## APPENDIX 8.2

## CLIMATE ASSESSMENT

### 8.1 INTRODUCTION

As described in detail elsewhere, the proposed Waste-to-Energy facility will be based on conventional grate incineration technology. The waste is tipped into a bunker prior to being fed into the furnace. In the furnace the waste is incinerated, producing heat, ash and combustion gases.

This study will describe and assess the impact of the proposed scheme, in terms of its impact on climate. Attention will be focused both on Ireland's obligations under the Kyoto Protocol and the effect of the scheme on the total national anthropogenic emissions of carbon dioxide and other greenhouse gases (GHGs) and also in the context of overall climatic impact on the presence and absence of the proposed development.

### 8.2 CLIMATIC BASELINE

#### 8.2.1 Climate Agreements

Ireland ratified the United Nations Framework Convention on Climate Change (UNFCCC) in April 1994 and the Kyoto Protocol in 1997(1,2). For the purposes of the EU burden sharing agreement under Article 4 of the Kyoto Protocol, Ireland agreed to limit the net anthropogenic growth of the six GHGs (see Table 8.1 and Table 8.2) under the Kyoto Protocol to 13% above the 1990 level over the period 2008 to 2012(3). In order to meet the ultimate objective of the Convention to prevent dangerous anthropogenic interference in the climate system, cuts of up to 70% in this century are expected to be required(4). The UNFCCC is continuing detailed negotiations in relation to GHGs reductions and in relation to technical issues such as Emission Trading and burden sharing. The most recent Conference of the Parties (COP11) to the agreement was convened in Montreal in Dec. 2005. In Article 5 of the Kyoto Protocol, it states that the methodologies for estimating anthropogenic emissions by sources and removal by sinks of all greenhouse gases (except those controlled by the Montreal Protocol) shall be those accepted by the Intergovernmental Panel on Climate Change (IPCC). The Kyoto Protocol entered into force on the 15th of February 2005. GHGs emissions in Ireland in 2004 were approximately 23.1% above 1990 levels, down from approximately 26.9% in 2001.

An important part of the approach to reducing greenhouse gas emissions, engrained in the Kyoto Agreement, is that emission reductions should reflect the most economically efficient cost of achieving the set target. As part of this approach, three "flexible mechanisms" are intended to facilitate the cost-effective implementation of the Protocol. These mechanisms are Emission Trading (ET), Joint Implementation (JT) and the Clean Development Mechanism (CDM). Emission trading is a development whereby polluting entities are allocated allowances for their emissions which can subsequently be traded with each other.

Emitters for whom it is very expensive to reduce emissions are likely to buy permits from emitters for whom emissions reduction is more cost-effective thus ensuring that a pre-determined environmental outcome will take place where the cost of reduction is lowest. Due to significant economic growth in Ireland since 1990, it is envisaged that emission trading could be of significant benefit to Ireland in meeting its commitments to limit the growth of greenhouse gas emissions[4] (see Table 8.2). Both Joint Implementation and the Clean Development Mechanisms allow states to share reduction credits by investing in another territory with the aim of reducing emissions. However, the Clean Development Mechanism differs in that the projects are specific to assisting developing countries that are particularly vulnerable to the adverse effects of climate change to meet the cost of adaptation.

### 8.2.2 Baseline Conditions

Anthropogenic emissions of greenhouse gases in Ireland included in the Kyoto Protocol are given in Table 8.1 and Table 8.2. Combustion of fossil fuels for energy purposes is the greatest source of emissions at 95% of $CO_2$ and 66% of total emissions (2004 data)[5]. The largest share of energy emissions in 2004 is from fuel combustion for power generation (23% of total emissions) and road transport (18.4%). Waste represented 2.7% of total emissions in 2004 and is envisaged to represent 1.5% of total emissions by 2010[4,5]. Emissions from waste consist mainly of $CH_4$ with small amounts of other GHGs.

Greenhouse gases have different efficiencies in retaining solar energy in the atmosphere and different lifetimes in the atmosphere. In order to compare different greenhouse gases, emissions are calculated on the basis of their Global Warming Potential (GWPs) over a 100-year period, giving a measure of their relative heating effect in the atmosphere. The GWP100 for $CO_2$ is the basic unit (GWP = 1) whereas $CH_4$ has a global warming potential equivalent to 21 units of $CO_2$ and $N_2O$ has a GWP100 of 310. Using the aggregated IPCC 100-year Global Warming Potentials, $CH_4$ emissions from landfills accounted for 90% of the Total GWP from waste in 2004[5].

### 8.2.3 IPCC Guidelines For National Greenhouse Gas Inventories

The Intergovernmental Panel on Climate Change (IPCC) has outlined detailed guidelines on compiling National Greenhouse Gas Inventories. The guidelines are designed to estimate and report on national inventories of anthropogenic greenhouse gas emissions and removals in order to ensure compliance with the Kyoto Protocol. Anthropogenic refers to greenhouse gas emissions and removals that are a direct result of human activities or are a result of natural processes that have been affected by human activities[6,7]. The quantity of carbon from natural cycles through the earth's atmosphere, waters, soils and biota is much greater than the quantity added by anthropogenic GHG sources. However, the focus of the UNFCCC and the IPCC is on anthropogenic emissions because it is these emissions that have the potential to alter the climate by disrupting the natural balances in carbon's biogeochemical cycle, and altering the atmosphere's heat-trapping ability. The carbon from biogenic sources such as paper and food waste was originally removed from the atmosphere by photosynthesis, and under natural conditions, it would eventually cycle back to the atmosphere as $CO_2$ due to degradation processes. Thus, these sources of carbon are not considered anthropogenic sources and do not contribute to emission totals considered in the Kyoto Protocol[6,7].

In relation to solid waste disposal sites (SWDSs) including municipal landfills, detailed guidelines have been outlined for the calculation of GHG emissions[6,7]. The main GHG emission from SWDSs is methane. Even though the source of carbon is primarily biogenic, $CH_4$ would not be emitted were it not for the human activity of landfilling the waste, which creates anaerobic conditions conducive to $CH_4$ formation. Although $CO_2$ is also produced in substantial amounts, the primary source of $CO_2$ derives from the decomposition of organic material derived from biomass sources (crops, forests) which are re-grown on an annual basis. Hence, these $CO_2$ emissions are not treated as net emissions from waste in the IPCC Methodology[7].

Similarly, in relation to incineration, a large fraction of the carbon in waste combusted (paper, food waste) is derived from biomass raw materials which are replaced by re-growth on an annual basis. Thus, these emissions should not be considered as net anthropogenic $CO_2$ emissions in the IPCC Methodology[7]. On the other hand, some carbon in waste is in the form of plastics or other products based on fossil fuel. Combustion of these products, like fossil fuel combustion, releases net $CO_2$ emissions. Thus, in estimating emissions from waste incineration, the desired approach is to separate carbon in the incinerated waste into biomass and fossil fuel based fractions and thereafter to use only the fossil fuel fraction in calculating net carbon emissions[6,7]. Other relevant gases released from combustion are net GHG emissions including $CH_4$ and $N_2O$.

The nature of municipal waste landfilled in Ireland has been catalogued in the National Waste Database Report 2004[8]. The breakdown of household and commercial waste is shown in Table 8.3 whilst the summary of major waste types landfilled in Ireland in 2004 is shown in Table 8.4. In relation to commercial and household waste, a significant fraction of the waste is derived from biogenic origins. An estimate of the fraction of biogenic and inert (inert in the sense that it does not contain carbon) waste from households and commercial waste landfilled in Ireland in general and in the current region surrounding the proposed scheme in 2004 would be of the order of 0.79 (see Table 8.3). In relation to non-hazardous municipal, commercial and industrial waste, the key factor from a climatic viewpoint is the percentage of carbon waste of non-biogenic origins. Although the detailed breakdown of each individual waste stream may vary significantly, non-hazardous waste from each sector would still be expected to consist mainly of biogenic or inert waste. Thus, the categories non-hazardous municipal, commercial and industrial waste have been grouped as MSW in Table 8.3. Furthermore, it is estimated that, as a worst-case, 0.206 of the MSW waste incinerated is of fossil fuel origin and is thus a net contributor to greenhouse gas emissions (derived from Table 8.3). This estimate has been used as outlined in Annex 1 for estimating the net GHG emissions from the incineration of 600,000 tonnes/annum of municipal, commercial and/or industrial waste. Data from the USEPA indicates that typical USA mixed municipal solid waste (MSW) has about 10% non-biogenic carbon in MSW[6] and thus the estimate of 20.6% in the current analysis is likely to be a worst-case scenario.

