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Original Research

End- of- Life Scenarios for Municipal Solid Waste of Defence Housing Authority Lahore, Pakistan

Azhar Ali[1]*, Shumaila Azam[1], Anam Khalid[1], Durr-e-Shahwar Noman[2], Nadia Jamil[1], Faiza Samina[3], Irfan Ahmed Shaikh[1]

[1]College of Earth and Environmental Sciences, University of the Punjab, Lahore, Pakistan
[2]School of Engineering, University of South Australia, Adelaide, South Australia
[3]Department of Botany, University of the Punjab

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Abstract

This paper evaluates the environmental impacts of various municipal solid waste (MSW) treatment options produced on-site simultaneously with energy and material recovery. The results present a comparison of life cycle assessment (LCA) for municipal solid waste management (MSWM) in five different waste scenarios along with baseline scenario of the Defence Housing Authority (DHA) in Lahore. All scenarios were modeled using EaseTech software. Nine impact categories were assessed and results were presented based on the ASTM D5231-92(2003) characterization method. Results revealed that a material recovery facility (MRF) had low global warming potential (GWP), but lower avoided burdens in other impact categories. The incineration process indicated fewer burdens on the environment such as GWP (-2.086×10^7 kg CO_2eq) as compared to landfills (2.461×10^7 kg CO_2eq). This was due to lower avoided emissions in the landfill process compared to incineration. The negative values in results represented higher avoided emissions in treatment processes. Bio-gasification avoided CO_2 emissions (-8.053×10^5 kg CO_2eq), but showed negative impacts in other categories. Almost all impact categories were high in composting except for freshwater eutrophication. LCA results provided good knowledge for decision makers as a tool to decide what alternative is a better change for sustainable waste management.

Keywords: end of life, municipal solid waste, waste management, waste characterization, life cycle assessment, LCA modeling

Introduction

Municipal solid waste (MSW) includes packaging waste, yard waste, wood, textile, newsprints, bottles, food waste, metals, and plastics. Trade, industry, and human population growth plus variations in living standards and in consumption patterns have been the main factors for progressive increase in generating MSW. As a consequence, management of MSW is one of the major challenges for municipalities in the 21st century [1-2]. In developing Asian countries, these factors are

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*e-mail: azhar.cees@pu.edu.pk

further aggravated because of insufficient resources, poor supervision, and inadequate technical skills within cities and government institutions. To solve this problem an integrated solid waste management (ISWM) approach could be selected based on Asian attitudes after assessing some SWM alternatives through a life cycle assessment (LCA) plan. The results of this approach provide a base to select the best option for innovative waste management services by the decision makers in local, provincial, and national establishments or industries in the region [3].

Like other developing countries, unfortunately Pakistan also faces serious environmental issues. None of its cities has a proper MSW management system, and dumping in open sites is a common practice throughout the country, hence adding to the air pollution because of uncovered dumped waste. Improperly managed, this can cause several environmental impacts such as pollution of soil, surface water, groundwater, and air and, most significantly, can be harmful to public health during every single phase of waste management (collection, processing, and final disposal), because of direct and indirect contact with harmful substances that are released to the environment from the waste [4-5]. Environmental impacts together with the economic restraints are the main driving forces for classifying solutions to reduce the impacts caused by MSW [6]. Safe disposal of MSW is the greatest challenge to sustainable SWM, and ISWM provides a solution to this problem by focusing on "cradle-to-grave" responsibility [7].

For the prevention and management of waste, waste hierarchy is defined in Directive 2008/98/EC of the European Parliament. According to this hierarchy, waste should be managed following the order of priority: prevention in waste generation, reuse, recycling, energy recovery, and final disposal of waste. But according to the directive, this hierarchy can be altered according to specific situations, as in the case of a life cycle assessment study [8]. In addition, disposing of biodegradable material in a landfill calls for regular separating and processing to meet all the objectives as defined in Directive 1999/31/EC of 26 April on landfill of waste [9].

Because of growing stress on waste managers, organizers, and waste controllers for sustainable methods, LCA has been extensively applied because it is a tool that captures and addresses the complexities of a typical integrated waste management system [10]. Many LCA studies have reported dealing with the entire MSW and other deal with the treatment of a single MSW fraction [11]. For the evaluation of MSWM strategies and selection of best MSW management strategy (best for the environment), LCA methodology provides an excellent framework [12]. Biological and mechanical treatment (BMT) in a newly developed ISWM system and LCA methodology has been employed for the comparison of environmental impact potential, three BMT- based methods with traditional incineration and landfilling. It has been clearly shown that the process that has highest acidification potential is traditional thermal treatment, and traditional landfilling is a major contributor toward global warming and eutrophication [13].

