An Economic Evaluation of Incineration as a Residual Municipal Solid Waste Management Option in Ireland

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Abstract:

The Environmental Protection Agency (EPA) and National Competitiveness Council (NCC) report that despite pressing EU policy requirements, Ireland remains heavily dependent on indigenous landfill capacity and overseas markets for its Residual Solid Waste (RMSW) reprocessing and waste to energy capacities. This deficit threatens Ireland's competitiveness and its environmental policy objectives. In the context of government revisions to national waste policy, economic analysis should underpin the policy choices used to identify indigenous RMSW management alternatives to landfill. This paper seeks to make a contribution to the debate by evaluating the RMSW treatment option of incineration by performing a cost-benefit analysis (CBA). The research demonstrates that certain configurations of RMSW incineration can provide a net benefit, relative to the status quo of landfilling RMSW in Ireland. In doing so, the study illustrates the sensitivity of an incineration project's benefits to its scale, operational costs and its capacity to recover energy. It finds that incineration does not provide a net benefit relative to landfill, if its scale and energy recovery capacity are insufficient. The methodology may be adapted to evaluate other RMSW infrastructure options e.g. mechanical, biological treatment (MBT).

Key words: Cost-benefit analysis, Residual municipal solid waste, Incineration

JEL codes: D61, Q51, Q52, Q53

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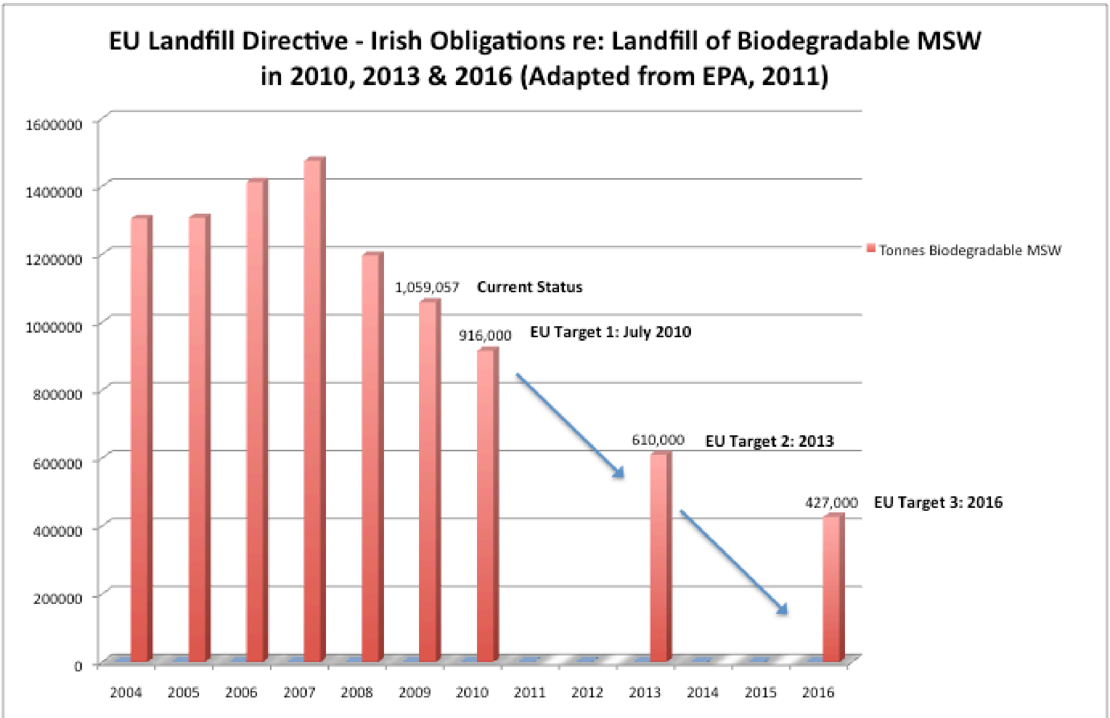
1. Introduction - The Economic Policy Context

Physical infrastructure, such as residual municipal solid waste (RMSW)[1] management infrastructure, enhances Ireland's relative economic position and facilitates the delivery of social and environmental policy objectives (O'Hagan and Newman, 2009). Despite its acknowledged importance, the Environmental Protection Agency (EPA)[2] and National Competitiveness Council (NCC)[3] report that Ireland has real and perceived waste management infrastructure deficits that threaten these objectives (NCC, 2010) (EPA, 2011a).

The EU Landfill Directive (CEC, 1999) requires Ireland to progressively reduce the biodegradable component of RMSW consigned to landfill and seek alternative management options. Figure 1 illustrates Ireland's current status in relation to the quantity of biodegradable RMSW it consigns to landfill and its EU Landfill Directive targets for biodegradable RMSW in the years 2010, 2013 and 2016 respectively.

Figure 1: Ireland's status in relation to its EU Landfill Directive obligations (EPA, 2011a)[4]



[1] RMSW is the fraction of collected municipal waste remaining after preliminary treatment that requires further treatment or disposal (EPA, 2011a)
[2] www.epa.ie
[3] http://www.competitiveness.ie/
[4] EPA collects and reports waste data retrospectively. It is likely that data from 2010 will be published in 2012

The 2010 target is likely to be achieved due to the economic slow-down. However the EPA note that "this low economic output basis for achievement of targets is not in itself sufficient to ensure continued compliance with EU requirements, particularly as the economy recovers. Accordingly efforts in waste prevention, diversion to recovery and the development of necessary supporting infrastructure must continue" (EPA, 2011a).

Ireland could potentially be fined by the European Court of Justice for non-compliance with the EU Landfill Directive. The range of fines for non-compliance is estimated to be between €25 - 225 million per annum[5] [6].

Irrespective of EU targets, at current fill rates 55% of Ireland's existing RMSW landfills will use up their consented capacity within three years (EPA, 2011a). Developing indigenous alternative RMSW management capacity is necessary to allow Ireland to respond to global economic shocks or market failures. In 2008, a shock to international commodity prices, linked to oil prices, impacted Irish waste management suppliers ability to develop indigenous or access international recycling markets, causing a short run supply issue in the recycling market (Bacon, 2008).

The EPA has granted operational licences for three planned commercial incinerator facilities in Ireland: Carranstown in Co. Meath, Ringaskiddy in Co. Cork and Poolbeg in Dublin. While construction is well advanced at Carranstown[7] and at an early stage in Poolbeg, none of these facilities are operational at the time of writing.

The NCC report that "…none of Ireland's municipal waste is converted into energy, compared to approximately half of the waste in Sweden and Denmark. Despite significant progress in increasing recycling, landfill, the least preferred waste solution from an environmental perspective, dominates in Ireland." (NCC, 2009)

Previous Programmes for Government (DoT, 2007 and DoT, 2009) committed the last administration to a review of Ireland's approach to waste management, which was completed for the DEHLG[8] in November 2009 (Eunomia et al., 2009). The review recommended the use of differentiated levies on all types of waste management facilities as a means to divert biodegradable municipal solid waste from landfill and to encourage the development of alternative behaviour and RMSW treatment infrastructure in Ireland.

However in encouraging infrastructure alternatives to landfill, the review and related DEHLG sponsored studies (AP EnvEcon, 2008) (Eunomia, 2009), reflected the last administration's political desire to "place a cap on incineration capacity to prevent waste being drawn to incineration, which could otherwise have gone to recycling… [and] not to alter the landfill levy in such a way as to give a competitive advantage to incineration..."

The review was the subject of significant public debate. The review did not provide a complete economic analysis of what the optimum RMSW management infrastructure

[5] Median estimate (AP EnvEcon, 2008)
[6] Median estimate (Eunomia and Tobin, 2007)
[7] The Carranstown site is expected to begin operations in late 2011, subject to an EPA licence review (EPA, 2011a)
[8] Department of Environment, Heritage and Local Government (DEHLG)

mix might be for Ireland (NCC, 2010). However the review's authors[9] have reasonably argued that this task was not within their terms of reference and that ideally the market should deliver an optimum waste management infrastructure portfolio based on a waste facility levy structure that reflects the environmental externalities of the infrastructure options available (Eunomia, 2010).

The review drew criticism from both the public and private waste management sector on the basis, level and application of the proposed levies (CEWEP, 2009a and CEWEP, 2009b). Dublin City Council commissioned the ESRI to comment on the Eunomia report (ESRI, 2010a and ESRI, 2010b). The ESRI papers[10] criticised the proposed waste policy of the last Government and the Eunomia approach to the review. On the diversion of biodegradable municipal solid waste from landfill, the ESRI agreed with the review on the use of differentiated waste facility levies, based on emissions from the various classes of residual waste treatment facilities that reflect their externalities. However the ESRI disagreed with the review on the basis, level and application of those levies.

The last government fell before new policy and legislative proposals arising from the review could be implemented, adding to ongoing market uncertainty around investment in alternatives to landfill[11] and the strategic direction of Ireland's waste policy.

The new Minister for the Environment, Heritage and Local Government, Phil Hogan T.D., summed up the situation as, "Much has been said since 2007 in relation to waste management policy, but little has been brought to conclusion and finality. However, there are a number of things which are certain. If we do not meet our EU obligations, Ireland will face significant fines. If the alternatives to landfill are not in place we will not meet our EU obligations. And, if we do not provide certainty, those alternatives [to landfill] will not be provided and Ireland will not be in a position to manage its waste in a sustainable manner" (DEHLG, 2011).

The new Government proposes to finalise a new waste policy by the end of 2011 (DEHLG, 2011). Economic analysis should underpin the policy options chosen to promote indigenous RMSW management alternatives to landfill. This paper builds on earlier work (O'Donovan, 2010) and seeks to make a contribution to the debate, evaluating the RMSW treatment option of incineration by performing a cost-benefit analysis.

Section 2 of this paper outlines the scope and boundaries of the analysis. Section 3 outlines the methodology used. Section 4 evaluates the impacts of landfill and incineration RMSW. Section 5 presents and discusses the results of the analysis. Section 6 concludes the paper.

