ComparativeAnalysis of Municipal Solid Waste Treatment Technologies – the case study of Western Macedonia

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Abstract

This study evaluates the environmental performance of the incineration and landfilling of municipal solid waste that is ready for the final disposal using the life cycle assessment (LCA) methodology. Data from the Prefecture of Western Macedonia and specifically for the regions of Kozani, Kastoria, Grevena and Florina were used to undertake this study. Sanitary Landfill and Incineration of the waste treatment technologies are studied. All technologies are favorable to abiotic and ozone layer depletion due to energy recovery from the waste treatment facilities. Results indicate that sanitary landfill has the significantly lower environmental impact. However, sanitary landfill has significant impact on photochemical oxidation, global warming and acidification.Landfill with energy recovery facilities is environmentally favorable. However, due to large land requirement, difficult emission control system and long time span, restriction on land filling is applying more in the developed countries.Life cycle assessment is an effective tool to analyze waste treatment technology based on environmental performances.

Keywords: Environmental assessment; Incineration; Sanitary landfill

1. Introduction

The disposal of municipal solid waste (MSW) constitutes onecomplex and multidisciplinary problem that local governments are facing globally. Increasing waste generation due to population growth, societal lifestyle changes, development and consumption of products that are less biodegradable, emphasize the need for integrated MSW management in various cities around the world [Asase et al., 2009]. Many municipalities follow some of the below management options: (1) waste prevention (2) recycling (3) biological treatment (4) thermal treatment (5) landfilling, as a hierarchical and not an integrated waste management system [Tchobanoglous et al., 2002]. Nonetheless,the idea behind integrated solid waste management (ISWM) is that, rather than accepting a simple hierarchy, alternatives should be examined systematically so that waste is managed in the most resourceful and environmentally friendly manner [Clift et al., 2000].

As far as waste management in Greece is concerned, it is noted thatGreece is among the countries in the EU which still maintain high rates of landfilling. The amount of MSW landfilled in 2010 was 4.2 million tonnes, equivalent to 81 % of the total generated MSW. Although the amount of MSW going to landfill has remained relatively stable over the last 10 years, amounting to around 4 to 4.3 million tonnes, the share of landfilling has decreased by 10 % between 2001 and 2010, from 91 % to 81 %. This trend can be attributed to recycling which has acquired an increased importance in Greek waste management in recent years, especially after the year 2007 when recycling (material and organic) peaked at 20 % of the total generated MSW [EEA, 2013].In 2010, the daily MSW production was around 15,000 tones, which correspond to 5.4 million tonnes of MSW on an annual basis. The waste management in Greece in 2011 is presented in **Fig. 1**

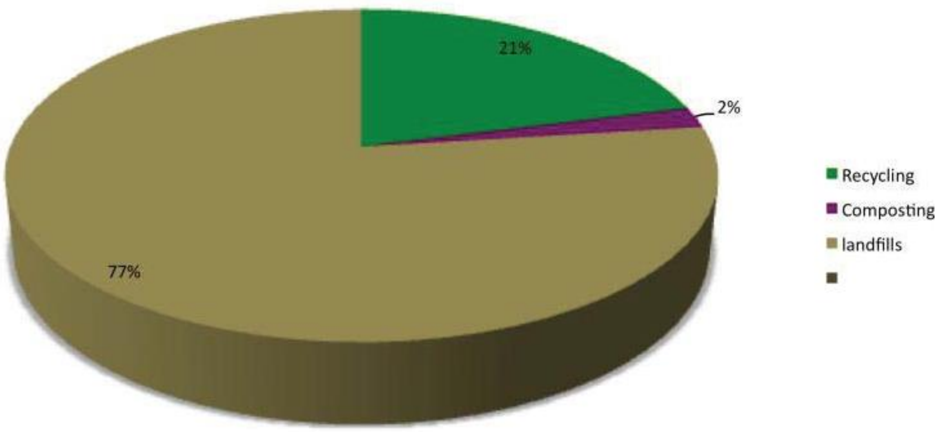

Figure 1.Waste management in Greece, 2011

Thermal treatment is currently a management option that is being dismissed as a possible method for treating waste. In making use of the ISWM concept, this study assesses the environmental implications of implementing different waste treatment methods such as incineration as well as landfill in the Prefecture of West Macedonia. A life cycle Impact assessment (LCIA)is used to carry out this study.

