Investigation of greenhouse gas emissions from alternative waste management strategies in Tehran by waste reduction model (WARM)

Fahimeh Rahimi, Farideh Atabi*, Jafar Nouri, GhasemAli Omrani,

Department of Environmental Management, Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran

* Corresponding author: E-mail address: far-atabi@jamejam.net (Farideh Atabi)

Abstract:

The goal of this study is the calculation and verification of greenhouse gas (GHG) emissions along the waste management system by means of waste reduction model (WARM). Climate change and greenhouse gas emissions have become a focal environmental issue around the globe. In this context, the present work describes an environmental life cycle analysis of waste management system, comparing two possible strategies in Tehran. The purpose of this study was to identify and assess the trends in greenhouse gas emissions associated with waste management system in Tehran. The waste reduction model was used to determine greenhouse gas emissions from baseline and alternative waste management, including source reduction, recycling, combustion, composting, and land filling. The results illustrate source reduction; reuse and recycling of materials which can reduce greenhouse gas emission and manage materials more sustainable. It can help waste managers and policy-makers to recognize the best options for greenhouse gas reductions during the materials management.

Keywords: greenhouse gas emission, combustion, reduction, life cycle assessment, waste management

Introduction

Global warming is one of the most critical environmental problems on a global scale which is quickly increasing with a strong potential on the humanity (Rockström et al., 2009). The generation of solid waste has increased drastically in the past century. Waste management decisions are becoming increasingly complex for policy makers and waste managers at all levels (Skovgaard et al., 2008). The expansion of new technologies, along with an increased awareness of the effect of waste management on anthropogenic greenhouse gases (GHGs) that are affecting on climate change, creates challenges as well as possibilities (UNFCCC, 2010). The GHG impacts of waste management options can be substantial and extremely changing (Gentil, 2011).

As a result, policy makers require analytical frameworks and tools to compare the greenhouse gas emissions in relation to different waste management options and for several types of materials. However, in 2006, the global production of waste was conservatively computed between 2.5 and 4 billion tons (Lacoste et al., 2007). This change has much to do with the growth of the world population and the growth in the personal consumption. In the mentioned reference, the 2006 globally collected municipal solid waste (MSW) was calculated at 1.2 billion tons which suggest an average of some 200 kg/cap.year, varying from less than 100 kg/cap/y in a country like Butan, to over 700 kg/cap/y in the USA. It should be realized that the collected waste is between 70 and 95% of the total MSW (Lacoste et al., 2007).

Source reduction, recycling, composting, combustion and land filling are all materials management alternatives that provide opportunities for reduction greenhouses gas emissions, depending on individual requirements. However source reduction and recycling are frequently the most cost-effective ways of greenhouse prospects. Comparison of specific substances can help waste managers and policy-makers detect the best choices for reducing greenhouses gas emissions from materials management (EPA, 2013).

EPA diagnosed that the best way to do such a comparative analysis is an efficient application of a life-cycle assessment (LCA). A full LCA is an analytical framework for apperceive the material inputs, energy inputs and environmental emissions related to the production, using, transporting and disposing by material (EPA, 2009). A full LCA generally including four parts: (1) goal definition and scoping; (2) life cycle inventory; (3) life cycle impact assessment; and (4) interpretation (ISO-14040, 2006). Environmental life cycle assessment is a systems investigation instrument. It developed quickly during the 1990s and has reached a definite level of harmonization and standardization (ISO-14040, 1997). An ISO standard has been developed as well as some guidelines (Heijungs et al., 1992; Lindfors et al., 1995). An LCA studies the environmental aspects and potential impacts across the 'product's' life (i.e. cradle-to-grave) from crude material acquisition through production, usage and disposal (ISO-14042, 2000). This is done by gathering an inventory of relevant inputs and outputs of a system (the inventory analysis), assessment the potential effects of those inputs and outputs (the impact assessment), and interpreting the results (the interpretation) in relation to the goals of the study (ISO-14044, 2006). Definition of the LCA, the term 'product' not only includes the product systems but can also include service systems, for example waste management systems (ISO-14041, 1998). LCA is already being used in different countries to assess various strategies for integrated solid waste management and to evaluate treatment options for specific waste fractions (Dalemo et al., 1997; Finnveden et al., 1995). Although the progresses have been made to LCA approach, there are still a number of unresolved problems that require further consideration (Udo de Haes and Wrisberg, 1997). This paper discusses aspects of LCA methodology which come into focus when applying LCA to integrated solid waste management systems (Dalemo et al., 1997; Nouri et al., 2012).

