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Life Cycle Analysis of Municipal Solid Waste Management Systems for Hlaing Tharyar Township

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Abstract

The goal of the study is to determine the most environmentally and economically feasible option of municipal solid waste management system for Hlaing Tharyar Township. Eight different solid waste management scenarios were developed and compared by using the life cycle analysis (LCA) methodology. The solid waste management methods considered in the scenarios were the household participation of waste separation, the mixed and separate collection of dry recyclable waste and wet biowaste, recycling by material banks and material recovery facility (MRF), composting, biogasification, incineration, refuse derived fuel (RDF) production, and landfilling. The waste management scenarios were compared using the LCA computer model known as "Integrated Waste Management – IWM-2". The inputs and outputs of each management stage were defined and the inventory analyses calculated by the model were presented as waste flows, quantities of solid waste landfilled, the key emissions to air and water, main contributions to climate change, fuel consumption and recovery, and economic cost. The impacts were then quantified with valuation method to evaluate and compare their importance. Sensitivity analysis has been used to test household source separation rate used in the initial life cycle model. The results showed that household participation of keeping the dry recyclable waste clean is more effective than keeping the wet biowaste clean; and introduction of the combination of MRF recycling and biogasification is the most sustainable option for Hlaing Tharyar Township.

Keywords: life cycle analysis, recycling, composting, biogasification, incineration, landfilling

Introduction

Hlaing Tharyar Township is now developing very rapidly with the rapid increase in urbanization and the rapid population growth. Therefore, it encounters significant increase of solid waste generation that causes adverse effects to human health and the environment. The total area of Hlaing Tharyar Township is 30.76 sq.mile (79.67 sq.km) and administratively divided into 20 Wards and 9 villages. According to the Department of Population, 235000 were living in Hlaing Tharyar in 2009. As of the latest survey conducted in

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2007, the amount of total waste generated in Hlaing Tharyar Township was 28,324 ton per year and waste generation rate was 0.331 kg/person/day (or) 121 kg/person/year. The organic materials were the main components of the waste stream, in terms of weight, constituting 74% of total solid waste, followed by plastic 10% and paper 6%. The rest were glass 2%, textile 3%, metal 1% and miscellaneous 3% (Seinn Lei Aye, Bo Bo Thet and Nwe Ni Win, 2007).

The solid waste management is one of the most important factors to be considered in environmental planning and management especially for large urban communities. As a fast growing urban center, Hlaing Tharyar Township needs proper environmental planning focusing on solid waste management in taking the road to sustainable development. There are some key questions that should be addressed before commencement of any waste management operation. What is the correct balance between environmental and economic factors of one waste management system compared to another? What is the correct mix of waste recycling, composting and energy recovery options? (Nilson-Djerf and McDougall, 2000).

The application of life cycle assessment (LCA) in the waste management sector has become a useful tool in comparing the environmental and economic cost of alternative waste treatment systems and identifying the most favourable one for system performance improvement. LCA has a lot to offer in terms of selection and application of suitable solid waste management techniques, technologies, and programs to achieve specific waste management objectives and goals. Thus, several studies in the literature used the LCA as a tool for municipal solid waste management (Sonesson et al., 2000; Arena et al., 2003; Dahlbo et al., 2005; Aye and Widjaya, 2006; Bovea and Powell, 2006; Ozeler et al., 2006; Emery et al., 2007; Lee et al., 2007).

IWM - 2 (Integrated Waste Management - 2) is a LCA software tool which was developed by McDougall et al. (2006). The software allows to model the waste collection, treatment and landfilling of municipal solid waste. The model predicts overall environmental burdens of municipal waste management systems and includes a parallel economic model. The model has been designed as a decision-support tool for waste managers in both industry and local government, who need to decide between various different options for waste management.

The objective of this study is to use the LCA as a tool to compare different solid waste management system options and determine the most economically and environmentally sustainable system for Hlaing Tharyar Township. To this purpose, eight different scenarios of municipal solid waste management systems that include different municipal solid waste processing and disposal methods were developed and, then, compared with respect to their environmental impacts and costs by using the Integrated Waste Management – IWM-2 Model.