2. Area under study

The region of Western Macedonia is located at north-western Greece, bordering with the peripheries of Central Macedonia (east), Thessaly (south), Epirus (west), and bounded to the north at the international borders of Greece with the Republic of Macedonia (Bitola region) and Albania (Korçë region). Although it covers a total surface of 9,451 km^2 standing for 7,2% of country's total, it has a total population of 302,892 inhabitants (2.9% of the country's total), thus it is a low-density populated region (standing for 32 per km^2). This can be attributed to the fact that 82% of the total surface is mountainous and semi-mountainous areas. This is also reflected in the population distribution, as the major part of the population (56%) lives in rural areas. The capital of the periphery is Kozani with 47,451 inhabitants. Other main towns are Ptolemaida (32,775), Grevena (16,704), Florina (14,318) and Kastoria (13,959). According to the unofficial data from ELSTAT (2011)the total population in the Region is 282.120 Inhabitants, reduced by 6.5% compared with the 2001 data.

Municipal solid wastes in the region are classified in three basic categories:

- Mixed domestic wastes (from green waste bins),
- Recyclable domestic wastes (packaging waste also included) : paper, plastic, glass, metals (ferrous materials basically), aluminum
- Bulky municipal solid wastes which include: waste electrical & electronic equipment (WEEE) and the rest bulky waste (furniture equipment, bed layers, nonmetallic frames etc).

Table 1summarizes the annual production rates of Municipal Solid Wastes (MSW) of the 12 municipalities conforming the region of West Macedonia . The sources of these wastes are various enterprises of semi-industrial scale in the region of West Macedonia.

MUNICIPALITIES	SOLID WASTES (tn/yr)			
	2008	**2009**	**2010**	**2011**
Amynteo	6.408,50	6.643,00	6.323,10	6.400,70
Voio	7.495,30	7,453,00	6.965,80	6.348,60
Grevena	10.672,90	11.295,00	11.131,50	10.347,50
Deskati	2.116,50	2.239,00	2.163,30	2.055,90
Eordea	20.450,80	20.921,00	19.843,30	18.811,60
Kastoria	16.306,60	17.006,00	16.001,60	14.915,20
Kozani	29.108,80	29.902,00	28.760,70	26.517,20
Nestorio	773,7	803	763,3	720,9
Orestidos	5.708,80	5.864,00	5.452.10	4.905,00
Prespa	656,9	685	669,8	590,3
Servia – Velvento	5.107,40	5.341.00	5.137,40	4.894,20
Florina	13.562,00	13.762,00	13.211,80	12.435,40
TOTAL	**118.368,20**	**121.914,00**	**116.423,70**	**108.942,40**

Table 1. Amount of Municipal Solid Wastes

The current waste management system includes a Waste Management Centre (WMC), which is designed around the Region of Western Macedonia. The WMC is located in the area of a former lignite mine and includes a Sanitary Landfill for non-hazardous waste and a Regional Recycling Facility. It should be noted that due to the fact that recyclables are separated at source (4-bin system), the Regional Recycling Facility is actually a large Temporary Storage facility, where all collected recyclables are processed (removal of any unwanted materials), baled (paper and plastics) and stored prior their sale to end users.

In order to transfer waste or separated at source recyclables a network of transfer stations is in operation that consists of 10 Transfer Stations: 4 in the Regional Authority of Kozani, 2 in Grevena, 1in Kastoria and 2 in Florina. The transfer stations also serve as local facilities for the Temporary Storage of Recyclables coming from the various municipalities, prior their transfer to the WMC. The existing infrastructure for **Mixed waste** includes: i) 6day collection with municipal waste vehicles ii) 10 Transfer Station iii) 1 Sanitary Landfill for non-hazardous residues. The existing infrastructure for **Recyclables** includes: i) source separation in (4) distinct bins for paper, plastic, glass and metals ii) 10 Local Temporary Storages for recyclables (for paper, plastic, glass and metals) iii) one Regional Recycling Facility.

