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Comparison of solid waste management scenarios based on life cycle analysis and multi-criteria decision making (Case study: Isfahan city)

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Abstract

Life cycle assessment (LCA) is one of the decision support systems which can be considered for assessing the different approaches of Waste Management. However, it only considers environmental effects and ignores other decision making options such as economic and social effects of solid waste management. In this research, we consider a combination of three decision making options including environmental, economic and social effects to compare current waste management system to six alternative scenarios for selecting the best scenario of solid waste management for Isfahan city where a total of approximately 1000 tons/day of waste is generated. SimaPro7 libraries through Eco-Indictor 99 method were used to obtain background data for the life cycle inventory and assessing mid and end points of environmental impacts. One ton of municipal solid waste of Isfahan was selected as the functional unit. Output of LCA along Economic and social effects were compared with Technique for Order Preference by Similarity to Ideal Solution method. According to Multi-criteria Decision Making, S5 and S1 (recycling, composting and landfilling) were selected as best scenario in terms of lower environmental impacts (human health, ecosystem quality and resources) and finance requirements.

Keywords: Waste Management Scenario; life cycle assessment; TOPSIS; Isfahan

1. Introduction

Wastes or undesired materials threaten all kinds of living things. That is why it must be disposed of without damaging the human mental and physical health, the animal health, flora, water and the welfare of the society, and comply with new regulations (Ulukan*et al.,* 2009). Thus, Waste Management is a basic need of any society. Regarding the rate of waste production and the composition of the waste, different alternatives might be used for Waste Management systems (SETAC, 1998). For this purpose, different techniques and options such as recycling, composting, incineration, etc. can be used. One of the ways to assess these options is modeling. Studies on modeling of solid waste management systems started in the 1970s and advanced with the development of computer models in 1980s. While models in 1980s were generally based on an economic perspective (Gottinger, 1988), models that included recycling and other waste management methods were developed for planning of municipal solid waste management systems in the 1990s (MacDonald, 1996). Models developed in recent years have taken an integrated solid waste management approach, and included both economic and environmental analyses. The models have included linear programming with Excel-Visual Basic (Abou Najmand, 2004). Decision Support Systems (Fiorucci*et al.,* 2003; Haastrupetal, 1998), fuzzy logic (Chang and Wang, 1997) and Multi Criteria Decision Making techniques (Hokkanen & Salminen, 1997). One important aspect of waste management planning is to ensure the identification of areas in which specific measures should be taken to reduce the environmental impacts of waste management. To demonstrate the performance of management alternatives in the decision-making process, authorities, communities, industry and waste management companies should consider environmental aspects in addition to the evaluation of technical and economic aspects (Obersteineretal., 2007). LCA is a holistic approach that is increasingly utilized for solid waste management especially in the decision-making process and in strategy-planning. LCA can be categorized as a hybrid approach since it utilizes equations for inventory analysis and recycling loops on the one hand, while on the other hand it requires expertise input for impact assessment and characterization.

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It is accepted that LCA concepts and techniques provide solid waste planners and decision makers with an excellent frame work to evaluate MSW management strategies (Obersteiner*et al.,* 2007).

In LCA of the waste, the point of birth, which is known as the cradle, is the door of the house and the burial is known as the grave. In each stage, consumed resources and outputs are considered. Such processes are considered as a system. Inputs (resources) and outputs (pollutants) are inventoried and finally are assessed and interpreted. (Khorasani et al. 2012). LCA developed rapidly during the 1990s and has reached a certain level of harmonization and standardization. An ISO standard has been developed, as well as several guidelines. There are four ISO standards specifically designed for LCA application: (Mark et al., 2004)

1) ISO 14040: Principle and framework
2) ISO 14041: Goal and Scope definition and inventory analysis
3) ISO 14042: Life Cycle Impact Assessment
4) ISO 14043: Interpretation.