## 8.3 CHARACTERISTICS OF THE PROPOSED DEVELOPMENT

### 8.3.1 Forecasting Methods

Predictions of greenhouse gas emissions from the waste management facility were carried out using the emission factors outlined in European Commission publication "Waste Management Options and Climate Change (2001)"[9] and the IPCC[7] and USEPA[10] publications. The prediction of GHG emissions from landfills was developed using the USEPA Landfill Gas Emission Model (LandGEM)[11] and using emission factors outlined in EU publication "Waste Management Options and Climate Change (2001)"[9] and the USEPA[10] and the IPCC[6].

### 8.3.2 Construction

There is the potential for a number of emissions to atmosphere during the construction of the development. Construction vehicles, generators etc., may give rise to $CO_2$ and $N_2O$ emissions.

### 8.3.3 Incineration

Incineration would be expected to be the dominant source of $CO_2$ and $N_2O$ emissions from the development. Detailed waste throughput information was obtained from Elsam Engineering A/S and this information has been used to estimate GHG emissions from the scheme. The annual waste throughput for the proposed Waste Management Facility will be within the range of 500,000 to 600,000 tonnes consisting of all non-recyclable household, commercial and/or industrial waste. For the purpose of this study the maximum annual throughput of 600,000 tonnes is used. The net greenhouse gas contribution from the waste was derived using the procedure recommended by the European Commission[9] and IPCC[6] and is outlined in Annex 1.

### 8.3.4 Alternative Scenarios In The Absence of Incineration

Ireland has recently formulated a strategy[14] to implement the targets set down in the Landfill Directive (1999/31/EC) to divert biodegradable municipal waste (BMW) from landfills. The Landfill Directive states that the landfilling of BMW shall be capped in 2016 at 35% of the total amount of BMW generated in 1995. In order to achieve this target, it is likely that a diversion rate of 80% of the BMW generated in 2016 will be required[14]. The strategy envisages that recycling of BMW will account for 38.6% of the waste produced with biological treatment accounting for another 19.5% leading to an overall "recycled" total of 58.1%. The aim thereafter is to landfill 19.9% of the BMW with the remaining 22% subject to residual treatment, mainly through incineration[14].

In the absence of incineration, the waste is likely to be landfilled at a municipal landfill facility thereby possibly exceeding the target for landfilling of biodegradable waste agreed in the Landfill Directive or alternatively the waste will be biologically treated (composted / anaerobic digestion). Therefore, in the current study an assessment has been made of the likely production of greenhouse gases in the absence of incineration assuming either of these two options. Of the total emission of greenhouse gases from waste in Ireland, landfilling currently accounts for 90% of the total[5].

**Scenario 1**

In scenario one, all non-recyclable waste is assumed to be disposed off at a municipal waste landfill. In order to make a reasonable comparison with the incineration option, the scenario where 600,000 tonnes of waste is landfilled over a 25-year period has been assessed. The landfill is assumed to open in 2012 for a 25-year period. It has also been assumed that the landfill is operated to best practise standards and thus a landfill gas recovery system is installed and has a collection efficiency of 75% for $CH_4$. This is probably significantly above actual capture rates with rates likely to be between 50-70% for new landfills and 40%, at most, from existing landfills[3].

It is assumed that all recovered methane is used for energy recovery. In the Waste Management Act 1996, all Waste Licences issued by the EPA for Landfills now require landfill gas capture and utilisation in energy production or flared where use in energy production is not feasible. 2001 data indicates that methane gas collection efficiency in Ireland averaged 50% with LFG utilisation for energy at 60%[9]. The calculation of landfill gas generation rates has followed USEPA methodology which recommends that landfill gas generation rates are derived from the USEPA Landfill Gas Emission Model (LandGEM)[11]. A summary of the methodology employed in the model is given in Annex 1.

**Scenario 2**

In scenario two, all non-recyclable putrescible waste is assumed to be anaerobically digested (it is likely that some of this waste will also be composted but an assumption that all of the putrescible waste will be anaerobically digested is a conservative assumption (i.e. greater net GHG benefit)). In order to make a reasonable comparison with the incineration option, the scenario where 242,220 tonnes (based on a ratio of 90:10 putrescible waste : paper i.e. 36.7% of the 600,000 tonnes of waste is putrescible waste and 10% is paper waste[9]) is anaerobically digested (AD) over a 25-year period has been assessed. It is assumed that the other 357,780 tonnes of non-putrescible waste per annum is landfilled based on the landfilling assumptions outlined in Scenario 1. A summary of the methodology employed in the model is given in Annex 1.

### 8.3.5 Road Traffic

Road traffic would be expected to be an additional source of greenhouse gas emissions as a result of the development. Waste will be transported from the source of the waste to the site for disposal whilst the ash will subsequently be removed from the facility to be landfilled or exported. In the absence of the development, this waste will also be collected and either disposed of to landfill or delivered to an AD facility. In the absence of a detailed breakdown of the sources of waste and specific landfill / AD locations, a detailed comparison of GHG emissions is not possible between the various options. However, it is likely that the transport associated with landfilling / AD and incineration will lead to similar levels of emissions and moreover these emissions will be minor compared to emissions from the landfilling or incineration of waste[9]. Thus, no detailed assessment has been carried out on the level of greenhouse gases from the transport of waste. However, analysis by the USEPA has estimated that the traffic-derived GHG emissions from both landfilling and waste-to-energy are approximately equivalent at 0.01 MTCE (metric tonnes of carbon equivalent) of anthropogenic $CO_2$ emission per ton (US) of material either landfilled or incinerated with the resulting ash landfilled[6]. In this context, the impact from the transport of waste accounts for less than 3.5% of the impact from the incineration of waste (excluding energy recovery) and thus is a minor contributor to the overall GHG emission total.

### 8.3.6 Modelling Methodology – Waste-to-Energy Facility

In order to calculate the scheme's net contribution to greenhouse gas emissions and the effect of the scheme on Ireland's obligations under the Kyoto Protocol, the total forecasted anthropogenic emissions of the proposed development has been calculated over a period of 25 years which is the lifespan of the development. The baseline year is assumed to be 2012. Given in Table 8.5 is the annual anthropogenic greenhouse gas emission from the site and the total over the period of the development (i.e. 25 years). The emissions have been compared with the estimated Total Greenhouse Gas Emissions in Ireland in 2012[15]. The contribution to the Total Greenhouse gas emissions, in the absence of power generation, is 0.19% of the Total Greenhouse Gas Emissions in Ireland in that year and thus is a minor source of GHGs.

During the incineration of waste at the facility the thermal energy generated by the burning of waste will be recovered and will give an electrical output of about 66MW. As approximately 6MW is required for electrical demand within the plant, the net electrical output from the plant for export to the national grid will be 60MW. Thus, the export of 60MW will give a direct benefit in terms of greenhouse gas emissions which would have been released in the production of 60MW from power stations.

Waste-base energy recovery systems such as incinerators and landfill gas schemes are continuous and thus will compete with base-load generation which have historically been open-cycle oil or natural gas fuelled steam turbines although new stations are now mainly combined-cycle gas turbines (CCGTs)[9]. By 2010 Ireland is committed to meeting the target set down in Council Directive 2001/77/EC ("RES-E Directive") of ensuring that 13.2% of electricity produced in Ireland is from renewable energy sources. It is envisaged that this target will be met mainly through wind power generation[13].

In order to calculate the net benefit in terms of greenhouse gas emissions, the likely greenhouse gas emissions from a Combined Cylce Gas Turbine (CCGT) power station (the most GHG efficient fossil-fuel power source) producing 60MW of power has been calculated and subtracted from the site's greenhouse gas emissions (see Table 8.6). Currently, the breakdown of electricity generation in Ireland for the four main fossil fuels is coal at 34%, others (including oil) at 15%, peat at 16% and natural gas at 35% (2003 data)[16]. $CO_2$ emissions from coal are 77% higher per Joule, peat is 110% higher per joule whilst oil is 49% higher per

Joule than natural gas[3]. Thus, the assumption that the displaced power generation is from a CCGT burning natural gas is a more pessimistic assumption than using the average fuel profile.

