

Climate Change

6. WASTE MANAGEMENT BASELINE SCENARIO AND MITIGATION MEASURES

6.1 INTRODUCTION

Waste management covers two major activities:

- Land disposal of solid waste; and
- Wastewater treatment (domestic, commercial, and industrial).

Depending of the method of waste disposal and the wastewater treatment technology, these two activities can result in greenhouse gas (GHG) emissions which include primarily the following gases:

- Methane (CH₄);
- Carbon dioxide (CO₂); and
- Nitrous Oxide (N₂O).

At any time, in order to estimate the amount of GHG emissions from solid waste disposal the minimum required data include the following:

- Population;
- Method of solid waste disposal;
- Solid waste composition; and
- Solid waste generation rates.

Similarly, at any time, in order to estimate the amount of GHG emissions from wastewater treatment the minimum required data include the following:

- Population;
- Method of wastewater treatment;
- Wastewater characteristics; and
- Wastewater generation rates.

For mitigation purposes, a baseline scenario should be established with respect to the projected status of facilities for solid waste disposal and wastewater treatment that are expected to come in operation at a certain year. In this report, the years 1994, 2005, 2015 and 2040 were selected as short term and long term baseline scenarios.

The remaining of this chapter will define the data described above that are used in establishing the baseline scenario and the GHG emissions associated with this scenario. Mitigation measures will then be discussed and the economics of implementing the most suitable and feasible measures in the context of the Lebanese situation will be presented.

6.1.1 Population Projections

Population projections for Lebanon have been conducted and reported [1] Table A6-1 presents a set of projected population estimates based on an average growth rate of 1.5%. The overall population will increase from 3.7 million in 1994 to about 7.4 million in 2040. While these projections are tentative estimates, they can serve as the basis for analysis of trends in mitigating GHG emissions. Fig. A6-1 is an illustrative depiction of overall future population growth in Lebanon.

Table A6-1. Projected population for Lebanon

<i>Mohafaza</i>	<i>1994</i> (<i>'000 persons</i>)	<i>2005</i> (<i>'000 persons</i>)	<i>2015</i> (<i>'000 persons</i>)	<i>2040</i> (<i>'000 persons</i>)
<i>Beirut</i>	1165	1372	1593	2311
<i>Mount Lebanon</i>	695	819	950	1378
<i>Bekaa</i>	460	542	629	912
<i>North Lebanon</i>	770	907	1053	1527
<i>South Lebanon</i>	635	750	868	1260
<i>Total</i>	3725	4390	5092	7388

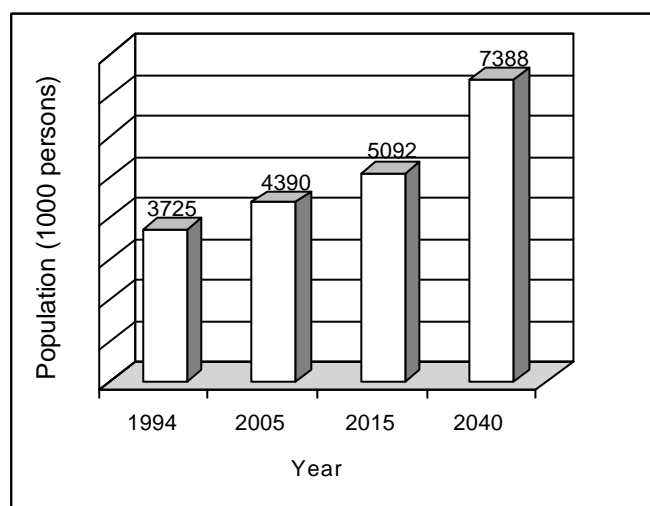


Fig. A6-1. Projected population for Lebanon

6.1.2 Methods of Solid Waste Disposal

Until recently, a comprehensive approach to solid waste management in Lebanon has been virtually absent. Slow burning and uncontrolled dumping on hillsides and on sea shores were still the common methods practiced for solid waste disposal. In urban areas, uncontrolled open dumps became quite large particularly along the coastal front (The Normandy and Burj Hammoud sites in Beirut, and the Nahr Abu Ali site in Tripoli, etc.). Incineration was also practiced at two relatively old facilities (Karantina and Amrousiyeh).

Certainly the trend is changing and there is a great deal of efforts to develop integrated solid waste management systems for most areas in Lebanon, particularly large urban areas. These efforts center around the construction of many well controlled sanitary landfills in combination with sorting, recycling, and composting facilities.

Based on experience to date at the Naameh controlled landfill site (which serves the City of Beirut and its surroundings and accounts for about 50% of the total solid waste generated in Lebanon) and the plans reported by the Council for Development and Reconstruction (CDR) [2], it is expected that upwards of 80% of the solid waste generated in Lebanon will be disposed of in relatively large size controlled sanitary landfills by the year 2005. This value is likely to exceed 90% by the year 2040.

