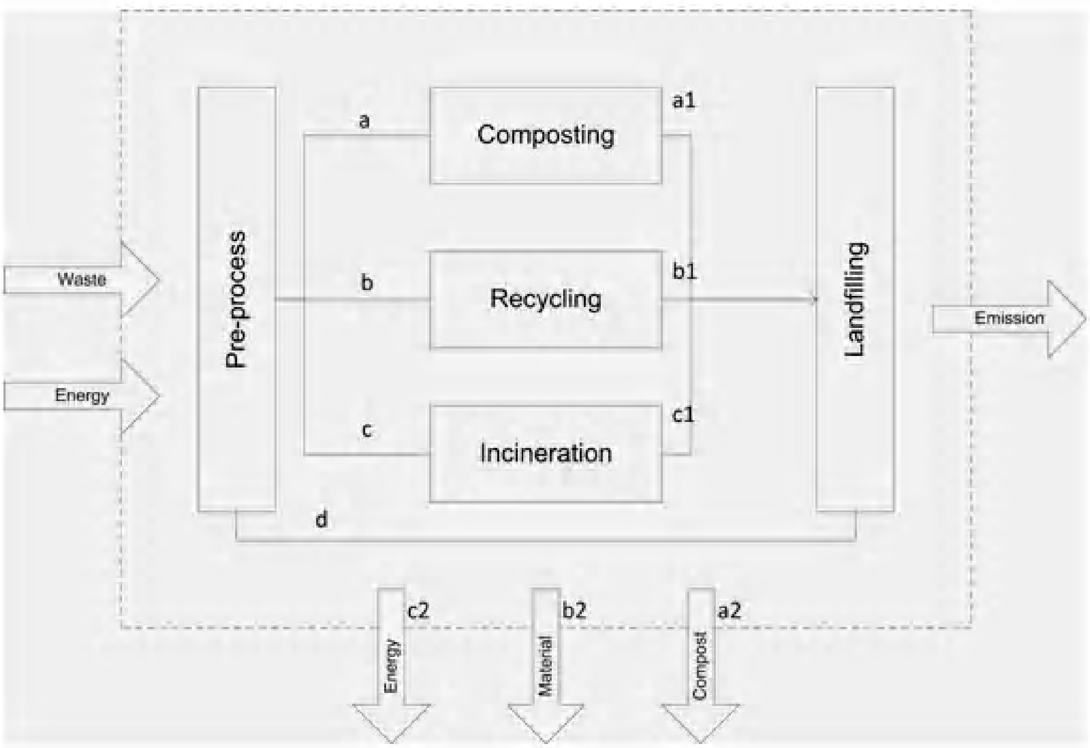

Fig. 1. Boundaries for scenarios

Table 2. Disposal solid waste scenarios

scenario	Compost (%)	Recycle (%)	Incineration (%)	Landfill (%)	Residue compost (%)	Residue recycle (%)	Residue incineration (%)	Final landfill (%)
	a	b	c	d	a1	b1	c1	
1	68.3	29.4	0	2.3	20	5	0	17.5
2	0	29.4	68.9	1.7	0	5	10	9.3
3	44.1	29.4	26.5	0	20	5	10	3

including; Landfilling, composting, recycling and incineration are suggested as solid waste management scenarios. These four processes were chosen due to popularity and their previous successful usage, for instance recycling is known as a valuable component of waste management systems (Abdoli, 2009). The three selected scenarios are briefly discussed as follows.

Recycling, composting and landfilling are considered as the disposal facilities in scenario one where the landfill is assumed without any leachate or gas collection system. The wet wastes and bread (organic wastes) are moved to the composting facility whereas glass, plastic, ferrous and non-ferrous metal and paper are recycled. However, other wastes are buried in the landfill. The second scenario includes recycling, incineration and landfilling. It should be mentioned that the landfill in scenario 2 is assumed with leachate collection system with %70 efficiency. The wood, bread and wet wastes are burned in the incinerator, also paper, glass, plastics and ferrous and non-ferrous metals are recycled and finally other wastes are moved to landfill. On the other hand, recycling, composting, incineration and landfilling are considered in scenario three. In this scenario a leachate collection system with %70 efficiency for the landfill is assumed. Additionally, plastic, ferrous and non-ferrous metals and glass are recycled, wood and paper are burned in incinerator, wet waste and bread are moved to the composting facility and other wastes and residue are landfilled. Moreover, the produced bottom ash and recycling and composting residue in all scenarios are moved to landfill.