Materials and Methods

Solid Waste Management Methods Considered in the Study

The solid waste management methods considered in the study were recycling by material banks (MB) and material recovery facility (MRF), composting(CP), biogasification (BG), incineration(IC), refuse-derived fuel (RDF) production and landfilling.

The Functional Units and System Boundaries

The functional unit selected for the comparison of the alternative scenarios was the management of 1 tonne of municipal solid waste. The system boundaries selected for the life cycle of solid waste were defined as the moment when material ceases to have value, becoming waste and when waste becomes inert landfill material or was converted to air and/or water emissions or regains some value.

Development of Eight Solid Waste Management Scenarios

Baseline Scenario 1 – Landfilling. All wastes will be sent to sanitary landfill with landfill gas collection and energy recovery, and leachate collection and treatment.

Scenario 2 - Recycling by Material Banks. Material bank collection of PET bottles and recyclable paper (newspaper, dry paper, cardboard) for reprocessors; restwaste sent to sanitary landfill.

Scenario 3 - Recycling by Material Banks, Composting. Material bank collection of PET bottles and recyclable paper (newspaper, dry paper, cardboard) for reprocessors; restwaste sent to composting plant.

Scenario 4 - Recycling by Material Banks, Incineration. Material bank collection of PET bottles and recyclable paper (newspaper, dry paper, cardboard) for reprocessors; restwaste sent to incinerator.

Scenario 5 - Intensive Recycling at MRF, Composting. Kerbside collection of clean recyclables (paper, plastic, glass, metal) and sent to MRF; restwaste sent to composting plant.

Scenario 6 - Intensive Recycling at MRF, Biogasification. Kerbiside collection of clean recyclables (paper, plastic, glass, metal) and sent to MRF; restwaste sent to biogasification plant.

Scenario 7 - Intensive Composting, RDF production. Kerbside collection of dean biowaste (food waste, garden waste and dirty paper) and sent to composting plant; restwaste sent to thermal treatment plant for RDF production.

Scenario 8 - Intensive Biogasification, RDF production. Kerbside collection of clean biowaste (food waste, garden waste and dirty paper) and sent to biogasification plant; restwaste sent to thermal treatment plant for RDF production.

Full description of the scenarios is given in Figure 1.