The production of power for export to the national grid transforms the site from a net producer of GHGs to having a net positive annual impact on GHG emissions of the order of 0.11% of the Total Greenhouse Gas Emissions in Ireland in 2012.

### 8.3.7 Modelling Methodology – Landfill

As stated above, for scenario 1, it is assumed that 600,000 tonnes of waste will be landfilled annually in the absence of the development. The impact on climate of the landfilling of this waste over a 25-year period has been calculated using the USEPA approved Landfill Gas Emission Model (LandGEM)[11]. The model gives the production rate in terms of mass (in tonnes/annum) and volume (in terms of $m^3$/annum) for both $CH_4$ and $CO_2$. Shown in Figure 8.1 is the production rate of $CH_4$ (in tonnes of $CO_2$ equivalent) from a landfill which is in operation for 25 years. The model indicates that the peak in production of $CH_4$ occurs 25 years after opening. Indeed, significant quantities of landfill gas are produced even after 50 years of closing. In the model it is assumed that 50% of the landfill gas is $CH_4$, which is the default value recommended by the European Commission[9], USEPA[10] and the IPCC[6]. Results are also compared with the default emission factors outlined by the European Commission[9] (see Annex 1).

After the calculation of both $CH_4$ and $CO_2$ generation rates, it is assumed that emissions from the landfill are controlled by installing a gas collection system followed by combustion of the collected gas through the use of turbines. Gas collection efficiencies are assumed to be 75% whilst the collection efficiency of the control device are assumed to average around 95%. These are probably significantly above actual capture rates with rates likely to be between 50-70% for new landfills and 40%, at most, from existing landfills[3]. The controlled $CH_4$ emission was estimated as shown in Annex 1. The controlled GHG emission total over the period of gas generation is shown in Table 8.7. The controlled emission for $CH_4$ also includes for oxidation of the $CH_4$ which may occur in the top layer of soil over the landfill. The USEPA recommended 10% oxidation rate of methane generated has been applied in the current assessment[12]. This factor has also been applied in the current assessment. As stated previously, the primary source of $CO_2$ derives from the decomposition of organic material derived from biomass sources (crops, forests) which are re-grown on an annual basis and thus $CO_2$ emissions are not treated as net emissions from waste in the IPCC Methodology[6].

Total GHG emissions occurs over a period of 100 years with peak generation occurring after 25 years at approximately 130,000 tonnes of $CO_2$ equivalent emitted in that year. The contribution to the total greenhouse gas emissions, ignoring the generation of power, from the landfilling of 600,000 tonnes of waste is 0.25% of the total greenhouse gas emissions in Ireland in 2012 and thus is minor.

Again, energy recovery is possible using landfill gas as the fuel source. Based on data from the European Commission[9], there is a net benefit in terms of greenhouse gas emissions, as a result of power generation from landfill gas as a fuel source, which would otherwise have been provided by fossil fuels. If the emissions are condensed to a 25-year time period (i.e assuming that all emissions occur within a 25 year timeframe instead of 100 years in reality), to allow a comparison with incineration, the annual contribution to the total greenhouse gas emissions, including the beneficial effect of the generation of power, is equivalent to 0.23% of the total greenhouse gas emissions in Ireland in 2012.

An additional consideration is the issue of carbon sequestering in landfills which is not currently considered in the IPCC methodology. During the storage of organic material in landfills, anaerobic conditions inhibit the decomposition of certain wastes such as woody material(9) and thus this biogenic organic material is removed from the carbon cycle. It has been proposed that landfilling should be given a credit for reducing carbon dioxide emissions(9). Thus, carbon sequestering in landfills has been included as an option in the calculations as shown in Table 8.8. The annual contribution to the total greenhouse gas emissions, including the beneficial effect of the generation of power and carbon sequestering, from landfilling 600,000 tonnes/ annum leads to a net positive impact equivalent to 0.08% of the total greenhouse gas emissions in Ireland in 2012.

### 8.3.8 Modelling Methodology – Anaerobic Digestion (AD)

The anaerobic digestion (AD) facility is assumed to open in 2012 for a 25-year period. It has also been assumed that the facility is operated to best practise standards and that the AD facility produces a gas rich in methane (60% methane generation is assumed)(9). The relevant emission factors are shown in Table 8.9 are taken from the European Commission report "Waste Management Options and Climate Change" (2001)(9).

Given in Table 8.9 is the greenhouse gas emission from the AD facility processing 242,220 tonnes of putrescible waste taking into account the generation of power both annually and over the 25-year study period. The emissions have been compared with the estimated Total Greenhouse Gas Emissions in Ireland in 2012(12). The contribution to the Total Greenhouse gas emissions from the anaerobic digestion of 242,220 tonnes of waste per annum is to lead to a net positive impact of 0.01% of the Total Greenhouse Gas Emissions in Ireland in that year.

Again, an additional consideration is the issue of carbon sequestering by soils, whereby a proportion of the carbon becomes converted to very stable humic substance which can persist for hundreds of years. This issue is currently under consideration by the IPCC(9). Taking a conservative approach, carbon sequestering by anaerobic digestion has been included as an option in the calculations as shown in Table 8.9.

Table 8.10 summarises Scenario 2 including the anaerobic digestion of 242,220 tonnes (i.e. 36.7% of the 600,000 tonnes of waste is putrescible waste and 10% is paper waste(9)) and the landfilling of the remaining 357,780 tonnes of non-putrescible waste per annum based on the landfilling assumptions outlined for Scenario 1. The annual contribution to the total greenhouse gas emissions, including the beneficial effect of the generation of power, from Anaerobic Digestion / Landfilling leads to a net negative impact equivalent to

0.04% of the total greenhouse gas emissions in Ireland in 2012. If carbon sequestering is taking into account both for the landfill and the anaerobic digestion, the Anaerobic Digestion / Landfilling scenario leads to a net positive impact equivalent to 0.14% of the total greenhouse gas emissions in Ireland in 2012.

## 8.4 IMPACT OF DEVELOPMENT ON CLIMATE

### 8.4.1 Construction

The effect of construction on climate will not be significant.

### 8.4.2 Incineration

The contribution of the Waste-to-Energy Facility to total greenhouse gas emissions in Ireland is equivalent to a net positive impact of 0.11% of total emissions in 2012, when energy recovery in taken into account (see Figure 8.2). In the absence of the development, greenhouse gas emissions may occur from the landfilling / AD of the waste. The contribution to the total greenhouse gas emissions from landfilling 600,000 tonnes of waste, including the generation of power but excluding carbon sequestering, condensed to a 25-year period, is equivalent to 0.23% of the total greenhouse gas emissions in Ireland in 2012. Thus, the overall annual impact of the proposed Waste-to-Energy Facility on climate, relative to the landfilling of the waste, is to produce a net benefit of approximately 0.34% of the total greenhouse gas emissions in Ireland in 2012 and thus will be of minor positive impact in terms of Ireland's obligations under the Kyoto Protocol (see Figure 8.2). When allowing for the diversion of biodegradable waste to anaerobic digestion, the overall annual impact of the proposed Waste-to-Energy Facility on climate is still positive by approximately 0.16% of the total greenhouse gas emissions in Ireland in 2012.

Thus, if carbon sequestering is ignored, incineration with energy recovery offers a net saving over both landfilling only and landfilling in conjunction with anaerobic digestion by 0.34% and 0.16% of the total greenhouse gas emissions in Ireland in 2012, respectively.

If carbon sequestering is taken into account (currently the IPCC does not take into account carbon sequestering by landfills and is considering the issue of AD[9]), incineration with energy recovery still offers a net saving over landfilling only of the order of 0.03% of the total greenhouse gas emissions in Ireland in 2012. However, landfilling in conjunction with anaerobic digestion offers a small net savings over incineration of the order of 0.03% of the total greenhouse gas emissions in Ireland in 2012 (see Figure 8.2).

