The total present value cost (at different discount rates) of managing and protecting the existing forested areas and OWL, as well as managing reforested areas, to ensure that the stocks continue to sequester carbon, are presented in Table 3-18. The costs reflect the investment and operational costs to be incurred between the years 2011 to 2030 to implement the proposed mitigation scenario.

Table 3-18 Total discounted costs for forest protection and management

Discount Rate	PV (cost in USD) up to 2030	Cost (USD/t of incremental C sequestered) (up to 2030)	Cost (USD/ tCO_2 sequestered) (up to 2030)
5%	242,899,386	39.4	10.76
10%	162,550,434	26.3	7.20
15%	117,495,326	19.0	5.21

Mitigation scenario 2: Afforestation and reforestation including agroforestry and sylvo-pastoral systems

In order to optimize the success rate of reforestation campaigns, the National Reforestation Plan (NRP) in Lebanon stipulated the use of native species in each site according to the ecological criteria, the climate and soil characteristics in the related ecosystem and has banned the introduction of non-native species. However, very limited measures are currently taken to identify and prevent the introduction of alien species, ascertain the origin of the seedlings, encourage production of native species and monitor the establishment and development success of those reforestation campaigns. In addition to the control of the alien species, a forest genetic resources conservation and management strategy should be implemented, including the management of seeds provenances.

Reforestation success rate for coniferous, deciduous and mixed wood areas can be as low as 20-30% (Castro et al., 2004) in stressful environments such as Mediterranean ecosystems including Lebanon. Moreover, scientific evidence (Benayas et al., 2005; Castro et al., 2004) has shown that planting methods such as seeding or relying on bushes or species from the understory to initiate successful forest dynamics are more successful than direct planting, but require significantly more time to result in effective ecosystem development.

Any action aiming at replanting trees on barren or degraded areas that were previously covered by forests and would contribute to the overall carbon sequestration balance is identified as “reforestation”. The action of establishing forests on sites that were not previously considered as forests is called afforestation. In this perspective, all efforts of agroforestry or even urban greening (recreation areas, urban parks, etc.) are included. Linking forests and OWL through corridors (forest trees, wild fruit trees and local species) is of utmost importance in enhancing the green cover and conserving existing stands. Spillover effects from creating contiguous forest lands include the reduced habitat fragmentation.

Mitigation scenario 3: Substituting fossil fuels by forest-based biofuels: a CDM option

In addition to their role in reducing global carbon equivalent rates, forests can positively contribute to mitigating climate change effects by substituting fossil fuels with forest-based fuels.

In Lebanon, the forest growth rate is relatively low when compared to the annual demand for wood fuel and unless sustainable forestry practices are adopted and implemented, a recommendation to increase the supply of forest-based fuels is hardly applicable and should be considered with care. OWL can serve as the main source of biofuel from wood clipping and sylviculture practices. The density of forests and OWL can also be reduced to provide biofuel while also reducing the fire risk.

In conclusion, even if the direct benefit of forests in Lebanon cannot be properly highlighted through their contribution to GHG emissions removal, the economic value of those forests in terms of ecosystem services and other secondary benefits (wellbeing, cultural, etc.) should be considered while valuing Mediterranean forests.

3.5. Waste

The waste sector, including wastewater, is the largest source of CH_4 emissions in Lebanon. The sector generated 2,227 Gg CO_2 eq. in 2004, or 11% of the total GHG emissions for the same year. Calculations for the years 2000 to 2004 indicate an increase of 28% in waste GHG emissions by 2004 (base year 2000).

The discussion on mitigation potential from the waste sector will focus on solid waste management which accounts for the majority of emissions in this sector.

3.5.1. Baseline scenario

With the absence of actual targets for waste reduction, sorting at the source, composting and landfilling, it is difficult to predict how the different waste streams are going to be managed by 2030. However, it is acknowledged that the infrastructure and installations are being set up to realize the national solid waste management plan of 2006, which consists of establishing regional sanitary landfills, sorting and composting facilities while rehabilitating existing dumpsites. The following assumptions are proposed for constructing a future baseline scenario:

- The current 2006 plan would be implemented over the next 20 years (2010-2030);
- The open dumpsites would be rehabilitated therefore transferring the waste from unmanaged sites to managed sites with CH_4 gas collection in the proposed sanitary landfills, and rehabilitation of the dumpsites through closure and collection of gas. Landfill gas recovery rates are projected to grow with the assumed increase in the proportion of waste going into 'managed' sites;
- Solid waste disposal on land would gradually decrease by an annual rate of 3.5%, thereby constituting 68% of the total waste generated by 2030 (compared to 84% in 2006). It is assumed that recycling and composting rates will increase to cover 32% of the total waste stream by 2030;
- The generated municipal waste stream that would be disposed of on land by 2030 is assumed to be managed;
- The per capita MSW generation rates are assumed to follow the GDP growth that is predicted for Lebanon at an annual average rate of 4.3% (IMF, 2009).