6.1.3 Solid Waste Composition

As for other countries worldwide, the composition of the solid waste in Lebanon vary substantially with socio-economic conditions, location, season, waste collection and disposal methods, sampling and sorting procedures, and many other factors. Table A6-2 presents average composition of unsorted municipal solid waste from the Beirut area. Despite the variability in its composition, solid waste in Lebanon as in most developing countries can be characterized by a high percentage of total organic content with relatively elevated moisture content.

Table A6-2. Composition of unsorted municipal solid waste in Lebanon [3, 4]

<i>Waste Category</i>	<i>Average Composition % by weight</i>
<i>Paper/cardboard</i>	11.3
<i>Food waste</i>	62.4
<i>Diapers/garments</i>	4.2
<i>Plastics</i>	11.0
<i>Glass/Brick</i>	5.6
<i>Metals</i>	2.9
<i>Other (wood)</i>	2.6

6.1.4 Solid Waste Generation Rates

Several survey studies have been conducted to estimate waste generation rates by examining small daily samples from a large number of communities of different sizes. The most relevant of these studies with respect to the 1994 target year, is a survey conducted by the American University of Beirut [3, 4]. Table A6-3 presents generation rates for different localities (Caza) in Lebanon as reported in this study.

Table A6-3. Solid waste generation rates for different Cazas

<i>Caza</i>	<i>Generation Rate kg/capita/day</i>
<i>Aley</i>	0.78
<i>Baabda</i>	0.86
<i>Beirut</i>	0.74
<i>Chouf</i>	0.64
<i>Kesrouan</i>	0.77

<i>Metn</i>	0.70
<i>Tripoli</i>	0.64
<i>Zahle</i>	0.95
<i>Other Communities (Lowest-Highest)</i>	0.35-1.61

For estimation purposes, a rate of 0.8 kg/capita/day has been commonly used [1, 5] for present conditions. Under normal growth conditions, it is expected that this rate will increase. For the baseline scenario, it is assumed that the generation rate will increase by 1.5% annually to reach an average of 1.6 kg/capita/day for the year 2040, respectively. It is likely that this rate will stabilize in the future and perhaps decrease as witnessed in industrial countries. Using these average per capita wastewater generation rate and population estimates mentioned above, the total yearly quantity of solid waste generated for the baseline scenario are summarized in Tables A6-4 for different localities (Mohafaza) in Lebanon and depicted in Fig. A6-2.

Table A6-4. Solid waste generation in Lebanon

	1994)	2005	2015	2040
<i>Generation Rate (kg/capita/day)</i>	0.8	0.94	1.12	1.6
<i>Mohafaza</i>	('000 ton)			
<i>Beirut</i>	340	471	651	1350
<i>Mount Lebanon</i>	203	281	388	805
<i>Bekaa</i>	134	186	257	533
<i>North Lebanon</i>	225	311	430	892
<i>South Lebanon</i>	185	257	355	736
<i>Total Amount Generated</i>	1087	1506	2082	4315

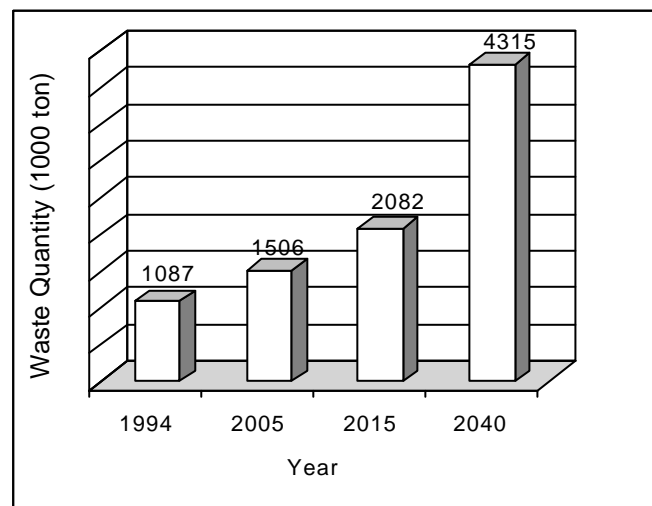


Fig. A6-2. Solid waste generation in Lebanon

6.1.5 Methods of Wastewater Treatment

Similar to solid waste, municipal wastewater management in Lebanon has been absent particularly during the many years of civil unrest during which existing treatment plants were destroyed and/or put out of

operation. The general trend for wastewater management in urban areas along the seashores where the greater majority of the population resides, has been limited to a deteriorated wastewater collection system that typically discharges into the sea. In other urban as well as rural areas, untreated wastewater is directly dumped into rivers, irrigation channels, valleys, and ravines as well as septic systems and then land disposal. This method of treatment has been practiced for all types of wastewater including domestic, commercial, and industrial.