## 8.5 DESCRIPTION OF MITIGATION MEASURES

### 8.5.1 Construction

As there will be no significant impact on climate, no mitigation measures are proposed.

### 8.5.2 Incineration

During the incineration of waste at the facility the thermal energy generated by the burning of waste will be recovered and will give an electrical output of about 66MW with a net electrical output from the plant for export to the national grid will be 60MW (see Table 8.6). Thus, the export of 60MW will give a direct benefit in terms of greenhouse gas emissions which would have been released in the production of 60MW from power stations.

The Waste-to-Energy facility will also recover and recycle ferrous materials during the incineration process. The recycling of metals will require less energy than processes using virgin inputs and thus lead to a direct saving in energy and thus GHG emissions. A recent USEPA report has estimated that approximately 0.01 MTCE per ton (US) of mixed MSW is saved through recycling of metals[(6)].

## 8.6 REFERENCES


(1) Framework Convention On Climate Change Ireland - Report On The In-Depth Review Of The Second National Communication Of Ireland (1999)

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(3) ERM Limitation and Reduction of $CO_2$ and Other Greenhouse Gas Emissions in Ireland (1998)

(4) Department on Environment & Local Government Report on the Options For Greenhouse Gas Emission Trading (1999)

(5) EPA Ireland's Emissions of Greenhouse Gases For The Period 1990 - 2004 (2006)

(6) USEPA Greenhouse Gas Emissions From Management of Selected Materials in Municipal Solid Waste (2002)

(7) IPCC Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (1996)

(8) EPA National Waste Database Report 2004 (2006)

(9) European Commission Waste Management Options and Climate Change (2001)

(10) USEPA Solid Waste Disposal 2.1- Refuse Combustion, AP-42 (1996)

(11) USEPA Landfill Gas Emission Model (Version 3.02) LandGEM (2005)

(12) USEPA Landfills, Volume III: Chapter 15, Emission Inventory Improvement Program (2001)

(13) DOCMNR/SEI Options for Future Renewable Energy Policy, Targets & Programmes (2003)

(14) DOEHLG National Strategy On Biodegradable Waste (2006)

(15) Department of Environment & Local Government National Climate Change Strategy (2000)

(16) ICF Consulting-Byrne Ó Cléirigh Determining the Share of National Greenhouse Gas Emissions for Emissions Trading In Ireland (2004)

**Table 8.1: Greenhouse Gas Emissions (2003) ('000 tonnes)[5]**

| Category | $CO_2$ | $CH_4$[1] | $N_2O$[1] | HFC | PFC | $SF_6$ | Totals |
|---|---|---|---|---|---|---|---|
| Energy | 41979 | 8.5 | 4.9 | | | | 43,665 |
| Industrial Processes | 2360 | | | | | | 2972 |
| Solvents & Other Product Use | 111 | | | | | | 111 |
| Agriculture | | 507 | 26.1 | | | | 18,747 |
| Land Use Change & Forestry | -981 | | | | | | -981 |
| Waste | 0 | 91.9 | 0.42 | | | | 2060 |
| Total | 43469 | 515.5 | 31.0 | 288 | 224 | 100 | 66573 |

(1) The global warming potential of $CH_4$ is 21 times that of $CO_2$ whilst $N_20$ is 310 times that of $CO_2$.

**Table 8.2: Greenhouse Gas Emissions ('000 tonnes $CO_2$ equivalent)[15]**

| Year | $CO_2$ | $CH_4$ | $N_2O$ | HFC, PFC, $SF_6$ | Total Emissions | Emission Index | Sinks (Kyoto basis) | Net Total | Net Index |
|---|---|---|---|---|---|---|---|---|---|
| **Base Year (1990)** | 31,575 | 12,836 | 9,085 | 256 | 53,752 | 100.0 | 0 | **53,752** | **100.0** |
| **1998** | 40,028 | 13,631 | 10,069 | 256 | 63,984 | 119.0 | -745 | **63,239** | **119.6** |
| **2000** | 42,675 | 13,139 | 9,630 | 799 | 66,243 | 123.2 | -991 | **65,252** | **121.4** |
| **2005** | 47,210 | 12,940 | 9,692 | 1,342 | 71,184 | 132.4 | -1,523 | **69,660** | **129.6** |
| **2010 Low** | 51,373 | 12,185 | 9,720 | 672 | 73,950 | 139.6 | -2,056 | **71,894** | **133.8** |
| **2010 High** | 51,373 | 12,185 | 9,720 | 1,885 | 75,163 | 139.8 | -1,369 | **73,794** | **139.3** |

**Table 8.3: Composition of Household and Commercial Waste Landfilled In Ireland In 2004[8]**

| Material | Household | | Commercial | | Total | |
|---|---|---|---|---|---|---|
| | (%) | (tonnes/annum) | (%) | (tonnes/annum) | (%) | (tonnes/annum) |
| Paper | 19.2% | 233,446 | 35.3% | 212,860 | 24.5% | 446,306 |
| Glass | 3.7% | 45,313 | 1.5% | 9,330 | 3.0% | 54,643 |
| Plastic | 13.8% | 167,261 | 12.0% | 72,725 | 13.2% | 239,986 |
| Ferrous | 1.5% | 18,557 | 1.0% | 5,892 | 1.3% | 24,449 |
| Aluminium | 1.4% | 16,795 | 0.6% | 3,584 | 1.1% | 20,379 |
| Other Metals | 0.4% | 4,849 | 1.2% | 7,381 | 0.7% | 12,230 |
| Textiles | 11.0% | 133,310 | 2.3% | 13,676 | 8.1% | 146,986 |
| Organics | 36.2% | 440,131 | 39.6% | 226,944 | 36.7% | 667,075 |
| WEEE | 0.8% | 9,179 | 0.4% | 2,677 | 0.7% | 11,856 |
| Wood | 0.9% | 11,152 | 0.5% | 3,027 | 0.8% | 14,179 |
| Others | 11.1% | 134,916 | 9.5% | 45,516 | 9.9% | 180,432 |
| **Total Fossil Fuel[1]** | 23.2% | 282,220 | 15.8% | 95,440 | 20.6% | 377,660 |
| **Total Non-Fossil Fuel** | 76.8% | 932,687 | 84.2% | 508,188 | 79.4% | 1,440,870 |
| **Total** | 100% | 1,214,908 | 100% | 603,628 | 100% | 1,818,530 |

Note: "Others" mainly refers to composites, fine elements such as ash, unclassified incombustibles and unclassified combustibles including wood wastes.

(1) Derived from plastics (100%), WEEE (100%) and textiles (50%) only and assumes that all WEEE and 50% of textiles are synthetic & carbon based leading to the fraction of fossil carbon of 0.206. Others is assumed to 29% fossil fuel[9].

**Table 8.4: Summary of Major Waste Types Accepted into Landfills In Ireland In 2004[8]**

| Landfill Type | No. | Waste Accepted (tonnes) | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Household** | **Commercial** | **Construction** | **Industrial** | **Others** | **TOTAL** |
| Local Authority | 34 | 1,213,998 | 355,579 | 13,275 | 21,685 | 60,210 | 1,664,747 |
| Private / Industrial | 33 | 910 | 248,049 | 0 | 4,523,284 | 1,095 | 4,773,338 |
| **TOTAL** | **67** | **1,214,908** | **603,628** | **13,275** | **4,544,969** | **61,305** | **8,780,201** |

**Table 8.5: Greenhouse Gas Emissions At Dublin Waste To Energy Facility, Poolbeg, Based On 600,000 Tonnes/Annum**

| | **$CO_2$** | **$N_2O$** | **$CH_4$** | **% Of Ireland's Total Emissions[1]** |
|---|---|---|---|---|
| Total / Annum (tonnes)[2] | 124,857 | 30.0 | 48[3] | - |
| Total / Annum (tonnes $CO_2$ Equivalent) | 124,857 | 9,300 | 1,008 | 0.19 |
| **Total (tonnes $CO_2$ Equivalent) Over 25 Years** | 3.12E+6 | 2.3E+5 | 2.5E+4 | - |

(1) Based on an approximate total emission of 69.5 million tonnes $CO_2$ equivalent in 2012 (based on estimates given in reference 15 for average over the period 2008-12 (base case))

(2) Based on Revised IPCC Guidelines as outlined in Appendix 1 and references 6 & 9 and using a fraction of fossil carbon as derived from Table A8.2 of 0.206

(3) Assuming, as a worst-case, that all organics emitted as TOC from the incinerator are composed of methane.