The infrastructure kerbiside collection includes five types of bins:

• Mixed waste: 4-wheeled bins-1.100L

• Paper: 2-wheeled bins-360L

• Plastic: 2-wheeled bins-360L

• Glass : 2-wheeled bins-360L

• Metals: 2-wheeled bins-360L

Collection vehicles for mixed waste and recyclables include:

• Waste Collection Vehicle with Press 16m^3

• Waste Collection Vehicle with Press 12m^3

• Waste Collection Vehicle with Press 8m^3

The transportation of mixed waste from the network of Transfer Stations to the WMC is done with semi-trailers equipped with a compression system and a capacity of 36m^3.

3. Methods

An LCA is a useful tool to evaluate the performance of MSW management systems [Ekvall et al., 2007; Liamsanguan and Gheewala, 2008]. The international standard ISO 14040-43 defines LCA as a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [Arena et al., 2003].The use of LCA for resources and waste management issues implies a slightly different focus than traditional product-oriented LCAs [Obersteiner et al., 2007]. The popularity of LCAs in analyzing MSW management systems is illustrated by the numerous published studies of the life cycle emissions of these systems, as well as by the substantial number of LCA computer models addressing MSW management [Cleary, 2009]. There are four phases for LCA, which include: (1) goal and scope definition (2) inventory analysis (3) impact assessment or LCIA (4) interpretation.

The objective of this study is to evaluate the environmental performance of the incineration and landfilling of MSW that is ready for the final disposal while accounting for existing waste diversion initiatives. The Prefecture of West Macedonia is used as a selected study site for this assessment due to its increasing number of waste diversion initiatives as well as accessible detailed documentation of its waste diversion initiatives and landfill operations.In this analysis, two different waste management scenarios, with both recovering electricity only, were investigated:

- Scenario 1: The landfilling option. All the waste is sent to the landfill without any further treatment.
- Scenario 2: Waste will be incinerated.

The life cycle of MSW in this study begins after the material recovery processes. Therefore, it is assumed that the waste collection, separation processes, and transfer station operations will be the same for both waste management scenarios and can be omitted from the LCA. The scope of this LCA is on the treatment of the waste. The system boundaries for where the LCA applies in each scenario are illustrated in **Figs. 1**and **2**. The environmental performance of the incineration and landfilling options were analyzed over the period 2006 to 2021. This study focused on the active life phase of the landfill and did not include the environmental implications of landfill closure and post-closure emissions. The functional unit of this study is 1 ton of MSW. Using an average of previous data,it was estimated that in 2021, approximately 173,989tonnes of residential waste would be generated.

The following elements were not considered :

- auxiliary fuel requirements;
- emissions related to ash disposal;
- emissions relating to leachate treatment from the landfill;
- emissions relating to the use and transport of daily and finalcover for the landfill facility.