[9] A consortium of consultants, led by Eunomia Research & Consulting (http://www.eunomia.co.uk/)
[10] Referred to collectively as ESRI (2010) in this paper
[11] NCC, 2010

2. Scope and Boundaries of the Analysis

Several alternative infrastructure options may be considered for the management of Ireland's RMSW, including:

- A business as usual (BAU) scenario, the continued landfill of RMSW as the predominant treatment option in Ireland
- The incineration of RMSW in Ireland
- The incineration of Ireland's RMSW in an export market
- The co-incineration of RMSW in suitable industrial processes in Ireland that displace fossil fuels e.g. use of processed RMSW as a fuel in a cement kiln
- The Mechanical Biological Treatment (MBT) of RMSW in Ireland. MBT "encompasses a broad range of distinct technologies that can be combined to treat RMSW typically at the same facility" (Guinan et al., 2008)

The scope of this paper is limited to evaluating incineration against a counterfactual of landfill, as an alternative RMSW management option in the Republic of Ireland by undertaking a cost benefit analysis of the alternatives.

Cost-benefit analysis (CBA) is a methodology that compares the net social benefits of investing resources in a particular project with the net social benefits of another hypothetical project that would be displaced if the project under evaluation were to be implemented (Boardman et al., 2006).

The research questions asked are:

What are the benefits and costs of providing indigenous incineration capacity as an alternative to landfill in the State?

Is there a net benefit from providing indigenous incineration capacity as an alternative to landfill in the State and under what circumstances?

The scope of this paper has both a national and global perspective i.e. it looks at the local costs and benefits of RMSW incineration and landfill to residents in the Republic of Ireland and also at the costs and benefits of RMSW incineration and landfill affecting everyone irrespective of where they reside e.g. environmental emissions that create global impacts such as climate change.

3. Methodology

The methodology follows that of a typical CBA (Boardman et al., 2006). The internalities and externalities of RMSW landfill and RMSW incineration are examined.

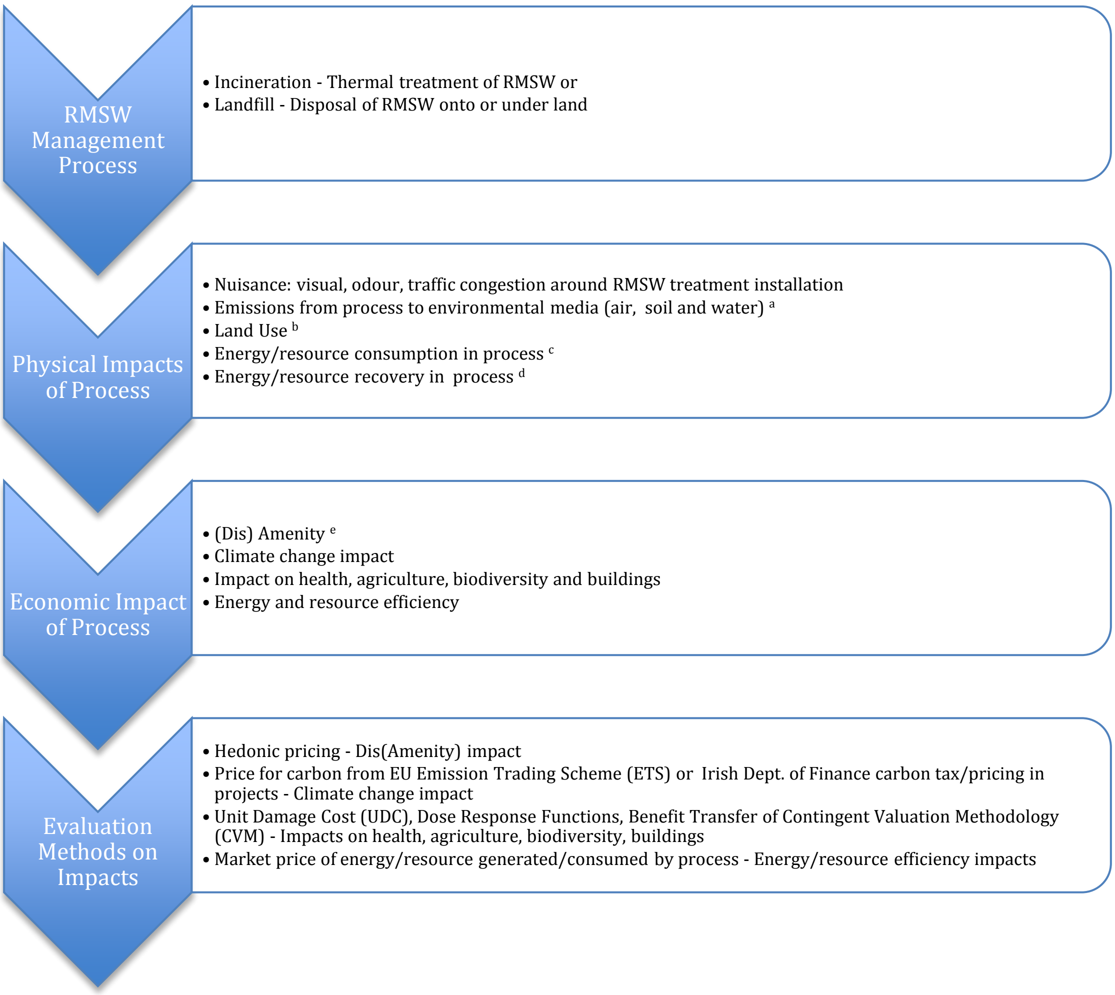
The internalities or traditional financial costs and benefits of operating a waste management facility can be paid for with a price determined by the market e.g. capital investment, operation and management costs and gate fees.

Externalities or 'spill-over effects' arise when economic activity[12] affects a third party directly rather than through the market. Externalities can be positive (benefits) or negative (costs) for third parties. Environmental emissions that are not covered in the price of a good or service are classed as negative externalities (McAleese, 2004). An externality is internalised if the loss of welfare is accompanied by compensation equal to the damage cost from the agent causing the externality e.g. a landfill levy or a carbon tax (O'Hagan and Newman, 2009).

The economic valuation of the externalities associated with the landfill and incineration of RMSW is generally based on a European Commission study (COWI, 2000). An overview of the Commission's 'impact pathway approach' is illustrated in Figure 2.

[12] Production or consumption activities

Figure 2: Evaluating the externalities of waste management processes[13]



Notes:
(a) The cost of environmental emissions are negative variable externalities i.e. the externality is related to the quantity of waste managed
(b) Unlike landfill, incineration is generally assumed to be independent of land-use capacity
(c) Some fossil fuel is used in the start-up and shut down of incineration. Energy and auxiliary materials is used in treatment of environmental emissions in both processes. Energy is used in collection systems, weighing stations and on-site vehicles in both processes.
(d) The benefit of the avoided costs of displaced pollution or recovered materials is a positive variable externality. Treatment systems mitigate pollution from the process. With incineration, energy may be recovered from the combustion process in the form of heat or electricity. Metals may be recovered from the combustion process. With landfill, energy may be recovered in the form of landfill gas (LFG) where the facility has an engineered LFG collection system.
(e) Disamenity is a fixed externality i.e. It does not vary with the quantity of waste managed.

[13] Source: Adopted from COWI, 2000 and Bartleings et al., 2005

This approach lists the externalities associated with the waste management processes. Based on Figure 2, the scope of this paper will focus on the economic valuation of six impacts from RMSW incineration and RMSW landfill processes in Ireland, namely:

- The capital expenditure (Capex)
- The operational expenditure (Opex)
- Externalities:
    - Environmental emissions from the process that give rise to climate change damage impacts
    - The process capacity in relation to energy and resource recovery savings
    - Other emissions from the process to environmental media (i.e. soil, water and air) that give rise to health impacts
    - Disamenity

Subsequently the impacts of these effects on economic activity and human welfare are assessed in physical terms, based on the findings of a review of the relevant literature available. Eunomia et al. (2009), found that most international methodologies used to evaluate environmental emissions from RMSW management "use a 'unit damage cost' (UDC) approach to assess the harm caused by specific pollutants. This is referred to as a 'top down' approach. A 'bottom up' approach is where the impact of emissions are modelled through 'dose-response functions' applied to the locality in which an activity takes place."

The costs and benefits of the impacts are then monetised, in a cost benefit model that 'enables the aggregation of different effects across different media into a common monetary unit' (Eunomia et al., 2009) and allows consistent comparisons between the alternatives. As this paper is a generic study, both incineration and landfill are evaluated in terms of a cost per tonne of RMSW treated (expressed as € per tonne RMSW) over a typical 20 year operational lifespan (Economopoulos, 2010). Discounting the results to obtain present values facilitates consistent comparisons across different treatment options with significantly different profiles relating to emissions over time (ESRI, 2010). A net present value (NPV) of each alternative is then computed.

It is acknowledged that in common with the existing literature on the externalities of landfill and incineration that the results presented in this section are often associated with uncertainties resulting from data deficits or assumptions underlying the calculations. Uncertainty also arises around the debate on which social discount rate to use and how to value health and disamenity impacts in the analysis. It is for these reasons that a sensitivity analysis is used to test how robust the results are.

4. Evaluating the Impacts of RMSW Landfill and Incineration

This section attempts to establish nominal values for the costs and benefits of landfill and incineration based on a review of the relevant research literature and a series of estimation assumptions. Four categories of impacts are considered:

- Capital and operational expenditure
- Net climate change impacts
- Health impacts
- Disamenity impacts

The values established in this section are subsequently used in the CBA calculations in Section 5.

4.1. Capital and Operational Expenditure

The total estimated Capex and Opex associated with the building, operation, remediation and aftercare of one tonne of incinerator and landfill capacity in Ireland over a 20 year timescale are presented in Table 1. The estimates of capex and opex presented in Table 1 are based on values established in referenced literature and adjusted for inflationary changes and capacity.

Table 1: Capex and Opex for Incineration and Landfill Capacity in Ireland[14]

RMSW Treatment [a]	Impact	Total Unit Cost of Capacity € (2008) per tonne RMSW		
		Min.	Max.	Median
Landfill [b]	Capex			642.52
	Opex			328.26
			Sub-total	970.78
Incineration [b,c,d]	Capex	387.62	813.13	600.13
	Opex	437.39	954.85	696.12
			Sub-total	1296.25

Notes
a. Assumed that operational lifespan of all facilities is 20 years (Economopoulos, 2010)
b. Eunomia et al. (2001): Landfill capacity for treating 100,000 tonnes RMSW p.a.; Incineration capacity for treating 200,000 tonnes RMSW p.a. Unit capacity costs are adjusted to 2008 prices, see note (e) below.
c. European Commission (2008): Incineration capacity for treating 300,000 tonnes RMSW p.a.
d. Guinan et al. (2008): Incineration capacity for treating 150,000 tonnes RMSW p.a. Unit capacity costs are adjusted from 2007 prices to 2008 prices, see note (e).
e. CSO (2010): Capital Goods Price Index (CGPI) for building & construction is assumed to reflect inflationary changes in Capex. Consumer Price Index (CPI) assumed to reflect inflationary changes in opex. Estimated CPI rose by 4.1% and CGPI rose by 3.7% between 2007 & 2008. CPI rose by 28.6% and CGPI rose by 41.7% between 2001 & 2008

For ease of comparison between data on the Capex and Opex of waste facilities found in the literature, all prices are expressed at 2008 levels.