**Table 8.6:** **Greenhouse Gas Emissions At Dublin Waste To Energy Facility, Poolbeg As A Result of Exporting 60MW**

| | $CO_2$ | $N_2O$ | $CH_4$ | % Of Irelands Total Emissions[(1)] |
|---|---|---|---|---|
| CCGT Producing 60MW[(2)] (tonnes) | 210,240 | 4.6 | - | - |
| CCGT Producing 60MW (tonnes $CO_2$ Equivalent) | 210,240 | 1430 | - | |
| Total / Annum (tonnes $CO_2$ Equivalent) After Subtraction Of Power | (85,383) | 7870 | - | **- 0.11** |
| **Total (tonnes $CO_2$ Equivalent) Over 25 Years** | **(2.13E+6)** | **2.0E+5** | **-** | **-** |
| **Total After Power Generation Over 25 years** | **Sum = (1.93E+6) Tonnes $CO_2$ Equivalent** | | | |

(1) Based on an approximate total emission of 69.5 million tonnes $CO_2$ equivalent in 2012 (based on estimates given in reference 15 for average over the period 2008-12 (base case))

(2) Based on an energy saving of 0.40t $CO_2$ / MWh CCGT for electricity generation [(9)]

**Table 8.7:** **Total Greenhouse Gas Emissions From The Landfilling Of 600,000 Tonnes/Annum For 25 Years - Option 1**

| | $CO_2$ | $N_2O$ | $CH_4$ | Annual % Of Irelands Total Emissions[(1)] |
|---|---|---|---|---|
| Total Emissions (tonnes $CO_2$ Equivalent)[(2,3)] Over 25 years | - | - | 4.34E+6 | 0.25 |
| Greenhouse Gas Avoid (tonnes $CO_2$ Equivalent)[(4)] | (3.3E+5) | | | |
| **Total After Power Generation (excluding sequestering)** | **Sum = 4.0E+6 Tonnes $CO_2$ Equivalent** | | | **0.23** |
| Greenhouse Gas Sequestered (tonnes $CO_2$ Equivalent)[(5)] | (5.4E+6) | | | |
| **Total After Power Generation (including sequestering)** | **Sum = (1.4E+6) Tonnes $CO_2$ Equivalent** | | | **- 0.08** |

(1) Based on an approximate total emission of 69.5 million tonnes $CO_2$ equivalent in 2012 (based on estimates given in reference 15 for average over the period 2008-12 (base case))

(2) Total over a period of 100 years: peak generation will occur after 25 years

(3) Based on a collection efficiency of 75% and an oxidation rate of 10%

(4) Base on the European Commission default value for raw MSW of 22 kg $CO_2$ eq / tonne MSW[(9)].

(5) Based on the European Commission default value as shown in Table A8.5.

**Table 8.8: Comparison of the Climatic Impact of Incinerating 600,000 Tonnes/Waste versus Landfilling of 600,000 Tonnes/Waste For 25 years - Option 1**

| Process | Emissions of Carbon Dioxide Equivalent (Tonnes) |
|---|---|
| Total Incineration After Power Generation Over 25 Years | Sum = (1.93E+6) Tonnes $CO_2$ Equivalent |
| Total Landfilling After Power Generation Over 25 Years (IPCC Regulations) | Sum = 4.0E+6 Tonnes $CO_2$ Equivalent |
| **Net Impact Of Incineration On Climate (IPCC Regulations)** | **(5.9E+6) Tonnes $CO_2$ Equivalent**<br>**(Net positive impact equivalent to 0.34% of emission total in 2012)** |
| Total Landfilling After Power Generation Over 25 Years (including sequestering) | Sum = (1.4E+6) Tonnes $CO_2$ Equivalent |
| **Net Impact Of Incineration On Climate (Including Landfill Sequestering)** | **(5.3E+5) Tonnes $CO_2$ Equivalent**<br>**(Net positive impact equivalent to 0.03% of emission total in 2012)** |

**Table 8.9: Greenhouse Gas Fluxes From AD of Putrescible Wastes Assuming Average EU electricity replaced (kg $CO_2$ eq / tonne MSW)[9]**

| | **Anaerobic Digestion & CHP (kg $CO_2$ eq / tonne MSW)** | **Anaerobic Digestion & CHP (Tonnes $CO_2$ eq.) (Based on 242,220 tonnes / annum)** | **Anaerobic Digestion & CHP (Tonnes $CO_2$ eq.) (Based on 25 years)** |
|---|---|---|---|
| Avoided Energy & Materials | (23) | (5,571) | (1.39E+5) |
| Energy Use $CO_2$ | 2 | 484 | 1.2E+4 |
| **Net Flux (excluding sequestering)** | | | **(1.27E+5)** |
| Carbon Sequestered | (7) | (1,696) | (4.2E+4) |
| **Net Flux (including sequestering)** | | | **(1.69E+5)** |

**Table 8.10: Total Greenhouse Gas Emissions From The Landfilling Of 357,780 Tonnes/Annum For 25 Years & AD of 242,220 Tonnes of Putrescible Waste - Option 2**

| | $CO_2$ | $N_2O$ | $CH_4$ | Annual % Of Irelands Total Emissions[1] |
|---|---|---|---|---|
| Total Landfill Emissions (tonnes $CO_2$ Equivalent)[2,3] Over 25 Years | - | - | 1.1E+6 | 0.06 |
| Greenhouse Gas Avoid (tonnes $CO_2$ Equivalent)[4] Over 25 Years | (2.0E+5) | | | |
| Net Flux From Anaerobic Digestion (tonnes $CO_2$ Equivalent) Over 25 Years (excluding sequestering) | (1.27E+5) | | | |
| **Total After Power Generation / Annum (IPCC Regulations)** | **Sum = 7.7E+5 Tonnes $CO_2$ Equivalent** | | | **0.04** |
| Greenhouse Gas Sequestered (tonnes $CO_2$ Equivalent) Anaerobic Digestion Over 25 Years | (4.2E+4) | | | |
| Greenhouse Gas Sequestered (tonnes $CO_2$ Equivalent) From Landfilling Over 25 Years | (3.2E+6) | | | |
| **Total After Power Generation / Annum (Including Sequestering)** | **Sum = (2.5E+6) Tonnes $CO_2$ Equivalent** | | | **- 0.14** |

(1) Based on an approximate total emission of 69.5 million tonnes $CO_2$ equivalent in 2012 (based on estimates given in reference 15 for average over the period 2008-12 (base case))

(2) Total over a period of 100 years: peak generation will occur after 25 years

(3) Based on a collection efficiency of 75% and an oxidation rate of 10%

(4) Base on the European Commission default value for raw MSW of 22 kg $CO_2$ eq / tonne MSW[9].

**Table 8.11: Comparison of the Climatic Impact of Incinerating 600,000 Tonnes/Waste versus Landfilling Of 357,780 Tonnes/Annum For 25 Years & AD of 242,220 Tonnes of Putrescible Waste - Option 2**

| Process | Emissions of Carbon Dioxide Equivalent (Tonnes) |
|---|---|
| Total Incineration After Power Generation Over 25 Years | Sum = (1.93E+6) Tonnes $CO_2$ Equivalent |
| Total Landfilling / AD After Power Generation Over 25 Years (IPCC Regulations) | Sum = 7.7E+5 Tonnes $CO_2$ Equivalent |
| **Net Impact Of Incineration On Climate (IPCC Regulations)** | **(2.7E+6) Tonnes $CO_2$ Equivalent** **(Net positive impact equivalent to 0.16% of emission total in 2012)** |
| Total Landfilling / AD After Power Generation Over 25 Years (including sequestering) | Sum = (2.5E+6) Tonnes $CO_2$ Equivalent |
| **Net Impact Of Incineration On Climate (Including Landfill Sequestering)** | **5.7E+5 Tonnes $CO_2$ Equivalent** **(Net negative impact equivalent to 0.03% of emission total in 2012)** |

**Annex 8.1 To Appendix 8.2**

**Revised 1996 IPCC Guidelines On The Incineration of Waste**

Consistent with the IPCC Guidelines[7], only $CO_2$ emissions resulting from the incineration of waste of fossil origin (e.g. plastics, rubber, waste oil etc) should be included in emission estimates. The carbon fraction that is derived from biomass material (e.g. paper, food waste) is not included.

