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Introducing an Integrated Municipal Solid Waste Management System: Assessment in Jordan

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Abstract

Municipal solid waste management (MSWM) is considered one of the challenging environmental problems in the Middle East and North Africa (MENA) region. Municipal solid waste increased significantly due to rapid population growth and fast urbanization, change in lifestyles and consumption patterns. Major problems associated with MSWM are poor collection rates, open dumping, and improper recycling that pose environmental damages. An environmental impact analysis of Jordan's MSWM was required to look into opportunities for bringing in an integrated solid waste management (ISWM). In this paper, we analyzed the country's MSWM as a case study in the MENA region. Our goal was to identify the most environmentally-friendly and economically-viable alternative to the current situation. Based on the Life Cycle Assessment (LCA), we evaluated the potential environmental and economic impacts of 10 MSWM scenarios adopting different waste treatment technologies. Indicators of the environmental performance used were four impact categories of EDIP 2003 assessment method: Climate Change (GWP 100a), Acidification Potential, Eutrophication Potential and Human Toxicity. The results showed that improving the current MSWM with 72% of sanitary landfills with energy recovery and 28% of dry recyclable materials was the best scenario in terms of environmental impacts and economic cost. The cost recovery of this scenario was 155% compared to an average of 55.5% of the current cost recovery. The study also revealed that the materials recycled could be increased by 33.5% if the waste separation was applied at the source of generation.

Keywords: climate change, ISWM, LCA, MENA region, MSWM, sustainability

1. Introduction

A World Bank report prepared by Hoornweg and Bhada-Tata (2012) revealed that the world cities generate about 1.3 billion tons of solid waste per year (1.2 kg/capita/day) and is expected to reach 2.2 billion tons (1.42 kg/capita/day) by 2025. The report estimated that the Middle East and North Africa (MENA) region's urban population generates 63 million tons of municipal solid waste (MSW) annually with an average of 1.1 kg/capita/day. The total waste produced in the MENA region accounted for 6% of the world's MSW generation. Excluding the OECD countries, this amount accounted for 10.3% of the waste generated from the developing countries. According to the same report, 85% of the waste was collected, and its organic composition represented 61.1% of the waste stream that was significantly high.

Another alarming report released by SWEEP-NET (2012) concluded that solid waste management (SWM) remains one of the key challenges facing the MENA region. This situation puts an urgent need for evaluating municipal solid waste management (MSWM) system performance in the MENA countries and introducing an integrate and holistic approach to improve the MENA countries' waste management performance. The integrated approach must integrate all aspects of waste management activities from generation to final disposal (Latifah et al., 2008). Planning for MSW involves three phases as described by Muchangos et al. (2015): development, implementation, and review and update. The integrated approach is a crucial part of the development phase. It is essential because not all types of all waste can be managed with a single treatment method. As McDougall et al.

(2001) explains, "No one single method of waste disposal can deal with all materials in waste in an environmentally sustainable way. Ideally, a range of management options is required". The EPA (2002) explains: the integrated solid waste management (ISWM) approach is a comprehensive and holistic management system that combines waste prevention and waste stream from the point of generation to final disposal; it manages the waste effectively to protect human health and the environment. ISWM also examines the current waste management system needs and then helps to select the most appropriate waste management method for a certain city or country (EPA, 2002). ISWM goes beyond the safe disposal of waste, and it suggests a solution to the waste problem by emphasizing life cycle thinking based on the cradle to the grave principle (McDougall et al., 2001). The advantages of applying the ISWM approach are to (1) handle MSW effectively (2) achieve environmental benefits and (3) optimize economic cost.