Numerous projects are underway to construct treatment plants around the country and for the short term baseline year of 2005 it is expected that about 70% of the domestic and commercial wastewater generated in Lebanon will be collected and treated at a wastewater treatment facility before final disposal. This value is likely to reach 90% by the year 2040. While the type and level of treatment will vary depending on the location, the majority of these facilities involve aerobic processes which are typically associated with little to no methane emissions. At some facilities, anaerobic processes may be introduced in a hybrid fashion with aerobic ones. The methane emitted from such processes will be flared or used as an energy resources at the facility itself. Therefore, it is not appropriate to include the amount of methane emissions from wastewater treatment as a baseline source.

As such it is assumed in this report that aerobic processes will be adopted for wastewater treatment. This assumption along with the actual usage methane from potential anaerobic processes (if adopted) must be verified in the future as facilities come into operation. Note also that wastewater treatment are planned for primarily domestic and commercial wastewater.

While a national industrial wastewater action plan has been prepared [6], no provisions have been made to date for the treatment of industrial wastewater. However, illegal dumping into sewer lines will not be surprising in which case the wastewater from the industry will find its way to the treatment facilities planned for commercial and domestic wastewater. While in such an event the treatment process at these facilities may get adversely affected, it is not possible to estimate whether and how much methane can be generated from illegal dumping.

At this stage, it was assumed that industrial wastewater management will be monitored and proper enforcement to prevent illegal dumping will be implemented. Industrial wastes are assumed to be handled at the source and no GHG emissions as methane will be generated from this sector since industrial wates are treated primarily through aerobic processes. This assumption must be checked in the future as plans for industrial waste management becomes more available and ready for implementation. In the event anaerobic processes are adopted, methane emissions should be accounted for.

6.1.6 Wastewater Characteristics

Wastewater is typically characterized in terms of several parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and nitrates as nitrogen (N) amongst other parameters. Table A6-5 summarizes available information on wastewater characteristics in Lebanon [6].

Table A6-5. Wastewater characteristics in Lebanon

<i>Parameter</i>	<i>Range (mg/l)</i>	<i>Average (mg/l)</i>
<i>BOD</i>	30-230	128
<i>COD</i>	250-820	630
<i>Nitrate-N</i>	30-160	100

Note that Table A6-5 represents domestic and commercial wastewater characteristics. Industrial wastewater characteristics is highly variable and depends on the type of industry as well as the industrial process itself. While attempts at characterizing and quantifying industrial wastewater in Lebanon have been conducted [1], the reported results have not been accepted particularly by the industry itself. Therefore, at this stage these results are not reported until a consensus is reached regarding this matter. For this purpose, industry cooperation in providing accurate data is essential.

6.1.7 Wastewater Generation Rates

Data on wastewater quantities can be estimated using a daily per capita average wastewater generation rate multiplied by the number of population. The daily per capita average rate can vary with location and season. For estimation purposes, the present average rate that has been reportedly commonly used for Lebanon is about 120 liter/capita/day [1, 5]. Similar to solid waste generation, this average is expected to increase with time. A likely increase rate of 1.5% will bring the average wastewater generation rate to 240 liter/capita/day for the year 2040.

Using this average per capita wastewater generation rate and the average wastewater characteristics with the population estimates mentioned above, the total yearly quantity and quality of domestic wastewater generated for the baseine scenario are summarized in Tables A6-6a to d for different localities (Mohafaza) in Lebanon. Note that the per capita wastewater generation rate as well as the wastewater characteristics were assumed constant for the entire baseline scenario. This assumption must be verified in the future if methane emissions are to be estimated accurately from wastewater treatment processes. Figs. A6-3 and 4 depicts the total wastewater generation and characteristics in Lebanon.

Table A6-6a. Quantity of wastewater generation: 1994

<i>Mohafaza</i>	<i>1994 Population '000</i>	<i>1994 Wastewater Mm³</i>	<i>1994 BOD '000 ton</i>	<i>1994 COD '000 ton</i>	<i>1994 N '000 ton</i>
<i>Greater Beirut Area</i>	1165	51	6.5	32.1	5.1
<i>Mount Lebanon</i>	695	30	3.9	19.2	3.0
<i>Bekaa</i>	460	20	2.6	12.7	2.0
<i>North Lebanon</i>	770	34	4.3	21.2	3.4
<i>South Lebanon</i>	635	28	3.6	17.5	2.8
<i>Total Lebanon</i>	3725	163	20.9	102.8	16.3