In Ankara, LCA was used for the comparison of the different methods of Waste Management. In that study, five scenarios, which were applied in Waste Management, were defined and considered. Afterward, the environmental load of each scenario was inventoried and presented. Impact assessment of life cycle was not conducted and by comparing the results of the life cycle inventory, suitable alternatives were chosen and presented. Finally, distance reduction from the source had the least environmental impact and was presented as the best method of solid Waste Management (Ozeler, 2006). Cherubini *et al.,* (2008) compared current waste management with the different alternatives of Waste Management that were based on the basis of energy economizing and lesser environmental impacts in the city of Rome. They showed that recycling the energy by Waste Management could supply 15% of the required electrical energy for the city (Cherubini *et al.,* 2008). Other LCA studies on urban waste management such as the study of Cherubini et al. (2009) shows that landfilling is the worst strategy considering environmental impacts (Cherubini *et al.,* 2009). From a life cycle point of view recycling of paper is environmentally equal or better than incineration with energy recovery according to the study of Merrild *et al.,* 2008. Iriarte *et al.,* (2009) analyze environmentally the selective collection management of municipal solid waste. Their goal is to compare and quantify different collection systems by means of LCA (Iriarte *et al.,* 2009). Buttol et al. (2007) examined the MSW management system of the Bologna district in Italy. The scope of the study was to compare three different MSW scenarios in the Bologna district. Scenario 1 was based on the current MSW practices; scenario 2 anticipates a strong increase in the fraction sent to incineration with energy recovery, the percentage increasing from 30% to 50% of the total MSW; scenario 3 anticipates a fraction sent to incineration equal to 37% of the total waste and a separated collection equal to 31%. Data were obtained from the actual MSW management operations in Bologna and WISARD software was used for life cycle Inventory. They suggested that, there is a clear environmental benefit in increasing recycling and incineration with energy recovery.

De Feo, & Malvano (2009) studied various MSW management scenarios in southern Italy. The aim of this study was to apply the LCA procedure to MSW management on the Province of Avellino in Italy in order to choose the "best" management system in environmental terms. The MSW management scenarios considered can be divided into two categories: the first includes scenarios that are based on the incineration of the dry residue, while the second does not consider the thermal treatment of dry residue. All the data necessary for the construction of the analyzed scenarios were obtained from the Province of Avellino and the two MSW management companies and WISARD software was used for LCAI. The selection of the best scenario depends on the impact category examined. More specifically the scenario that includes 80% separate collection, no Refuse Derived Fuel (RDF) incineration and dry residue sorting was the most preferable for the following six impact categories, "renewable energy use, total energy use, water, suspended solids and oxidable matters index, eutrophication and hazardous waste". On the other hand, the scenario with 80% separate collection and RDF production and incineration is preferable for the following three impact categories: non-renewable energy use, greenhouse gases and acidification. Finally, the scenario with 35% separate collection, RDF production and incineration is the most preferable for the mineral and quarried matters and non-hazardous waste impact categories.

Banar *et al.* (2009) studied various MSW management methods for Eskisehir, Turkey. The scope of the study included the development of five alternative scenarios to the current MSW management system, which is uncontrolled dumping. Scenario 1 is an improved version of the current system assuming a 92.7% landfilling; Scenario 2: A source separation system with 50% efficiency was added as an improvement to scenario 1. The recyclables obtained from source separation were sent to the MRF; Scenario 3: The flow of recyclables is similar to scenario 2, while the organic fraction from the MRF is transported to the composting facility. Scenario 4: An incineration process was added instead of a composting facility. All organic wastes and the wastes from the separated recyclables are transported to the incinerator (85%); Scenario 5: all MSW is sent to the incineration facility (100%). Data were gathered from actual applications in Eskisehir, literature and the database of SimaPro 7. They found that recycling of materials leads to lower abiotic depletion. Also, the scenarios that include recycling (S2, S3 and S4) are better than the others in terms of human toxicity (mainly due to the recycling of aluminum). Scenario 3 is the best option in terms of global warming, acidification (because of the displacement of fertilizer), eutrophication and photochemical ozone depletion.

2. Description of the Scenarios

As a result of increasing population and developing cities, the quantity of municipal solid waste is rising rapidly. According to governmental reports approximately 1000 tons of MSW is generated daily in the city of Isfahan and population of the central part of the township in 2009 was 1689465 people with growth rate equal 1.42 percent. Two private companies are employed to collect the municipal solid waste from city. The first group collects recycle materials and the second group collects the rest of the solid waste from residential areas. The recyclable wastes are collected in one bag and biological waste and mixed waste are collected in another bag. Vehicles collect wastes in plastic bags that are discarded and piled up on the streets by the residents, and transport them to the dumping site. At first, mixed and biological wastes go through MRF system (separation, recycling) then are transferred to landfill. Biological waste is transported to the composting facility.