$CO_2$ Emissions

The most accurate $CO_2$ emission estimates results from disaggregating the activity into different waste types (municipal solid waste, sewage sludge, hazardous waste etc.) as the emission factor is based on the carbon content of the waste that is of fossil origin only. The following equation details the calculations involved:

$$CO_2 \text{ emissions (tonnes/yr)} = \Sigma_I( IW_i \times CCW_i \times FCF_i \times EF_i \times 44/12)$$

Where:

| | | |
|---|---|---|
| $i$ | = | Municipal Solid Waste (MSW) |
| $IW_i$ | = | Amount of incinerated waste of type i (tonnes/yr) |
| $CCW_i$ | = | Fraction of carbon content in waste of type i |
| $FCF_i$ | = | Fraction of fossil carbon in waste of type i |
| $EF_i$ | = | burn out efficiency of combustion of incinerators for waste of type i |
| 44/12 | = | conversion from C to $CO_2$ |

**Table A8.1: Default Data For Estimation of $CO_2$ Emissions From Waste Incineration[7]**

| | **MSW** | **Sewage Sludge** | **Clinical Waste** | **Hazardous Waste** |
|---|---|---|---|---|
| C Content of Waste | 33-50%<br>default = 40% | 10-40%<br>default = 30% | 50-70%<br>default = 60% | 1-95%<br>default = 50% |
| Fossil Carbon as % of Total Carbon | 30-50%<br>default = 40% | 0% | 30-50%<br>default = 40% | 90-100%<br>default = 90% |
| Efficiency of Combustion | 95-99%<br>default = 95% | 95% | 50-99.5%<br>default = 95% | 95-99.5%<br>default = 99.5% |

Note: MSW refers to non-hazardous municipal, commercial and industrial waste

Shown in Table A8.2 is the European Commission default emission factors for incineration[9]:

**Table A8.2: Incineration Treatment Emissions**[9]

| Waste Type | Composition of Waste (Ireland 2004)[8] | Carbon Content %C | % Fossil Carbon | Fossil $CO_2$ kg/t | $N_2O$ kg/t |
|---|---|---|---|---|---|
| **Paper / Card** | 24.5% | 33% | 0% | 0 | 0.05 |
| **Average Putrescibles** | 36.7% | 19% | 0% | 0 | 0.05 |
| **Plastics** | 13.2% | 61% | 100% | 2237 | 0.05 |
| **Glass** | 3.0% | 0% | 0% | 0 | 0.05 |
| **Metals** | 3.1% | 0% | 0% | 0 | 0.05 |
| **Textiles** | 8.1% | 39% | 50% | 715 | 0.05 |
| **Others** | 11.4% | 24% | 29% | 255 | 0.05 |
| **Total** | | **29.0%** | **0.206%** | | |

In the current scenario:

$$CO_2 \text{ emissions (tonnes/yr)} = \Sigma_I( IW_i \times CCW_i \times FCF_i \times EF_i \times 44/12)$$

$$CO_2 \text{ emissions (tonnes/yr)} = 600{,}000 \times 0.29 \times 0.206 \times 0.95 \times 44/12$$

**$CO_2$ emissions = 124,857 tonnes/yr**

Where:

| | | |
|---|---|---|
| i | = | MSW |
| $IW_i$ | = | Amount of incinerated waste of type i (600,000 tonnes/annum) |
| $CCW_i$ | = | Fraction of carbon content in waste of type i (national average = 0.29) |
| $FCF_i$ | = | Fraction of fossil carbon in waste of type i (national average = 0.206) |
| $EF_i$ | = | Burn out efficiency of combustion of incinerators (default = 0.95) |

In relation to the fraction of waste of non-biogenic origin, this has been estimated based on the detailed breakdown of household and commercial waste currently landfilled in Ireland in 2004 (see Table 8.3).

$N_2O$ Emissions

The calculation of $N_2O$ emissions is based on waste input to the incinerators and an emission factor:

$$N_2O \text{ emissions (Gg/yr)} = \Sigma_I( IW_i \times EF_i) \times 10^{-6}$$

Where:

| | | |
|---|---|---|
| $IW_i$ | = | Amount of incinerated waste of type i (Gg/yr) |
| $EF_i$ | = | Aggregate $N_2O$ emission factor for waste of type i (kg $N_2O$/Gg) |

**Table A8.3: Default Data For Estimation of $N_2O$ Emissions From Waste Incineration**[7]

| **Incineration Plant Type** | **MSW** Kg $N_2O$ / Gg waste (dry) | **Sewage Sludge** Kg $N_2O$ / Gg sludge (dry) | **Clinical Waste** Kg $N_2O$ / Gg waste (dry) | **Hazardous Waste** Kg $N_2O$ / Gg waste (dry) |
|---|---|---|---|---|
| Hearth of grate | Germany 5.5-66 (average 5.5-11) UK Highest value - 30 | 400 (Japan: wet) | NA | NA |
| Rotating | NA | NA | NA | 210-240 (Germany) |
| Fluidised Bed | 240–660 Japan (wet) | 800 (Germany) 100-1500 (UK) 300–1530 (Japan: wet) | NA | NA |

In the current scenario, using the values outlined in the report from the European Commission[9]:

$N_2O$ emissions (Tonnes/yr) = 600,000 Tonnes/annum x 0.05 kg/Tonnes waste

**$N_2O$ emissions = 30.0 tonnes /annum**

## AP-42 - Municial Solid Waste Landfills

The biodegradation of refuse in landfills produces landfill gas, mainly methane ($CH_4$) and carbon dioxide ($CO_2$) both of which are also greenhouse gases although only $CH_4$ is considered of non-biogenic origin. The USEPA[12] recommends that landfill gas emissions are calculated using the Landfill Gas Emission Model (LandGEM)[11]. Although other fates can exist for the gas generated in a landfill, including capture and subsequent microbial degradation, the bulk of the gas generated will be emitted through cracks or other openings in the landfill surface. For the purposes of estimating emissions both the IPCC[6] and USEPA[10] recommend the use of a 50% $CH_4$:50%$CO_2$ LFG ratio.

Emissions from landfills may be controlled by installing a gas collection system and combusting the collected gas through the use of flares or turbines. Gas collection efficiencies are typically around 75% whilst the collection efficiency of the control device averages around 95 - 99%. The First-Order Decomposition Rate Equation is shown below:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_o \left( \frac{M_i}{10} \right) e^{-kt_{ij}}$$

Where:

$Q_{CH4}$ = annual methane generation in the year of the calculation *($m^3$/year*)

i = 1-year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1-year time increment

k = methane generation rate (*year*$^{-1}$)

$L_o$ = potential methane generation capacity (*m*$^3$*/Mg*)

**Landfill Gas Emission Model (LandGEM)**

The landfill gas emission model (LandGEM) estimates air emissions from landfills. The biodegradation of refuse in landfills produces landfill gas, mainly methane ($CH_4$) and carbon dioxide ($CO_2$). The model estimates emission rates based on the landfill gas generation rate and the amount of refuse in the landfill. The landfill gas generation rate in the model is based on a first order decomposition model, which estimates the landfill gas generation rate using two parameters: $L_O$, the potential methane generation capacity of the refuse, and k, the methane generation decay rate, which accounts for how quickly the methane generation rate decreases, once it reaches its peak rate. In the current model the $L_O$ has been calculated as shown below(7):

**Option 1 - 600,000 Mixed MSW Landfilled**

$L_O$ = (MCF x DOC x $DOC_F$ x F x 16/12) (Mg $CH_4$/Mg Waste)

Where:

| | | |
|---|---|---|
| MCF | = | methane correction factor (default = 1) |
| DOC | = | Degradable organic carbon fraction (Mg C/Mg MSW) |
| $DOC_F$ | = | Fraction DOC dissimilated |
| F | = | Fraction by volume of $CH_4$ in landfill gas (IPCC Default = 0.50) |

And where:

DOC = (0.4 x A) + (0.17 x B) + (0.15 x C) + (0.3 x D)

Using Table 8.3:

| | | |
|---|---|---|
| A | = | fraction of MSW that is paper and textiles (approx. 33%) |
| B | = | fraction of MSW that is garden waste etc |
| C | = | fraction of MSW that is food waste (sum of B & C = 37%) |
| D | = | fraction of MSW that is wood (approx. 0.8%) |

Thus:

DOC = (0.4 x 0.33) + (0.16 x 0.37) + (0.3 x 0.008)

DOC = 0.194

This should be compared with the IPCC default value of DOC = 0.21 and a value of DOC = 0.186 (see below) using the default values given by the European Commission(9). The derivation of DOC and DDOC based on the methodology of the European Commission[9] is shown below using the actual waste breakdown in the National Waste Database Report 2004[8]:

**Table A8.4: Derivation of DOC and DDOC Based On National Waste Breakdown - Option 1**

| Waste Type | Total Carbon (TC) Content | Proportion of TC which is degradable | Degradable Organic Carbon (DOC) | Composition of Waste (Ireland 2004)[8] | DOC x Composition of waste | % of DOC which is dissimilable | Dissimilable organic carbon (DDOC) |
|---|---|---|---|---|---|---|---|
| **Paper** | 33% | 100% | 33% | 24.5% | 8.1% | 35% | 11.6% |
| **Average Putrescibles** | 19% | 100% | 19% | 36.7% | 7.0% | 64% | 12.2% |
| **Textiles** | 39% | 50% | 20% | 8.1% | 1.6% | 30% | 6.0% |
| **Miscellaneous / Fines** | 25.5% | 70% | 18.5% | 9.9% | 1.8% | 47.5% | 8.8% |
| **Total** | | | | | **18.6%** | | **49.5%** |

Thus:

**DOC = 0.186**

DDOC = 0.495 (derived as shown in Table A8.4)

Thus:

$L_O$ = (1.0 x 0.186 x 0.495 x 0.50 x 16/12) (Gg $CH_4$/Gg Waste)

$L_O$ = (0.062) (Mg $CH_4$/Mg Waste)

**$L_O$ = 92 $m^3$/Mg (site specific)**

This value should be compared with the two suggested values given in the LandGEM model:

<u>AP-42</u>

Methane Generation Rate k = 0.04 1/yr

Methane Generation Potential $L_O$ = 100 $m^3$/Mg

<u>Clean Air Act (CAA)</u>

Methane Generation Rate k = 0.05 1/yr

Methane Generation Potential $L_O$ = 170 $m^3$/Mg

Methane Percentage = 50% (IPCC and USEPA Default)

The site-specific parameters have been used in the following calculations as they represent the most appropriate values for the site. In order to enable a comparison between the landfill option and the waste-to-energy option, a length of active operation of the landfill of 25 years has been assumed.

Shown below is the methane generation rate (kg $CH_4$/t) derived using the default emission factors[9] and the Irish National Waste averages for 2004[8]. Results for methane generation are within 10% of the LandGem results although the LandGEM data has been used in the calculations as it allows a more site-specific assessment.

Table A8.5 also outlines the derivation of the carbon sequestering calculation using the European Commission methodology[9]. This result has been used in the assessment.

**Table A8.5: Estimate of $CO_2$ and $CH_4$ generation and carbon sequestered from landfilled waste - Option 1**

| Waste Type | Degradable Organic Carbon (DOC) | Dissimilable organic carbon (DDOC) | Methane Generation (kg $CH_4$/t) = DDOC*50%*16000/12 | $CO_2$ Generation (kg $CO_2$/t) = DDOC*50%*44000/12 | Carbon sequestered (kg $CO_2$/t) = (DOC-DDOC)*44000/12 |
|---|---|---|---|---|---|
| **Paper** | 33% | 11.6% | 77.3 | 212.7 | 784.7 |
| **Average Putrescibles** | 19% | 12.2% | 81.3 | 223.7 | 249.3 |
| **Textiles** | 20% | 6.0% | 40.0 | 110.0 | 513.3 |
| **Miscellaneous / Fines** | 18.5% | 8.8% | 58.7 | 161.3 | 355.7 |
| **Total** | | **49.5%** | | | |
| **Dublin WTE/Annum based on 600,000 tonnes (tonnes $CO_2$ eq) over 25 years** | | **49.5%** | **4.1E+6[1]** | | **5.4E+6** |

(1) Results relative to the LandGem model are within 10%.

## Option 2 - 357,780 Non-putrescible MSW Landfilled

$L_O$ = (MCF x DOC x $DOC_F$ x F x 16/12) (Mg $CH_4$/Mg Waste)

Where:

| | | |
|---|---|---|
| MCF | = | methane correction factor (default = 1) |
| DOC | = | Degradable organic carbon fraction (Mg C/Mg MSW) |
| $DOC_F$ | = | Fraction DOC dissimilated |
| F | = | Fraction by volume of $CH_4$ in landfill gas (IPCC Default = 0.50) |

And where:

DOC = (0.4 x A) + (0.17 x B) + (0.15 x C) + (0.3 x D)

Using Table 8.3:

| | | |
|---|---|---|
| A | = | fraction of MSW that is paper and textiles (approx. 30.2%) |
| B | = | fraction of MSW that is garden waste etc |
| C | = | fraction of MSW that is food waste (sum of B & C = 0%) |
| D | = | fraction of MSW that is wood (approx. 0.8%) |

Thus:

DOC = (0.4 x 0.302) + (0.16 x 0.0) + (0.3 x 0.008)

DOC = 0.123

This should be compared with a value of DOC = 0.107 (see below) using the default values given by the European Commission(9). The derivation of DOC and DDOC based on the methodology of the European Commission(9) is shown below using the actual waste breakdown in the National Waste Database Report 2004(8):

**Table A8.6: Derivation of DOC and DDOC Based On National Waste Breakdown - Option 2**

| Waste Type | Total Carbon (TC) Content | Proportion of TC which is degradable | Degradable Organic Carbon (DOC) | Composition of Waste (Assuming Diversion To AD)(8) | DOC x Composition of waste | % of DOC which is dissimilable | Dissimilable organic carbon (DDOC) |
|---|---|---|---|---|---|---|---|
| **Paper** | 33% | 100% | 33% | 22.1% | 7.3% | 35% | 11.6% |
| **Average Putrescibles** | 19% | 100% | 19% | 0% | 0% | 0% | 0% |
| **Textiles** | 39% | 50% | 20% | 8.1% | 1.6% | 30% | 6.0% |
| **Miscellaneous / Fines** | 25.5% | 70% | 18.5% | 9.9% | 1.8% | 47.5% | 8.8% |
| **Total** | | | | | **10.7%** | | **37.1%** |

**DOC = 0.107**

DDOC = 0.371 (derived as shown in Table A8.6)

Thus:

$L_O$ = (1.0 x 0.107 x 0.371 x 0.50 x 16/12) (Gg $CH_4$/Gg Waste)

$L_O$ = (0.026) (Mg $CH_4$/Mg Waste)