Data were collected from currently Lavan island waste management reports and also the interviews and site visiting of the disposal facilities. The gathered information contains the quality and quantity of the collected waste, profile of climate and climatic, characteristics of the disposal facilities, number of employees, distance among facilities, energy consumptions and land usage. In addition, to estimate the generated emissions based on the generated solid waste a computer program named Integrated Waste Management (IWM) software was used. The inventory results for the scenarios are shown in Table 3. However, Eco-indicator 99 was used to weight the impacts of the emissions.

Due to the uncertainties of the chosen impact assessment procedure, three different approaches namely; Egalitarian (E), Hierarchist (H) and Individualist (I) perspective are introduced in Eco-indicator 99 (PRé, 2001). There are different normalizing factor and

Table 3. The inventory results of each scenario (per functional unit)

Substances	Scenario 1	Scenario 2	Scenario 3
Air			
CO_2 (kg)	-2318.702359	-2361.399837	-2304.56704
CH_4 (kg)	-19.08101027	-13.73816595	-20.78576064
NO_x (kg)	-8.236070014	-2.898509478	-6.192233048
SO_x (kg)	-9.935591622	-8.225385974	-9.28119857
HCl (kg)	-111.4730203	-110.7605984	-111.1993503
PM (kg)	-1.951188115	-2.545877915	-2.281513443
VOCs (kg)	-8.950478826	-8.511204134	-8.791788878
Pb (kg)	-0.000318197	0.003437196	0.001126035
Hg (kg)	-2.52712E-05	0.001396163	0.000521417
Cd (kg)	-8.92426E-06	0.000361812	0.000133629
Dioxins (TEQ) (g)	9.509E-13	3.69337E-09	1.41939E-09
Water			
Pb (kg)	-0.000529602	-0.000547085	-0.000563967
Hg (kg)	3.82177E-06	2.81116E-06	3.08929E-06
Cd (kg)	8.3145E-05	2.74212E-05	2.30628E-05
BOD (kg)	2.835170194	1.854749647	1.864735245
Dioxins (TEQ) (g)	1.11586E-11	2.86035E-12	2.44722E-12

weights for each procedure. Hereupon, the Egalitarian and Individualist are focused more on the radical reality than the Hierarchist one, which due to its moderation, is therefore recommended as a default (PRé, 2001; Cordella et al. 2008). So, Eco-indicator 99 in the Hierarchist perspective was utilized in this study.

Eco-indicator 99 evaluates damages to human health, ecosystem quality and mineral and fossil which are discussed in detail as follows. Human health damages assume the basic possible problems for human kind including: transmitted illnesses by environment, disabilities due to pollution or premature deaths, climate change, ozone layer depletion, ionizing radiation, respiratory effects and carcinogenesis (Geodkoop and Spriensma 2001). Ecosystem quality assesses the acidification, eutrophication, ecotoxicity and regional/local effect on vascular plant species which are related to the drawbacks of disruptive changes of the non-human species' population and geographical distribution (Geodkoop and Spriensma 2001). Additionally, the measurements of the additional energy requirement to compensate the lower future ore grade are evaluated as the damage to mineral and fossil resources (Geodkoop and Spriensma 2001). There are eleven impact categories which would present the potential environmental impacts of the various solid waste management systems in Lavan Island; a) Human health: carcinogenic, organic substances, inorganic substances, climate change, ionizing radiation and ozone layer depletion, b) Ecosystem quality: ecotoxic emissions, the combination of acidification & eutrophication and double coating, c) mineral and fossil resources: extraction of minerals and the fossil fuels.

RESULTS & DISCUSSION

The amount of generated emissions for each scenario is presented in Table 4, obtained from IWM model. The considered emissions in IWM model are greenhouse gases (CO_2 and CH_4), acid gases (NO_x, SO_x and HCI), smog precursors (NO_x, PM and VOCs), heavy metals and organic (Pb, Hg, Cd and Dioxins). Moreover, the emissions are considered in both water and air environments. The given data of heavy metals and organics are the summation of both water and air amounts. The emissions and damages for each scenario based on the Eco-indicator 99 are evaluated and given in Table 5. Moreover, impact categories are discussed as follows.