GHG accounting and waste management

The accounting, reporting and modeling of greenhouse gas emissions started to be implemented on a global scale since the inception of the Kyoto Protocol, back in 1997 and earlier for some countries. With this protocol in place, ratified and signed by 187 states, a number of reporting protocols have been developed to enable the quantification of anthropogenic GHG emissions (Damgaard, 2010). The most major greenhouse gases for purposes of analyzing residential waste management alternatives are CO, CH_4, and NO. Most carbon dioxide emissions resulting from energy consummation, especially fossil fuel combustion. Methane, is produced when organic waste degradations in an oxygen free (anaerobic) environment, such as a landfill. Nitrous oxide emissions were calculated from only one management practice, waste combustion (Gentil, 2011). The global direct GHG emissions resulting from waste management activities were around 1.3Gt CO_2 eq. or approximately 3 – 5% of total anthropogenic emissions in 2005 (IPCC 1996). For several years, most companies in the waste sector have implemented emission reporting systems, notably for GHG emissions. Several calculation tools were published for specific emissions from various waste treatment methods.

Tehran – a case study

Tehran as the capital city of Iran has more than eight million inhabitants leading to 8000 tons/day waste generation. Most of the wastes (80%) are disposed in the Aradkuh landfill and the rest is composted (15%) or recycled (5%) (TWMO, 2013). Additionally, there are a few extra waste disposal facilities near Tehran such as biomechanical composting plant which have not been able to solve problems in acceptable level (Abduli, 1995). Until 1993, industrial wastes were also disposed in the Kahrizak landfill (Abduli, 1996).

Unfortunately, there are significant problems with Aradkuh disposal site namely (Abduli and Safari, 2003; Abduli, 2002; Zand and Abduli, 2008); (1) lack of gas emission control systems, (2) incompatibility of the imported technology with the local waste composition (in the case of composting units), and (3) seeping of leachate from landfilling and composting sites, which made a critical environmental situation in the nearby location. The current solid waste management system in Tehran includes:

- Collection and transport;
- Intermediate facilities;
- Material recycling;
- Composting
- Landfills

The municipal solid waste system is shown in Fig 1 (TWMO, 2013). In this comparison, the functional unit was 1 ton of municipal solid wastes.