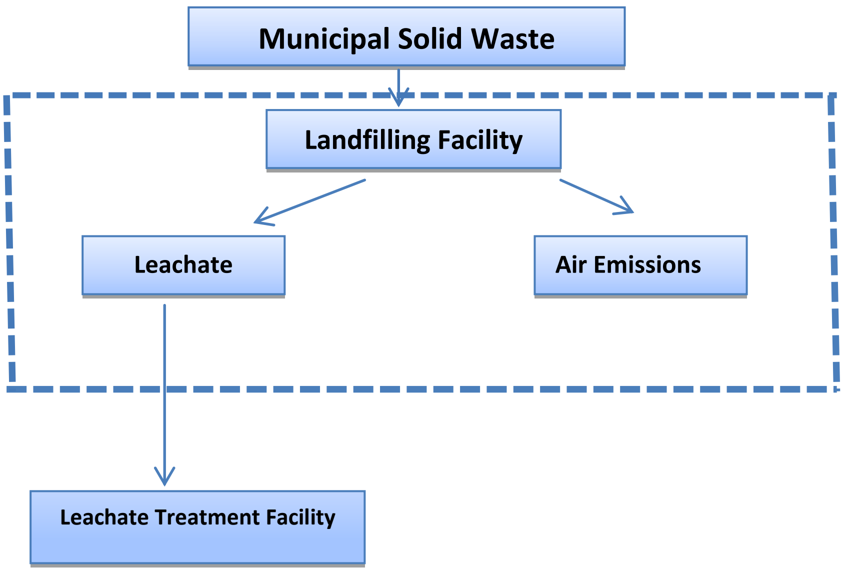

Fig. 1 Scenario 1 - Landfilling option

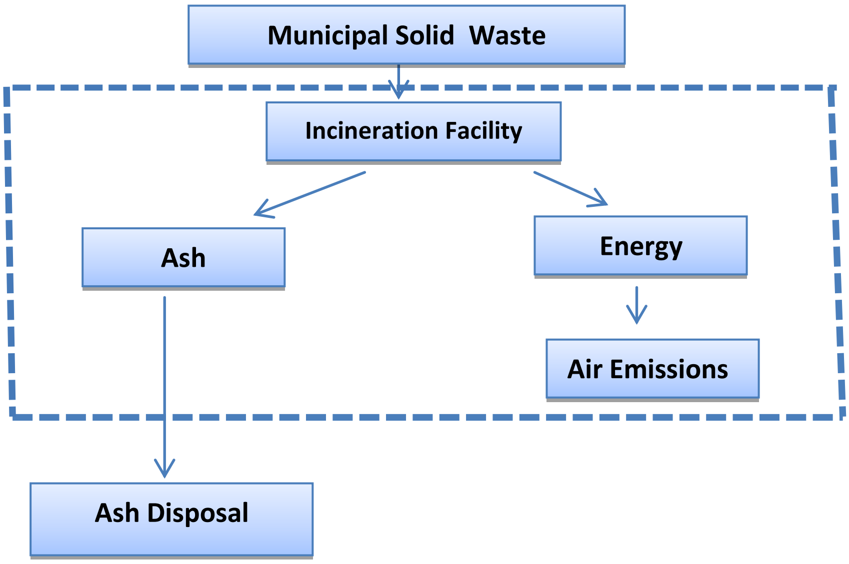

Fig. 2 Scenario 2 - Incineration option

Leachate treatment was not included in the scope. Furthermore, the treatment of leachate from the landfill was not included. It is pointed out that the more substantial aspect of managing ash landfills is the management of leachate. Therefore, the disposal of the ash was also not included to keep the scenarios comparable.

3.1 Waste Composition

An important aspect of this work is its ability to account for changes in waste quantity and composition.All compositions, presented **in Table 2**, were determined based on the tonnage of waste, and are assumed to remain constant throughout the life of the study. The composition of the waste diverted was determined by analyzing 5 years-worth of diversion data from the Prefecture of West Macedonia.Also**Table 3**, summarizes the forecasted quantities of waste till 2021.

MSW Components	Composition (% by weight)	
	Generated	Diverted
Food	46,2%	47,3%
Paper	19,4%	17,50%
Plastics	14,4%	14,7%
Ferrous	2,2%	2,3%
Glass	1,9%	2,0%
Wood	5,2%	5,3%
Other	10,6%	10,9%
Total	100,0%	100,0%

Table 2. Waste Composition of the Area under study

Year	MSW (tn)
2006	114.026
2007	116.988
2008	119.950
2009	123.062
2010	125.884
2011	129.301
2012	132.886
2013	136.646
2014	140.588
2015	144.720
2016	149.051
2017	153.588
2018	158.341
2019	163.318
2020	168.531
2021	173.989

Table 3. Forecasted quantities of MSW for the Area under study

3.2 Life Cycle Inventory

The life cycle inventory was developed using a combination of publicly available LCA model technical reports, greenhouse gas inventory guidelines and LCA literature.

3.2.1 Air Emissions

The following air emissions of compounds have been estimated for both the landfilling and incineration systems: Criteria Air Contaminants (CAC); Greenhouse gases (GHGs); and acid gases. GHGs are comprised of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF6), perfluorocarbons(PFCs) and hydrofluorocarbons (HFCs). Nonetheless , only CO_2, CH_4 and N_2O emissions were included in this study as emission factors for the rest of the GHGs are not common.The CO_2 emissions from the combustion of biomass materials (e.g., paper, food, and wood waste) contained in the waste are biogenic emissions and were not included in the CO_2 emission estimates [IPCC, 2006].

3.2.2 Incineration Plant Emissions

The incineration facility was modeled using a mass burn/waterwall design with a capacity of 1000 tonnes/day. The anthropogenic CO2 was calculated by determining theamount of fossil fuel carbon in each MSW component while theother emissions were determined based on the heating value ofthe waste. Both the amount of fossil fuel carbon in the MSW componentsand the heating value of the MSW components are dependenton the MSW compositions and would be adjusted as the MSWcomposition changes.The energy produced is recovered only as electricity, of which20% will be used for in-house purpose with the remainder soldto the grid. The mass burn incinerator is assumed to have a conservativeenergy recovery efficiency of 20%.All auxiliary fuels required to run the facility are not included inthis study.**Table 4**summarizes the calculated energy content (expressed in MJ) of the MSW.