We acknowledge that Ireland has suffered significant economic downturn since 2008. The costs in Table 1 may appear high as the cost to construct a waste management facility at the time of writing may be cheaper. However 2008 was chosen as the base year for this research to ensure a level of consistency across the literature sources reviewed as:

- The construction of the first RMSW incineration facility in Ireland began in August 2008[15]. For ease of comparison in the CBA, it is useful to determine and compare the costs of an incinerator and landfill in 2008.

[14] Table 1 references the source literature and assumptions used in the estimate.

- It is arguable that while costs have come down since 2008, the access to capital for utility projects today is constrained so it is not entirely clear if it is easier to finance an utility project today than 2008 (Goodbody Stockbrokers, 2010).

Nevertheless we will revisit this issue in the sensitivity analysis to take account of the possibility of a lower Capex and Opex for an incinerator and landfill[16].

The ranges for the Capex and Opex for incineration in Table 1 reflect the greater economies of scale that may be achieved as incineration capacity is increased from a capacity of 150,000 to 300,000 tonnes per annum. The gap in Capex between landfill and incineration narrows as its capacity increases (and hence economies of scale improve, reducing the Capex). The combined median Capex and median Opex of a RMSW incinerator is estimated to be 33% higher than that of a RMSW landfill in Ireland, however this disadvantage is reduced as the capacity of an incinerator is increased. The significant difference in Opex between the two technologies reflects the technical complexity and higher ongoing cost of emission abatement at incinerators relative to landfill. Increasing the scale of the incinerator reduces its Opex but it still remains higher relative to landfill.

For the purpose of this research, the median values in Table 1 were chosen. However, both incineration projects currently under construction in Ireland are state of the art and have a planned capacity ≥ 200,000 tonne RMSW per annum. It is reasonable to assume that the incinerator (Min.) scenario in Table 1 could apply or at the very least economies of scale would be maximised when constructing incineration capacity. The combined Capex and Opex of a RMSW incinerator (Min. Scenario in Table 1) is estimated to be 15% lower than that of a typical 100,000 tonne capacity RMSW landfill in Ireland.

[15] http://www.indaver.ie/fileadmin/IE/pdf/NewsletterJuly08.pdf

[16] In the sensitivity analysis (section 5) we assume the Capex and Opex levels remain at 2001 price levels i.e. we use the non-inflated data from Eunomia et al., 2001.

4.2. Net Climate Change Impacts

The scientific and inter-governmental consensus is that anthropogenic emissions[17] of 'greenhouse gases' (GHGs) are contributing to a rise in global temperatures and that some form of control is necessary to avoid or mitigate the potential adverse consequences of climate change. There are several GHGs but emissions are generally measured in terms of carbon equivalence or tonne $CO_{2\ eq}$ (UN Intergovernmental Panel on Climate Change, 2007).

Estimated greenhouse gas emissions up to 2009, shows that the waste sector contributed 2% of Ireland's total greenhouse gas emissions (EPA, 2011b). While emissions from landfill and incineration have climate change impacts, these impacts may be offset somewhat by the recovery of energy or materials in the treatment processes.

In general, when accounting for the climate change impacts of a RMSW management process:

$N_{Process} = E_{Process} - O_{Process}$ where:

$N_{Process}$ = Net GHG emissions of the RMSW management process
$E_{Process}$ = Primary and indirect[18] emissions of the RMSW management process
$O_{Process}$ = Offsets[19] in the form of energy recovery in the process

The primary GHG emission from the landfill of RMSW is methane (CH_4) generated by the anaerobic degradation of the organic waste matter inside the landfill. The volume of CH_4 generated depends on the material landfilled and its biogenic carbon content. Indirect emissions also arise from the combustion of fuel on-site in machinery used in the landfill process. The global warming contribution of landfill gas (LFG) emissions may be attenuated either by landfill design[20] or by gas capture and combustion in flares or in gas utilisation technologies thereby off-setting potential GHG emissions from alternative energy generation sources based on fossil fuels. Biogenic carbon that is not released within a 100 year period is assumed to be equal to an avoided emission of biogenic CO_2 and is assumed to be a saving with respect to global warming. This is known as carbon sequestration (Astrup et al., 2009). The 2006 IPCC *Guidelines for National Greenhouse Gas Inventories* (Eggleston et al., 2006) provide detailed guidelines on how annual GHG emissions from landfill can be estimated.

The primary GHG emissions from the incineration of RMSW arise from a near complete oxidation of organic matter to carbon dioxide (CO_2). Depending on the flue gas treatment system used in the incinerator, another GHG, nitrous oxide (N_2O) may also be emitted. Indirect emissions include: the consumption of auxiliary fuels and materials[21] at the plant; and treatment of air pollutant control (APC) residues and bottom ash.

[17] Including emissions from waste management and the consumption of fossil fuels for power, transport and heat

[18] Emissions from: transportation of waste or treatment residues to and from site; waste pre-treatment; and from the construction of the facility; are not accounted for.

[19] Energy recovered and used for power and heat. The extent of the offset depends on what alternative source of energy production is substituted for. It is assumed that no offset is obtained when substituting for another low carbon renewable energy e.g. wind energy.

[20] E.g. microbial oxidation of emissions using top soil cover on the landfill

[21] E.g. chemicals used for cleaning flue gases from waste combustion before emission to air

Methane and trace gases are not considered significant in the case of modern incineration installations. However, energy recovered in the form of electricity or heat from an incineration process can off-set potential GHG emissions from alternative energy generation sources based on fossil fuels. The recovery of metals from RMSW in an incineration process is also categorised as an offset, as it mitigates emissions associated with resource extraction elsewhere (Astrup et al., 2009).

Table 2 outlines the results from several relevant studies that examined the monetised net climate change impacts of landfill emissions.

Table 2: Literature review on the cost of net climate change impacts from landfill emissions

Literature Source	Carbon Accounting Function	Cost in € per tonne RMSW
Dijkraaf and Vollebergh 2004	Net emissions excluding carbon sequestration	0.65
Bartleings et al., 2005		3.07
Rabl et al., 2008		Range 10.9 - 10.9
Eunomia et al., 2009		Range 63.06 - 79.80
ESRI, 2010		33.90

There is agreement in the literature that landfill generally has a net cost impact in terms of climate change. However, the literature review in Table 2 shows significant variation primarily caused by differences in assumptions related to allocation principles, the pricing of carbon and the boundary conditions used in the respective studies e.g. the assumed energy recovery capacity of landfill and the potential of this capacity to offset emissions.

In Table 2 only Eunomia et al. (2009) and ESRI (2010) provide estimates on the climate change impact of Irish landfills. Both studies use EPA data on RMSW composition in Ireland and value of CH_4 emissions from one tonne of RMSW over the lifetime of a typical landfill. The studies differ on how they price climate change impacts. The Eunomia study assumes a UK methodology and a shadow price for carbon, while the ESRI studies use the IPCC guidance to estimate carbon emissions generated from one tonne of waste in a landfill over a 20 year lifetime and the Irish Department of Finance guidance (DoF, 2009) on pricing carbon into projects.

Table 3: Estimated Net Climate Change Impacts of Incineration (€ per tonne RMSW)

Literature Source	€ per tonne RMSW
Dijkraaf and Vollebergh 2004	-9.96
Bartleings et al., 2005	-7.52
Rabl et al., 2008	Range -2.19 to 8.81
Astrup et al., 2009	-7.28
ESRI, 2010*	5.60
Guinan et al., 2008*	Range -4.92 to -0.81
Green, 2006*	Range -6.90 to -1.05
***Note:**	
Assumed price of carbon is €15 per tonne CO_2	

Table 3 outlines the results from a literature review of various studies that examined the net climate change impacts of incineration. It also reflects a significant variation in the impact of emissions from incineration. The variation is primarily caused by differences in assumptions related to allocation principles, the pricing of carbon and the boundary conditions used in the studies. In general the literature concludes that resource recovery capacity is a more important factor in determining the net benefit of incineration, if any, than it is for landfill.

The magnitude of the net climate change saving from an incinerator with energy and resource recovery capacity, is related to its technological configuration, its efficiency and the alternative source of energy generation that the incinerator displaces. Rabl et al. (2008) demonstrate that incineration with energy recovery delivers environmental benefits when displacing energy generation with a higher carbon intensity e.g. a fossil fuel power station. The authors demonstrate that an incinerator with only electricity recovery may provide reduced or no environmental benefits in France because its electricity generation portfolio is predominantly nuclear, a low carbon energy generation source (see authors range in Table 3 above). Dijkraaf and Vollebergh (2004) while agreeing that incineration with electricity recovery brings net environmental benefits, suggests that it is not the most efficient way to generate electricity.

Average data on electricity provision in the EU shows large variations from country to country due to different fuels being used and different efficiencies for electricity production in individual countries with somewhat less variation in emissions being found for heat production (Astrup et al., 2009). Eunomia et al. (2009) argue that Ireland's future electricity generation portfolio is likely to be based upon a 40% share of renewable energy sources, with the remainder based on gas powered generation stations or electricity imports via interconnection with the UK and France by 2020. Gas has a lower carbon intensity than other fossil fuels. It is for this reason that Eunomia et al. (2009) suggest that the environmental benefits of incineration may decrease with time as Ireland's electricity generation becomes decarbonised.

However, this argument does not consider the fact that Ireland must also make significant progress in developing renewable heat capacities by 2020 (SEAI, 2010). Rabl et al. (2008) demonstrate that while incineration can be used to generate electricity, it is a more efficient source of generating renewable heat. In addition incineration can provide a constant supply of energy unlike other intermittent sources of renewable energy. It is for these reasons that incineration with both electricity and heat recovery capacities may be considered as a source of renewable energy up to 2020.

Eunomia et al. (2009) estimate the climate change impact of incineration to be in the range of €21.75 per tonne RMSW to €26.24 per tonne RMSW. The authors assume a UK shadow price for carbon, while the ESRI studies use the Irish DoF guidance on pricing carbon into projects. In addition ESRI follow IPCC guidelines on reporting CO_2 emissions from incineration.