The dumping site and recycling facilities are located 60 km away from Isfahan city (average distance). Electricity consumption of the MRF for sorting equipment and compressing bales is 0.06 kWh/ton. The composition of the Isfahan MSW is given in Table1.

Table 1. Composition of MSW in Isfahan

Component	Composition (wt. %)
Paper	8.16
Glass	2
Plastics	7.16
Metal	0.61
Pet	1.1
Organic waste	70.75
Others	10.22

3. Waste scenarios

The aim of this study is to select an optimum waste management system for Isfahan by evaluating life cycle from an environmental and economic point of view because the recovery of solid waste is considered economically and environmentally worthwhile. It can decrease raw materials need of the industry and to decrease energy consumption for the raw material production as well. The recovery of solid waste will also reduce the amount of land filling. But the recovery quality depends on how waste is collected. In this study, recycling was carried out in two ways, source separation and MRF system. We developed six alternative scenarios to the current waste management system in Isfahan that are explained below.

3.1. Scenario 1

This scenario was based on the current waste management system. In this scenario, there are a material recovery facility (MRF), source separation, composting and landfilling. The percentages of recycling and landfilling are demonstrated in Fig. 1. The recyclable fraction (12%) collected by scavengers is directly sent to recycling process with recycling efficiency between 50-90 percent and the rest of recyclables (9.25%) was separated in the MRF with recycling efficiency 40-70 percent depending on the kind of waste (Table 2). The organic material (70.75%) was separated in the MRF and then sent to composting process with 90% efficiency. The residuals after the recycling and composting process were landfilled.

Table 2. Recycling efficiency of different kind of waste

Waste sources	Material	Efficiency (%)
Source separation of recyclables	paper	90
	glass	90
	plastic	50
	metal	50
	pet	70
	other	
Separation of recyclables from mixed waste	paper	70
	glass	70
	plastic	40
	metal	40
	pet	50
	other	0
	Organic materials	90

3.2. Scenario 2

An incineration process was added to previous scenario instead of landfilling. (Fig. 2)

3.3. Scenario 3

MRF system was removed from scenario 1 and only recycling process carried out on source separation waste (Fig. 3).

3.4. Scenario 4

This scenario is the same as the previous scenario 3 but an incineration process was added instead of landfilling (Fig. 4).

3.5. Scenario 5

In this scenario a source separation system with efficiency of 90% was added as an improvement to Scenario 1 and recyclables material from MRF was deleted. (Fig. 5).

3.6. Scenario 6

In this scenario it was considered that all MSW is sent to the landfill (100%). (Fig. 6)

3.7. Scenario 7

In this scenario it was considered that all MSW is sent to the incineration facility (100%). (Fig. 7)

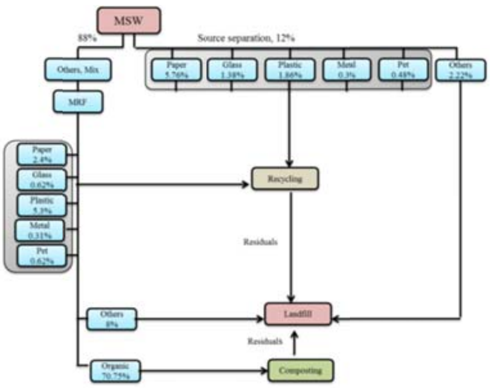

Fig. 1. Flowchart of the scenario 1 (after efficiencies). 12.5% recycling + 23.8% landfilling + 63.7 %composting

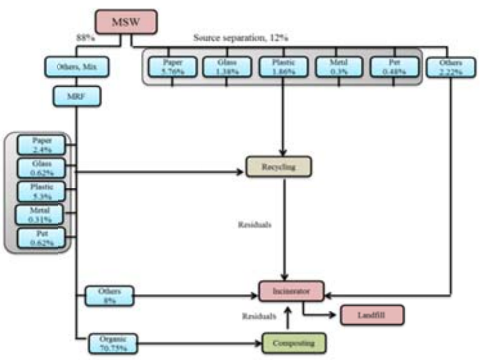

Fig. 2. Flowchart of the scenario 2 (after efficiencies). 12.5% recycling+63.7 %composting+23.8% incineration