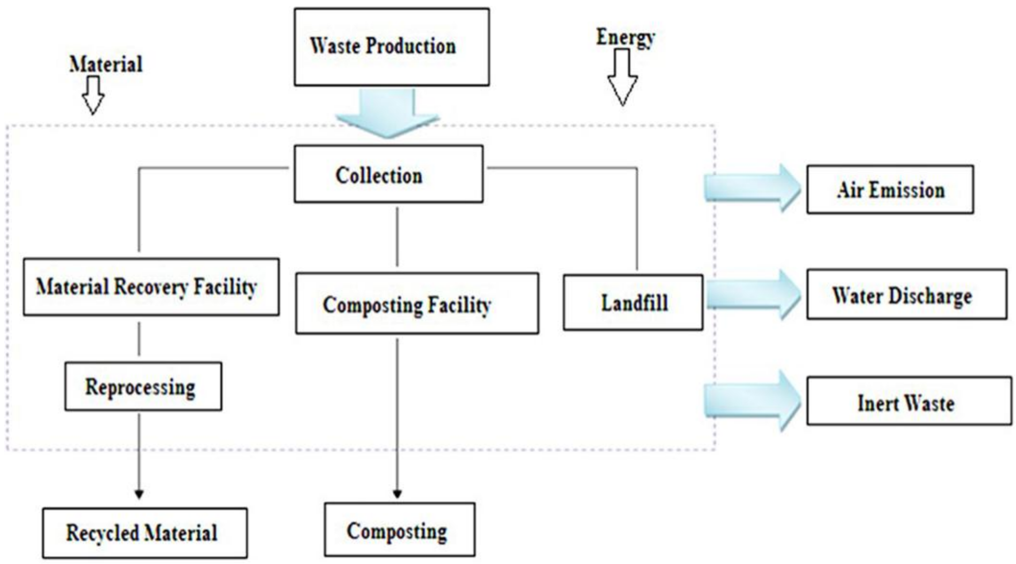

Fig. 1. Tehran Waste Management System (Source: TWMO)

Materials and methods

Calculating the GHG emissions of waste management needs to analysis of three factors:

1. Greenhouse gas emissions throughout the life cycle of the material (such as the management option selected)
2. To what extent carbon sinks are affected by production and disposal; and
3. How to improve energy management options that can be used to displace energy that would be generated at an electric utility, thus reducing GHG emissions.

WARM is the LCA-modeling used in the present study (latest version Updated June 2013), to estimate greenhouse gas emissions from different waste management options (EPA, 2013). WARM evaluates the GHG emissions according to investigation of three main features: (1) GHG emissions during the life cycle of the material; (2) the extent to which carbon sinks are affected by manufacturing, recycling and disposing of the material; and (3) the extent to which the management strategy recovers energy (EPA, 2013). This tool compares waste management scenario in order to provide pathway for decision-makers with comparative emission results (EPA, 2013). WARM represent relative GHG emissions in metric tons of CO2 equivalents ($MTCO_2E$), which uses the tool of GWP to allow all emissions to be compared on equal terms. WARM uses GWPs from IPCC (EPA, 2013). WARM compute emission impacts from a waste generation reference point, rather than a raw materials extraction reference point. This distinguishes it from other Life Cycle approaches (EPA, 2013).

Results and discussion

GHG emissions in the current and alternative scenario in Tehran waste management system was calculated by using WARM model. Input data and the results of running the model was presented in Table 1 to Table 5. As the tables show greenhouse gases and energy consumption in the waste management system of Tehran offers with model. The composition of the waste materials that were not available was excluded from the data. Alternative scenario with respect to the composition and capabilities of Tehran solid waste systems have been set up. CO_2, CH_4, N_2O and PFCs are very different gases in terms of their heat-trapping potential. The Intergovernmental Panel on Climate Change (IPCC) has established CO2 as the reference gas for calculate of heat-trapping potential (IPCC, 1997). According to Table 2, a greenhouse gas emission rate from the current system of waste management in Tehran was 4776 $MTCO_2E$. In Alternative scenario investigated the impact of source reduction and increasing recycling and composting on greenhouse gas emissions. The model output indicates that a greenhouse gas emission in this state was 763015 - ($MTCO_2E$). According to the model results source reduction and recycle can greatly reduce greenhouse gas emissions. Fig 2 Show Annual greenhouse gases emissions, from different waste management treatments. Incremental GHG Emissions from Projected Alternative Management of Municipal Solid Wastes was 979257 $MTCO_2E$ (Table 3). Model was calculated Energy Use from Baseline and Alternative Waste Management system. Based on Table 4 energy Use from Baseline was “408444- “million BTU and from alternative scenario was “10014908-“ million BTU.

Results show energy usage reduce when use alternative scenario. Fig 3 shows annual energy using from different waste management treatments. Total incremental GHG energy consumption according this model was 9606463.6 million BTU (Table 5). The subsequent situations influence the net GHG emissions of a material:

• Through source reduction

• Through recycling

• Composting with application of compost to soils results in carbon storage.

• Land filling results in both CH4 emissions from biodegradation and biogenic carbon storage.

• Combustion of waste may result in electricity utility emissions offset if the waste is burned in a waste-to-energy facility, which displaces fossil-fuel-derived electricity.