4.2.1 Cost Benefit Model (CBM) of the net climate change impact of RMSW landfill and RMSW Incineration in Ireland

The estimated climate change impact of one tonne of RMSW in a landfill over a 20 year timescale is presented in Table 4

Table 4: Climate change impact of one tonne of RMSW in a landfill over 20 years

Year [(a)]	CH_4 Lifetime distribution of 1 tonne RMSW (%)	Tonnes CO_2 eq per tonne RMSW	Tonnes CO_2 emitted per tonne RMSW	CO_2 price - current € [(b)]	CO_2 Price PV (4%TDR)	Total Cost PV € (TDR 4%)
2009	0	0	0.000	13.4	13.4	0.00
2010	6.00%	0.4755	0.029	15	14.4	0.41
2011	16.40%	0.4755	0.078	15	13.9	1.08
2012	18.10%	0.4755	0.086	15.69	13.9	1.20
2013	7.90%	0.4755	0.038	16.76	14.3	0.54
2014	5.60%	0.4755	0.027	17.93	14.7	0.39
2015	5.50%	0.4755	0.026	39	30.8	0.81
2016	4.90%	0.4755	0.023	39	29.6	0.69
2017	4.40%	0.4755	0.021	39	28.5	0.60
2018	4.40%	0.4755	0.021	39	27.4	0.57
2019	3.90%	0.4755	0.019	39	26.3	0.49
2020	3.40%	0.4755	0.016	39	25.3	0.41
2021	3.40%	0.4755	0.016	39	24.4	0.39
2022	3.40%	0.4755	0.016	39	23.4	0.38
2023	2.90%	0.4755	0.014	39	22.5	0.31
2024	2.60%	0.4755	0.012	39	21.7	0.27
2025	2.30%	0.4755	0.011	39	20.8	0.23
2026	1.70%	0.4755	0.008	39	20.0	0.16
2027	1.30%	0.4755	0.006	39	19.3	0.12
2028	1.00%	0.4755	0.005	39	18.5	0.09
2029	1.00%	0.4755	0.005	39	17.8	0.08
					Total	**9.22**
Notes:						
(a) Methodology adopted from ESRI (2010)						
(b) Source: DoF (2009)						

The ESRI methodology for estimating the climate change impact of landfilling waste is adopted for the analysis in Table 4 as it follows the Irish DoF guidance more closely.

Unlike incineration, greenhouse gases are not emitted from a landfill in a constant uniform manner, as the biodegradable constituents of a tonne of RMSW placed in a landfill will degrade at different times and over extended timescales. In Table 4 the carbon emission capacity of one tonne of RMSW is dispersed over a 20 year timescale. The carbon emission capacity[22] is converted into carbon equivalence emitted per tonne of waste as "tonne CO_2 emitted per tonne waste" and monetised using DoF (2009) guidance on the pricing of carbon in Irish projects.

For a project that has costs or benefits that accrue over extended timescales, there is a need to aggregate the benefits and costs that arise in different years. In cost benefit analysis (CBA), future benefits and costs are discounted relative to present benefits and costs using a 'discount factor', in order to obtain the present values (PV). The discount factor formula is:

Discount factor = $1/(1+i)^n$ where: i = interest rate; and n = the number of years time the amount accrues.

[22]The capacity (tonne CO_2eq per tonne RMSW) in Table 4 is the median net emission from a landfill with energy recovery, excluding carbon sequestration (Green 2006 and Guinan et al., 2008)

The literature on discounting provides little agreement on the appropriate interest rate (Clinch and Healy, 2000). It is noted that ESRI (2010) use a 3.5% social discount, however the test discount rate (TDR) for use in CBA of public sector projects is 4%. This is a rate expressed in real terms (i.e. excluding projected inflation) (DoF, 2009).

Four possible impact scenarios have been developed for the landfill Cost Benefit Model (CBM) and the results are outlined in Table 5.

Table 5: Net Climate Change Impact of One Tonne of RMSW in Various Landfill Configurations Over 20 Years

Landfill Scenario	Description of Median Net Emissions	Carbon capacity of a tonne of RMSW (tonne CO_2 eq per tonne RMSW)	Total Cost - PV €			
			(TDR 0%)	(TDR 4%)	(TDR 5%)	(TDR 10%)
Landfill with energy recovery [a,b]	Emissions excluding carbon sequestration	0.4755	12.6	9.22	8.59	6.26
	Emissions including carbon sequestration	0.0985	2.61	1.91	1.75	1.3
Landfill with no energy recovery [b,c]	Emissions excluding carbon sequestration	1.43	37.83	27.68	25.79	18.81
	Emissions including carbon sequestration	0.85	22.53	16.48	15.4	11.2
State of the art Landfill with extensive energy recovery [d]	Emissions excluding carbon sequestration	0.17	4.51	3.3	3.07	2.24
	Emissions including carbon sequestration	0.0115	0.305	0.22	0.2	0.15
Low Organic Waste Input to Landfill [d]	Emissions excluding carbon sequestration	0.058	1.54	1.12	1	0.8
	Emissions including carbon sequestration	-0.026	-0.69	-0.5	-0.47	-0.3
Notes:						
(a) Guinan et al., (2008)						
(b) Green (2006)						
(c) ESRI (2010)						
(d) Manfredi et al., (2009)						

A literature review of the net carbon emission capacity[23] of one tonne of RMSW in a variety of landfill configuration scenarios are provided in Table 5. The first two scenarios presented in the Table most closely represent the Irish situation[24] (ESRI, 2010). As previously stated, some carbon may be sequestered by landfill, reflecting another potential GHG offset. The net carbon emission capacity potential of the landfill scenarios are presented, with and without considering carbon sequestration.

A range of present values for all the scenarios in Table 5[25] were estimated using a range of discounts varying between 0-10% for the purpose of comparative and sensitivity analysis, with the median being considered the optimum statistical measure of all the impacts. The DoF's test discount rate of 4% was considered the key rate for determining the implications for government policy. In addition it was assumed that both landfill and incinerator facilities have a comparable operational lifespan of 20 years.

The reasons that the energy recovery capacity differs between the landfill scenarios are that: different energy recovery technologies and efficiencies are deployed in each scenario; and the assumptions vary around the type of energy generation displaced by

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[23] $N_{Landfill}$

[24] Manfredi et al. (2009) reflects average data on state of the art EU landfill practices and provides the latter two scenarios in Table 5. In the last scenario in Table 5, it is assumed that RMSW collection and pre-treatment standards significantly reduce the quantity of biodegradable or organic waste accepted at landfill in the future, thereby reducing the potential for emissions. It is assumed that this data is applicable to this analysis for comparative purposes.

[25] Methodology for PV estimates as Table 4

energy recovered at the landfill i.e. a form of energy recovery that displaces fossil fuel based energy generation is more desirable from a carbon accounting perspective.

Table 5 shows that, excluding carbon sequestration capacity, landfill emissions generally have a net climate change cost impact. It is noted that theoretically landfill with extremely high pre-treatment standards and high energy recovery, may have a reduced impact. However, the economics of installing energy recovery capacity at a landfill is also reduced when you decrease the organic waste input (Manfredi et al., 2009)

In Table 5, the median carbon emission capacity of one tonne of waste placed in an Irish landfill is estimated be 0.9528 tonne CO_2eq per tonne RMSW, excluding carbon sequestration[26] and 0.4743 tonne CO_2eq per tonne RMSW, including carbon sequestration[27]. The net climate change impact of one tonne of waste placed in an Irish landfill for 20 years[28] is estimated be in the range of €9.22 per tonne RMSW - €27.68 per tonne RMSW, excluding carbon sequestration[29] and €1.91 per tonne RMSW - €16.48 per tonne RMSW, including carbon sequestration[30].

However this is not the full story, the analysis above covers the climate change impact of 'one tonne of waste' in a range of landfill configurations over 20 years, but what is the impact of a median 'landfill' that operates for 20 years?

As the median impact of one tonne of waste is known, we can estimate the impact of a median 'landfill' that operates for 20 years in Ireland. For simplicity it is assume that one tonne of waste is placed into the landfill per annum. The results are graphed in Figure 3.

[26] The first two scenarios in Table 5 reflects the standard of Irish landfills (ESRI, 2010). The median estimate is based on a range of emission capacities, excluding carbon sequestration, between 0.4755 and 1.43 tonne CO_2eq per tonne RMSW in Table 5.
[27] The first two scenarios in Table 5 reflects the standard of Irish landfills (ESRI, 2010). The median estimate is based on a range of emission capacities, including carbon sequestration, between 0.0985 and 0.85 tonne CO_2eq per tonne RMSW in Table 5.
[28] Assuming that the first two scenarios of Table 5 are representative of Ireland landfill standards (ESRI, 2010). Median results and TDR of 4% used.
[29] Median of €18.50 per tonne RMSW
[30] Median of €9.20 per tonne RMSW

Figure 3 Net Climate Change Impact of an Irish Landfill with an operational lifetime of 20 years (PV € per tonne RMSW vs. Years)