Table A6-6b. Quantity of wastewater generation: 2005

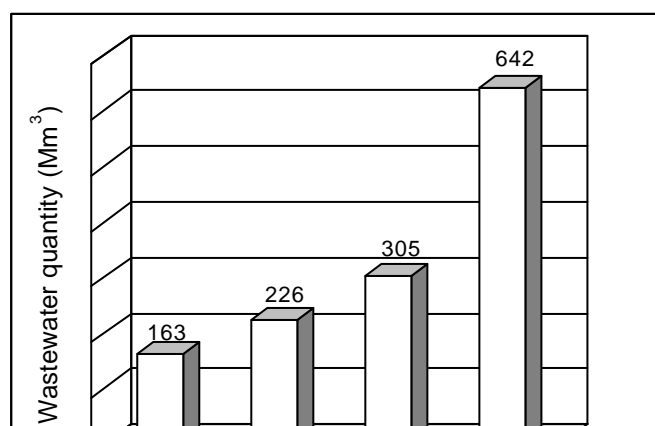
<i>Mohafaza</i>	<i>2005 Population '000</i>	<i>2005 Wastewater Mm³</i>	<i>2005 BOD '000 ton</i>	<i>2005 COD '000 ton</i>	<i>2005 N '000 ton</i>
<i>Greater Beirut Area</i>	1372	71	9.1	44.6	7.1
<i>Mount Lebanon</i>	819	42	5.4	26.6	4.2
<i>Bekaa</i>	542	28	3.6	17.6	2.8
<i>North Lebanon</i>	907	47	6.0	29.5	4.7
<i>South Lebanon</i>	750	39	5.0	24.4	3.9
<i>Total Lebanon</i>	4390	226	29.0	142.7	22.6

Table A6-6c. Quantity of wastewater generation: 2015

<i>Mohafaza</i>	<i>2015 Population '000</i>	<i>2015 Wastewater Mm³</i>	<i>2015 BOD '000 ton</i>	<i>2015 COD '000 ton</i>	<i>2015 N '000 ton</i>
<i>Greater Beirut Area</i>	1593	95	12.2	60.1	9.5
<i>Mount Lebanon</i>	950	57	7.3	35.8	5.7
<i>Bekaa</i>	629	38	4.8	23.7	3.8
<i>North Lebanon</i>	1053	63	8.1	39.7	6.3
<i>South Lebanon</i>	868	52	6.7	32.7	5.2
<i>Total Lebanon</i>	5092	305	39.0	192.1	30.5

Table A6-6d. Total quantity of wastewater generation: 2040

<i>Mohafaza</i>	<i>2040 Population '000</i>	<i>2040 Wastewater Mm³</i>	<i>2040 BOD '000 ton</i>	<i>2040 COD '000 ton</i>	<i>2040 N '000 ton</i>
<i>Greater Beirut Area</i>	2311	201	25.7	126.5	20.1
<i>Mount Lebanon</i>	1378	120	15.3	75.4	12.0
<i>Bekaa</i>	912	79	10.1	49.9	7.9
<i>North Lebanon</i>	1527	133	17.0	83.6	13.3
<i>South Lebanon</i>	1260	109	14.0	69.0	10.9
<i>Total Lebanon</i>	7388	642	82.1	404.3	64.2



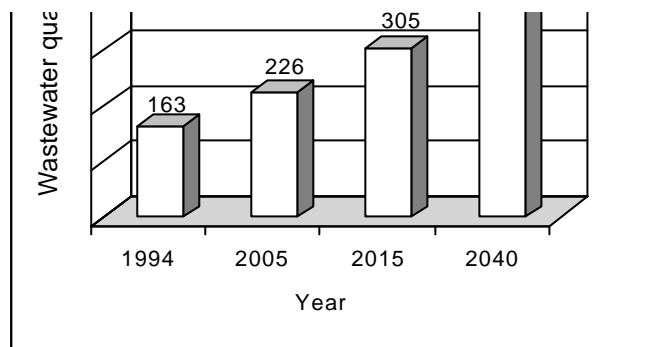


Fig. A6-3. Wastewater generation in Lebanon

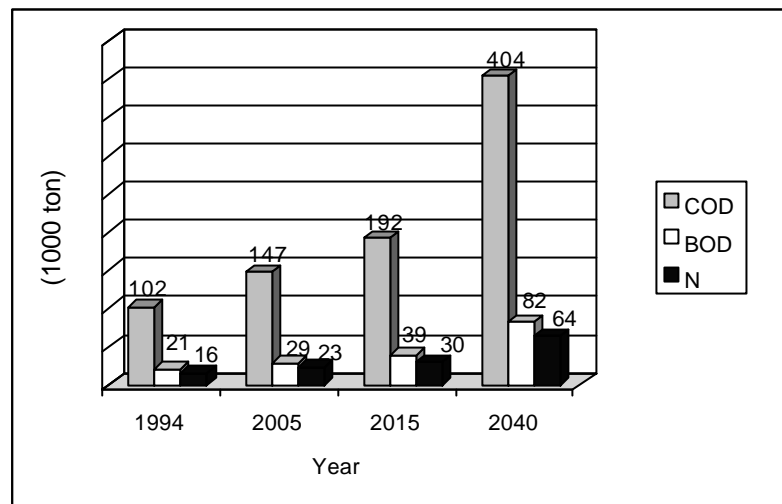


Fig. A6-4. Wastewater characteristics in Lebanon

Once again, Note that Tables 6-6a to d represent only domestic and commercial wastewater quantities. Industrial wastewater quantities are highly variable and depend on the type of industry as well as the industrial process itself. At present, these quantities can be estimated with little degree of certainty because of the general lack of regulatory monitoring and enforcement. While some statistics have been reported in this respect [1, 7], none has been included in this report because of the general controversy surrounding these statistics and the assumption that industrial wastewater will be handled at the source and no GHG emissions as methane will be generated from this sector. The validity of this assumption should be continuously checked when preparing updates for country GHG emissions.