Jordan ranked the third among MENA countries for the Environmental Sustainability Index (ESI) that compared environmental performance in 2005 (World Bank, 2009). Moreover, the country decided to move away from a traditional MSWM to ISWM system (Abu Qdais, 2007a). Thus, there are opportunities for an ISWM implementation as a case study for similar countries in the region. In this study, the ISWM approach was applied to the whole life cycle of the waste streams including collection, sorting, recycling, landfilling, and other possible options to treat MSW. Previous studies analyzed the MSWM issues in the country without considering either the environmental impacts or the economic cost. Studies such as Abbassi et al. (2009) evaluated the current MSWM in Salt City. The study aimed to evaluate the existing MSWM only through surveying the citizens on the quality of services of MSWM. Mrayyan and Hamdi (2006) and Abu Qdais (2007a) researched the management and assessment of MSWM. The study of Mrayyan and Hamdi (2006) assessed the current operational and management practices of solid waste in Zarqa City and evaluated associated issues with solid waste processes through conducting a survey and statistical analysis. Abu Qdais (2007a) discussed the practices and challenging of SWM from both technical and economic perspectives and their environmental impacts through reviewing the most recent literature. Other studies like Abu Qdais (2007b) and Aljaradin and Persson (2010) researched landfill-related issues by reviewing the potential environmental impacts of landfills. Aljaradin and Persson (2012a) studied alternative options of MSWM to mitigate climate change effects. Their approach was comparing the potential reduction of GHG emissions by focusing on composting and waste digestion through the traditional waste management approach. However, the study did not consider the variety of environmental impacts and economic cost of adapting those MSWM treatment technologies. To the best of our knowledge, this study is the first systematic and comprehensive study that assesses the environmental and economic benefits of alternative waste handling systems in Jordan.

In this study, we aimed to identify the most environmentally-friendly and economically-viable waste management systems by applying the ISWM approach and the LCA method. We focused on Jordan's MSWM where development in the country proceeded, and the potential of applying ISWM was presumably high as a case of the MENA region.

2. Description of the Current Situation

2.1 The Current MSWM Situation

The material flows of the waste are illustrated in Figure 1 where the collection coverage is 70%, 90% and 100% in rural, urban areas and Amman City respectively. In all cities, landfills are the primary disposal method in the country's waste management plan. Twenty landfill sites are available throughout the country, but only one sanitary landfill, the only and the biggest sanitary landfill is available, that receives waste from the capital city and nearby cities. Currently, 35% of the MSW is treated at the sanitary landfill site in the capital city. 50% of the waste generated in the entire country is placed in any of the 19 controlled landfill sites, 8% is open dumped, and the remainder is unofficially recycled (SWEEP-NET, 2010). The current landfills are still causing environmental problems such as water contamination in groundwater and surface water resources. The landfill sites and their adverse impacts issue was thoroughly investigated in recent literature (Abu Qdais, 2007a, Abu Qdais, 2007b, Al-Jarrah and Abu-Qdais, 2006, Aljaradin and Persson, 2010, Aljaradin and Persson, 2012b, and Aljaradin and Persson, 2013).