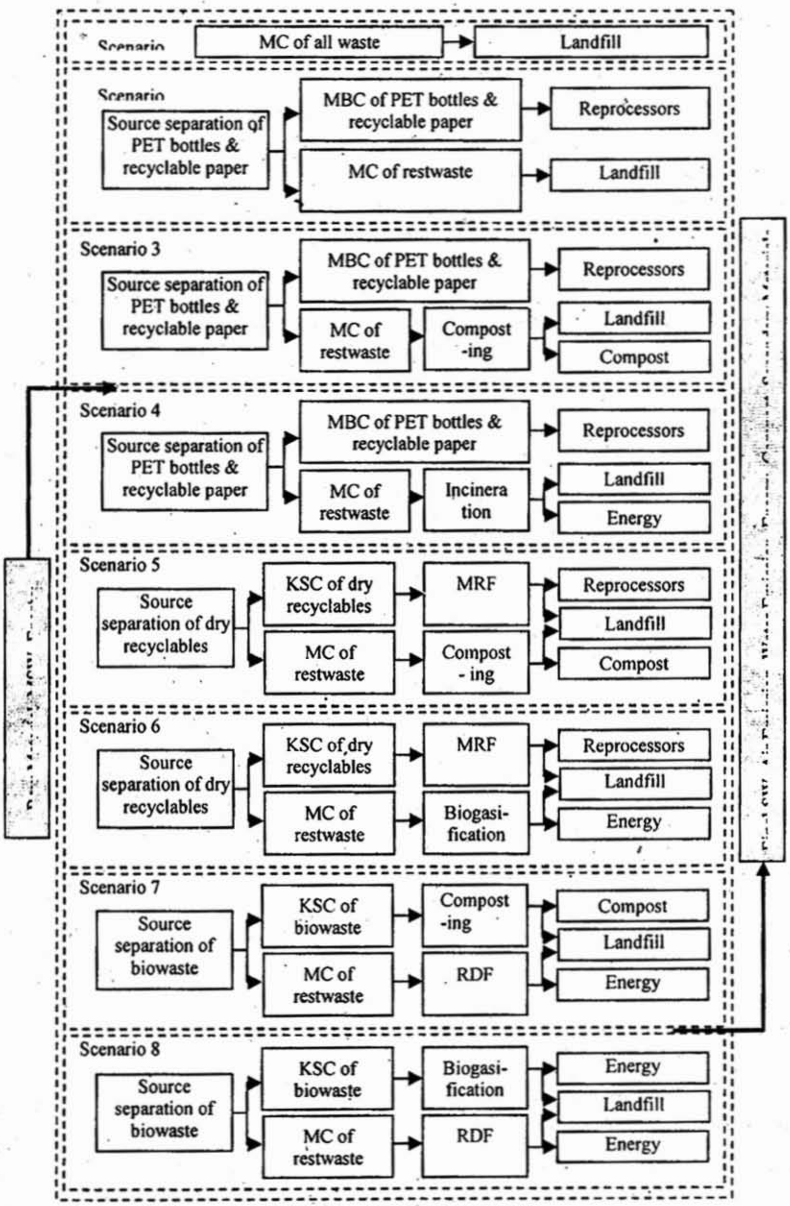

Figure 1. Eight scenarios of MSWM systems used in the study
MC- mixed collection, MBC- material bank collection, KSC- kerbside collection (----) system boundary, (→)

Analysis of the Results

Analysis calculated by the model were represented as waste flow, quantities of solid waste landfilled, key emissions to air and water, main contributions to climate change, fuel consumption and recovery, and economic cost. The results take into account the upstream and downstream emissions and resource consumption associated with energy recovery, avoided use of conventional fertilizers, and the avoidance of virgin materials due to recycling.

The environmental impacts resulted from the model were quantified and converted into monetary units by valuation method. The externalities for global warming potential and air emissions were estimated from the findings of the work of Eshet et al., 2005.

Sensitivity analysis has been used to test the assumptions used in the initial life cycle model by varying household participation/source separation rate. The effect of changing the percentage of source separation rate of waste from 80% to 60% was studied.

Results and Discussion

Waste Disposal

Table 1 presents municipal solid wastes flows in a classical way (a "local perspective", not considering life cycle thinking). For Hlaing Tharyar Township, the introduction of a combination of MB recycling and incineration (scenario # 4), MRF recycling and composting (scenario # 5) and MRF recycling and biogasification (scenario # 6) would result in a greater than 80% decrease in waste going locally to landfill.

Final Solid Waste Destined for Landfill

Table 2 presents the amount of waste being sent for disposal to landfill taking into account a "life cycle perspective" i.e. considering upstream and downstream reductions, or increases, in wastes going to landfill associated with the production of compost, the avoidance of extracting virgin materials due to recycling and the generation of energy. To help further rank the scenarios, the Landfill Diversion Rate (LDR) presents the percentage of the solid waste stream that is diverted away from final disposal in a landfill. Scenario# 5 (combination of MRF recycling and composting) and scenario # 6 (combination of MRF recycling and biogasification) **are best options** in eliminating the waste to landfill.

$$\text{LDR} = 100\,\%\ \text{x}\left[1-\frac{\text{amount of waste entering landfill}}{\text{total amount of waste entering system}}\right]$$

Table 1 Waste Flow and Its Ultimate Destination (Local Perspective)

Scenario	Recycled materials*		Combusted**		Landfilled ***	
	Quantity (ton/yr)	% (w/w) of total waste input	Quantity (ton/yr)	% (w/w) of total waste input	Quantity (ton/yr)	% (w/w) of total waste input
1. Landfilling	0	0.0	0	0.0	28435	100
2. MB	1537	5.4	0	0.0	26898	94.6
3. MB + CP	12100	42.5	10563	37.1	5773	20.3
4. MB + IC	1537	5.4	22856	80.3	4042	14.2
5. MRF + CP	13225	46.5	10540	37.0	4671	16.4
6. MRF + BG	9009	31.6	14756	51.8	4671	16.4
7. CP + RDF	8192	28.8	13479	47.4	6364	23.7
8. BG + RDF	5022	17.6	16648	58.5	6764	23.7

* Recycled materials: collected recyclables + marketable products from composting, biogasification and RDF. This can be also named as Overall Material Recovery Rate.