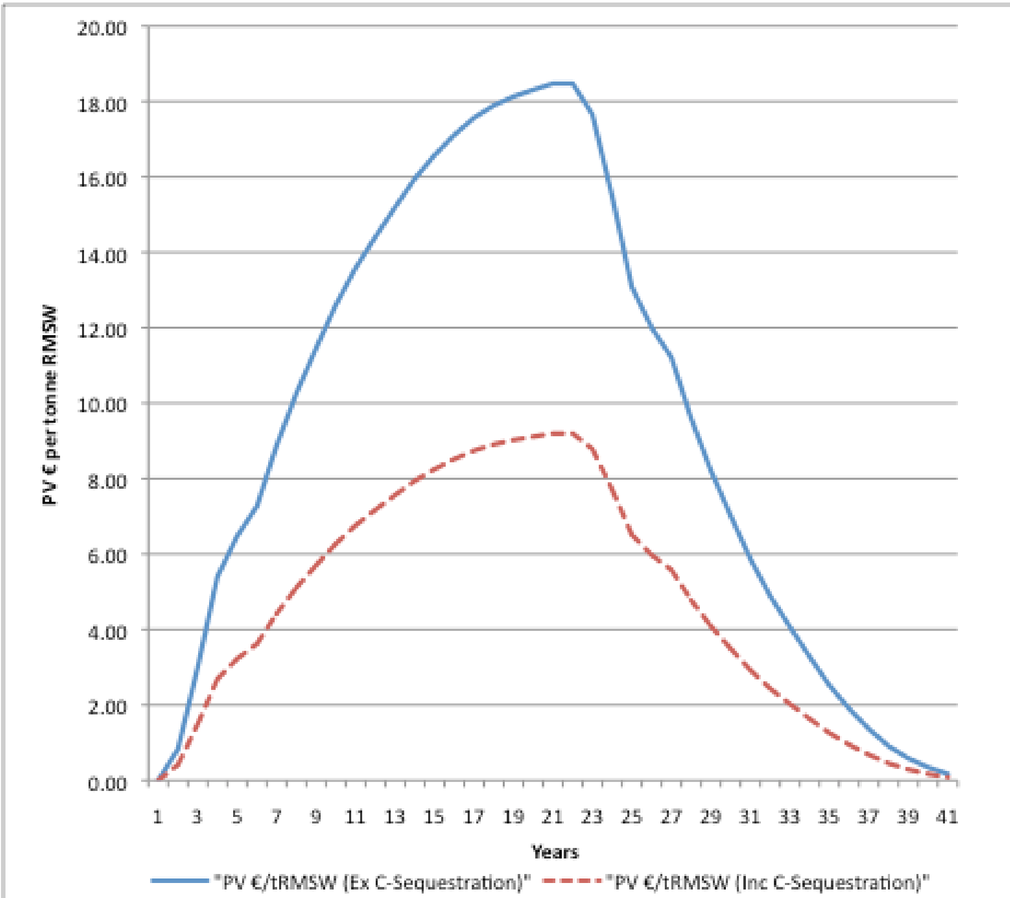

Figure 3 illustrates that the climate change impact of a landfill happens beyond its operational lifespan of 20 years. Assuming the landfill is fully utilised, the figure illustrates its impact over 40 years (years 1-41) and differientates between landfills with and without carbon-seqestration[31].

The total PV for an average Irish landfill over a 20 year lifespan is estimated to be between €193 per tonne RMSW (including carbon sequestration) and €388 per tonne RMSW (excluding carbon sequestration[32]). Given the variation in landfill's ability to sequester carbon or mitigate carbon emissions, the median value (€290.50 per tonne RMSW) is assumed to be representative of the net climate change impact of an average landfill that operated for 20 years.

Figure 3 is consistent with the findings of Green (2006) who analysed the extended climate change impacts of Irish landfill.

The estimated net climate change impact of incinerating one tonne of RMSW in a potential Irish incinerator with electricity recovery capacity over a 20 year timescale (TDR, 4%) is presented in Table 6.

[31] After 100 years, carbon sequestration capacity may be considered in the CBM (Green, 2006 and Manfredi et al., 2009).

[32] See Appendix 1, Estimating the net climate change impact of an average landfill

Table 6: Net Climate Change Impact of an Incinerator with Electricity Recovery, over 20 years

Year	Median Net tonnes CO_2 emitted per tonne RMSW [a]	CO_2 price - current € [b]	CO_2 Price PV (4%TDR)	Total Cost PV € (TDR 4%)
2009	0.00	13.4	13.4	0.00
2010	-0.06	15	14.4	-0.87
2011	-0.06	15	13.9	-0.83
2012	-0.06	15.69	13.9	-0.84
2013	-0.06	16.76	14.3	-0.86
2014	-0.06	17.93	14.7	-0.88
2015	-0.06	39	30.8	-1.85
2016	-0.06	39	29.6	-1.78
2017	-0.06	39	28.5	-1.71
2018	-0.06	39	27.4	-1.64
2019	-0.06	39	26.3	-1.58
2020	-0.06	39	25.3	-1.52
2021	-0.06	39	24.4	-1.46
2022	-0.06	39	23.4	-1.41
2023	-0.06	39	22.5	-1.35
2024	-0.06	39	21.7	-1.30
2025	-0.06	39	20.8	-1.25
2026	-0.06	39	20.0	-1.20
2027	-0.06	39	19.3	-1.16
2028	-0.06	39	18.5	-1.11
2029	-0.06	39	17.8	-1.07
			Total	**-25.66**
Notes:				
(a) Incineration with electricity recovery scenarios adapted from Guinan et al., (2008) and Green (2006)				
(b) Source: DoF (2009)				

Four possible impact scenarios were developed for the incineration CBM and the results are outlined in Table 7. The table presents the results of a review of the estimated net carbon emission capacity of one tonne of RMSW (tonne CO_2 eq per tonne RMSW) for several incineration configurations. The net climate change impact of the configurations is estimated using the methodology in Table 6.

Table 7: Net Climate Change Impact of Various Incineration Configurations Over 20 Years

	Emissions (tonnes CO_2 eq per tonne RMSW)			Total Cost PV € per tonne RMSW			
Incineration Configuration	**Direct Emissions**	**Emission Offsets: Energy & Material**	**Net Emissions**	**(TDR 0%)**	**(TDR 4%)**	**(TDR 5%)**	**(TDR 10%)**
State of the art incinerator, with energy recovery[a]	0.44	-0.93	-0.49	-326.04	-209.58	-189.36	-119.85
Irish Incinerator with both Electricity & Heat recovery[b]	0.39	-0.78	-0.39	-259.50	-166.80	-150.72	-95.39
Irish Incinerator with Electricity recovery only[c]	0.39	-0.45	-0.06	-39.92	-25.66	-23.19	-14.68
Irish Incinerator with no resource recovery capacity[d]	0.38	0	0.38	249.52	160.39	144.92	91.72
Notes:							
(a) Emission data from Astrup et al., (2009)							
(b) Median emission data from Green (2006) and Guinan et al., (2008)							
(c) Median emission data from Green (2006) and Guinan et al., (2008)							
(d) Emission data from ESRI (2010)							

The four potential incineration configurations in Table 7 include:

1. Energy recovery capacity in the form of electricity
2. Energy recovery capacity in the form of electricity and heat
3. A state of the art incinerator with extensive energy recovery capacities based on best practice in the EU coupled with improved RMSW pre-treatment criteria
4. No energy recovery capacity

The configurations 1-3 above, most closely represent the Irish situation (ESRI, 2010). Configuration 4 is presented for use in the sensitivity analysis. As before, a range of present values for all the scenarios in Table 7 were estimated using a range of discounts varying between 0-10% for the purpose of comparative and sensitivity analysis, with the median being considered the optimum statistical measure of all the impacts. The DoF's test discount rate of 4% was considered the key rate for determining the implications for government policy.

Using the 4% TDR, an incinerator's climate change impact can range from - €209.58 to €160.39 per tonne RMSW over 20 years depending on its technical configuration. While landfill is generally a net climate change cost, incineration with resource recovery capacity provides net climate change savings. It is noted that incineration with no energy or material recovery capacity, has a net climate change cost impact.

4.3. Health Impacts[33]

Saffron et al. (2003) conducted a major review of the literature on the health effects of waste facilities and concluded that the evidence for adverse health effects was insufficient. However inadequate management of emissions to soil, water and air can pose health and environmental concerns[34]. The norm in the literature that evaluates the environmental externalities of waste management facilities, is to model the impact pathways of pollutants from waste facilities on human health.

Rabl et al. (2008) stress that impacts from well regulated and compliant landfills are negligible and report that even if the impact pathway of leachate[35] could be analysed in a satisfactory manner, there is no clear solution for the choice of time horizon and discount rate. This is consistent with several other studies that do not value the external cost of leachate from landfill e.g. Dijkgraaf and Vollebergh (2004), Eunomia et al. (2009) and ESRI (2010).

Bartelings et al. (2005) contend that generally there is little known about the emissions of specific air pollutants from landfills and the level of human exposure to these pollutants, however there is research that offers a link between the vicinity of landfill and an increased risk of birth defects. Bartelings et al. (2005) assumed that the only potential impact pathways are air pollution and stress and anxiety from residing near the landfill. They estimate this impact to be €0.70 per tonne of waste. This data is difficult to transfer to an Irish situation as our population density residing in the vicinity of landfill versus the Netherlands is different.

Eunomia et al. (2009) also report that landfills "produce less of the pollutants for which dose response functions are tolerably well known". The authors estimate the median health impact of selected air pollutants from landfill in Ireland to be €3.09 per tonne RMSW. The Unit Damage Costs (UDCs) of the pollutants used by Eunomia were in 2009 prices.

The ESRI (2010) estimated the median health impact of selected air pollutants from Irish landfills to be €3.69 per tonne RMSW. However the unit damage costs (UDCs) used by ESRI in its estimates were in 2000 prices.

In order to allow a comparison with Eunomia et al. (2009), it is necessary to inflate the ESRI's unit damage costs to 2009 price levels. A re-calculation of the ESRI's estimated health impact of selected air pollutants emitted from landfill using the Eunomia UDC estimates from 2009 yields a range between €3.07 and €8.85 per tonne RMSW [median €5.96 per tonne RMSW].

In summary, the estimated health impact of selected air pollutants from landfill range between €3.09 per tonne RMSW[36] and €5.96[37] per tonne RMSW. The median value of €4.53 per tonne RMSW was used in performing the CBA in Section 5.

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[33] Future amendments to EU Regulation on Persistent Organic Pollutants (POPs) Regulation (EC) No. 850/2004 may mean changes to the range of pollutants and associated unit damage costs (UDC) that are considered in waste management activities. See http://ec.europa.eu/environment/waste/studies/pdf/POP_Waste_2011.pdf

[34] Case studies in Cavan http://www.epa.ie/whatwedo/enforce/prosecute/2005/name,14047,en.html and Kildare http://www.epa.ie/news/pr/2011/name,30632,en.html

[35] Potential liquid emissions from landfill process to water and soil

[36] Eunomia et al. (2009)

The three most recent and applicable studies used to analyse the externalities associated with non-greenhouse gas emissions to air from incineration in Ireland include: Rabl et al. (2008), Eunomia et al. (2009) and ESRI (2010). The studies follow an impact pathway approach[38] or adapt the data from secondary literature.

Rabl et al. (2008) compared the impacts and costs of incineration and landfill in France. The authors claim that their methodology and results are applicable to other EU countries. The study uses an impact pathway analysis and based on the 'ExternE' (Externalities of Energy[39]) project series of the European Commission rather than a contingent valuation analysis of the impacts. The ExternE project is a source for information on the environmental externalities of air pollutants found in most of the literature. The authors used the latest ExternE assumptions and data from 2004 to quantify the health impacts of selected air pollutants associated with emissions from incineration. The authors found that the health impacts associated with selected air pollutant emissions from incineration range from €7.18 per tonne RMSW to €10.11 per tonne RMSW assuming that the incinerator is compliant with the minimum air emission quality standards set in the EU Waste Incineration Directive (WID) (CEC, 2000).