Year	FOOD	PAPER	PLASTIC	FERROUS	GLASSES	TOTAL
2006	477.404	1.909.616	3.341.828	76.385	14.322	5.728.849
2007	489.805	1.959.221	3.428.638	78.369	14.694	5.877.664
2008	502.207	2.008.827	3.515.447	80.353	15.066	6.026.480
2009	515.237	2.060.948	3.606.660	82.438	15.457	6.182.845
2010	527.053	2.108.212	3.689.370	84.328	15.812	6.324.635
2011	541.357	2.165.428	3.789.499	86.617	16.241	6.496.284
2012	556.366	2.225.464	3.894.561	89.019	16.691	6.676.391
2013	572.108	2.288.433	4.004.758	91.537	17.163	6.865.299
2014	588.614	2.354.457	4.120.299	94.178	17.658	7.063.370
2015	605.916	2.423.663	4.241.411	96.947	18.177	7.270.989
2016	624.047	2.496.187	4.368.327	99.847	18.721	7.488.561
2017	643.043	2.572.170	4.501.298	102.887	19.291	7.716.511
2018	662.941	2.651.764	4.640.587	106.071	19.888	7.955.292
2019	683.782	2.735.126	4.786.471	109.405	20.513	8.205.378
2020	705.606	2.822.423	4.939.241	112.897	21.168	8.467.270
2021	728.458	2.913.832	5.099.206	116.553	21.854	8.741.496

Table 4.MSW's energy content –expressed in MJ- per each category

3.2.3 Landfill Facility Emissions

The landfill facility was designed as a sanitary landfill. Landfillgas is composed of mainly CO_2 and CH_4, but can contain trace concentrationsof compounds such as VOCs and HCl. The quantity ofCO_2 and CH_4 were determined using the Scholl Canyon model-**Eqs (1)**and **(2),**which is the most commonly used modelfor determining methane gas generation [US EPA, 2005].

$$Q_{T;x} = kMxLoe^{-k\,(T-x)} \quad \textit{Eq. 1}$$

whereQT,x = the amount of CH_4 generated in the current year, (T) by the waste, Mx, tonnes CH_4/year, X = the year of waste input, Mx = the amount of waste disposed of in year x, tonnes, K = CH_4 generation rate constant/yr, L_0 = CH4 generation potential, kg CH_4/t waste, T = current year.

$$Q_T = \sum Q_{T,x} \quad \textit{Eq. 2}$$

where Q_T = the amount of CH_4 generated in the current year (T), tonnes CH_4/year. The CH_4 generation potential (L_0) represents the amount of CH_4 that could be theoretically produced per ton of waste landfilled. Based on this model the calculated emissions of Landfill Gas and Methane are illustrated in **Fig. 3**.