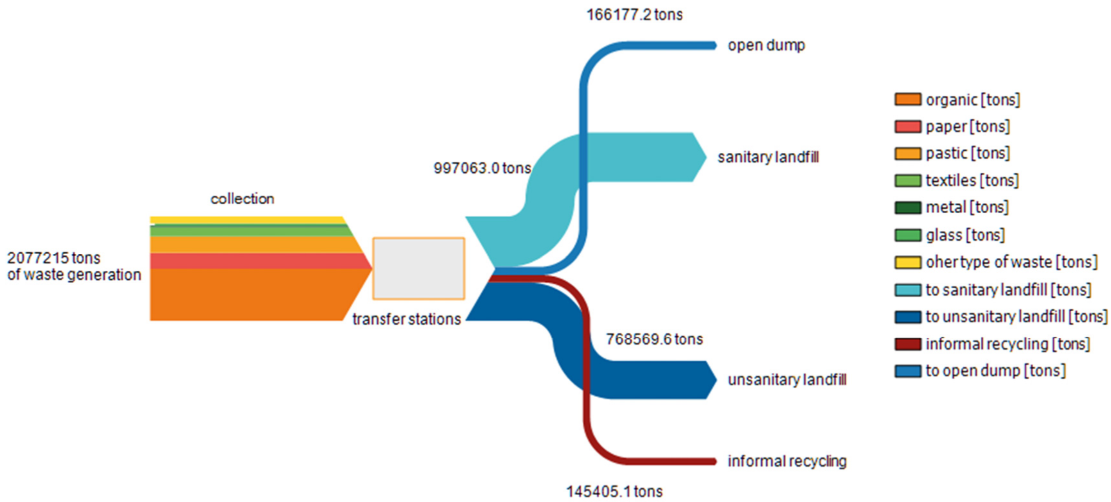

Figure 1. Material flows of the entire MSWM System

To tackle such issues with the current MSWM, the country had to improve its waste management over the last ten years. Amman City has successfully moved from unsanitary landfills to more sanitary methane collection with electricity generation are planned and has registered two Carbon Development Mechanism (CDM) projects. This improvement led us to examine waste-to-energy conversion scenarios through introducing the incineration technology besides a scenario that implements sanitary landfilling in which they can recover energy and take advantage from CDM.

2.2 The Current MSWM Situation in Amman

Amman City, with a population of 2,400,000 comprises 38% of the total population. The service area is 1,680 km^2. The city's waste generation is seasonal because the country is a destination for individual and medical tourism. During summer, the city's population increases to 3,000,000 (Alhyasat, 2012a) by a factor of 25%. The city is the backbone of the country's economy; about 50% of the country's employment opportunities are in the city, which comprises 80% of the country's economy (World Bank, 2004).

The residents generate 2,731 tons of waste per day (996,815 tons per year). The city is divided into six operational zones and 27 districts. MSW is collected in 20,000 containers with the size of 1.1 m^3 (Alhyasat, 2011). Thirty-five percent of the waste generated in the entire country is deposited at the Al-Ghabawi landfill site, the only sanitary landfill. This landfill, which was established based on international standards such as combined landfill gas and leachate collection, also meets the World Health Organization (WHO) standards (MoEn, 2009). The Al-Ghabawi site was established with the help of the World Bank and registered as a CDM project (100,000-150,000 t-CO_2 per annum). The groundwater and surface water contamination risk is unlikely to be significant due to the landfill's physical characteristics (World Bank, 2008). The background information provided in the introduction section was used to design and model different MSWM scenarios. That includes waste composition, collection, material flow of waste, the status of landfill sites (sanitary and unsanitary) and potential generation of electricity from sanitary landfill sites and incineration. We took these situations into consideration and designed MSWM scenarios that explained later in section 3.2.

3. Methods

3.1 MSW Forecasting

MSWM requires accurate estimation of solid waste generation (Dyson and Chang, 2005). The amount of MSW in the future was calculated by multiplying population in the future and the waste generation per capita (Eq. (1)).

$$W(n) = \frac{[365 \times P(n) \times P_c(n)]}{1000} \quad (1)$$

Where *W(n)* is the amount of waste in *n* year in the future (ton), *P(n)* is the population in *n* year obtained from JDoS (2015), $P_c(n)$ is waste generation per capita in *n* year (kg/person/day). The current waste generation per capita rate is 0.9 kg/person/day. According to the World Bank, the waste generation per capita in the country will reach 1.3 kg/person/day in 2025 (Hoornweg and Bhada-Tata, 2012). Based on Eq. (1), the waste amount will reach 4 million tons by the year of 2025.

The MSW generation is affected by several factors, such as population and population density, education or illiteracy, public awareness level, and GDP (Gross Domestic Product) per capita or income level. Such data were obtained from JDoS (2012) and statistically analyzed with Eq. (2).

$$W(n) = a + \alpha X_1 + \beta X_2 + \gamma X_3 + \delta X_4 \quad (2)$$

Where a is a constant; α, β, γ, and δ are correlation coefficients; X_1 is population; X_2 is population density; X_3 is GDP per capita; X_4 is illiteracy rate.

3.2 MSWM Scenarios

The modeled scenarios were designed to improve gradually the current MSWM system (the baseline scenario, S0), and then to introduce advanced technologies. The modeled scenarios are explained as below:

- S0: the baseline scenario that represents the current waste management in the entire country, where approximately 85% of the waste stream is landfilled. In this scenario, the waste composition was modeled as 52% organic, 16% film and dense plastic, 20% paper and cardboard, 2% glass, 2% ferrous and non-ferrous metals, and 8% textiles. The same waste composition was modeled in the all the other scenarios.
- S1: in this scenario, the current MSWM was improved by introducing waste separation to the baseline S0 scenario through a material recycling facility (MRF). The recycling rate was two times the current ratio (14%). The purpose was to investigate how much proper recycling could improve the current waste management system, both environmentally and economically.
- S2-A: the MSW is fully treated in sanitary landfills.
- S2-B: it is similar to S2-A scenario with the exception that, the recycling rate was increased from 7% to 14%.