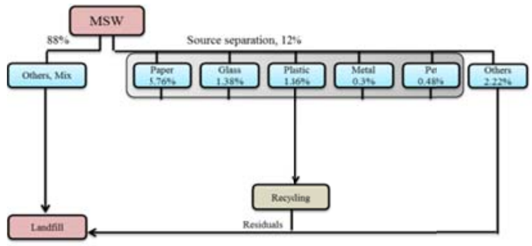

Fig. 3. Flowchart of the scenario 3 (after efficiencies). 7.8% recycling + 92.2% landfilling

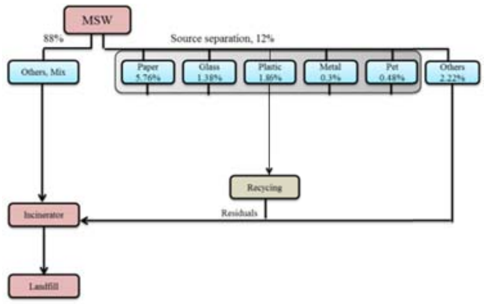

Fig. 4. Flowchart of the scenario 4 (after efficiencies). 7.8% recycling + 92.2% incineration

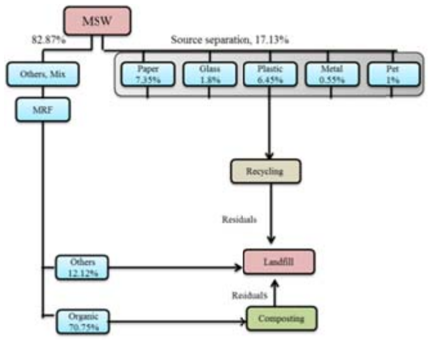

Fig. 5. Flowchart of the scenario 5 (after efficiencies). 12.4% recycling + 63.7 %composting +23.9% landfilling.

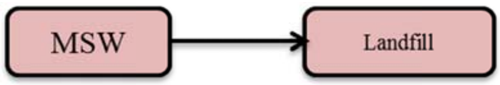

Fig. 6. Flowchart of the scenario 6 (after efficiencies). 100% landfilling

Fig. 7. Flowchart of the scenario 7 (after efficiencies). 100% incineration

4. Materials and Methods

The LCA methodology based on TSE EN ISO 14040-44: 1996 was used to conduct an environmental comparison of the alternative scenarios to the current waste management system. An LCA system comprises four major stages: goal and scope definition, life cycle inventory, life cycle impact analysis and interpretation of the results. The functional unit selected for the comparison of the alternative scenarios is the management of 1 ton of municipal solid waste. The system boundary of the study starts with collection of MSW from residential areas and includes waste transport, waste treatment alternatives (recycling, composting and incineration) and landfilling of waste. In this study, life cycle analyses of the secondary materials obtained from the recycling and composting processes were not considered. The data for life cycle inventory was gathered from actual applications in Isfahan, the related literature, and the database of the SimaPro7. In Life Cycle Impacts Assessment result of inventory, a life cycle converts to objective units and consequently managerial form would be achieved. (Hofstetter *et al.,* 1999). Eco-indicator'99 was used to compare different developed solid waste scenarios. It provides one of the best mid and end points of environmental impacts including 10 categories such as carcinogens, respiratory organics, respiratory inorganic, climate change, radiation, ozone layer, eco toxicity, acidification/ eutrophication, land use minerals. Endpoint impacts were originally developed in 1995 to provide designer and design engineers with environmental information in a simple single value format and are intended for internal use. The midpoint was combined into three different categories including; Human Health; measured in disability-adjusted life years, that is, the different disabilities caused by diseases are weighted. Climate change, which is an international concern, is categorized under this damage category. DALY (Disability Adjusted Life Years) which is a measure of the disability caused by different environmental impacts and the impact on human health. Ecosystem quality or ecotoxicity; which is measured in PDF m2year (Potentially Disappeared Fraction of plant species). The impact category of acidification is listed under this environmental category. In terms of Eco toxicity, the measured aspect is the percentage of all species present in the environment living under toxics tress (potentially affected fraction or PAF m2 year). Resources; the last category measures the additional energy requirement to compensate lower future ore grade, and the unit of measurement is in mega joule (MJ) surplus. (Tan et al., 2006). TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was developed by Hwang and Yoon (1981) as an alternative to the ELECTRE method. The basic concept of the method is that the selected alternative should have the shortest distance to the ideal solution and the farthest distance to the negative-ideal solution. The Euclidian distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution (Triantaphyllou, 2000). It solves the dilemma of the choice between ideal and anti-ideal by using an idea that Dasarathy (1976) applies to the data analysis. The TOPSIS method evaluates the decision matrix which refers to alternatives which are evaluated in terms of criteria (POMEROL, 1993). Different collection methods (scenarios) are compared with a multi-criteria decision making tool on the basis of economic and environmental criteria. The end points of environmental impact evaluation (resource depletion, human health, ecological impacts) were entered as the first three criteria in TOPSIS decision making process and two other criteria were selected recovery rate and cost of each waste scenario. Environmental impacts, cost and recovery rate are the criteria and different waste scenarios are the alternatives in multi criteria decision support analysis (Table 3). Weight assigned using expert opinions and 0 and 1 in min/max row show a negative and positive relation consequently.