** Combusted figures include: Composting and biogasification process lost due to moisture, lost and degradation; RDF fuel lost due to drying and pelletising.

*** Landfill: Waste sent for landfilling without pre-treatment + residues after any treatment.

Climate Change

The "Global Warming Potential" (GWP) is expressed in CO_2 equivalents and calculated for CO_2, CH_4 and N_2O using the following relationship: $1CO_2 = 21\ CH_4 = 310\ N_2O$. The results in Table 3 showed that scenario # 6 would become the best solution. Scenarios # 1 and # 2 would become the worst solution due to methane emission and scenario # 4 can be the worse solution due to the large emissions of CO_2 during the thermal processes.

Table 2 Net Amounts Originating from Waste Management Operations and Final Solid Waste Destined for Landfill (Life Cycle Perspective)

Scenario	Sortin g (ton/yr)	Biologica l (ton/yr)	Thermal (ton/yr)	Landfill (ton/yr)	Recyclin g (ton/yr)	Total (ton/yr)	LDR * (%)
1. Landfilling	0	0	0	28435	0	28435	0
2. MB	0	0	0	26831	- 1636	25194	12
3. MB + CP	0	5818	0	4	-1636	4185	85
4. MB + IC	0	0	3825	6	-1636	2195	93
5. MRF + CP	1358	3359	0	0	-3259	1458	95
6. MRF + BG	1358	3234	0	0	-3259	1333	95
7. CP + RDF	4900	1290	318	0	-399	6109	80
8. BG + RDF	4900	1195	318	0	-399	6014	80

* LDR = Landfill Diversion Rate

Table 3 Effect on the Climate Change, Reflected as Global Warming Potential - in tons of CO_2 equivalent (Life Cycle Perspective)

Scenario	Collection (ton/yr)	Sorting (ton/yr)	Biologica l (ton/yr)	Thermal (ton/yr)	Landfill (ton/yr)	Recycling (ton/yr)	GWP (kg/ton)
1. Landfilling	0	0	0	0	36058	0	1268
2. MB	18	0	0	0	34405	- 466	1194
3. MB + CP	18	0	317	0	2134	-917	56
4. MB + IC	18	0	0	20589	6	-466	708

Scenario	Collection (ton/yr)	Sorting (ton/yr)	Biologica l (ton/yr)	Thermal (ton/yr)	Landfill (ton/yr)	Recycling (ton/yr)	GWP (kg/ton)
5. MRF + CP	300	45	334	0	2753	-2326	39
6. MRF + BG	300	45	-682	0	2753	-2146	9
7. CP + RDF	313	114	233	-2299	5718	-921	111
8. BG + RDF	313	114	-542	-2299	5718	-786	88

Air Emissions

The emissions associated with the provision of virgin material versus recycling operations can result in significant reductions in environmental emission. These reductions are presented as negative values in Table 4. Positive numbers represent generation and negative numbers represent savings. The introduction of RDF production facility (scenario # 7 & 8) results in the greatest avoided emissions for particulate matters, SO_x, and nickel. Intensive MRF recycling (scenarios # 5 & # 6) results in the highest avoided emissions in the case of arsenic, but at the same time provides the highest emissions of lead.