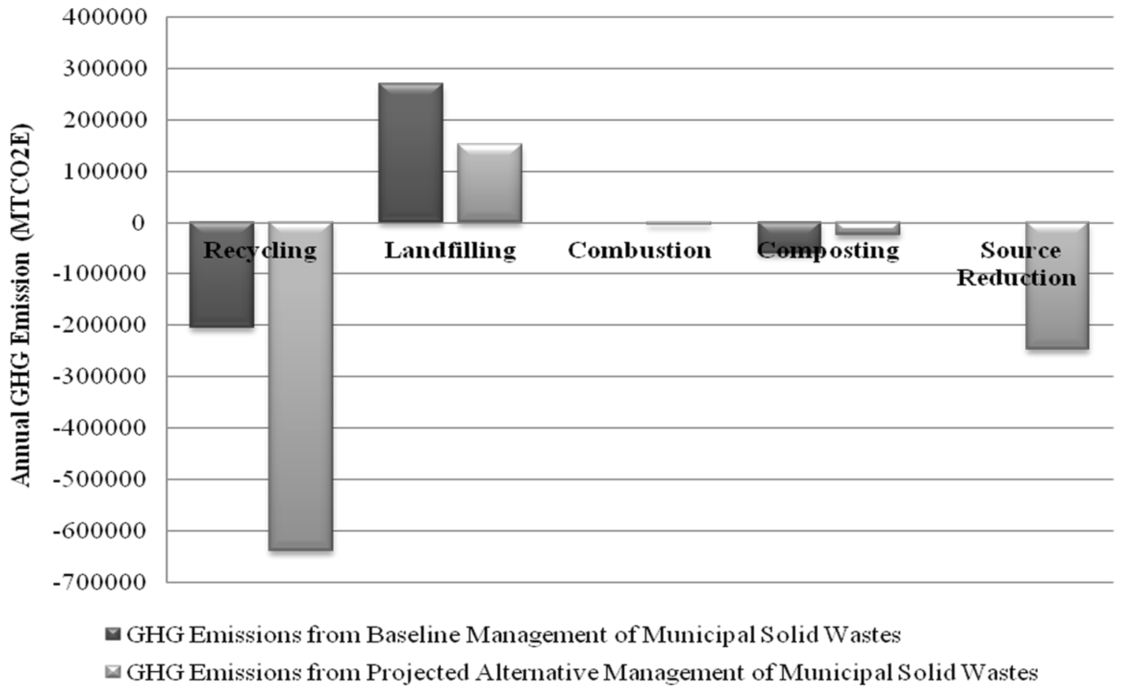

Fig. 2. Annual GHG emissions, from different waste management treatments (Baseline and Alternative MSW)

Table 1. Describe the baseline and alternative MSW management scenarios

Material	Baseline Scenario				Tons Generated	Alternative Scenario				
	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted		Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted
Aluminum Cans	823.0	4655		NA	5478.0	2000	1739	1739		NA
Steel Cans	4380.0	39420		NA	43800.0	10000	15210	18590		NA
Glass	19710.0	45990		NA	65700.0	25700	20000	20000		NA
HDPE	1314.0	15111		NA	16425.0	4025	1860	10540		NA
LDPE	NA	60225		NA	60225.0	20000	NA	40225		NA
PET	2300.0	16863		NA	19163.0	0	9582	9581		NA
LLDPE	NA	60225		NA	60225.0	0	NA	60225		NA
PP	NA	19162		NA	19162.0	7162	NA	12000		NA
PS	NA	16425		NA	16425.0	0	NA	16425		NA
PVC	NA	169725		NA	169725.0	70000	NA	99725		NA
Food Scraps	NA			282510	282510.0	132510	NA	45000		105000.0
Yard Trimmings	NA			42171	42171.0	12171	NA	18000		12000.0
crass	NA			6749	6749.0	0	NA	675		6074.0
Leaves	NA			35422	35422.0	0	NA	7085		28337.0
Mixed Paper (general)	51876	169862		NA	221738	NA	166303	44348	11087	NA