Table 3. Characterization of criteria and scenarios in Topsis model

Scenarios	Resource	Humanhealth	Ecosystem	Recoveryrate	Cost
SC1	0.000398292	0.004591265	0.0001141	76.2	Low
SC2	0.000831887	0.009836136	0.00016326	76.2	High
SC3	0.001575276	0.01899087	0.0004406	7.8	Low
SC4	0.003018314	0.029628604	0.00061453	7.8	High
SC5	0.000400566	0.004670227	0.00011436	76.1	Very Low
SC6	0.00170229	0.021144284	0.00047244	0	Moderate
SC7	0.003225409	0.031587362	0.00066455	0	Very High
Weight	0.2	0.3	0.2	0.15	0.15
max/min	0	0	0	1	0

5. Results

5.1. Environmental Impacts

The results of the end point characterization analysis per functional unit (1 ton of MSW) for each impact category are demonstrated in Fig. 8

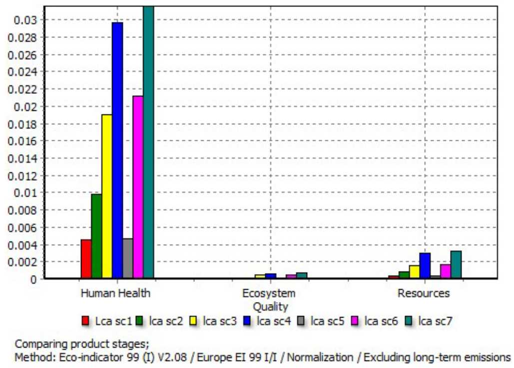

Fig. 8. End point characterization analysisfor each impact category

As shown in Fig 8, the human health has the most environmental impact in all scenarios. S7 is higher than the other scenarios due to climate change and carcinogen; they mostly result fromcarbon dioxide and fossil fuel at the air and arsenic ion in the water produced by incinerator. S1 and S5 have lower impacts on human health (Table 4). All of the scenarios show approximately the same trend for ecosystem quality and resource depletion. S1 and S5 are the best scenarios for this impact category through the recycling and separating resources. S1 and S5 are the best scenarios in resources impact category. S7 has the highest resources effect due to nickel, 1.98%in silicates, and 1.04% in crude ore, in ground (Table 4). Considering the life cycle, the fifth system is the most environmentally friendly system because the source separation is higher than other scenarios so recycling is better than other scenarios.

5.2. Combination of Economic and environmental impacts

According to TOPSIS decision making process (Table 5) the most suitable collection system is the S5 and S1. They are the most friendly environmental systems and have a higher recovery rate compared with the others.