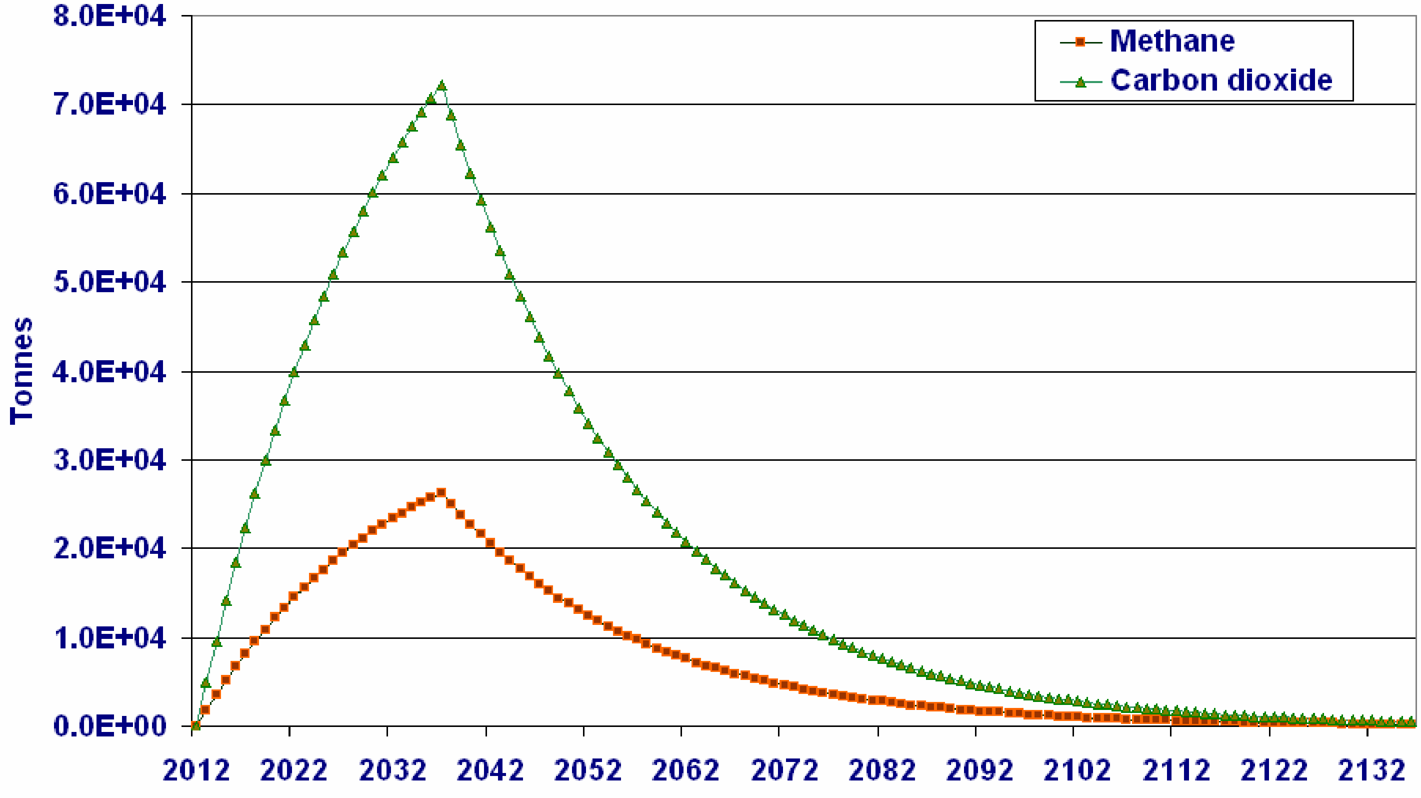
**$L_O$ = 39.6 $m^3$/Mg (site specific)**

**Table A8.7: Estimate of $CO_2$ and $CH_4$ generation and carbon sequestered from landfilled waste - Option 2**

| Waste Type | Degradable Organic Carbon (DOC) | Dissimilable organic carbon (DDOC) | Methane Generation (kg $CH_4$/t) = DDOC*50%* 16000/12 | $CO_2$ Generation (kg $CO_2$/t) = DDOC*50% *44000/12 | Carbon sequestered (kg $CO_2$/t) = (DOC-DDOC)*44000/12 |
|---|---|---|---|---|---|
| **Paper** | 33% | 11.6% | 77.3 | 212.7 | 784.7 |
| **Average Putrescibles** | - | - | - | - | - |
| **Textiles** | 20% | 6.0% | 40.0 | 110.0 | 513.3 |
| **Miscellaneous / Fines** | 18.5% | 8.8% | 58.7 | 161.3 | 355.7 |
| **Dublin WTE/Annum based on 357,780 tonnes (tonnes $CO_2$ eq) over 25 years** | | **37.1%** | **1.6E+6**(1) | | **3.2E+6** |

(1) Results relative to the LandGem model are within 30%. LandGEM results used in this analysis.

Figure 8.1: Landfill Gas Generation From A 600,000 Tonnes/Annum Landfill Opened For 25 Years




**Project**

Dublin Waste To Energy Climate Assessment

**Reference**

06_3018AR02

**Figure 8.1**

Landfill Gas Generation From 600,000 Tonnes/Annum Landfill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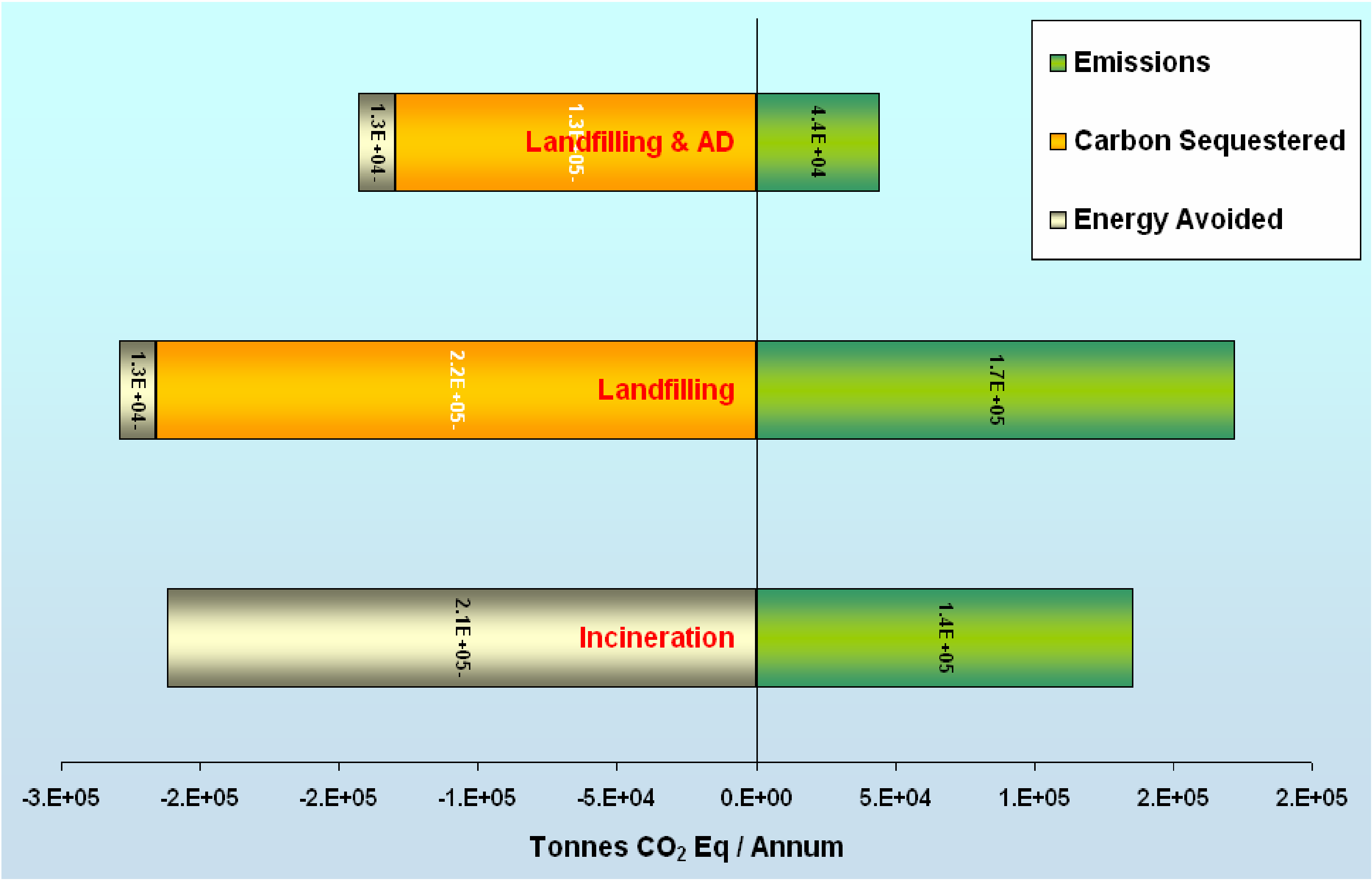


**Project**

Dublin Waste To Energy Climate Assessment

**Reference**

06_3018AR02

**Figure 8.2**

Comparison of GHG Emission Between Incineration, Landfilling and Anaerobic Digestion


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