With respect to the generation of Iran's electricity specifications, the energy consumption of each scenario is given in Table 6. IWM software calculated the amounts of emissions in respect to the concept of from cradle to grave. In addition, the main sources of

Table 4. Emissions and damages for the scenarios

Substances	Scenario 1	Scenario 2	Scenario 3
Air			
CO_2	-12.63692785	-12.86962911	-12.55989037
CH_4	-2.181570066	-1.570711989	-2.376477586
NO_x	-22.60801219	-7.956408517	-16.99767972
SO_x	-14.91531014	-12.34794942	-13.93293529
HCl	0	0	0
PM	-18.47775144	-24.10946385	-21.6059323
VOCs	-0.150368044	-0.142988229	-0.147702053
Pb	-0.063003056	0.680564865	0.222954973
Hg	-0.001632521	0.090192158	0.033683568
Cd	-0.038035205	1.542041117	0.569528139
Dioxins (TEQ)	4.43148E-06	0.01721222	0.006614794
Water			
Pb	-0.000305051	-0.000315121	-0.000324845
Hg	5.88553E-05	4.32919E-05	4.7575E-05
Cd	0.156927967	0.05175482	0.04352869
Dioxins (TEQ)	0.000585989	0.00015021	0.000128515
Total	-70.91533833	-56.61550756	-66.74445591

Table 5. Impact assessment results for the scenarios

	Scenario 1	Scenario 2	Scenario 3
Damage category human health			
Carcinogenic effects on humans	0.1230844	1.3380124	0.5184337
Respiratory effects on humans caused by organic substances	-0.1567029	-0.1475493	-0.1546029
Respiratory effects on humans caused by inorganic substances	-51.529253	-42.456084	-49.02737
Damage to human health caused by climate change	-14.812163	-14.43578	-14.929467
Human health effects caused by ionizing radiation	-1.241E-11	1.341E-10	4.392E-11
Human health effects caused by ozone layer depletion	0	0	0
Total	**-66.375**	**-55.7014**	**-63.593**
Damage category ecosystem quality			
Damage to by ecotoxic emissions	-0.068483	1.0436312	0.3577277
Damage by the combined effect of acidification and eutrophication	-4.4718212	-1.9577381	-3.509177
Double counting	0.0076999	0.0050927	0.0063044
Total	**-4.5326**	**-0.90901**	**-3.14514**
Damage category resources			
Damage to resources caused by extraction of minerals	7.196	7.196	7.196
Damage to resources caused by extraction of fossil fuels	-284.52504	-299.24994	-290.53969
Total	**-277.329**	**-292.054**	**-283.344**

Table 6. Sources of energy supply in Iran

Energy	percent of generation	Fuel needed			weighted damage factor		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Coal (Kg)	0.4	-1.11E+01	-1.17E+01	-1.14E+01	-6.68E-02	-7.02E-02	-6.82E-02
Natural Gas (m^3)	72.9	-1.63E+03	-1.71E+03	-1.66E+03	-2.13E+02	-2.24E+02	-2.18E+02
Diesel & Light Fuel Oil (Kg)	8.2	-1.59E+02	-1.68E+02	-1.63E+02	-2.30E+01	-2.41E+01	-2.34E+01
Heavy Fuel Oil (Kg)	17.3	-3.36E+02	-3.54E+02	-3.43E+02	-4.84E+01	-5.09E+01	-4.95E+01
Hydro	1.2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	**100**	**-2.13E+03**	**-2.24E+03**	**-2.18E+03**	**-2.85E+02**	**-2.99E+02**	**-2.91E+02**