6. Discussion and Conclusion

The primary aim of this study was to select an optimum waste management system for Isfahan on the basis of an environmental-economic point approach. In most of the studies, economic and social aspects are used to compare these methods but due to multiplicity of environmental factors and their complexity, environmental aspect has been neglected. Scenario 5 and scenario 1 were selected as the best waste management scenario because they had less impact on the human health, ecosystem quality and resources (Table 3). These scenarios include recycling, composting and landfilling. Recycling saves energy and helps mitigate carbon dioxide (CO2) emissions (Tan et al., 2006). Burning of wastes (Sc7, Sc4, Sc2) can generate pollutants such as sulfur oxides and nitrogen oxides), cadmium, copper, lead, mercury, and dioxins/furans, which could potentially contribute to environmental problems, like acidification, human toxicity, and ecotoxicity (Table 4). Wasteful consumption patterns exploit and diminish natural resources. To preserve the natural environment and conserve natural resources, there is an obligation for the community to minimize waste output and to recycle as much waste as possible. The recovery of solid waste is economically and environmentally worthwhile. Instead of landfilling materials as glass, plastic, metal, ceramic and paper, they can be assessed as secondary raw materials. Thus, it is possible to decrease the raw material need of the industry and to decrease energy consumption for the raw material production as well. The recovery of solid waste will also reduce the amount of landfilling. Combination of Life Cycle Analysis and Multi-criteria Decision Making can help the environmental designers to make better decisions in relation to different waste scenarios. In this study, waste management alternatives were investigated from environmental and economic points of view. For that reason, it might be supported with other decision-making tools that consider the social effects of solid waste management.

Table 4. Effect of waste scenarios management on the end point environmental impacts (sc=scenario)

	Substance	Compartment	Lca sc1	lca sc21	lca sc3	lca sc4	lca sc5	lca sc6	lca sc7
Human health	Carbon dioxide, fossil	Air	0.000209	0.008322	0.000774	0.024429	0.000208	0.000823	0.02574
	Methane, biogenic	Air	0.0034982	7.367E-07	0.014898	3.1E-06	0.003578	0.01676	3.43E-06
	Arsenic, ion	Water	5.172E-05	0.0008193	0.000207	0.0026873	5.328E-05	0.0002445	0.003141
	Particulates, < 2.5 um	Air	0.000274	0.0003298	0.0010767	0.0012411	0.0002769	0.0011733	0.001338
Ecosystem Quality	Remaining substances		4.401E-05	3.547E-05	0.000169	0.000133	4.42E-05	0.000183	0.000142
	Occupation, traffic area, road network	Raw	6.679E-05	8.042E-06	0.00026	3.38E-05	6.69E-05	0.000279	3.68E-05
	Occupation, dump site	Raw	5.331E-05	1.024E-05	0.000207	4.32E-05	5.34E-05	0.000223	4.72E-05
	Transformation, to dump site, sanitary landfill	Raw	5.275E-05	2.683E-07	0.000205	1.04E-06	5.28E-05	0.00022	1.13E-06
	Nitrogen oxides	Air	2.905E-05	0.0001241	0.000111	0.000466	2.92E-05	0.00012	0.000506
	Transformation, from dump site, sanitary landfill	Raw	-5.27E-05	-2.683E-07	-0.000205	-1.04E-06	-5.28E-05	-0.00022	-1.13E-06
	Transformation, from pasture and meadow	Raw	-7.91E-05	-1.454E-05	-0.000306	-6.18E-05	-7.94E-05	-0.000332	-6.75E-05
Resources	Remaining substances		5.475E-05	0.0001217	0.000205	0.000428	5.51E-05	0.000222	0.000456
	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	0.0002387	0.0005351	0.000934	0.001982	0.000239	0.001004	0.002127
	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Raw	5.963E-05	9.988E-05	0.000248	0.000347	6.04E-05	0.000271	0.000366
	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Raw	4.524E-05	7.522E-05	0.000188	0.000261	4.58E-05	0.000205	0.000276

Table 5. Ranking of Waste scenarios

Name of scenario	Priorities	Ranking
SC7	0.000	7
SC4	0.105	6
SC6	0.385	5
SC3	0.463	4
SC2	0.760	3
SC1	0.931	2
SC5	0.998	1

References

Abou Najm, M., & El-Fadel, M. (2004).Computer-based interface for an integrated solid waste optimization model. *Environmental Modeling and Software* 19,1151–1164.

Banar, M., Cokaygil, Z., & Ozkan, A. (2009). Life cycle assessment of solid waste management options for Eskisehir, Turkey. *Waste Management*, 29, 54–62

Bjarnadóttir, H. J., Friðriksson, G. B., Johnsen, T., & Sletsen, H. (2002). *Guidelines for the use of LCA in the waste management sector.* Nordtest, Finland

Buttol, P., Masoni, P., Bonoli, A., Goldoni, S., Belladonna, V., & Cavazzuti, C. (2007). LCA of integrated MSW management systems: Case study of the Bologna District. *Waste Management*, 27, 1059–1070

Chang, N. B., & Wang, S. F. (1997). A fuzzy goal programming approach for the optimal planning of metropolitan solid waste management systems. *European Journal of Operational Research*, 99(2), 303–321.