Table 4 Air Emissions according to the Scenarios

Scenarios	Emissions (kilograms / yr)			Emissions of metals (grams / yr)		
	PM	NO_x	SO_x	Arsenic	Lead	Nickel
1. Landfilling	- 1116	323	- 4956	0	- 193	- 1316
2. MB	- 1238	- 2584	- 8309	0	- 171	- 1137
3. MB + CP	174	- 2854	- 2641	0	76	502
4. MB + IC	- 2157	- 6267	- 12350	4	22	- 1844
5. MRF + CP	- 241	- 3513	2654	- 18171	14539	112
6. MRF + BG	- 1390	- 5204	- 2137	- 18171	14539	- 1176
7. CP + RDF	- 2746	- 259	- 12693	0	678	- 3311
8. BG + RDF	- 3623	- 1553	- 16350	0	521	- 4292

Water Emissions

Table 5 shows that introduction of RDF facility (scenario # 7 or # 8) generally have low water emissions in terms of BOD, TOC, SS, chloride, nitrate and sulphate.

Table 5 Water Emissions according to the Scenarios

Scenario	Emission (kilogram / year)						
	BOD	COD	TOC	SS	CL^-	NO_3^-	SO_4^-
1. Landfilling	2130	2136	- 71	- 214	- 3554	- 12	- 4677
2. MB	3203	-38506	2539	2496	10533	726	2779
3. MB + CP	3007	-37513	2627	2809	15414	741	8619
4. MB + IC	1176	-40529	2606	2707	13997	738	7244
5. MRF + CP	2648	- 23906	1745	- 7	10194	492	5160
6. MRF + BG	1341	-25260	1674	- 314	5696	480	551
7. CP + RDF	1622	2508	- 1	224	3330	1	- 728
8. BG + RDF	640	1491	- 55	- 16	- 101	- 8	- 4243

Total Fuel

The benefits offsetting the fuel from incineration, RDF production, biogasification and landfilling come from the recovery of energy and electricity production. As shown in Table 6, scenario # 6 is the best option for fuel.

Table 6 Total Fuel Considering a Life Cycle Perspective

Scenario	Collection (ton/yr)	Sorting (ton/yr)	Biological (ton/yr)	Thermal (ton/yr)	Landfill (ton/yr)	Recycling (ton/yr)	Fuel (MJ/ton)
1. Landfilling	0	0	0	0	- 21095	0	- 1
2. MB	293	0	0	0	- 20146	- 41548	- 2
3. MB + CP	293	0	8203	0	- 1193	- 41548	- 1
4. MB + IC	293	0	0	- 38801	96	- 41548	- 3
5. MRF + CP	4878	989	7408	0	- 1626	- 93568	- 3
6. MRF + BG	4878	989	- 15221	0	- 1626	- 93568	- 4

Scenario	Collection (ton/yr)	Sorting (ton/yr)	Biological (ton/yr)	Thermal (ton/yr)	Landfill (ton/yr)	Recycling (ton/yr)	Fuel (MJ/ton)
7. CP + RDF	5080	2520	5177	- 53872	- 3473	- 18484	- 2
8. BG + RDF	5080	2520	- 12082	-53872	- 3473	- 18484	- 3

Net Cost (Economic and Environmental Cost)

Table 7 presents the direct economic cost for waste management scenarios from a life cycle perspective. The results showed that scenario # 2 is the best option and scenario # 6 would be the second best option.

Table 8 shows the environmental cost for the pollutants. The unit values used were CO_2 - $ 0.0238/kg, CH_4 - $ 0.6242/kg, N_2O - $ 6.334/kg, particulate matters - $ 36.156/kg, NO_x - $ 6.8104/kg, SO_x - $ 5.383/kg, heavy metals - $ 293/kg, following Eshet et al., 2005. The results showed that scenarios # 6, # 7 and # 8 have positive impact to the environment. Among them, scenario # 8 is the best option in terms of environmental cost.

Table 9 indicates the environmental, economic and net costs for waste management operations of each scenario. From the results it can be concluded that introduction of the combination of MRF recycling and biogasificaiton (scenario # 6) is the most environmentally and economically feasible option for Hlaing Tharyar Township. The net cost for the introduction of scenario # 6 is the lowest at $ 5 (K.5000) per tonne of waste.