Based on these assumptions, the projected future baseline CH_4 emissions and corresponding waste inflows into solid waste disposal sites were calculated (reaching 6,000 Gg of CO_2 eq.), as presented in Figure 3-8.

3.5.2. Mitigation scenarios and costs

The proposed mitigation options tackle both the waste and energy sectors as it considers energy recovery as an alternative waste management option. However, it is highly recommended that in the implementation of any or both mitigation scenarios, strict control and enforcement of pollution emissions controls be applied to prevent adverse impacts on public health and the environment.

Mitigation scenario 1: Landfilling with gas recovery for electricity generation

Based on the assumptions of the baseline scenario for the different parameters mentioned, the amount of waste to be deposited on land was calculated, along with the volume of methane which could be used in the future

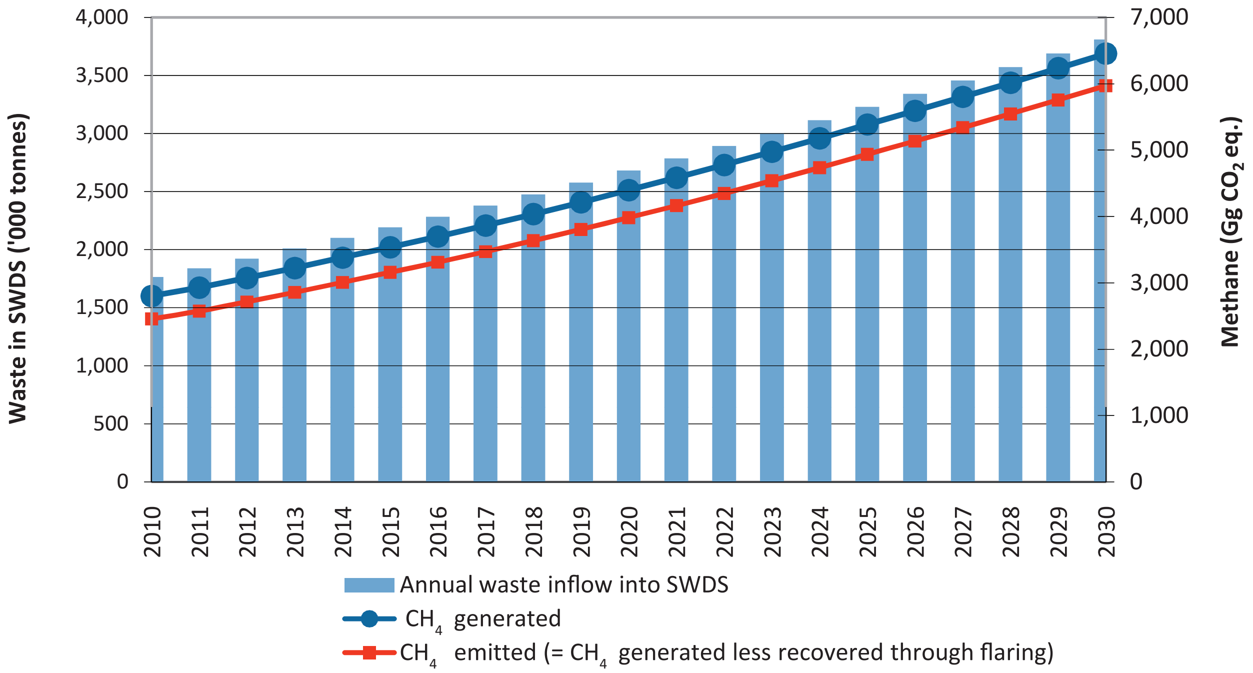

Figure 3-8 Projected baseline quantities of municipal solid waste in disposal sites and methane generation from SWDS

to generate electricity. The estimated methane volumes from solid waste disposal on land exclude the recovered volumes which would undergo flaring under the current policy. Thus, measures to capture the increasing volumes of methane emissions are considered to be 'additional' mitigation measures and their cost is accounted for accordingly.