6.2 METHANE EMISSION PROCESS DESCRIPTION

Solid waste including municipal, commercial and industrial wastes, as well as municipal wastewater contains a large percentage of organic materials which can decompose under appropriate environmental conditions. In the absence of oxygen (anaerobic conditions), the decomposition process produces primarily CH₄ and CO₂ and insignificant quantities of other gases. This process is carried to completion through a series of microbial populations the most important of which are referred to as methanogens or methane producing bacteria. These latter are sensitive to the waste composition and several environmental factors such as temperature, pH, and availability of nutrients.

Assuming that favorable conditions for methane production persists, the objective of the present work is to estimate the amount and type of emissions from solid waste disposal and wastewater treatment.

6.3 EMISSION ESTIMATION

6.3.1 Solid Waste

The revised default methodology developed by the Intergovernmental Panel on Climate Change (IPCC) was followed in order to estimate emissions from solid waste disposal on land [8]. The method follows a mass balance approach that involves estimating the degradable organic carbon (DOC) content of the solid waste to calculate the amount of CH₄ that can be generated by the waste.

Note that degradation processes will typically generate an approximately equivalent percent by volume of CO₂. However, the IPCC methodology assumes that the decomposition of organic material derived from biomass sources (e.g. crops, forests) which are regrown on an annual basis is the primary source of CO₂ released from waste. Hence, CO₂ emissions from land disposal of solid waste are not treated as net emissions from waste in the IPCC methodology. They are rather reported under the Agriculture and Land-Use Change and Forestry if biomass raw materials are not being sustainably produced. An inventory on methane emissions for the base year 1994 was completed in the first phase of this study [5]. The IPCC methodology is performed in four steps described below.

Step 1. Estimation of MSW generated and disposed of in solid waste disposal sites.

The total MSW generated for the year 1994 was estimated at 1087.7 x10³ tonnes (Table A6-4). In Lebanon, about 70 percent of the population reside in urban areas. Waste generated from these areas is typically deposited in open dumps or incinerated thus accounting for about 761x10³ tonnes. Incineration at Amrousiyeh and Karantina accounted for about 400 tonnes/day [9] which are equivalent to 146x10³ tonnes per year. Therefore, the total amount of MSW disposed of in open dumps in the year 1994 is 615x10³ tonnes (615 Gg).

For the later years, 2005, 2015, and 2040, controlled landfills are planned for the disposal of solid waste. The percent of waste landfilled is expected to reach 80, 85, and 90 percent for the three years selected for the baseline scenario. The corresponding total amount of waste landfilled is summarized in Table A6-7 and compared with waste generated in Fig. A6-5.

Table A6-7. Solid waste disposed of in deep landfills

	1994	2005	2015	2040
<i>Generation Rate (kg/capita/day)</i>	0.8	0.94	1.12	1.6
<i>Population Count, '000 persons</i>	3725	4390	5092	7388
<i>Amount of Waste Generated, Gg</i>	1087	1506	2082	4315
<i>Landfilled Waste, %</i>	56.5	80	85	90
<i>Amount of Waste Landfilled, Gg</i>	615	1205	1769	3883

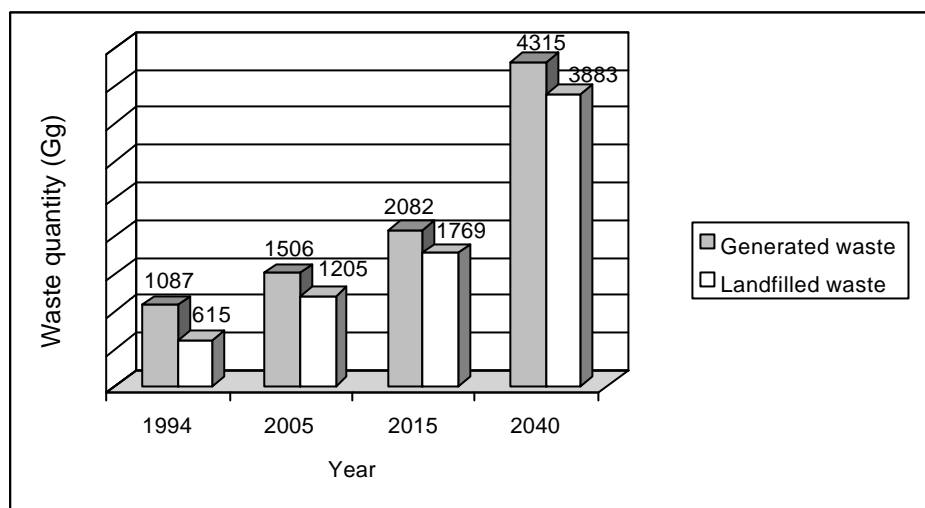


Fig. A6-5. Solid waste disposal of in deep landfills

Step 2: Determination of the methane correction factor

As indicated above, a good percentage of MSW is disposed of in open dumps (1994) or in controlled landfills (2005, 2015, and 2040). These facilities will reach a depth far in excess of 5 meters. According to the IPCC guidelines, this corresponds to a methane correction factor of 0.8 [6].