Table 7 Economic Cost of Waste Management Scenarios

Scenario	Collection ($/yr)	Sorting ($/yr)	Biological ($/yr)	Thermal ($/yr)	Landfill ($/yr)	Recycling ($/yr)	Total Cost ($/ yr)
1. Landfilling	0	0	0	0	368248	0	368248
2. MB	- 130378	0	0	0	374293	- 60066	183849
3. MB + CP	- 130378	0	435284	0	97105	- 60066	341945
4. MB + IC	- 130378	0	0	418395	57256	- 60066	285207
5. MRF + CP	14745	- 150810	339226	0	75276	- 13680	264256
6. MRF + BG	14745	- 150810	288049	0	75276	-13680	213580
7. CP + RDF	62265	105452	175421	- 145035	101937	0	300040
8. BG + RDF	62265	105452	195991	- 145035	101937	0	320610

Table 8 Environmental Cost of Waste Management Scenarios

Scenario	Externalities ($/ year)							
	CO_2	CH_4	N_2O	PM	NO_x	SO_x	HM	Total
1. Landfilling	164223	866763	- 63	- 40350	2200	-26678	- 293	965802
2. MB	145565	827338	133	-44761	-17598	-44727	-293	865657
3. MB + CP	1703	51995	-4383	6291	-19437	-14216	293	22246
4. MB + IC	479044	281	190	-77988	-42681	-66480	-586	291780
5. MRF + CP	-21541	66261	-4440	-8714	-23925	14286	-879	21049
6. MRF + BG	-42388	64842	-2673	-50257	-35441	-11503	-1465	-78885
7. CP + RDF	-30488	136905	-3439	-99284	-1764	-68326	-586	-66931
8. BG + RDF	-46361	135823	- 2109	-130993	-10577	-88012	- 879	-143107

Sensitivity Analysis

In order to test the validity of the findings, sensitivity analysis was performed. The effect of changing the percentage of source separation rate of waste from 80% to 60% was studied. The sensitivity analysis show that increase of household participation of source separation is very important if intensive recycling scenarios (scenarios # 5 or # 6), where the dry waste is kept clean, is introduced to the Township. On the other hand, it does not have significant benefit if intensive biological scenarios (scenarios # 7 or 8), where the wet waste is kept clean, is introduced.

Table 9 Net Cost of Waste Management Scenarios

Scenario	Economic cost ($ / year)	Environmental cost ($ / year)	Net cost ($ / year)	Net cost ($ / tonne)	Net cost (Kyat* / tonne)
1. Landfilling	368248	965801	1334049	47	47000
2. MB	183849	865657	1049506	37	37000
3. MB + CP	341945	22246	364191	13	13000
4. MB + IC	217419	291780	509199	18	18000
5. MRF + CP	264756	21049	285805	10	10000
6. MRF + BG	213580	-78885	134695	5	5000
7. CP + RDF	300040	-66931	233109	8	8000
8. BG + RDF	320610	- 143107	177503	6	6000

* 1USD = 1000 Kyats

Conclusion

The IWM-2 model indicated that scenario # 4 seems to be the best alternative when considering the amount of waste going to the landfill. But these scenarios have great negative environmental impacts on global warming potential. Although scenario # 8 also seems to be the best alternative when considering air and water emissions for solid waste treatment and environmental cost, the operating cost is very high compare to other scenarios. Scenario # 6 is the best choice which cost least among all the scenarios, and it still involves environmental improvements. Therefore, if the budget is tight and the environmental situation demands improvements, scenario # 6 could be a right choice. The model also showed that biogasification is more attractive than composting in the case of biological treatment methods. It can be concluded that the introduction of combination of MRF recycling and biogasification (scenario # 6) is the most environmentally and economically feasible option for Hlaing Tharyar Township. Introduction of combination of biogasification and RDF production (scenario # 8) is the second favourable options and introduction of combination of composting and RDF production (scenario # 7) is the third one. It can also be concluded that household participation of keeping the dry recyclable waste clean (scenarios # 5 and # 6) is more effective than keeping the wet biowaste clean (scenarios # 7 and # 8).

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