Different LCA modeling has been used as a tool for the analysis of different waste management options, especially in Europe, which clearly indicates that sanitary landfills with energy recovery facility have fewer burdens on the environment, but this option is land intensive, having difficulty in the control of emission systems and a longer time period and legislative restrictions in the developed countries discourage landfilling for the waste treatment [14]. MSW is considered as a source of renewable energy production in many countries, e.g., a study shows that in South Korea producing energy from waste is the best method in which non-recyclable waste is used and its results show that the present level of greenhouse gas emissions can be reduced by the increased use of energy from waste (EfW) [15].

MSW incineration has gradually become more recognized as a potential source for waste to energy process and mainly produces valuable outputs with no residues to be disposed of (Fig. 1) [16]. MSW incineration plants can be an important element of industrial ecology as they provide waste disposal services and can help to close material and energetic cycles [17].

The primary goal of this study is the evaluation of the environmental impacts of different methods for the management of MSW of DHA to achieve environmental sustainability in an LCA context. For this evaluation different components were considered: collection of waste, transportation of waste, transfer to MRF, composting, thermal treatment, and landfilling. Five different scenarios consisting of different methods for the management of MSW were developed and compared according to their environmental performance, energy, and fuel consumption. The results were compared in order to identify the best possible solid waste treatment option(s).

Materials and Methods

Study Area

DHA is located in southern Lahore in 11 phases. It supports a population of 170,000 and total MSW generation per day is 170 tons. The Walton Cantonment Board is the concerned authority for the managing MSW in DHA. The dumping site for Walton Cantonment Board is located in Kamahan, which has no official status of MSW of DHA, and other municipalities are brought through collection vehicles by different companies.

Analysis of MSW

Standard procedure was followed for annual sampling of MSW ASTM D5231-92 [18]. A large number of samples were required to determine mean composition of MSW, collection, and manual segregation. MSW samples were taken from the dumpsite where vehicles discharged their load. The collected sample from each discharged vehicle load was prepared before sorting, mixing, conning, and quartering. After sampling, the MSW samples were transferred to the sorting place and manual segregation was done for classifying the MSW into different categories: organics (putrescible – food and yard waste), paper (mixed paper, corrugated), plastic, leather, wood, textile, rubber; inorganic (glass, metals, inert materials – stones and construction waste); and miscellaneous (diapers, sanitary napkins).

For further analysis the samples were subjected to different treatments. Initially samples were placed into an oven and kept there for 5 to 24 hours at 105°C. The size of all the materials was reduced manually using knives and scissors. These samples were then placed into the shredder for mixing and grinding. The samples were preserved after shredding. Samples were subjected to different analyses. Proximate analysis is when the percentages of moisture content, volatile combustible matter, ash content, and fixed carbon were calculated. ASTM standards E790, E830, and E897 were followed for sample analysis [19]. In ultimate analysis the percentage of different elements, carbon, hydrogen, nitrogen, Sulphur, and ash content were calculated by following ASTM standards E777 and E778. The calorific value was determined according to ASTM standard E 955.

Collection and transportation of MSW to the disposal site and to the treatment facility constitutes the environmental burdens because of the use of diesel during transportation. The transportation distance from collection point to the Kahana disposal site is almost 22 km, so the distance for the transportation of waste to each treatment facility is assumed to be 22 km.

For the purpose of pretreatment plants investigation, data was directly collected from the concerned authority responsible for the management of MSW in DHA. This data included population of DHA, quantity of waste, types of vehicles used for collection and transportation of waste, distance to dumping site (km), consumption of diesel fuel (liters), and exiting MSW management practices in DHA.

EaseTech software was used for carrying out LCA of MSW using a database for calculating environmental loads of each process.

Functional Unit and System Boundaries

The functional unit for the study was one ton of MSW generated annually in DHA, Lahore. All inputs and outputs such as emissions to the environment, energy consumption and generation, and materials used were included in this functional unit. The system boundaries for LCA of MSW are defined as the moment when the things cease to have some value, become waste and are sent to a landfill, are transformed to air or water releases, or recover some value through MRF, composting, thermal treatment, and RDF. The system boundaries include all the elements of the system, including all inputs and outputs of the operation for all the waste treatment options. Fig. 1 shows the system boundaries for this study.