Table 7. Land occupation

Land use	Land occupation per day (m^2)			weighted damage factor		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Landfilling	0.017922909	0.014864232	0	0.001607685	0.001333322	0
Composting	0.058707865	0	0.03792551	0.005266096	0	0.003401918
Incineration	0	0.032700803	0.023147979	0	0.002933262	0.002076374
Recycling	0.009209947	0.009209947	0.009209947	0.000826132	0.000826132	0.000826132
Total	**0.085840721**	**0.056774983**	**0.070283436**	**0.007699913**	**0.005092716**	**0.006304424**

energy supply in Iran are coal, natural gas, diesel, heavy fuel oil and hydro which their participations are presented in Table 6. However, it depicts that energy saving must carried out especially in natural gas consumption. It is the evident that scenario two has the maximum positive impact on comparison with the other two scenarios. Further, the amount of land occupation is estimated and presented in the Table 7. The daily land needed for scenarios one, two and three are 0.86, 0.057 and 0.070 m^2, respectively. The weights of land usage are calculated according to the Eco-indicator 99.

The most responsible elements on carcinogenesis are Cd and Dioxins. As shown in Table five, scenario one has the least negative effect whereas scenario two by far has the maximum damage. The CH_4 and VOCs emissions as organic substances lead to adverse human health. However, all the scenarios have positive effects, but scenario two has less effect on human health whereas scenarios one and three with identical amounts have more positive effects. Inorganic substances such as No_x, So_x and PM10, have respiratory effects on human health. However, their weights are more or less the same but with a little difference scenario two, three and one have less effects on human health, respectively. In all the scenarios methane and Carbon Dioxide have significant effects on climate change impact category. However, in scenario two because of more Landfilling material more methane gas is produced and leads to be found as the most undesirable among the others. Predictably, the amount of disposed waste in the landfill has a direct relationship to methane generation that would leave adverse effect on climate change. Scenarios three and one have less positive effect on the climate change, respectively. Emission of Pb in air leads to ionizing radiation in the all scenarios. Moreover, scenario one has positive effect on human health whereas scenarios two and three have negative effects. However, scenario two has by far the most damage. In all the scenarios, the emissions which would cause damage to the ozone layer depletion are not in the output of IWM model. Hence, there will not be any adverse effect on the depletion of ozone layer. In addition, Dioxins and heavy metals including Pb, Hg and Cd in gaseous and liquid forms are considered as the main sources for the ecotoxic hazardous impacts. It should be noted that Cd concentration is obtained significantly higher than other metals. However, scenario one reduces the ecotoxicology of the system whereas other scenarios are harmful. Moreover, scenarios three and two have negative impacts on ecosystem quality which is significantly caused by the incineration facility. Acidification and eutrophication are mainly caused by No_x and So_x gases where the effect of No_x is more than the So_x gases. Additionally, scenarios one, two and three show positive impacts on the ecosystem quality and it should be noted that scenario one has the least drawbacks due to the production of these gases during the burning process. Scenarios one, two and three need 0.086, 0.057 and 0.07 m^2 lands per day, respectively. Based on the results obtained by the Eco-indicator 99, scenario two has the minimum effects on the land usage whereas scenario one has the maximum effects. It should be noted that the evaluated scenarios due to the lack of available land in island are chosen according to the least land usage.

Moreover, there are negative impacts on the material recovery caused by recycling of Iron and Aluminum. All the scenarios with the same intensity lead to negative impacts on the mineral resources. Fossil fuels such as coal, natural gas, diesel (light fuel oil) and heavy fuel oil are considered to leave adverse impacts on the resources. Scenarios two, three and one have positive impacts on fusil fuel resources. However, scenario two has the maximum positive impacts on the energy resources and the scenario one has the minimum positive impacts. Impact assessment of all the scenarios on the human health, ecosystem quality and damage to the resource are illustrated in the Fig. 2. Subsequently, these three scenarios are compared in three categories. According to the Fig. 2, all the scenarios have approximately same final weights and also they have positive effects on the environment based on the life cycle assessment methodology. Scenario one has more positive impacts on human health and ecosystem quality than the other two scenarios whereas scenario two has more positive effects on damaging the resources. To sum up, the final weights of the scenarios are shown in Fig. 3. It should be noted that the positive weights are presumed as drawbacks and the negative weights are assumed as benefit. Therefore, based on the Fig. 3, scenario three is selected as the proper solid waste management system among the other scenarios. The final LCA weights of the scenario one, two and three are -348.237, -348.664 and -350.082, respectively.