Most of the literature reflects the debate on what methodology should be used by economists for the valuation of mortality. Should mortality valuation be based on VOLY (Value of Life Year) or on the value of a prevented fatality (also called VSL or "Value of Statistical Life")? If mortality is being based on accidental deaths, VSL is the correct measure for accidents and has been used for that by ExternE. But whereas most accidents involve a large loss of life expectancy per death, the loss per air pollution death tends to be small (the population average being on the order of months). Furthermore, the true number of deaths due to air pollution is not known whereas the loss of life expectancy can be calculated; thus only VOLY can be used for the total mortality due to air pollution (Rabl, 2003). This has not yet been universally recognised and some analysts, especially in the USA, continue to use VSL for air pollution.

Eunomia et al. (2009) used secondary literature and their own modelling for determining the impacts of air pollutants associated with incineration. The authors found that the health impacts associated with selected air pollutants from incineration range from:

- €8.92 per tonne RMSW - €25.48 per tonne RMSW assuming that the incinerator is just compliant with the minimum required air emission quality standards set in the WID or
- €1.17 per tonne RMSW - €3.27 per tonne RMSW [median €2.22 per tonne RMSW] assuming that the incinerator's compliance performance goes further than the minimum required air emission quality standards set in the WID

Eunomia looked at a slightly broader range of pollutants than Rabl et al. (2008) (e.g. VOCs and $PM_{2.5}$) and examined a range of low and high unit damage costs (i.e. the physical impacts) for the air pollutants selected using 2009 prices. In terms of estimating the quantity of air pollutants emitted from one tonne of waste in an incineration process, Eunomia based their estimates upon an ExternE analysis carried out in 1999.

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[37] Recalculated ESRI (2010), using the UDC values of Eunomia et al. (2009)

[38] Analyses impacts on health, agriculture, biodiversity and buildings

[39]See http://www.externe.info/

The ESRI (2010) looked at the same literature sources as Eunomia but did not inflate their UDC values to 2009 price levels. In terms of estimating the quantity of air pollutants emitted from one tonne of waste in an incineration process, ESRI based their estimates upon Rabl et al. (2008) and the latest ExternE analysis carried out in 2004 on incineration. The authors found that the health impacts associated with selected air pollutant emissions from incineration to be €11.20 per tonne RMSW assuming that the incinerator is compliant with the minimum air emission quality standards set in the WID.

Both Eunomia and ESRI make useful contributions to our knowledge around evaluating the health impacts of air emissions from incineration. In this research paper the UDCs in Eunomia et al. (2009) and the ExternE analysis in ESRI (2010) were combined to examine the scenario where an incinerator's emissions to air comply with the WID's minimum air quality requirements (Table 8).

Table 8: Estimated Health Impact of Incineration

Pollutant	Quantity Pollutant in RMSW [a]	Value of Low UDCs [b]		Value of High UDCs		Value of Median UDCs
	$g_{Pollutant}$ per tonne RMSW	€ per $kg_{Pollutant}$	€ per tonne RMSW	€ per $kg_{Pollutant}$	€ per tonne RMSW	€ per tonne RMSW
$PM_{2.5}$	51.5	18.54	0.95	51.91	2.67	1.81
Cd	0.20909	25.96	0.01	25.96	0.01	0.01
Cr^{VI}	0.0033475	21.01	0.0001	21.01	0.0001	0.00
NI	0.87035	2.6	0.0023	2.60	0.0023	0.00
SO2	257.5	5.93	1.53	17.30	4.45	2.99
Nox	1100	4.7	5.17	13.60	14.96	10.07
As	0.0721	98.88	0.01	98.88	0.01	0.01
Pb	0.5665	741.6	0.42	741.60	0.42	0.42
Hg	0.2575	7,416.00	1.91	7,416.00	1.91	1.91
Dioxins	0.000000515	45,732,000.00	0.02	45,732,000.00	0.02	0.02
VOCs	60	0.84	0.05	2.47	0.15	0.10
Totals			**10.07**		**24.60**	**17.34**

Notes:
Assumed incinerator complies with minimum air quality requirements of EU Waste Incineration Directive or EU WID (CEC, 2000)
(a) ExternE analysis from ESRI 2010
(b) Unit Damage Costs (UDCs) from Eunomia et al., (2009), ESRI does not price UDCs at 2009 levels

Therefore combining the methodologies of the ESRI and Eunomia studies, the health impacts of incineration used in Section 5 are assumed to be in the ranges:

- Median €17.34 per tonne RMSW for incinerators that are just compliant with the minimum standard requirements in the WID (Table 8) and
- Median €2.22 per tonne RMSW for incinerators whose compliance performance goes further than the minimum standard requirements in the WID. This assumption was made as Eunomia are the only researchers to date to have examined the air emission impacts of an Irish incinerator scenario that goes further than the minimum WID compliance requirements.

The analysis shows that incineration performance that exceeds the requirements of the EU's Waste Incineration Directive (WID) reduces the potential health impacts of the process.

The methodology developed in this section prices the health impacts of landfill and incineration in 2009 prices. These estimates are used in the analysis in Section 5 as it is assumed that health impacts are not discounted in the period 2008 to 2009[40].

[40] This research paper uses 2008 as its baseline (Section 4.1). The period 2008 to 2009 shows an annual decrease of 4.5% in the CPI. This suggests that the 2009 pricing of health impacts could be

4.4. Disamenity Impacts

Externalities associated with waste facilities are generally considered to be fixed i.e. the externality exists because the landfill exists, it does not depend on the levels of waste that the facility manages (COWI, 2000).

Cambridge Econometrics et al. (2003) found a statistically significant fixed disamenity impact within 0.5 miles of a landfill at the aggregate British level and estimated to be in range of €3.50 - €5.04 per tonne of waste landfilled. Bartelings et al. (2005) use a benefit transfer methodology to achieve Dutch values of €3.50 per tonne of waste landfilled from the Cambridge study.

Eunomia and Tobin (2008) assume a disamenity from Irish landfill to be €4.25 per tonne of waste based on a mid-point value of the Cambridge Econometrics study.

Rabl et al. (2008) argue that amenity impacts are limited to the population in the immediate vicinity of a waste facility. There is a danger in simply transferring disamenity values across studies because of the localised nature of disamenities caused by waste facilities.

ESRI (2010) estimated the disamenity cost associated with proximity to landfill by studying house price changes in the area surrounding Irish landfill facilities. This analytical technique is known as hedonic pricing. An important assumption in this approach is that the variation in house prices is caused solely by the existence of disamenities and not some other externality. The study ignored the impact of traffic associated with landfill. It is the only such analysis carried out in an Irish context.

ESRI estimated a fixed annualised disamenity range of €10.64-€21.29 per tonne RMSW landfilled. The median value of €15.97 per tonne RMSW was used in the CBA.

Kiel and McClain (1995) conducted a hedonic pricing study in relation to the disamenity associated with incineration in Massachusetts, USA. DEFRA (2004) interpreted the Kiel and McClain study and estimated a disamenity value of £21 per tonne of waste incinerated in the UK (at 2003 prices) but did not recommend the use of this value as they had concerns around the age of the American data and its applicability to the UK situation.

However Bartelings et al. (2005) transferred the Kiel and McClain findings to a Dutch scenario. Starting at 5.5 km from the incinerator, they found that house prices drop by €9,500 for every km approaching an incinerator. They also assumed a higher disamenity from incineration on the basis of negative publicity around dioxin emissions in the Netherlands in the early 1990s. The study estimated a range of €9.10-9.90 (2005 prices) per tonne of incinerated waste in the Netherlands.

Arnold and Terra (2006) carried a contingent valuation (CV) study in relation to incineration facilities in France i.e. a study on the willingness to pay (WTP) by residents within 2 km of a site to avoid disamenity. This study estimates the disamenity of incineration to be in the range of €3.70-€4.90 per tonne of waste incinerated.

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lower than 2008 and should be inflated to reflect 2008 pricing. However, an examination of the basket of services in the CPI shows that health costs increased between 2008 and 2009 and increased by 69.3% in the period 2000-2009 (CSO, 2010). It is assumed that health impacts were not discounted between 2008 and 2009. However, the issue of pricing health impacts of landfill and incineration in 2008 prices is addressed in the sensitivity analysis.

Eunomia and Tobin (2008) assumed the disamenity from potential incineration in Ireland to be the mean of the USA, Dutch and French studies €14.30 per tonne RMSW incinerated.

ESRI (2010) chose to adopt the French study to an Irish context. Hedonic pricing (HP) methods are generally preferred to CV methods for studying disamenity because they are based on observable housing market prices (Eshet et al., 2005). ESRI defend their methodology on the basis that Walton (2006) found that the results of both HP and CV methods are generally consistent.

ESRI took housing densities in a 2 km radius around the two Irish RMSW incinerators under construction in Poolbeg, Dublin and Carranstown, Co. Meath. An assumed WTP, to avoid disamenity to be €40-54 per household per year, was adjusted for purchasing power parity and inflation in order to establish an equivalent Irish price range in 2009. ESRI then discounted these results over 10 years using a 5-10% discount rate. Although the public sector discount rate in Ireland is currently 4%, higher rates were used by the ESRI as they argue the household discount rate can be expected to be much higher than the social discount rate.

The ESRI estimated the median total fixed disamenity associated with the combined capacity of the planned Poolbeg and Carranstown incinerators to be €3.27 per tonne RMSW at a 10% discount and €3.93 per tonne RMSW at a 5% discount. Disamenity impacts were found to be higher for urban incineration than rural incineration, due to the population densities surrounding the facilities (€5.07 per tonne RMSW at a 5% discount). For the purpose of this analysis, the data with the lowest social discount was chosen i.e. disamenity at a 5% discount.

The results from ESRI (2010) were adopted for this research as the only specific work found to have been carried out on evaluating the disamenity from incineration and landfill facilities in Ireland.

The disamenity of:

- Landfill is in the range of €10.64-€21.29 per tonne RMSW [median €15.97 per tonne RMSW]
- Incineration is in the range of €3.34– €4.51 per tonne RMSW [median €3.93 per tonne RMSW]

As disamenity from waste facilities is assumed to be a fixed externality, the impacts from both landfill and incineration are assumed to be constant over the 20 year lifespan of the respective projects. High and low disamenity impacts are presented for the purpose of sensitivity analysis with the median being considered the optimum statistical measure of the impacts of landfill and incineration.