Step 3: Estimation of methane production rate per unit of waste

The methane production rate per unit of waste is a direct function of the waste composition which is presented in Table A6-2. The data in this table was used as described in the IPCC guidelines.

Step 4: Estimation of the total net annual methane emissions

The total net annual methane emissions was calculated assuming a zero value for the methane oxidation correction factor. For the year 1994, this is a reasonable assumption given the fact that solid waste is deposited in open dumps with no potential gas entrapment at the surface of the dump. Gas will be emitted unobstructed into the atmosphere leaving no time for oxidation to occur. For subsequent years, the current practice for methane emission management is passive venting into the atmosphere. However, there appear to be provisions to cover future landfills. At this stage, it was assumed that passive venting will continue with minimal interference.

Following this approach, estimates of methane emissions for the years 1994, 2005, 2015, and 2040 of the baseline scenario were conducted and the results are summarized in Table A6-8 and depicted graphically in Fig. A6-6.

Table A6-8. Methane emissions from solid waste disposal (Gg/year)

Year in Baseline Scenario	STEP 1	STEP 2	STEP 3						STEP 4				
	A	B	C	D	E	F	G	H	J	K	L	M	N
	Total Annual MSW Disposed to SWDs (Gg MSW)	Methane Correction Factor (MCF)	Fraction of DOC in MSW	Fraction of DOC Which Actually Degrades	Fraction of Carbon Released as Methane	Conversion Ratio	Potential Methane Generation Rate per Unit of Waste (Gg CH ₄ /Gg MSW)	Realised (Country-Specific) Methane Generation Rate per Unit of Waste (Gg CH ₄ /Gg MSW)	Gross Annual Methane Generation (Gg CH ₄)	Recovered Methane Per Year (Gg CH ₄)	Net Annual Methane Generation (Gg CH ₄)	One Minus Methane Oxidation Correction Factor	Net Annual Methane Emissions (Gg CH ₄)
							$G = (C \times D \times E \times F)$	$H = (B \times G)$	$J = (H \times A)$		$L = (J - K)$		$N = (L \times M)$
1994	615	0.8	0.17	0.77	0.5	16/12	0.087	0.0696	43	0	43	1	43
2005	1205	0.8	0.17	0.77	0.5	16/12	0.087	0.0696	85	0	85	1	85
2015	1769	0.8	0.17	0.77	0.5	16/12	0.087	0.0696	123	0	123	1	123
2040	3883	0.8	0.17	0.77	0.5	16/12	0.087	0.0696	269	0	269	1	269

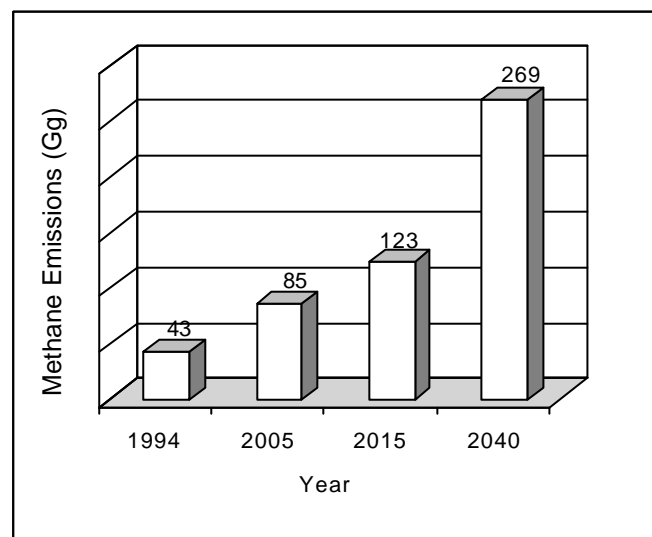


Fig. A6-6. Methane emissions from solid waste disposal

6.3.2 Wastewater

Similar to solid waste, the revised default methodology developed by the IPCC can be followed in order to estimate emissions from domestic, commercial, and industrial wastewater treatment [8]. The amount of methane that can be emitted is a direct function of the BOD and COD annual loading and the treatment process which were described above. At this stage, the assumptions adopted in this report would result in no methane emissions from wastewater treatment. As stated earlier, the validity of these assumptions must be continuously checked when updating inventory and mitigation reports for GHG emissions.