For this mitigation scenario, gas recovery projects for electricity generation are assumed to apply to all current and future sanitary landfills and rehabilitated dumpsites. However, the economic feasibility of such projects would need to be scrutinized on a site-by-site basis. The amount and composition of waste deposited are key factors that help determine the methane generation potential, which in turn determines the economic viability of gas recovery projects. A landfill gas energy project may not be feasible for small waste quantities with low organic fractions or high moisture content. Most landfill gas recovery projects for energy use run on internal combustion engines with capacities in the range of 1-15 megawatts (MW) (Bogner et al., 2007). The determination of the engines' capacity needed for power generation from captured landfill gas is carried out by a series of conversions and assumptions of the portion of methane in landfill gas (50%), collection efficiency (50%), portion of captured methane used for power generation (90%) and other combustion engine parameters. Flares are installed even if the landfill gas is intended to be recovered for electricity generation in order to prevent accidental releases.

Regarding the collect and flare systems, the capital cost and operation and maintenance costs are driven by the amount of waste disposed. While absolute total costs increase with larger amounts, the unit costs per tonne of waste decrease reflecting economies of scale. Table 3-19 shows average costs of a collect and flare system for the generation of electricity. It should be noted that only additional costs represented by investments to utilise the methane gas for electricity production were taken into consideration. Table 3-20 shows the energy potential from the methane emissions and the power capacity needed to convert the thermal energy into electric energy. The methane emissions captured for energy generation are considered to be the emissions avoided. It is assumed that no CO_2 emissions from electricity production will be avoided, given that the current power generation rates do not meet the electricity demand. The installed

Table 3-19 Capital and operational costs of a collect and flare system and internal combustion engine for electricity generation from landfill methane gas

Parameter	Value
Capital Cost of a Collect and Flare system	USD 0.87/ tonne of MSW
Operation & maintenance cost	USD 0.13/tonne of MSW
Capital cost of an internal combustion engine/ generator	USD 1,791,000/MW
Operation & maintenance cost of an internal combustion engine/ generator	USD 181,000/MW
Depreciation period	10 years
Project Lifetime	20 years
Discount rate	10%, 15%

Source: USEPA, 1999. Estimated in 2004 USD

Table 3-20 Power capacity needed, energy potential from landfills' methane and methane emissions avoided for selected years

	2015	2020	2025	2030
Methane generated (Mm^3 CH_4)	209.85	264.65	327.89	396.52
Methane captured (Mm^3 CH_4)	104.93	132.32	163.94	198.26
Methane used for power generation (Mm^3 CH_4)	94.43	119.09	147.55	178.43
Energy content of "usable" methane (10^6 MJ)	3,563	4,493	5,567	6,732
Thermal energy generation potential (GWh_{th})	990	1,249	1,548	1,871
Electric energy generation potential (GWh_e)	225	284	352	426
Minimum engine capacity needed (MW)	29.0	36.6	45.3	54.8
Engine capacity to be installed (factoring in engine availability) (MW)	34.1	43.0	53.3	64.5
Methane emissions avoided (Gg CO_2 eq.)	1,579	1,992	2,468	2,984

capacity for electricity generation from landfill methane gas would start with 26.6 MW in 2010 and increase to 64.5 MW by 2030. It is assumed that the internal combustion engines will have to be replaced by 2020.

The marginal cost of the reduction in CO_2 eq. was calculated using the net present value of the capital and operating costs for the landfill gas collection and electricity generation system and the net present value of the annual benefits from electricity generation. The revenues from electricity generation were calculated based on an average electricity price of USD 0.09 /kWh, and hypothetical increases in the price of 10 to 50% over the 20-year period. It is considered that the GHG emissions saved (tCO_2 eq.) are those saved through the collection of 50% of the methane gas, as allows the technology. At current electricity prices, the marginal cost of reducing 1 tCO_2 eq. landfill methane emissions is USD 1.85 (at a discount rate of 10%) or USD 1.75 (at a discount rate of 15%) (Table 3-21).