A significant change in the public perception of incineration or its disamenity value in Ireland would need to occur, to narrow the gap between the two technologies e.g. a major accident with a significant associated disamenity impact. Bartelings et al. (2005) placed a higher disamenity value on incineration precisely because of the population densities in the Netherlands and the perceived risk from safety concerns that arose there in the 1990s.

If we use a higher disamenity estimate of €14.3 per tonne RMSW incinerated from Eunomia and Tobin (2008), the disamenity impact of the incineration is around 1% less than a landfill. However the Eunomia and Tobin estimates are based on data that is not transferrable to the Irish situation.

For the purpose of sensitivity analysis it is assumed that the highest disamenity from incineration is represented by urban incineration. In addition sensitivity analysis is also used to investigate the impact if the disamenity of landfill and incineration are perceived to be the same.

5. Results and Discussion

The objective of this research paper is to evaluate whether or not the incineration of RMSW in Ireland, provides a Net Social Benefit (NSB) relative to the status quo of landfilling RMSW here.

The Net Present Value (NPV) of a proposal is equal to the present value of its Net Social Benefit i.e.

$$NPV = PV\ (NSB)$$

In this section we estimate the NPV of RMSW incineration in Ireland based on the data values established in Section 4. As previously discussed, there may be considerable uncertainty in estimating the NPV, due to uncertainty in the predicted impacts of incineration and landfill, the valuation of these impacts and assumptions around the type of landfill and incineration configuration used in the cost-benefit model. Therefore a sensitivity analysis will be performed by computing the NPV of incineration in different scenarios. The implications of these results will be discussed.

The Net Present Value of an alternative (NPV), equals the difference between the present value of the benefits and the present value of the costs:

$$NPV = PV(B) - PV\ (C)$$

The decision rule for a single alternative (relative to the status quo) is to adopt the proposal if the NPV is positive. The caveat is that this applies only to the alternative specified. Other alternatives may conceivably be better. So another decision rule is included in the analysis, a cost-benefit test, where the benefit-cost ratio of the proposal must be greater than one.

5.1 NPV of Incineration

The NPV of incineration is presented in Table 9. It is assumed for the purpose of this research that the social benefits for the regulated and engineered management of RMSW (health, safety and sanitation) is fixed i.e. the social benefits are the same for both landfill and incineration. It is also assumed that the NPV of landfilling RMSW relative to an unregulated and non-engineered approach to RMSW management such as dumping and the backyard burning of RMSW is positive i.e. landfill of RMSW has a positive NSB.

In Table 9 the median impacts of incineration and landfill from the research and analysis in Section 4 are presented (PV € per tonne RMSW). The DoF's test discount rate of 4% is assumed. Where the PV impact of incineration is higher than landfill it is recorded as a net cost. Where the PV impact of incineration is lower than landfill it is recorded as a net saving. The NPV and benefit-cost ratio of incineration is then calculated.

Table 9: NPV of Incineration against Landfill Counterfactual (€ per tonne RMSW)[41]

Impacts[a]	Capex		Opex		Net Climate Change		Health		Disamenity		Totals
Landfill (L)[a]					Low	193	Average Irish Landfill	3.09	Low	10.64	
					High	388	Landfill with high energy recovery potential	5.96	High	21.29	
		642.52		328.26	Median	290.5	Median	4.53	Median	15.97	1281.77
Incineration (I)[a]	Low	387.62	Low	437.39	Electricity & Heat Recovery	-166.8	Exceeds compliance with WID[c]	2.22	Low	3.34	
	High	813.13	High	954.85	Electricity Recovery Only	-25.66	Meets minimum requirements of WID	17.34	High	4.51	
	Median	600.38	Median	696.12	Median	-96.23	Median	9.78	Median	3.93	1213.97
											NPV (I)
											67.80
											BC Ratio (I)
Cost/Saving?[b,d]		42.15		-367.86		386.73		-5.26		12.04	1.20

Notes:

(a) Impacts: See Section 4 of this paper. Results presented as € per tonne RMSW. Assumed TDR of 4% for climate change impacts.

(b) Landfill is the counterfactual for the purpose of this analysis. Costs presented as (-), Savings presented as (+)

(c) WID stands for Waste Incineration Directive.

(d) It is assumed that the social benefits of treating RMSW (i.e. health & sanitation) are equivalent for incineration and landfill

NPV(I) in Table 9 is found to be positive and the benefit-cost ratio (I) is >1.

An examination of the share of costs and benefits in the median incineration configuration in Table 9, indicates that operational costs and environmental savings are key determinants for incineration as an alternative to landfill.

[41] It is assumed that incineration and landfill facilities in the analysis are built in 2008/2009 and have an operational lifespan of 20 years. It is also assumed that climate change impacts from landfill continues after operation ends and remediation begins.

5.2 Sensitivity Analysis

There may be uncertainty about the predicted impacts and the appropriate monetary valuation of each unit of the impact because of the assumptions chosen in the analysis. The purpose of a sensitivity analysis is to test how robust the analysis is. To test how robust the result in Table 9 is, we vary the scenarios used. Scenario 1 in Table 10, illustrates the benchmark case illustrated in Table 9. The sensitivity analysis takes account of both deflationary and inflationary pressures (e.g. energy price volatility in alternative fuels or developments in policy, regulatory standards or technology).

Table 10: Sensitivity Analysis of Incineration NPV [42]

	Scenarios	Impacts [e]					NPV (I)	BC Ratio of Incineration vs. Landfill
		Capex	Opex	Net Climate Change	Health [f]	Disamenity		
1	Median Incinerator vs. Median Landfill [a]	42.15	-367.86	386.73	-5.26	12.04	67.8	1.2
2	Median Incinerator vs. State of the art Landfill [b]	42.15	-367.86	289.23	-3.82	6.72	-33.58	0.9
3	Incinerator with increased scale vs. Median Landfill [c]	254.9	-109.13	386.73	-5.26	12.04	539.28	5.7
4	Incinerator with: increased scale; electricity recovery potential only; complies with minimum requirements of WID vs. Median Landfill [d]	254.9	-109.13	316.16	-12.82	12.04	461.15	4.8
5	Incinerator with: increased scale; electricity recovery potential only; exceeds WID compliance requirements vs. Median Landfill [d]	254.9	-109.13	316.16	2.31	12.04	476.28	5.4
6	Incinerator with: increased scale; both electricity and heat recovery potential; exceeds WID compliance requirements vs. Median Landfill [d]	254.9	-109.13	457.3	2.31	12.04	617.42	6.7
7	Median Incinerator but with no energy recovery potential vs. Median Landfill	42.15	-367.86	130.11	-5.26	12.04	-188.82	0.5
8	Median Incinerator but with high disamenity vs. Median Landfill	42.15	-367.86	386.73	-5.26	11.46	67.22	1.2
9	Median Incinerator vs. Median Landfill (but assuming both have equivalent disamenity)	42.15	-367.86	386.73	-5.26	0	55.76	1.1
10	Median Incinerator vs. Median Landfill (but Capex and Opex of both set @2001 prices)	32.06	-261.64	386.73	-5.26	12.04	163.93	1.6
11	Median Incinerator vs. Median Landfill (assuming health impacts inflated to 2008 CPI levels, Section 4.3)	42.15	-367.86	386.73	-5.49	12.04	67.57	1.18

Notes:
(a) See Table 9, landfill is the counterfactual for the purpose of this analysis.
(b) Landfill configuration has high energy recovery potential and low net climate change/disamenity impacts
(c) Median incinerator configuration with low capex/opex
(d) Incinerator configuration includes median disamenity. WID means Waste Incineration Directive.
(e) Impacts: Results presented as €.tonne RMSW. Assumed TDR of 4% for climate change impacts.
(f) Impact of emissions from the RMSW treatment options on health.
Costs presented as (-) Savings presented as (+)
It is assumed that the social benefits of treating RMSW (i.e. health & sanitation) are equivalent for incineration and landfill

In Scenario 2 in Table 10 median incineration is compared to a landfill scenario with a high level of energy recovery and use on-site, with low disamenity impacts i.e. a state of the art landfill that exceeds current performance. The NPV(I) is found to be negative and the benefit-cost ratio is <1. The scenario illustrates that the environmental savings on climate change must be sufficiently high for the incineration configuration to offset its opex and offer an economic alternative to state of the art landfill.

[42] See Table 9

In Scenario 3 median landfill is compared to a median incineration scenario with an increased capacity scale, greater or equal to 200,000 tonnes per annum The net benefit of incineration versus landfill is increased, the NPV(I) is positive and the benefit-cost ratio remains >1. The scenario illustrates the sensitivity of incineration projects to scale.

In Scenario 4 median landfill is compared to an incineration scenario with: an increased capacity scale, greater or equal to 200,000 tonnes per annum; electricity recovery capacity and complies with the minimum requirements of the EU's Waste Incineration Directive (WID) on air emission standards. The NPV(I) remains positive and the benefit-cost ratio remains >1.

Scenario 5 is the same as Scenario 4, except that the incinerator exceeds WID compliance requirements. Scenario 6 is similar again, but this time employs both electricity and heat recovery capacities. The NPV(I) remains positive and the benefit-cost ratio remains >1 in scenarios 5 and 6. The NPV(I) and BC ratio (I) increase with increased scale, energy recovery capacity and emission abatement standards.

Scenarios 4-6 illustrate the sensitivity of incineration projects to scale, the type and level of energy it recovers and the level of emission abatement technology employed. Scenario 6 is closest to current proposed incineration facilities in Ireland.

Scenario 7 compares a median landfill with energy recovery to a median incinerator with no energy recovery capacity. The net benefit of incineration versus landfill is reduced and could even be reversed if other costs were increased. The NPV(I) is found to be negative and the benefit-cost ratio <1. Scenario 7 illustrates the sensitivity of incineration projects to the level and type of energy recovered. Without the savings from energy recovery an incinerator cannot offset its high Opex.

In Scenario 8 median landfill is first compared to a median incineration scenario with a high disamenity estimate. In Scenario 9, the comparison is repeated but this time the median incinerator has the same disamenity value of landfill i.e. is treated as a fixed disamenity (COWI, 2000). Again, the NPV(I) is found to be positive and the benefit-cost ratio >1 but the Scenarios illustrate that increasing the disamenity value of incineration reduces its NPV.