LCA Scenarios

Five strategies (including a baseline scenario) were proposed for managing MSW in the Defence Housing Authority Lahore. All of these strategies were selected

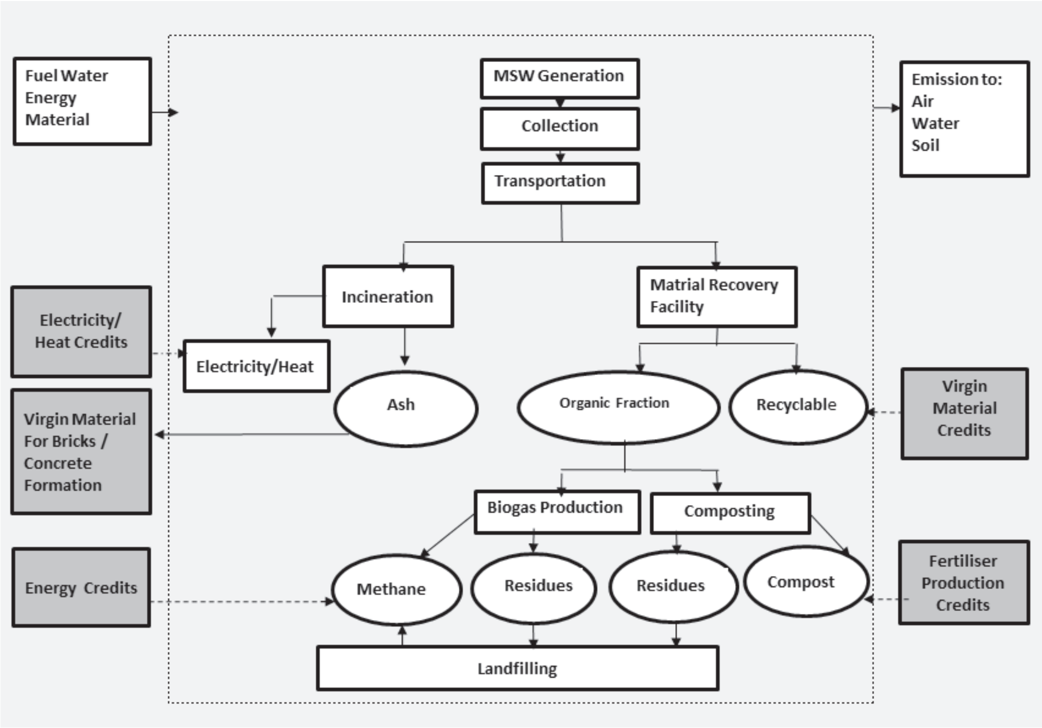

Fig. 1. System boundaries for MSWM and a picture of end-of-life scenarios.

according to the European Union hierarchy of alternatives for MSWM. A picture of all end-of-life scenarios are shown in Fig. 1.

- (S-O): The baseline method defines the existing situation for management of MSW in DHA. According to this all waste is disposed of in an open dumping site.
- (S-1): Managing MSW using a material recovery facility (MRF) following the home sorting process of waste.
- (S-2): The waste management incineration process with energy recovery. Waste collection for this is in a non-selective way.
- (S-3): A management system for MSW by the process of anaerobic digestion for the production of biogas, followed by segregation of waste and incineration of the rejected fraction.
- (S-4): A waste management process called composting by aerobic maturation of prior source despite of organic fraction of waste.
- (S-5): An alternative that defines the management of MSW by landfilling along with energy generation and leachate management.

Selected Impact Categories

In this paper life cycle impact assessment (LCIA) of all the processes were identified and calculated in EaseTech according to the defined functional unit. GWP describes the emissions of greenhouse gases to the environment in all treatment processes. Human toxicity describes the fates, acquaintances, and impacts of harmful materials for an unlimited time period and it is expressed as kg 1.4-DB eq [20]. Photochemical oxidation potential describes those substances that contribute to the formation of photochemical ozone (such as volatile organic compounds) and it is expressed as kg C_2H_4. Eutrophication is a process that adversely affects the terrestrial as well as freshwater ecosystem and nutrients in this process are phosphorous and nitrogen. The impact category acidification potential describes the number of hydrogen ions produced and it is expressed as kg SO_2eq [21]. Recourse depletion and particulate matter was also considered in this study.