Table 2. GHG Emissions Waste Management Analysis for Tehran SWMS (Project Period for this Analysis: 2011.03.21 to 2012.03.20)

GHG Emissions from Baseline Waste Management ($MTCO_2E$): 4776						GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): 763015-							Change (Alt - Base) $MTCO_2E$
Commodity	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$	Commodity	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total $MTCO_2E$	
Aluminum Cans	823	4655	-	NA	-6942[a]	Aluminum Cans	2000	1739	1739	-	NA	-25152	-18209
Steel Cans	4380	39420	-	NA	-4809	Steel Cans	10000	15210	18590	-	NA	-57298	-52489
Glass	19710	45990	-	NA	-1389	Glass	25700	20000	20000	-	NA	-17019	-15629
HDPE	1314	15111	-	NA	44	HDPE	4025	1860	10540	-	NA	-6647	-6691
LDPE	NA	60225	-	NA	4486	LDPE	20000	NA	40225	-	NA	-32895	-37381
PET	2300	16863	-	NA	1215-	PET	-	9582	9581	-	NA	-9582	-8367
LLDPE	NA	60225	-	NA	4486	LLDPE	-	NA	60225	-	NA	4486	0
PP	NA	19162	-	NA	1427	PP	7162	NA	12000	-	NA	-10178	-11606
PS	NA	16425	-	NA	1223	PS	-	NA	16425	-	NA	1223	0
PVC	NA	169725	-	NA	12642	PVC	70000	NA	99725	-	NA	-130842	-143483
Food Scraps	NA	-	-	282510	-46281	Food Scraps	132510	NA	45000	-	105000	48593	94874
Yard Trimmings	NA	-	-	42171	-6909	Yard Trimmings	12171	NA	18000	-	12000	2305	9213
Grass	NA	-	-	6749	-1106	Grass	-	NA	675	-	6074	623-	482
Leaves	NA	-	-	35422	-5803	Leaves	-	NA	7085	-	28337	-6497	-694
Mixed Paper	51876	169862	-	NA	54923	Mixed Paper (general)	NA	166303	44348	11087	NA	-522888	-577811
Total Change in GHG Emissions ($MTCO_2E$)[b]										-767791			

[a] Note: a negative value indicates an emission reduction; a positive value indicates an emission increase.

[b] Metric tons of carbon dioxide equivalent ($MTCO_2E$)

Table 3. Incremental GHG Emissions from Projected Alternative Management of Municipal Solid Wastes

Material	Source Reduction Tons	Incremental GHG Emissions from Source Reduction $MTCO_2E$	Incremental Recycling Tons	Incremental GHG Emissions from Recycling $MTCO_2E$	Incremental Landfilling Tons	Incremental GHG Emissions from Landfilling $MTCO_2E$	Incremental Combustion Tons	Incremental GHG Emissions from Combustion $MTCO_2E$	Incremental Composting Tons	Incremental GHG Emissions from Composting $MTCO_2E$	Total Incremental GHG Emissions $MTCO_2E$
Aluminum Cans	2000	9879	916	8113	2916	217	0	0	NA	NA	18209
Steel Cans	10000	31787	10830	19151	20830	1552	0	0	NA	NA	52490
Glass	25700	13623	290	71	25990	1936	0	0	NA	NA	15630
HDPE	4025	5901	546	450	4571	341	0	0	NA	NA	6692
LDPE	20000	35891	NA	NA	20000	1490	0	0	NA	NA	37381
PET	0	0	7282	7825	7282	542	0	0	NA	NA	8367
LLDPE	0	0	NA	NA	0	0	0	0	NA	NA	0
PP	7162	11072	NA	NA	7162	534	0	0	NA	NA	11606
PS	0	0	NA	NA	0	0	0	0	NA	NA	0
PVC	70000	138270	NA	NA	70000	5214	0	0	NA	NA	143484
Food Scraps	132510	0	NA	NA	45000	65794	0	0	177510	29080	94874
Yard Trimmings	12171	0	NA	NA	18000	4271	0	0	30171	4943	9214
Grass	0	0	NA	NA	675	372	0	0	675	111	483
Leaves	0	0	NA	NA	7085	1855	0	0	7085	1161	3016
Mixed Paper general	NA	NA	114428	398666	125515	174132	11087	5013	NA	NA	577811
Total	283568	246423	134292	434274	213506	117375	11087	5013	215441	35294	979257