In Section 4.1, we discussed the possibility that a fall in capex and opex may affect the results of the analysis. In Scenario 10, median landfill is compared to median incineration and the Capex and Opex is set at 2001 prices for both technologies. As in Scenario 1[43] the NPV (I) is found to be positive and the benefit-cost ratio >1. The table illustrate that a fall in capex and opex increases the BC ratio and does not alter the outcome dramatically.

In Section 4.3, we discussed the possibility that pricing health impacts in 2009 prices rather than 2008 prices may affect the results of the analysis. In Scenario 11, median landfill is compared to median incineration and the health impacts are inflated to 2008 prices for both technologies based on CPI movements in the period. The NPV (I), while slightly lower, is found to be positive and the benefit-cost ratio >1.

The results in Table 10 indicate that certain incineration configurations can deliver net benefits to Irish society relative to the current status quo depending on its scale and energy recovery capacity. While an attempt has been made to evaluate all costs and

[43] Table 9

benefits, there are a number of drawbacks that should be considered when interpreting the findings outlined above:

i. Some assumptions are made on the basis of secondary literature rather than primary research on all the waste management sites in Ireland. There is uncertainty in some of the assumptions made, hence the use of sensitivity analyses.

ii. Not all impacts were analysed e.g. land use impacts; the cost of fines for failure to meet the EU Landfill Directive; the cost of landfilling hazardous ash; water and soil impacts; some social benefits of managing waste and the cost of upstream emissions and disamenity from vehicles entering and leaving facilities. However this approach is generally consistent with the literature reviewed.

iii. The analysis did not fully take the location of an incinerator into account, although it is possible to develop that scenario from this research.

iv. While the scenarios modelled reflect regulated waste facilities, the analysis does not fully take into account the extent to which certain externalities may or may not be internalised e.g. some emissions may be already regulated but regulatory compliance may vary site to site.

v. The analysis does not take into account the impact of the existing landfill levy or proposed waste facility levies.

vi. The analysis does not look at the private costs and benefits of these projects. Dijkgraaf and Vollebergh (2004) found that the private cost of incineration is higher than landfill.

vii. The analysis does not take the current structure of the Irish waste management market into account. This structure may impact the delivery of alternative waste infrastructure.

viii. Last, the analysis did not evaluate other RMSW management alternatives to landfill that may substitute for incineration in Ireland e.g.

- Incineration of Ireland's RMSW in an export market
- The co-incineration of RMSW in suitable industrial processes in Ireland that displace fossil fuels e.g. use of processed RMSW as a in a cement kiln
- The Mechanical Biological Treatment (MBT) of RMSW in Ireland

However, it should be possible to evaluate these options using the methodology provided in this analysis.

These uncertainties demonstrate the challenge of developing a perfect CBA methodology for waste management facilities in Ireland and the need for further research. Nevertheless the results indicate that certain incineration configurations can deliver net benefits to Irish society relative to the current status quo depending on its scale and energy recovery capacity.

6. Conclusion

The EU Landfill Directive 1999 requires Ireland to seek infrastructure alternatives to the landfill of RMSW. The EPA and NCC report that Ireland remains heavily dependent on indigenous landfill capacity and overseas markets for its RMSW reprocessing and waste to energy capacities. This deficit threatens Ireland's competitiveness and its environmental policy objectives.

Government proposes to finalise a new waste policy by the end of 2011 (DEHLG, 2011). Economic analysis should underpin the policy options chosen to promote indigenous RMSW management alternatives to landfill. This paper seeks to make a positive contribution to the debate, evaluating the RMSW treatment option of incineration by performing a cost-benefit analysis.

Specifically, this research asks:

- What are the benefits and costs of providing indigenous incineration capacity as an alternative to landfill in the State?
- Is there a net benefit from providing indigenous incineration capacity as an alternative to landfill in the State and under what circumstances?

The results of the research in Section 5 show that a median value incineration of RMSW in Ireland provides a Net Social Benefit (NSB) relative to the status quo of landfilling RMSW here. The research also indicates that NPV of existing landfill capacity could be improved with increased RMSW pre-treatment standards and employing higher levels of landfill gas capture and utilisation.

An incinerator scenario with: a capacity greater or equal to 200,000 tonnes per annum; both electricity and heat recovery capacity and one that exceeds the minimum requirements of the EU's Waste Incineration Directive on air emission standards (Table 10) delivers the highest NPV of the alternatives examined.

NPVs are predicted values. To account for the uncertainties in the analysis, a sensitivity analysis has been included. The analysis took account of both deflationary and inflationary pressures. The results of the sensitivity analysis indicate the sensitivity of incineration's NPV to: its scale, its operational costs and the environmental benefits accrued in the form of climate change mitigation and resource recovery. The benefits of incineration were found to be driven mainly by environmental savings in the form of energy and resource recovery. The costs of incineration are driven its Opex due to its technological complexity. It was found in the analysis that incineration does not provide a net benefit against landfill if its scale and energy recovery capacity are insufficient i.e. scenarios 2 and 7 in Table 10.

The sensitivity analysis demonstrates the challenge of developing a perfect CBA methodology for waste management facilities in Ireland and the need for further research. Nevertheless the results indicate that certain incineration configurations can deliver net benefits to Irish society relative to the current status quo depending on its scale and energy recovery capacity. However the value of this research recommendation is dependent upon whether such projects can be effectively implemented.

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Appendix 1: Estimating the net climate change impact of an average landfill

Table 11 illustrates the median net climate change impact of one tonne of RMSW placed in an Irish landfill with an operational life of 20 years[44], excluding carbon sequestration.

Table 11: Median Net Climate Change Impact of One Tonne of RMSW in an Irish Landfill (excluding carbon sequestration) over 20 years (€ per tonne RMSW)

Year	CH_4 Lifetime distribution of 1 Tonne RMSW (%)	Tonnes CO_2 eq per tonne RMSW*	Tonnes CO_2 emitted per tonne RMSW	CO_2 price - current €	CO_2 Price PV (4% Discount)	Total Cost - PV € (4% Discount)
2009	0	0.0000	**0.000**	13.4	**13.4**	0.0
2010	6.00%	0.9528	**0.057**	15	**14.4**	0.8
2011	16.40%	0.9528	**0.156**	15	**13.9**	2.2
2012	18.10%	0.9528	**0.172**	15.69	**13.9**	2.4
2013	7.90%	0.9528	**0.075**	16.76	**14.3**	1.1
2014	5.60%	0.9528	**0.053**	17.93	**14.7**	0.8
2015	5.50%	0.9528	**0.052**	39	**30.8**	1.6
2016	4.90%	0.9528	**0.047**	39	**29.6**	1.4
2017	4.40%	0.9528	**0.042**	39	**28.5**	1.2
2018	4.40%	0.9528	**0.042**	39	**27.4**	1.1
2019	3.90%	0.9528	**0.037**	39	**26.3**	1.0
2020	3.40%	0.9528	**0.032**	39	**25.3**	0.8
2021	3.40%	0.9528	**0.032**	39	**24.4**	0.8
2022	3.40%	0.9528	**0.032**	39	**23.4**	0.8
2023	2.90%	0.9528	**0.028**	39	**22.5**	0.6
2024	2.60%	0.9528	**0.025**	39	**21.7**	0.5
2025	2.30%	0.9528	**0.022**	39	**20.8**	0.5
2026	1.70%	0.9528	**0.016**	39	**20.0**	0.3
2027	1.30%	0.9528	**0.012**	39	**19.3**	0.2
2028	1.00%	0.9528	**0.010**	39	**18.5**	0.2
2029	1.00%	0.9528	**0.010**	39	**17.8**	0.2
					Total	18.5
Note:						
*Table 5, Section 4.2 (Median emission capacity of one tonne of waste placed in an Irish Landfill)						

However, this is not the full story as the analysis in Table 11 provides the impact of one tonne of waste in a landfill, excluding carbon sequestration, over an operational lifetime of 20 years. The climate change impact of a landfill continues after its closure (Green, 2006) so what is the impact of a median landfill that operates for 20 years, excluding carbon sequestration? For simplicity we assume that one tonne of waste is placed in the landfill per annum for 20 years. Table 12 shows that the climate change impact continues after its 20 year operational lifetime.

[44] See discussion around Table 5 in Section 4.2.

Table 12: Estimated net climate change impact of an average Irish landfill with an operation lifetime of 20 years in € per tonne RMSW, excluding carbon sequestration.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	Total
2009	0.0																					0.0
2010	0.8	0.0																				0.8
2011	2.2	0.8	0.0																			3.0
2012	2.4	2.2	0.8	0.0																		5.4
2013	1.1	2.4	2.2	0.8	0.0																	6.5
2014	0.8	1.1	2.4	2.2	0.8	0.0																7.3
2015	1.6	0.8	1.1	2.4	2.2	0.8	0.0															8.9
2016	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0														10.3
2017	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0													11.5
2018	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0												12.6
2019	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0											13.6
2020	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0										14.4
2021	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0									15.2
2022	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0								16.0
2023	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0							16.6
2024	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0						17.1
2025	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0					17.6
2026	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0				17.9
2027	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0			18.1
2028	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0		18.3
2029	0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	0.0	18.5
2030		0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	0.8	18.5
2031			0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	2.2	17.7
2032				0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	2.4	15.5
2033					0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	1.1	13.1
2034						0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	0.8	12.0
2035							0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	1.6	11.2
2036								0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	1.4	9.6
2037									0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	1.2	8.2
2038										0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	1.1	7.0
2039											0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	1.0	5.9
2040												0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	0.8	4.9
2041													0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	0.8	4.1
2042														0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.8	3.3
2043															0.2	0.2	0.2	0.3	0.5	0.5	0.6	2.5
2044																0.2	0.2	0.2	0.3	0.5	0.5	1.9
2045																	0.2	0.2	0.2	0.3	0.5	1.4
2046																		0.2	0.2	0.2	0.3	0.9
2047																			0.2	0.2	0.2	0.6
2048																				0.2	0.2	0.3
2049																					0.2	0.2
																					Total	388.0
Note:																						
It is assumed that only one tonne of RMSW is added to the landfill per annum																						

The total PV for an average Irish landfill with a 20 year lifespan, excluding carbon sequestration, is estimated to be €388 per tonne RMSW.

The results in Table 12 are graphed in Figure 3 of Section 4.2 (Net Climate Change Impacts). Using the same methodology the total PV for an average Irish landfill with a 20 year lifespan, including carbon sequestration, is estimated to be €193 per tonne RMSW.