6.4 MITIGATION OF METHANE EMISSIONS

As indicated above, solid waste disposal in landfills constitutes the major source of methane emissions in Lebanon. There are two approaches to reducing methane emissions from landfills namely, methane recovery or reduction of landfilled waste. Both approaches involve several options to manage the gas as presented in Table A6-9. The applicability of these options is highly dependent on the availability of technical skills and policies for solid waste management at a particular location.

Table A6-9. Technical options for reducing methane emissions from landfills [10]

<i>Considerations</i>	<i>Methane recovery and utilization</i>	<i>Alternative waste management practices</i>
Recovery/reduction techniques	<input type="checkbox"/> Recovery wells <input type="checkbox"/> Collection systems	<input type="checkbox"/> Source reduction <input type="checkbox"/> Incineration <input type="checkbox"/> Composting
Gas use/combustion options	<input type="checkbox"/> Electricity generation <input type="checkbox"/> Natural gas supply <input type="checkbox"/> Flaring	None
Availability	Currently available	Currently available
Capital requirements	Medium	Low/medium
Technical complexity	Medium/high	Low/medium
Applicability	<input type="checkbox"/> Existing and new landfills <input type="checkbox"/> Nearby gas use <input type="checkbox"/> Capital/technology dependent	Widely applicable
Methane reductions	50-90% of total emissions	Up to 100% of total emissions

6.4.1 Methane Recovery

Methane can be recovered from landfills and managed either through flaring or usage as an energy resource. In both cases, the methane gas is combusted to emit primarily carbon dioxide which is much less potent as a GHG. Landfill gas recovery technologies have been demonstrated and are widely used in several countries, and offer a great potential for expanding worldwide.

Landfill gas recovery offers significant environmental, economic, and energy benefits. These benefits are enjoyed by many including the landfill owner-operator, the project developer, the energy product purchaser and consumer, and the community living near the landfill. From an environmental perspective, besides the potential reduction in GHG emissions as methane, gas recovery systems provide a good control of volatile organic compounds that are usually released into the atmosphere with the landfill gas.

Economically, the landfill may realize a profit with the sale or use of landfill gas when site specific conditions are favorable. Local communities may also benefit in terms of both jobs and revenues through the development of local energy resources. Because landfill gas is generated continuously, it provides a reliable fuel for a range of energy applications including power generation and direct use. Electric utilities that participate in landfill gas to energy projects can benefit by enhancing customer relations, broadening their resource base and gaining valuable experience in renewable energy development. Finally, Landfill gas projects provide important demand side management benefits, as transmission losses from the point of

generation to the point of consumption are negligible.

6.4.2 Reduction of Landfilled Waste

Reduction of landfilled waste can be accomplished through source reduction, recycling or other waste management practices such as composting or incineration. The success of a waste reduction program is highly dependent on the waste stream characteristics, public participation (i.e. recycling), by-product market availability (i.e. recyclables, compost), public perception (i.e. incineration), and of course, the adoption of integrated solid waste management policies.

6.4.3 The Lebanon Context

In Lebanon, the historic background of solid waste management (described above) consisted primarily of waste disposal in large open dumps. The current and future government policy on solid waste management advocates an integrated waste management system of recycling, composting and landfilling. Incineration was completely phased out due to public pressure that emanated from the adverse impacts of operating two old incinerators. The current policy did not succeed to date. In fact, the market for recyclable materials has been very weak. The target for recyclables was set at 10 percent but did not achieve more than 1 percent. The experience with composting was not successful either. The one year experience was plagued with operational problems: system overload, odor generation, and a low quality compost product. As a result, the majority of compost material was disposed of in landfills. Efforts continue to improve processing and composting facilities. For the years of the baseline scenario, there are several possible solid waste management alternatives which will dictate mitigation options. These alternatives are presented below with their corresponding likely hood of occurrence.

Alternative 1.

Continue with the current waste management policy (recycling, composting, landfilling) until it succeeds. To date, this appears to be one alternative that is adopted by the government at some locations. Under this alternative, a great part of degradable organics are removed from the waste stream that may reach a landfill thus reducing the economic incentive for the installation of gas recovery systems since the amount of methane that can be produced would not cover the cost of gas recovery. The best remaining mitigation measure under this alternative would be methane gas flaring which again, on and by itself, does not present any rate of return on investment. As such, unless the government requires and enforces gas flaring, methane emissions will be completely released into the atmosphere and no reduction in GHG emissions from the waste sector would be expected.

Alternative 2.

Modify the current waste management policy and adopt complete landfilling of municipal solid waste. This is a second alternative that the government has adopted at many locations for the baseline years. The probability of occurrence of this alternative will increase if the recycling and composting policy continues to fail. Under this alternative, no degradable organics are removed from the waste stream that may reach a landfill thus increasing the economic incentive for the installation of gas recovery systems since the total amount of methane that can be produced would be available for recovery and energy production. While

flaring is a mitigation option under this alternative, gas recovery may provide a favorable option even if the government does not adopt a policy to reduce GHG emissions.

Alternative 3.