  The other scenarios present different waste management alternatives and technologies that attempt to eliminate or to reduce further the environmental problems resulting from improper waste management and are explained below:
- S2-C: is the same as the S2-B with the exception that energy is recovered from sanitary landfills.
- S2-D: the recycling rate was increased to 28%, and waste is sanitary landfilled with energy recovery from the sanitary landfills.
- S3-A, S3-B, and S3-C: the recycling rate was increased from 7% to 14%. The major change is that 10% of the waste is composted and biogasified for the S3-A and S3-B respectively, where S3-C considers both composting and biogasification.
- S4: incineration technology was introduced by incinerating 50% of the waste and energy was recovered and 80% of ferrous metal removed from bottom ash. In this scenario, gross electrical efficiency is considered as 20% and energy is recovered as electricity only.

All the scenarios consider 100% of waste collection coverage. The recycling rate represents the recycling percentage of dry recyclable waste in materials (paper and cardboard, plastic, metals, and glass) while the ratio of composting and biogasification represents the percentage of composting and biogasification from the organic waste stream. In scenarios S2-C and S2-D, gas collection efficiency in the landfill sites was modeled as 75%, assuming the maximum possible gas gathering. Table 1 shows the 10 scenarios for MSW treatment

Table 1. Assessed ten scenarios of MSWM

S. No.	Recycling		Landfill			Comp.	Biogas.	Incineration	Source of energy recovery
	Informal	Formal (MRF)	Open dump	Sanitary	Unsanitary				
S0	7%		8%	35%	50%				
S1		14%		43%	43%				
S2-A		7%		93%					
S2-B		14%		86%					
S2-C		14%		86%					Landfill
S2-D		28%		72%					Landfill
S3-A		14%		76%		10%			
S3-B		14%		76%			10%		
S3-C		14%		66%		10%	10%		
S4		28%		22%				50%	Incineration

**S.: Scenario.; Comp.:* Composting; *Biogas.: Biogasification; MRF: Material Recycling Facility*

3.3 Life Cycle Assessment (LCA)

The method of Life Cycle Assessment (LCA) was used to estimate the environmental impacts of each proposed MSW scenario. We took standard steps in the LCA procedure: goal and scope definition, inventory analysis, and impact assessment. In the step of goal and scope definition, the system boundary and purpose of this study were determined: to assess environmental impacts of the current MSWM system and other alternative scenarios. The scope of LCA in this study includes seven processes: collection, sorting, composting, biogasification, incineration, recycling, and two types of landfilling (unsanitary and sanitary). The system boundaries were defined as gate-to-grave of the End-of-Life phase from different proposed scenarios for a 20-year lifespan. Geographically, the boundaries included MSW collection and treatment in the entire country. The EDIP 2003 impact assessment method was used to evaluate and rank each scenario. Four environmental impact categories were used to assess MSW: Climate Change (GWP 100a), Acidification Potential, Eutrophication Potential and Human Toxicity. Among various available impact assessment methods, the EDIP 2003 was selected because of these reasons:

1) The environmental impact categories that are provided by the method are applicable for assessing MSW.
2) The method provides aggregated indicators for results across each impact category using numerical factors (weighting factors).

Using EDIP 2013, we ranked each scenario's environmental load associated with the MSWM system for a functional unit of one ton of annual MSW generation. The indicators were calculated from Eq. (3).

$$TWIC = \sum normalized\ IN_i \times Wf_i \quad (3)$$

Here, *TWIC* is the Total Environmental Weighted Impact Categories. *IN* is the normalized impact indicator, *Wf* is the weighting factor provided by EDIP 2003 method, and *i* is the impact category.

Where:

$$IN = \sum_i Iv_i \times Cf_i \quad (4)$$

Here *Iv* is the inventory result, and *Cf* is the characterization factor.