CONCLUSION

Among the different disposal methods for Lavan island such as landfilling, composting, recycling and incineration, three combinations are selected as the best practical solid waste management scenarios. Their environmental impacts are estimated and compared in accordance with the guideline of Eco-indicator 99 which is a damage oriented method for life cycle assessment. The results show that landfilling along with recycling, incineration and composting (scenario

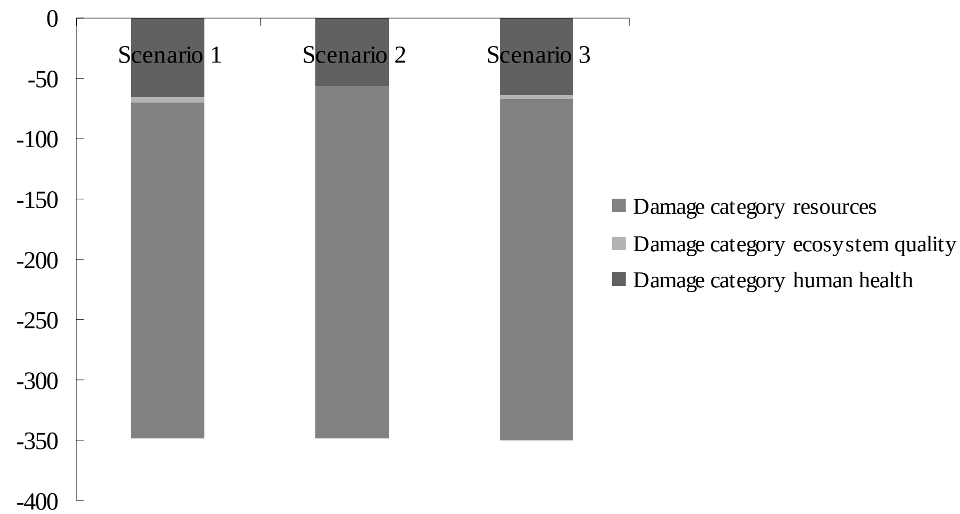

Fig. 2. Weighted impact category values

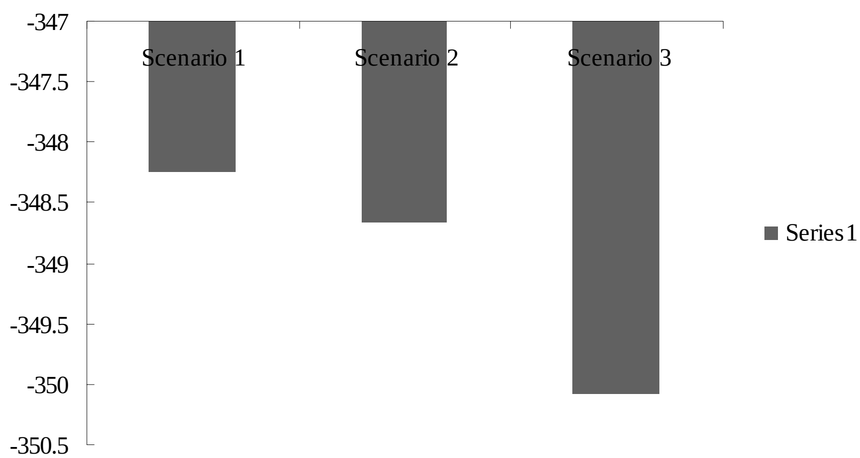

Fig. 3. Scenario's final weights

three) has the highest positive impacts on the human health, ecosystem quality and resources. In all the scenarios methane and CO_2 have the main effects on the air pollutions. Scenario two produces the maximum heavy metals especially Cd among the others that is generated by the incineration. Moreover, heavy metals including Cd and Hg show extreme role in the water pollution. Additionally, Sox and Nox are mostly the effective pollutants in scenario one. Land occupation is an important issue in small islands and due to the results scenario one has more rate of land usage whereas scenario two has the least. In addition, scenario two has the more positive impacts on energy consumption whereas scenario one has the least. Although, the final weights of all the three scenarios are closely the same but with a slight difference scenario three is recommended as the proper solid waste management system in Lavan island.

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