Table 4. Energy Analysis for Tehran SWMS (Project Period for this Analysis: 2011.03.21 to 2012.03.20)

Energy Use from Baseline Waste Management (million BTU): - 408444[a]						Energy Use from Alternative Waste Management Scenario (million BTU): - 10014908							Change (Alt - Base) BTU
Commodity	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total Million BTU	Commodity	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Total Million BTU	
Aluminum Cans	823	4655	-	NA	120636-	Aluminum Cans	2000	1739	1739	-	NA	442452-	321817-
Steel Cans	4380	39420	-	NA	45543-	Steel Cans	10000	15210	18590	-	NA	586124-	540581-
Glass	19710	45990	-	NA	13715	Glass	25700	20000	20000	-	NA	191158-	204873-
HDPE	1314	15111	-	NA	50284-	HDPE	4025	1860	10540	-	NA	328758-	278474-
LDPE	NA	60225	-	NA	60950	LDPE	20000	NA	40225	-	NA	1381108-	1442058-
PET	2300	16863	-	NA	55634-	PET	-	9582	9581	-	NA	293180-	237546-
LLDPE	NA	60225	-	NA	60950	LLDPE	-	NA	60225	-	NA	60950	0
PP	NA	19162	-	NA	19393	PP	7162	NA	12000	-	NA	465338-	484730-
PS	NA	16425	-	NA	16623	PS	-	NA	16425	-	NA	16623	0
PVC	NA	169725	-	NA	171769	PVC	70000	NA	99725	-	NA	3292659-	3464428-
Food Scraps	NA	-	-	282510	294894	Food Scraps	132510	NA	45000	-	105000	155145	139750-
Yard Trimmings	NA	-	-	42171	44020	Yard Trimmings	12171	NA	18000	-	12000	30743	13277-
Grass	NA	-	-	6749	7045	Grass	-	NA	675	-	6074	7023	21-
Leaves	NA	-	-	35422	36975	Leaves	-	NA	7085	-	28337	36750	225-
Mixed Paper (general)	51876	169862	-	NA	862681-	Mixed Paper (general)	NA	166303	44348	11087	NA	3341364-	2478683-
Total Change in Energy Use (million BTU[b])									-9606464				

[a] Note: a negative value indicates an emission reduction; a positive value indicates an emission increase.

[b] BTU = British thermal unit

Table 5. Incremental Energy Use from Projected Alternative Management of Municipal Solid Wastes

Material	Source Reduction Tons	Incremental Energy Consumption from Source Reduction million BTU	Incremental Recycling Tons	Incremental Energy Consumption from Recycling million BTU	Incremental Landfilling Tons	Incremental Energy Consumption from Landfilling million BTU	Incremental Combustion Tons	Incremental Energy Consumption from Combustion million BTU	Incremental Composting Tons	Incremental Energy Consumption from Composting million BTU	Total Incremental GHG Energy Consumption million BTU
Aluminum Cans	2000	179355	916	139511	2916	2951	0	0	NA	NA	321817
Steel Cans	10000	308246	10830	211254	20830	21081	0	0	NA	NA	540581
Glass	25700	178087	290	483	25990	26303	0	0	NA	NA	204873
HDPE	4025	246599	546	27249	4571	4626	0	0	NA	NA	278474
LDPE	20000	1421817	NA	NA	20000	20241	0	0	NA	NA	1442058
PET	0	0	7282	230176	7282	7370	0	0	NA	NA	237546
LLDPE	0	0	NA	NA	0	0	0	0	NA	NA	0
PP	7162	477482	NA	NA	7162	7248	0	0	NA	NA	484730
PS	0	0	NA	NA	0	0	0	0	NA	NA	0
PVC	70000	3393585	NA	NA	70000	70843	0	0	NA	NA	3464428
Food Scraps	132510	0	NA	NA	45000	45542	0	0	177510	185292	139750
Yard Trimmings	12171	0	NA	NA	18000	18217	0	0	30171	31494	13277
Grass	0	0	NA	NA	675	683	0	0	675	705	22
Leaves	0	0	NA	NA	7085	7170	0	0	7085	7396	225
Mixed Paper general	NA	NA	114428	2282106	125515	127026	11087	69551	NA	NA	2478683
Total	283568	6205172	134292	2890779	213506	216077	11087	69551	215441	224885	9606464