3.4 Cost Analysis

Data of expenditure costs, revenues, and cost of recovery were collected, and cost recovery and total cost were calculated from Eqs. (5) and (6). Cost recovery is a major issue in the current MSWM system because the current system could not recover the cost and thus, it was essential to calculate the cost recovery for all alternative scenarios. Both cost recovery and the total cost were calculated to compare the economic performance of each scenario.

$$Cost\ Recovery\ = \frac{Revenues}{Expenditure\ Cost} \times 100\% \tag{5}$$

$$Total\ cost = \ Expenditure\ Cost\ - Revenue \tag{6}$$

3.5 Data Collection

The foreground data were gathered for each scenario input from different sources, including official agencies (e.g. Ministry of Environment, Amman Greater Municipality, and officials from eight municipalities were interviewed), international organizations such as the World Bank and Japan International Cooperation Agency (JICA), regional organizations such as the Regional Solid Waste Exchange of Information and Expertise Network in Mashreq and Maghreb Countries (SWEEP-NET), the Arab Environment Forum, and literature addressing the waste management problem including: Abu Qdais (2007a), Abu Qdais (2007b), Aljaradin and Persson (2010), Aljaradin and Persson (2012a), and Aljaradin and Persson (2012b). The background data for LCA inventories was used from the Ecoinvent 3.1 database.

4. Results and Discussion

4.1 Results of Inventory Analysis in the Baseline Scenario

We estimated the pollution from the current MSWM system to raise the issues associated with the current system rather than alternative scenarios. The major pollutants of both air and water were estimated as shown in Tables 2 and 3 for the current baseline scenario (S0), that represents the current MSWM situation. CO_2 and CH_4 are mainly emitted from collection and landfill sites, and part of the pollution could be avoided through recycling. CH_4, NOx, and CO were emitted during waste collection and landfilling. The other pollutants to air and water were mainly caused by landfill processes. GHG emissions were compared with the country's national GHG inventory in section 4.3.

Table 2. Air pollution from the waste management system in the S0 baseline scenario (Unit: ton)

	Waste management processes			Total
	Collection	Landfill	Recycling	
GHG	25872	2110142	-86982	2049032
CO_2	25227	570190	-86400	509017
CH_4	31	73327	-49	73310
NOx	454	582	-382	654
Total HC	0	384	0	384
CO	138	305	-272	171
H_2S	0	37	0	37
HCl	0	19	-3	16

Table 3. Water pollution from the waste management system in the S0 baseline scenario (Unit: ton)

	Waste management processes			Total
	Collection	Landfill	Recycling	
Chloride	205	358	562	1,125
BOD	0	381	64	445
Sulphate	7	129	262	398
TOC	0	2	118	120
Suspended Solids	22	33	64	119
Nitrate	0	0	34	34
Iron	0	30	-2	28

4.2 Materials Recycled in the Scenarios

The amounts of actual recycled materials for each scenario were estimated. It was 58,160 tons in scenarios S0 and S2-A. 116,325 tons in Scenarios S1, S2-B, S2-C, S3-A, S3-B, and S3-C. 232,650 tons in Scenarios S2-D and S4. The results showed that the maximum dry recyclable waste (from paper, cardboard, plastic, metals and glass) was approximately 763,400 tons. However, only 534,390 tons of this amount can be practically recycled after assuming complete separation at a material recycling facilities (without kerbside sorting) and 30% materials loss due to recycling processes. Thus, the percentages of recycling in the modeled scenarios are 7%, 14%, and 28% represent 10%, 21.76% and 43.5% respectively of the maximum and actual recycling amounts (534,390 tons). The results also showed that the materials recycled could be increased by 33.5% if waste separation is applied at the source.