Cherubini, F., Bargigli, S., &Ulgiati, S. (2008). Life cycle assessment of urban waste management: Energy performances and environmental impacts. The case of Rome, Italy. *Waste Management*, 28(12), 2552–2564.

Cherubini, F., Bargigli, S., &Ulgiati, S. (2009). Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration. *Energy*, 34(12), 2116–2123

De Feo, G., & Malvano, C. (2009) The use of LCA in selecting the best management system. *Waste Management*, 29, 1901–1915

Fiorucci, P., Minciardi, R., Robba, M., & Sacile, R. (2003). Solid waste management in urban areas: development and application of a decision support system. *Resources, Conservation and Recycling,* 37(4), 301–328.

Gottinger, H. W. (1988). A computational model for solid waste management with application. *European Journal of Operational Research*, 35(3), 350–364.

Hellweg, S., Hofstetter, T. B., & Hungerbühler, K. (2001). Modeling waste incineration for life-cycle inventory analysis in Switzerland. *Environmental Modeling & Assessment,* 6(4), 219–235

Hofstetter, P., Braunschweig, A., Mettier, T., Müller, Wenk, R., & Tietje, O. (1999). The Mixing Triangle: Correlation and Graphical Decision Support for LCA-based Comparisons. *Journal of Industrial Ecology*, 3(4), 97–115

Hokkanen, J., & Salminen, P. (1997). Choosing a solid waste management system using multicriteria decision analysis. *European Journal of Operational Research*, 98(1), 19–36.

Iriarte, A., Gabarrell, X., & Rieradevall, J. (2009). LCA of selective waste collection systems in dense urban areas. *Waste Management*, 29(2), 903–914

Jahanshahloo, G. R., Lotfi, F. H., & Izadikhah, M. (2006). Extension of the TOPSIS method for decision-making problems with fuzzy data. *Applied Mathematics and Computation*, 181(2), 1544–1551

Khorasani, N., Naghibzadeh, S., Ghadiryanfar, M., & Badehian, Z. (2012) Life Cycle Assessment (LCA) of Municipal Waste Management System of Karaj.

MacDonald, M. L. (1996). Solid waste management models: a state of the art review. *Journal of Solid Waste Technology and Management*, 23(2), 73–83.

McDougall, F. R., White, P. R., Franke, M., & Hindle, P. (2008). Integrated solid waste management: a life cycle inventory. Wiley Com.

Geodkoop, M., & MichielOele*, Introduction to LCA with SimaPro Product Ecology Consultants*, September 2004.

Merrild, H., Damgaard, A., & Christensen, T. H. (2008). Life cycle assessment of waste paper management: The importance of technology data and system boundaries in assessing recycling and incineration. *Resources, Conservation and Recycling*, 52(12), 1391–1398.

Obersteiner, G., Binner, E., Mostbauer, P., & Salhofer, S. (2007). Landfill modeling in LCA–a contribution based on empirical data. *Waste Management,* 27(8), S58–S74.

Özeler, D., Yetiş, Ü., & Demirer, G. N. (2006). Life cycle assesment of municipal solid waste management methods: Ankara case study. *Environment International*, 32(3), 405–411.

Pomerol, J. C., & Barba-Romero, S. (1993) Choixmulticritère dans l'entreprise principe et pratique Hermès.

Setac,. "LCA New,".Vigon B. (Ed.), (1998). 18(6). www.setac.org.

Tan, R. B., & Khoo, H. H. (2006). Impact assessment of waste management options in Singapore. *Journal of the Air & Waste Management Association,* 56(3), 244–254.

Triantaphyllou, E. (2000). Multi-criteria decision making methods (pp. 5-21). Springer US.

Ulukan, H. Z., & Kop, Y. (2009, July). Multi-criteria decision making (MCDM) of solid waste collection methods using life cycle assessment (LCA) outputs. In Computers & Industrial Engineering, 2009. CIE 2009. International Conference on pp. 584-589. IEEE.