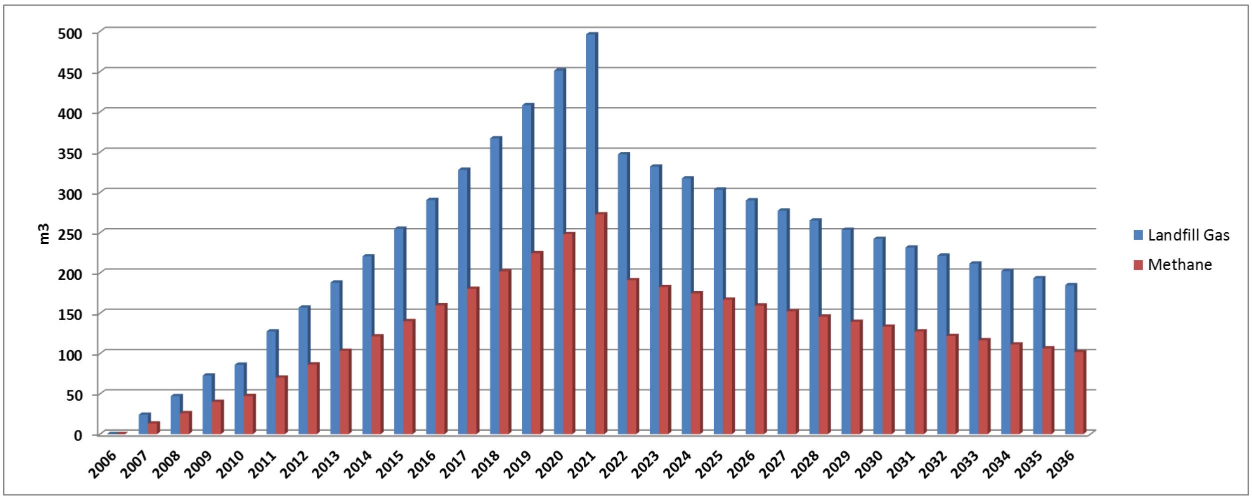

Figure 3. Production of Landfill Gas and Methane over the period of 2006-2036

Landfill leachate is produced from precipitation that falls directly on the site and percolates through the landfill cover (daily, intermediate, or final) into the waste. For the purpose of this study, a method that related the quantity of leachate directly to the average precipitation was used for simplification. The following values of leachate production as a percentage of precipitation are based on field data [Environmental Research and Education Foundation, 1999].

This leachate estimation method and the default parameters are valid for the gradual covering of a landfill. In reality, some parts of the site may never be covered with intermediate cover and be directly covered by final cover [EREF, 1999]. A volume of precipitation can be calculated given the precipitation in depth/year and an area of landfill surface. A certain percentage of that volume ends up as leachate depending on the time after the placement of the waste. Together, these values provide the amount of leachate generated per area of landfill surface. Table 5 illustrates the calculated PERC for the landfill.

Year	PERC
2006	18.319,68
2007	18.941,70
2008	19.563,72
2009	20.217,30
2010	20.809,95
2011	21.527,41
2012	22.280,22
2013	23.069,82
2014	23.897,72
2015	24.765,52
2016	25.674,93
2017	26.627,72
2018	27.625,77
2019	28.671,09
2020	29.765,74
2021	30.911,95

Table 5. Estimated PERC for the landfill

4. LifeCycleImpactAnalysis

Environmental impact categories were used to facilitate the environmental comparison between the two waste management technologies and to allow for a clear presentation of the results. This analysis only included the following categories: global warming potential (GWP) as well as acidification potential (AP),which are the most common impact categories included in the LCIA phase. The impact categories, their respective emissions, and equivalency impact factors applied in this study are presented in **Table 6**.

	Emission	Eq. Factor
Global Warming Potential 100 years (kg CO_2)	CO_2 (emissions to air)	1,00
	CH_4(emissions to water)	21,00
	N_2O (emissions to air)	320
Acidification (gSO_2)	SO_2(emissions to air)	1,00
	NO2 (emissions to air)	0,70
	HCl (emissions to air)	0,88

Table 6.Impact categories, emissions, and equivalency factors [Mendes et al, 2004]

Global warming potential (GWP) accounts for the emission of greenhouse gases (CO_2, CH_4, N_2O), whose characterization factors are based on the model developed by the Intergovernmental Panelon Climate Change [IPCC, 2006] and referred to a time horizon of 100 years (GWP100). ‘‘Greenhouse gases’’ (GHGs) refers to thegases (primarily water vapour, carbon dioxide, methane and nitrousoxide) present in the earth’s atmosphere which contributeto global temperatures through the greenhouse effect [Feo and Malvano, 2009]. **Fig. 4**shows the GWP expressed in tonnes CO_2.The CO_2emissions result from the landfilling option mainly due to the combustionof methane, whereas the CO_2 emissions from the incinerationfacility result from the combustion of plastics. In addition, thegas recovery system significantly decreased the uncontrolledmethane and VOCs emissions. Plastics are stable elements and therefore contribute little tothe methane generation.