4.3 Greenhouse Gas Emissions

Net greenhouse gas (GHG) emissions estimated in the S0 (the baseline scenario) were 2,035,500 tons per year. According to the inventory data published by UNFCC (2010), The country's GHG emissions were estimated as 20.14 million tons-CO_2 /year. Comparing our estimation to the inventory, we found that the country's GHG emission from solid waste accounted for 10% of the entire country's emissions since 2010. We also found that the GHG emission reduced from solid waste by 25% through establishing the sanitary landfill site in 2003 in Amman City. Scenarios S1, S2-A, S2-B, S2-C, S3-A, S3-B, S3-C, S4 and S2-D reduce GHG emissions by 28%, 44%, 47%, 48%, 50%, 51%, 54%, 74%, and 80% respectively. Figure 2 shows the calculated GHG emissions in all scenarios.

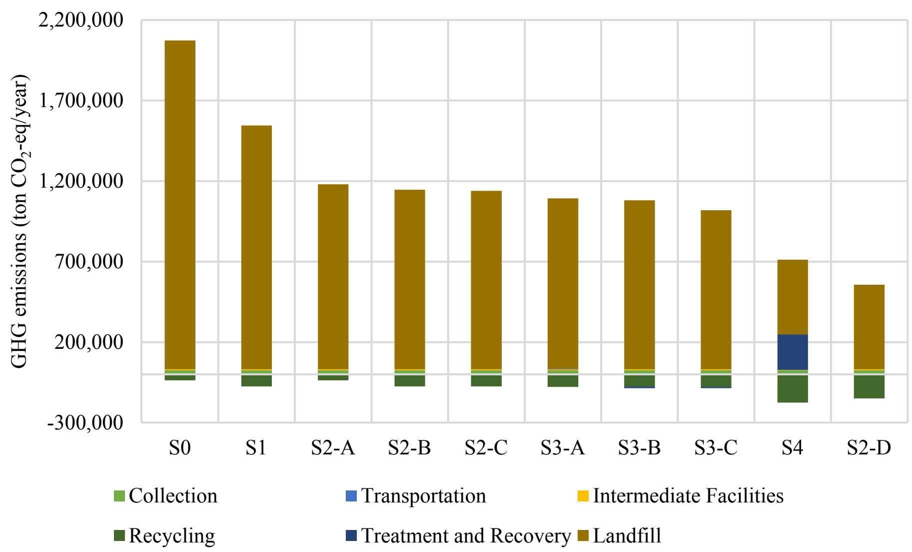

Figure 2. Greenhouse gas emission in each scenario

4.4 Results of Evaluation

The results for evaluating each scenario are shown in Figure 3. Each scenario was evaluated by applying the EDIP 2003 impact assessment method where a score was assigned to each scenario (the smaller the score, the better the performance). Scenario S2-D achieved the highest environmental performance, mainly because of replacing the unsanitary by sanitary landfills with energy recovery from landfills and implementing the highest recycling rate. Scenario S4 was the second best scenario were incineration technology was introduced with energy recovery. In this scenario, we assumed the maximum gross efficiency of electricity generation (30%), where energy is recovered as electricity only. The third best environmental performance was obtained through biological treatment technologies (composting or biogasification or both; see Scenarios S3-A, S3-B, and S3-C). However, their scores were very similar to scenarios S2-C and S2-B. Figure 4 shows the environmental impact categories excluding the climate change.

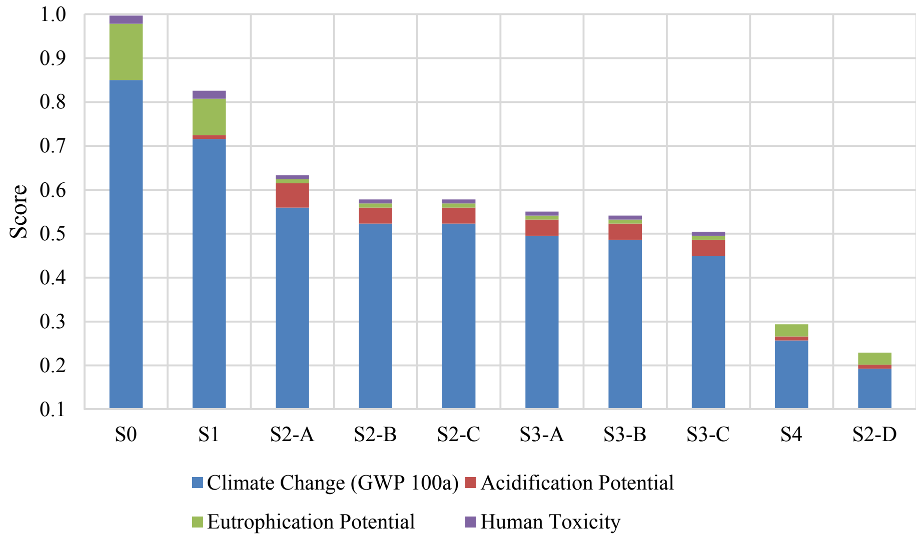

Figure 3. Scores of each scenario (lower is better)