Modify the current waste management policy and adopt complete landfilling of municipal solid waste with separation of food waste at the source. This alternative can be partially accomplished by requiring kitchen grinders but it requires significant public participation and government enforcement which decreases the probability of its occurrence. Similar to alternative 1, under this alternative, a great part of degradable organics are removed from the waste stream that may reach a landfill thus reducing the economic incentive for the installation of gas recovery systems since the amount of methane that can be produced would not cover the cost of gas recovery. The best remaining mitigation measure under this alternative would be methane gas flaring which again, on and by itself, does not present any rate of return on investment. As such, unless the government requires and enforces gas flaring, methane emissions will be completely released into the atmosphere and no reduction in GHG emissions from the waste sector would be expected.

Alternative 4.

Modify the current waste management policy and adopt complete incineration of municipal solid waste. This is the third likely alternative that the government may adopt. The probability of occurrence of this alternative is slim because of higher costs [11], lack of technical expertise, and public pressure. Under this alternative however, methane emissions can be eliminated or minimized.

Economy of Alternatives

In Lebanon, an economic assessment study was conducted to evaluate the cost of three waste management options (composting, incineration and landfilling) that are planned for several Lebanese cities. Table A6-10 summarizes the associated cost with the three options clearly favoring the landfilling option. Fig. A6-7 depicts these costs.

Table A6-10. Economy of waste management options [11]

<i>Waste management option</i>	<i>1995 \$ / ton</i>
<p>Incineration</p> <p>Incineration is a significantly more costly process, particularly in Lebanon, where the high technology is new and the high moisture content of the garbage makes it difficult to burn. Incineration would require complementary landfill facilities to dispose of residues which can represent up to 30 percent of the total waste incinerated.</p>	65-75
<p>Composting</p> <p>Composting represents a viable option particularly in agricultural areas where there is potential demand from farmers, as in the Bekaa valley (Zahle), in the southern coastal area (Saida and Tyre) and in the northern Akkar region (Tripoli). The costs shown Table 610 take no account of potential revenue from sales (manure is currently priced at US\$30 per ton) [11]</p>	35-40

<p>Landfilling</p> <p>Landfilling costs will vary according to the price of land and the extent of preparation needed for the site. For example in most of the landfills proposed within the Government plan, double impermeable layers are planned to ensure effective protection against possible contamination of water resources. On coastal areas a dyke would be built to ensure against spilling of refuse into the sea. Land prices are significantly lower in the Bekaa valley than along the coastal zone</p>	15-25
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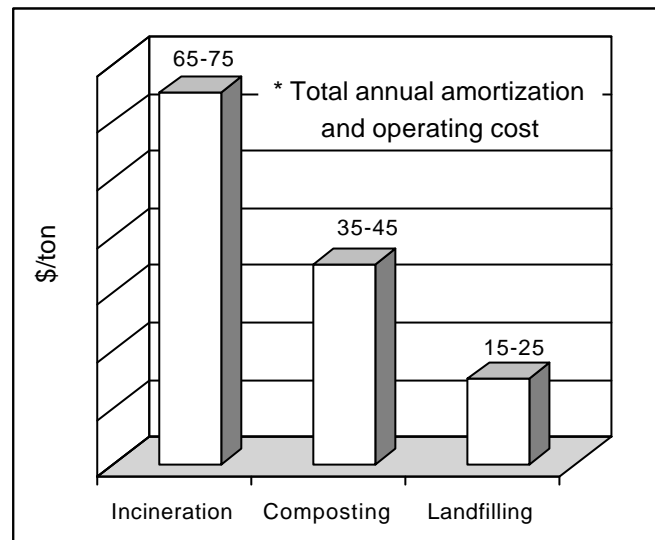


Fig. 6-7. Economy of waste management options

Potential Emission Reduction

Based on the above analysis, it appears that alternatives 1 and 2 constitute the likely alternatives for the baseline years. Under these alternatives, reduction of methane emissions can be accomplished through gas collection and flaring or recovery for energy use. A landfill can be considered in steady conditions once a steady gas generation rate has been reached and for a period of time, which includes at least that number of years during which a yearly equal amount of waste is landfilled. While new waste would generate a higher landfill gas rate than older waste, it is assumed that the two components would result in an average landfill gas flow over the life span of the landfill. Table A6-11 summarizes the energy content in landfill gas.

Table A6-11. Energy content in landfill gas

Year	1994	2005	2015	2040
Mass of CH ₄ generation potential, Gg	43	85	123	269
Volume of CH ₄ generation potential [1], 10 ⁶ Nm ³	60	119	172	377
Caloric value [2], 10 ¹² J	2153	4247	6160	13500
Oil value [3], 10 ³ tons	50	100	143	313
Thermal value [4], GW-hr _{th}	600	143	1717	3763
Electric value [5], GW-hr _{el}	180	313	513	1130

1. 1 Nm³ (at STP) = 714 g of CH₄
2. Caloric value of CH₄ = 35,900 kJ/Nm³ → Caloric value of LFG = 17,950 kJ/Nm³