Table 3-21 Marginal cost of abatement of landfill methane per tCO_2 eq. at varying electricity prices and discount rates

	Discount Rate = 10%	Discount Rate = 15%
Electricity Price (USD/kWh)	Marginal Cost (USD/ tCO_2 eq. saved)	
0.09	1.85	1.75
0.10	0.60	0.50
0.11	-0.65	-0.75
0.12	-1.90	-2.00
0.13	-3.15	-3.26
0.14	-4.41	-4.51

Mitigation scenario 2: Waste incineration and energy production

Given the relatively small and dispersed quantities of waste generated in Lebanon, it is assumed that three waste-to-energy plants could be installed in three urban poles: Beirut to serve Beirut and Mount Lebanon; Tripoli to serve urban Tripoli; and Saida to serve urban Saida. Given the current generated quantities in the three locations, it is assumed that two 300,000 tonnes/year plants would be built to serve Tripoli and Saida and one 600,000 tonnes/year would be built in the Greater Beirut Area to serve Beirut and Mount Lebanon.

It is assumed that the MSW quantity that would be diverted from landfills in 2015 in the event of adoption of waste incinerators (while maintaining the baseline recycling and composting rates) would be 935,195 tonnes, and would grow to 1,417,370 tonnes by 2030. Hence, the landfill methane emissions avoided would be 1,129,694 tCO_2 eq. in 2015 and would grow to 1,916,302 tCO_2 eq. by 2030. The cumulative avoided emissions would be 24,142,251 tCO_2 eq. for the entire period extending from 2015 to 2030. Deducting the CO_2 emissions from incineration from the avoided emissions, the effective cumulative savings would total 11,771,499 tCO_2 eq. (Table 3-22 and Figure 3-9).

Table 3-22 GHG emissions avoided through diverting MSW from landfilling to incineration in selected years

	2015	2020	2025	2030
Baseline emissions (Gg CO_2 eq.)	3,159	3,984	4,936	5,969
MSW amount eligible for incineration (thousand tonnes)	935.19	1,087.71	1,250.96	1,417.37
Avoided CH_4 emissions due to the diversion of MSW from landfilling to incineration (Gg CO_2 eq.)	1,130	1,370	1,636	1,916
CO_2 emissions from incineration (Gg CO_2 eq.)	617	718	826	935
CO_2 emission saving (Gg CO_2 eq.)	512	652	810	981

For Lebanon, the use of the grate technology with three different scenarios for flue gas treatment has been recommended (MoE-MSC-IPP, 2005). Average values on energy production from incinerators of different capacities using different flue gas treatment techniques are used in this analysis. Values used for the calculation of costs are based on the MSC-IPP study (2005) and are shown in Table 3-23. It should be noted that since this waste management option is not part of any decreed plans in the Lebanese government, the full costs of investment and operation were taken into consideration in the cost analysis to reflect the fact that a completely new technology for waste management would have to be adopted to allow reductions in GHG emissions.

The marginal cost of the reduction in CO_2 eq. was calculated using the present value of the capital and operating costs for the incineration technology with energy recovery and the present value of the annual benefits from electricity generation. The revenues from electricity generation were calculated similarly as in