Acidification potential (AP) is the process whereby air pollution, mainly ammonia, sulphur dioxide and nitrogen oxides, are converted into acidic substances. Some of the principal effects of air acidification include lake acidification and forest decline [Feo and Malvano, 2009]. Acidification Potential (AP) accounts for the emissions of NOx, SOx and ammonia. **Fig. 5** shows the AP, expressed as kg of SO_2 equivalent per kg of emission. The incineration option performed more poorly from an environmental perspective than the landfill option in terms of AP. Compounds such as sulphur dioxide, nitrogen dioxide and hydrogen chloride are emitted at much higher concentrations with incineration compared to landfilling. The amount of sulphur dioxide and hydrogen chloride emitted from incineration is dependent on the sulphur and chlorine content in the waste. Furthermore, landfill gases such as sulphur dioxide, nitrogen dioxide and hydrogen chloride; typically occur in concentrations less than 1% (v/v).

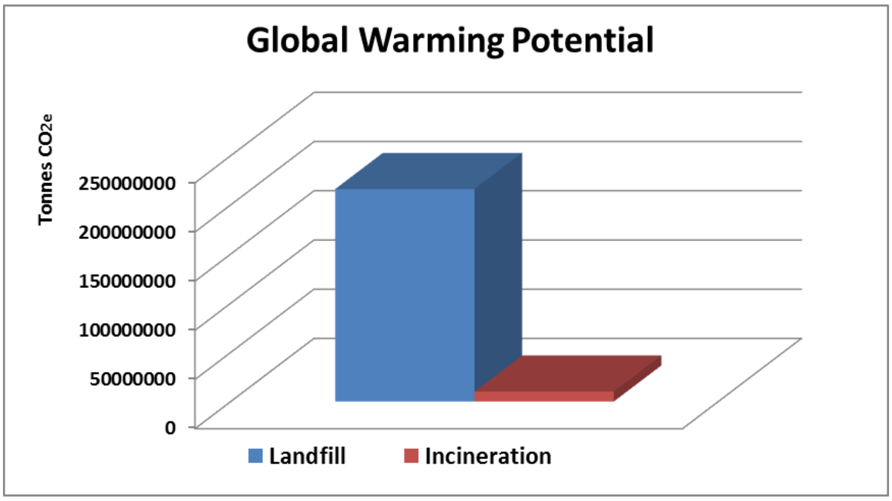

Fig. 4 Global warming potential results for incineration and landfilling option

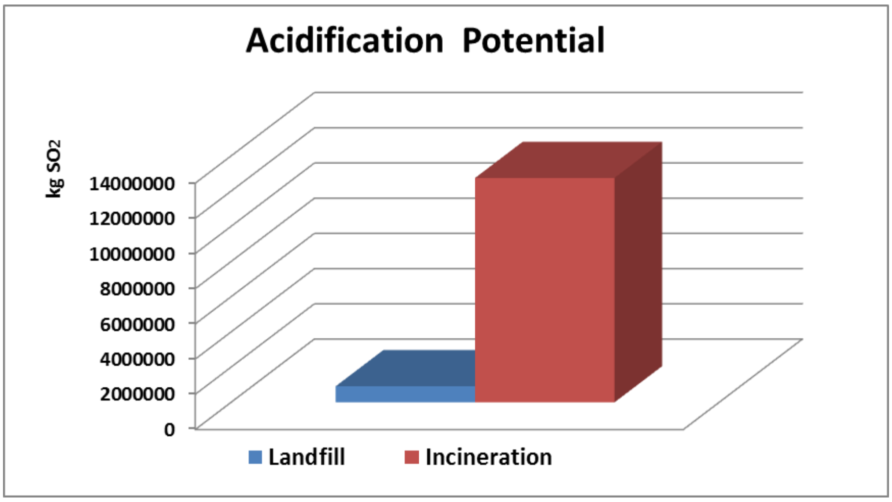

Fig. 5 Acidification potential results for incineration and landfilling option

5. Conclusions

The goal of this study was to compare the use of an incineration and landfilling facility in the management of municipal solid waste for the Prefecture of Western Macedonia from an environmental point of view. The results indicated that the use of an incineration facility to manage a portion of the waste is better environmentally in terms of global warming potential. The waste management option that included the incineration facility performed better environmentally.

This study can be considered as an improvement in the undertaking of municipal solid waste (MSW) life cycle assessments where many studies have assumed a constant MSW composition. More updated emission factors and more advanced waste quantity predictive methods would yield more accurate and realistic results. The inclusion of current waste diversion initiatives and a changing waste composition is one step closer towards carrying out an analysis that better reflects the realities in MSW management.

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