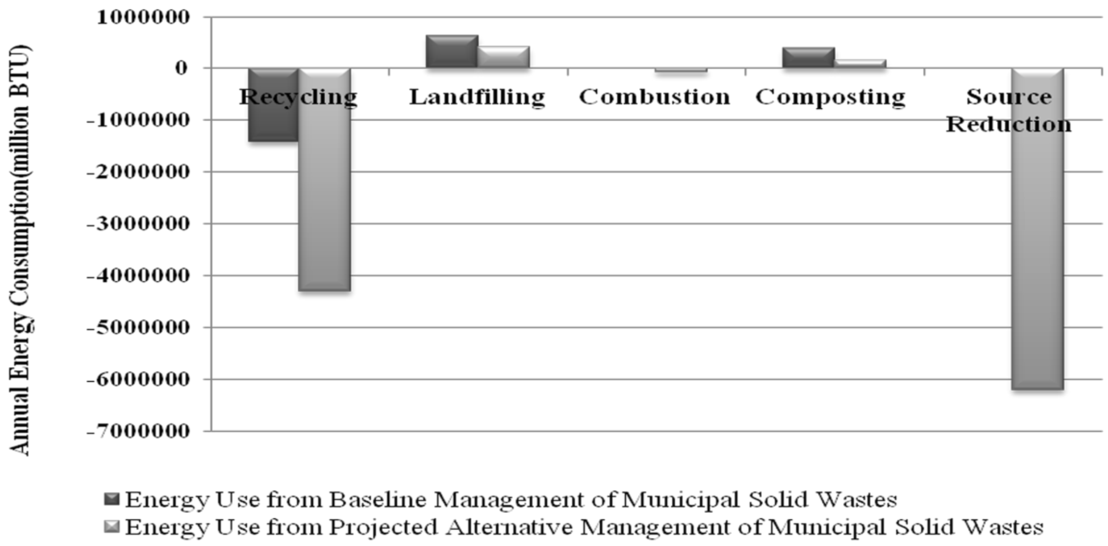

Fig. 3. Annual energy use, from different waste management treatments (Baseline and Alternative MSW)

According to the results of model, waste reduction in source and use of ways, that will lead to reuse of materials and energy, can be effective to reduce emissions to the environment. Some specific examples of source reduction practices are:

• Redesigning products to use fewer materials

• Reusing products and materials

• Extending the useful lifespan of products.

• Avoiding using materials in the first place (e.g., reducing junk mail).

Based on importance of GHG emissions and population growth in Tehran that led to increase in waste generation, choosing the appropriate waste management options can have a significant role in reducing GHG emissions. Select the appropriate strategy of waste management can also have economic benefits for government. Convenient option of waste treatment should be choose according to the quality of waste and existing facility in Tehran city to be environmentally and economically effective.

Conclusion

A new flexible waste management decision support model based on LCA methodology that takes into consideration conditions of uncertainty has been introduced. The results from this comparative analysis suggest that waste reduction in source and use of ways, that will lead to reuse of materials and energy, can be effective to reduce emissions to the environment.

The analysis clearly shows the importance of taking into account the impact of uncertainty when performing LCA of waste management alternatives. Uncertainty conditions have highest impacts on GWP estimates. This could be particularly important when estimating the GHG for the purpose of carbon trading and Credits. The results also show that despite the high level of uncertainty, ‘best waste management practices’ as described in Table 5 are likely to result in significant savings in avoided emissions in the GWP and acidification impact categories.

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