Figure 4. Environmental impact categories (excluding climate change)

4.5 Cost Analysis Results

Data extracted from Alhyasat (2012b) in Table 4 shows a detailed analysis of the current MSWM cost in Amman City. The collection cost accounted for 79.8% of the total cost, 35.8 USD/ton. The total cost per the weight of waste was 44.8 USD/ton with a cost recovery estimated at 60.6%. The cost of MSWM collection is partly recovered through a tariff system in the city, which represent a major economic issue in the current MSWM system. According to SWEEP-NET (2013), the charge for waste management was applied to the electricity bill with a flat rate of 28 USD/household and a proportional fee of 0.007 USD/kWh for electricity consumption when the monthly consumption of electricity is greater than 200 kWh/month.

Table 4. The current waste management cost with and without charge. Data extracted from Alhyasat (2012b)

MSWM Category	Without tariff system			With tariff system		
	Cost/ton (USD)	Total cost (Million USD)	% of total cost	Cost/ton (USD)	Total cost (Million USD)	% of total cost
Collection	35.8	32.6	79.8%	21.7	19.7	79.8%
Transfer	4.9	4.5	11.0%	3.0	2.7	11.0%
Disposal (landfilling)	4.1	3.7	9.1%	2.5	2.2	9.1%
Total	44.8	40.8	-	27.1	24.7	-

The city's municipality could not achieve a full cost recovery because of the relatively small charge for the MSWM services provided by the municipality (SWEEP-NET, 2013), and similar situations in other cities exist. Also, the electric company collects an MSW charge as part of the monthly electric bill and deducts 10% of the charge for administrative costs (SWEEP-NET, 2013). The total revenues, total cost and cost recovery for each scenario is presented in Table 5.

Table 5. Results of cost analysis for each alternative scenario (Million USD)

S. No.	Revenues					Total revenues	Total cost	Percentage of cost recovery
	Sorting	Biological	Thermal	Landfill	Recycling*			
S1	10.8	0	0	0	16.3	27.1	25.3	107
S2-A	5.3	0	0	0	4.8	10.1	20.5	50
S2-B	10.7	0	0	0	16.1	26.8	25.0	107
S2-C	10.8	0	0	6.6	16.3	33.7	25.3	133
S2-D	21.5	0	0	0	32.4	53.9	34.7	155
S3-A	12.8	47.3	0	0	18.9	79.0	63.7	124
S3-B	10.8	56.8	0	0	16.3	83.9	41.9	200
S3-C	30.4	54.7	0	0	75.2	160.3	85.9	187
S4	21.5	0	11.5	0	32.4	65.4	159.7	41

** Recycling cost includes both cost of dry recyclable materials and compost produced by biological treatment.*

5. Conclusion

This study attempted to introduce an ISWM that moves the waste management in Jordan towards an environmentally-sound system as a case study of the MENA region. We estimated the environmental burden of the current MSWM in the country and compared the environmental and economic benefits of alternatives with the current MSWM. The study aimed to examine the best waste disposal options that implement sanitary landfilling, recycling, and waste-to-energy. Based on the ISWM approach and the LCA method, 10 MSWM systems were modeled, and their environmental impacts were compared. In addition, the economic performance of each alternative was estimated. The study indicated that the scenario included 28% of dry recyclable materials through MRF and sanitary landfills with energy recovery of the remainder reduced GHG emissions by 80%. It recovered 155% of the costs while the current cost recovery in the current system was 55.6%. The study revealed that the recycled material amounts could be increased by 33.5% if the waste separation was practiced at the source.

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