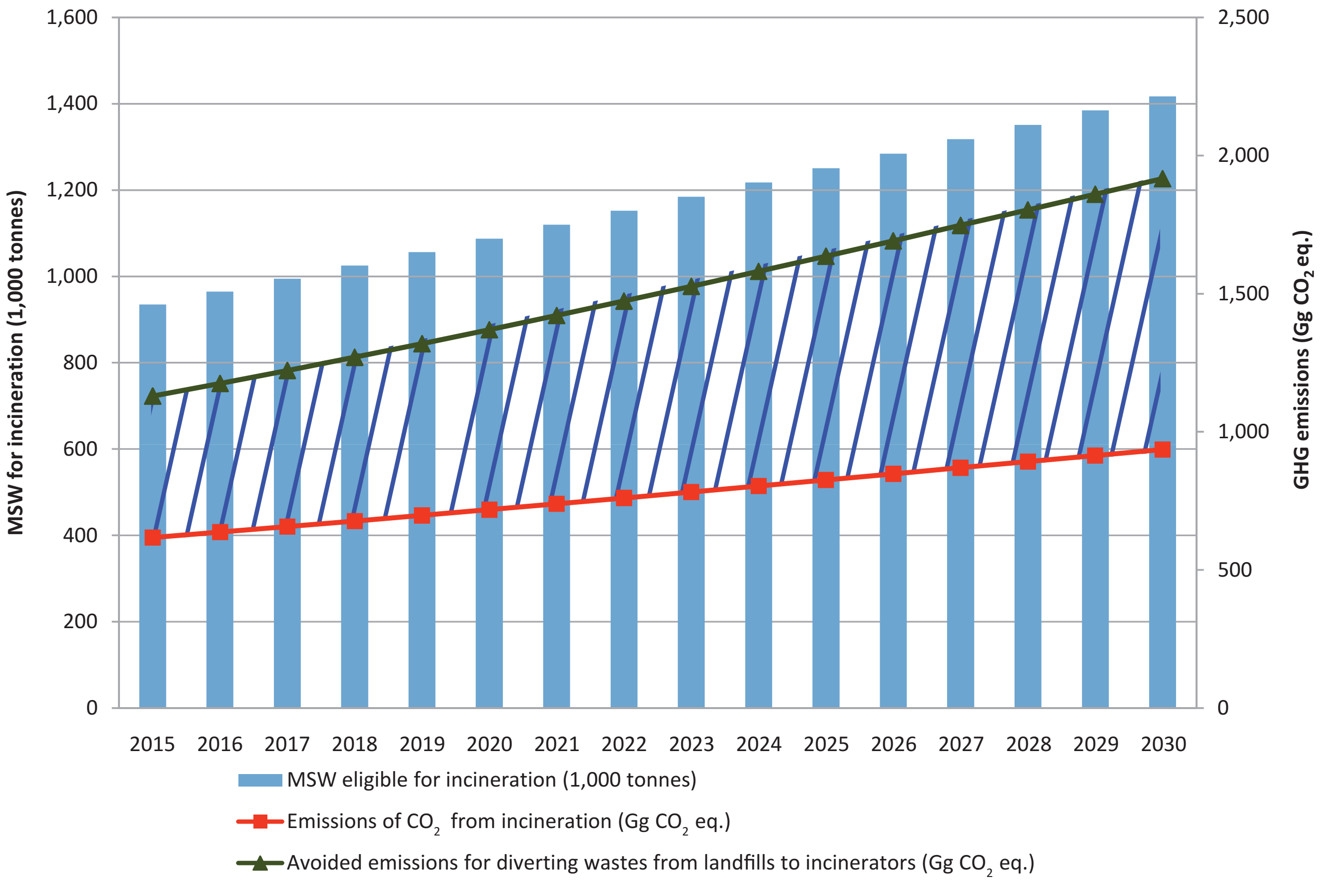

Figure 3-9 Projected quantities of municipal solid waste to be incinerated and avoided GHG emissions

Table 3-23 Energy potential from waste incineration and investment and operational costs of waste incineration for energy production

Parameter	Value
Average energy production from a 300,000 tonnes/yr facility	118,750 MWh
Average energy production from a 600,000 tonnes/yr facility	243,650 MWh
Average investment cost for all the proposed incineration capacity	USD 469.8 million
Average annual Operation & Maintenance cost for all the proposed incineration capacity	USD 92.9 million
Depreciation period	15 years
Project Lifetime	20 years

Estimated in 2004 USD
Source: MoE - MSC-IPP, 2005

mitigation scenario 1 above. It is considered that the GHG emissions saved (tCO_2 eq.) are those saved through the diversion of MSW from landfilling to incineration. At current electricity prices, the marginal cost of reducing 1 tCO_2 eq. of GHG emissions from solid waste using incineration ranges from USD 69.8 to USD 80.3 depending on the discount rate used (Table 3-24).

The marginal cost of abatement is significantly lower for landfill methane gas utilization given the larger potential to capture methane gas from the current waste management option in use in Lebanon. Waste incineration for energy production is an expensive mitigation option for Lebanon. Both mitigation scenarios can be applied successfully in settings with strict environmental and institutional controls to prevent any possible, inadvertent environmental pollution issues (Rand et al., 2000).

3.5.3. Mitigation Action Plan

The two proposed mitigation scenarios can be grouped under one mitigation action plan which recommends an increase in the share of renewable energy (from waste) in electricity production due to the potential for energy recovery and the expected avoidance of future CH_4 emissions from landfills. Additional activities to complement the action plan should include the development of the necessary legislation to ease barriers and provide incentives for landfill operators to invest in electricity generation from LFG.

Table 3-24 Marginal cost of abatement of GHG emissions through incineration per tCO_2 eq. at varying electricity prices and discount rates

	Discount Rate = 10%	Discount Rate = 15%
Electricity Price (USD/kWh)	Marginal Cost (USD/tCO_2 eq. saved)	
0.09	80.33	69.80
0.10	77.21	67.34
0.11	74.09	64.89
0.12	70.98	62.43
0.13	67.86	59.97
0.14	64.74	57.52