The positive and negative impacts of all these scenarios were assessed and the results of this comprehensive evaluation are shown in Table 4. In LCA of waste management positive values show negative impacts on the environment and negative values show savings, which means avoided burdens that are more in the treatment process [22].

Results and Discussion

The first step was to perform a characterization of MSW. Then LCA was carried out for all waste scenarios according to the defined functional unit.

Fig. 2 shows the distribution of components in MSW of DHA. The composition of MSW varies from region to region and it depends on a number of factors, such as economic conditions and the level of development.

Fig. 2 indicates that kitchen waste (58.98%) is a major component of MSW. The other dominating components are miscellaneous (11.55%), textiles (7.53%), polythene bags (6.34%), and paper waste (2.81%). From this type of composition it was concluded that all the waste is disposed of on the dumping site without any treatment. The compared result of MSW composition in the Kamahan dump site and overall Lahore are given in Table 1.

The moisture content of MSW varies according to different factors such as humidity, weather, and season. The moisture content of different waste components of DHA MSW is given in Fig. 3.

The results of laboratory analysis show an increasing trend in the values of volatile combustible matter and fixed carbon as compared to the typical values (Table 2). As the volume of waste depends on volatile combustible matter and fixed carbon, the increasing trend indicates that the volume of waste can be reduced.

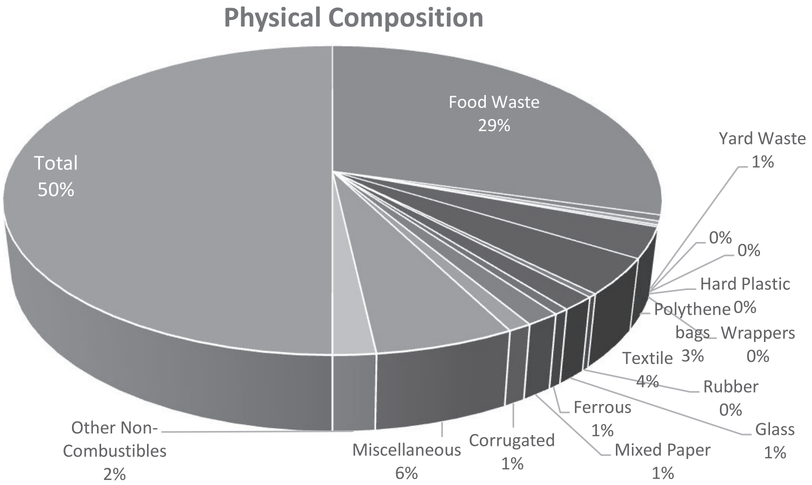

Fig. 2. Physical composition of DHA municipal solid waste.

Table 1. A comparison of physical composition of the waste generated from DHA and Lahore.

Sr. No.	Components	Observed values in DHA	*Typical values	Comments
1	Food Waste + Yard waste	60.2	63.46	Less
2	Hard Plastic	0.76	0.66	Almost same
3	Wrappers	0.40	3.69	Less
4	Polythene bags	6.34	9.77	Less
5	Textile	7.53	7.05	Almost same
6	Rubber	0.75	3.69	Less
7	Glass	2.92	0.85	More
8	Ferrous	1.25	0.04	More
9	Mixed Paper	2.81	3.84	Less
10	Corrugated	1.96	3.84	Less
11	Miscellaneous	11.55	6.75	More
12	Other Non-Combustibles	3.53	1.82	More

*Source ISTAC Report, 2010 on Lahore- LWMC

The correct proportion of carbon for energy and nitrogen for protein production in the process of composting is required by microorganisms. The results of ultimate analysis and C:N values observed in MSW of DHA are given in Table 3. Of the many elements required for microbial decomposition, carbon and nitrogen are the most important. Carbon provides both an energy source and the basic building block consisting of about 50 percent of the mass of microbial cells. Nitrogen is a crucial component of the proteins, nucleic acids, amino acids, enzymes, and co-enzymes that are necessary for cell growth and function. Table 3 shows that the MSW of DHA has a higher potential to use it as compost.

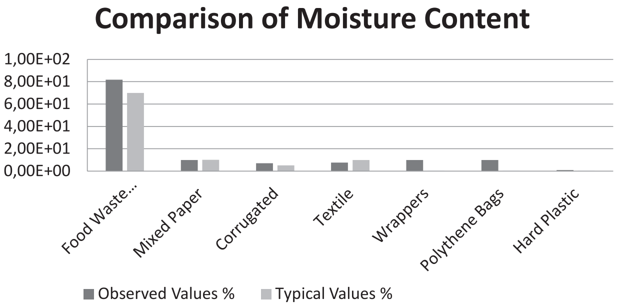

Fig. 3. Comparison of moisture content of the waste generated from DHA and Lahore.

Ultimate analysis of a material is actually a total elemental analysis, i.e., the evaluation of percentage composition of the respective sample. Chemical composition of solid waste is important to determine in order to evaluate the alternative processing and recovery facilities. The result of ultimate analysis is typically used

Table 2. A comparison of proximate analysis results.

Sr. No.	Components	VCM		Fixed Carbon		Ash Content	
		Observed values %	*Typical values %	Observed values %	*Typical values %	Observed values %	*Typical values %
1	Food Waste +Yard Waste	80	16.6	14	4	6	5
2	Mixed Paper	88	75.9	4	8.4	8	5.4
3	Corrugated	78	77.5	8	12.3	14	5
4	Textile	90	66	8	17.5	2	6.5
5	Wrappers	98	98.5	1.7	0.1	0.3	1.2
6	Polythene Bags	98	98.5	1.8	0.1	0.2	1.2

*Integrated Solid Waste Management by Tchobanologus, G., Theisen, H. and Vigil, S.A.

Table 3. Obtained results from ultimate analysis and calorific value and C:N.

Sr. No.	Components	Carbon % (C)	Nitrogen % (N)	Sulphur % (S)	Ash %	Gross calorific value Kcal/Kg	C:N %
1	Food Waste +Yard Waste	34.7	1.96	0.34	11.25	3,857.00	17.7:1
2	Mixed Paper	29.1	2.34	0.18	9.73	3,940.00	12.4:1
3	Corrugated	37.9	1.73	0.40	14.78	3,815.00	21.9:1
4	Textile	39.5	1.71	0.20	5.51	4,677.00	23.1:1
5	Wrappers+ polythene bags	60	1.18	-	6.71	17,695.96	50.8:1

to categorize the chemical composition of organic fraction of MSW of DHA.

Table 3 gives the calorific values of all the components of MSW. Determining calorific value of MSW is important because it plays a significant role in defining the measurement of MSW treatment as it is an indicator of combustible content in MSW [23]. From the results we can see that all the components of MSW solid waste have calorific value, especially polythene bags and wrappers because of higher combustible content.

The baseline scenario defines the existing situation for managing MSW in DHA. According to this, all waste is disposed of in an open dumping site. Disposal of waste in this way without energy recovery is the simplest and cheapest method, but its load on the environment cannot be avoided. This method is widely used in most countries for the disposal of MSW. However, disposal of waste in a landfill may cause many serious problems, including pollution of air, water, and soil; health problems; resource wastage; and more. The landfill option is considered to cause potential negative impacts on the environment as compared to the other waste s cenarios [7]. The landfilling treatment option with energy recovery also has environmental burdens. In the case of the climate change impact category illustrated in Table 4, scenario 5 has the highest global warming potential (2.461×10^7 kg CO_2 eq). In the landfilling process emissions of methane is the main factor for global warming. In scenario 5 a larger portion of methane is collected, but some percentage of methane is oxidized in landfill covers and released to the environment, which contributed to global warming as given in Table 4.

MRF shows the avoided burdens in relation to GWP because the emissions in this process credits the replacement of virgin resources with recycled materials. Scenario 1 also has some negative loads on the environment such as the highest impact on terrestrial eutrophication (7,464 kg PO_4eq) and then photochemical oxidation (499.7 kg C_2H_4), as shown in Table 4. This process reduces GHG emissions and GWP by reducing natural resource consumptions [24]. The study shows that this scenario is the second best option in reducing CO_2 emissions and GWP (-1.138×10^4 kg CO_2 eq). Because of its higher environmental savings, the results of several LCA studies show that MRF is a better option for managing MSW because it saves more energy as compared to composting and the bio gasification process by minimizing the use of virgin resources [25].

Table 4. Comparative characterized impact assessment for all treatment facilities.

Impact categories	Units	(S-1)	(S-2)	(S-3)	(S-4)	(S-5)
Climate change	kg CO_2 eq	-1.138×10^4	-2.086×10^7	-8.053×10^5	3.48×10^6	2.461×10^7
Human toxicity (carcinogenic)	kg 1,4-DB eq	5.54×10^{-5}	-0.001271	0.006243	0.0004458	5.09×10^{-5}
Human toxicity (non-carcinogenic)	kg 1,4-DB eq	0.002535	-0.1863	13.79	0.3828	-0.04421
Particulate matter	kg PM2.5 eq	-170.3	-2165	137.4	284.4	-156.1
Photochemical oxidation	kg C_2H_4	499.7	-1.947×10^4	1.108×10^4	4465	2.205×10^4
Freshwater eutrophication	kg 1,4-DB eq	-0.06858	-0.01001	-585.5	-25.87	0.01159
Abiotic resource depletion	kg Sb eq	4.525×10^5	-2.58×10^8	-2.292×10^7	1.88×10^7	-5.054×10^7
Terrestrial acidification	kg SO_2 eq	-991.8	-5.36×10^4	4487	8556	-720.6
Terrestrial eutrophication	kg PO_4 eq	7,464	-6.454×10^4	5.298×10^4	2.804×10^4	3.9×10^4

Incineration is the process indicating less burden on environment compared to other scenarios (Table 4). Negative values represent the least emissions using the incineration option in order to get energy. It avoids a maximum amount of CO_2 emissions and GWP (-2.086×10^7 kg CO_2eq).

Organic waste is feedstock for anaerobic digestion in S3. As a result of this process not only fuel gas is produced, but also soil fertilizer in the form of compost [26]. This process on the whole generates some benefits and some burdens to the environment. As compared to the composting process, the bio gasification process maintains and enhances the nutrient value of the raw material [27]. This process avoids (-8.053×10^5 kg CO_2 eq) CO_2 emissions because of fuel and compost production. The highest negative impacts to the environment are shown for photochemical oxidation (1.108×10^4 kg C_2H_4) and for terrestrial eutrophication (5.298×10^4 kg PO_4eq). This option brought some benefits for the management of MSW, but these benefits are smaller per kg compost materials, as compared to the other options.

The main contributors for global warming as a result of the composting process are CH_4 and N_2O because of organic matter degradation [28]. This scenario avoids natural fossil fuel consumption but contributes high global warming potential, and as a results less CO_2 emissions (3.48×10^6 kg CO_2 eq) – because in this process dinitrogen monoxide is released due to fertilizer production, creating a positive global warming impact on the environment. All other categories of S-4 were shown to be negative impacts except freshwater eutrophication (-25.87 kg 1.4-DB eq). Human toxicity was due to leaching of mercury, arsenic, and chromium. One disadvantage of this method is that some amount of important nutrients are leached – especially nitrogen by the volatilization process, and phosphorous and potassium [29-30].

By comparing the impacts of all the scenarios for the "ILCD recommended – 2013 NR" method it is shown that the landfilling alternative has the highest negative impact on the environment and incineration the least. All the selected scenarios have some main benefits: the MRF scenario major benefit is that by adopting this process resource consumption can be reduced. For organic waste bio gasification and composting the process can be used and the major benefits of these scenarios are the production of fuel and fertilizer. Landfilling has the highest impact on global warming, photochemical oxidation, terrestrial acidification, and human toxicity.

Conclusions

The results revealed that kitchen waste is the major component of MSW. Recyclable fraction (paper/cardboard, plastic, and glass) can be managed by recycling activities, and these activities can be improved by separating the waste at the source. The incineration process seemed to be the most environmentally friendly and could be the best alternative for combustibles in order to get energy. Impact categories have proved that incineration contributes the least burdens to the environment as compared to other scenarios. The landfilling scenario has the highest negative environmental impact because it is a major contributor toward greenhouse gases. LCA can be used as a tool for planning a municipal solid waste management system for municipalities because it directly compares the environmental impacts of different MSW treatment options. Moreover, the present system of MSW in DHA Lahore is not appropriate because of its extensive impacts on the environment. But for the future it can be managed by using one or a combination of different treatment options that are considered to be less of a burden on the environment.

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