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Working Paper
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ESRI working paper, No. 333

Provided in Cooperation with:
The Economic and Social Research Institute (ESRI), Dublin

Suggested Citation: Lyons, Seán; Murphy, Liam; Tol, Richard S. J. (2009) : Estimating historical landfill quantities to predict methane emissions, ESRI working paper, No. 333

This Version is available at:
http://hdl.handle.net/10419/50033

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Estimating Historical Landfill Quantities to Predict Methane Emissions

Seán Lyons,\textsuperscript{a} Liam Murphy\textsuperscript{a} and Richard S.J. Tol\textsuperscript{a,b,c}

Abstract: We estimate Irish historical landfill quantities from 1960 -2008 and Irish methane emissions from 1968-2006. A model is constructed in which waste generation is a function of income, price of waste disposal and, household economies of scale. A transformation ratio of waste to methane is also included in the methane emissions model. Our results contrast significantly with the Irish Environmental Protection Agency’s (EPA) figures due to the differences in the underlying assumptions. The EPA’s waste generation and methane emission figures are larger than our estimates from the early 1990s onwards. Projections of the distance to target show that the EPA overestimates the required policy effort.

Key words: methane emissions, landfill, modelling

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Estimating Historical Landfill Quantities to Predict Methane Emissions

Introduction

A substantial amount of methane is emitted by waste decaying in landfills. This is a slow process, with methane being emitted for 25 years or more after waste disposal. Methane is the second-most important anthropogenic greenhouse gas. Emission reduction targets are often formulated relative to 1990. This implies that waste data going back to 1965 are needed to estimate methane emissions from landfill in 1990. In the absence of such data, a model can be used. This paper describes a method for estimating historical disposal of waste in landfills in order to predict historical and future emissions of methane, and it applies the method to data from Ireland.

Articles 4 and 12 of the United Nations Framework Convention on Climate Change (UNFCCC) state that signatory countries must publish their national inventories and removals of all greenhouse gases not controlled by the Montreal Protocol (United Nations 2009). Ireland’s Environmental Protection Agency (EPA) is mandated to report emission data to the UNFCCC. These greenhouse gas inventory levels are particularly important due to Ireland’s commitment to reduce greenhouse gas levels to at least 20% below 1990 levels by 2020. Biodegradable waste disposed of in landfills is an important source of methane, but these emissions are not normally directly measured: they must be imputed by plugging historical waste disposal data into a model of waste decomposition.

The measurement of waste and the gas emissions (in particular greenhouse gas emissions) that the waste emits is not an exact science. There are numerous papers which have cast doubt upon the official greenhouse gas emission figures from waste. Ramirez et al. (2008) consult experts and previous studies on the model parameters to construct a Monte Carlo simulation on GHG emissions. They find that there is up to a 15% uncertainty in Dutch methane emission levels at 95% confidence intervals. They believe the main contributor to uncertainty in methane emissions to be managed solid waste
disposal. Similarly Winiwarter and Rypdal (2001), who use a similar methodology to Ramirez et al. conclude that “the amount of waste stored in landfills was identified as the parameter that contributed most strongly to trend uncertainties.” They find uncertainty in Austrian methane emissions of 48.3% for 1990 and 47.5% for 1997 (again at 95% confidence intervals) which are the only two years analysed. Both papers underline the fact that there is large uncertainty in waste production and greenhouse gas emissions.

In Ireland the historical waste series is incomplete, which implies that we must first estimate waste totals before predicting methane emissions. In the National Inventory Report 2009, the EPA published statistics on Ireland’s generation of BMW and non-BMW from 1990-2007. Actual data is only available in 1995, 1998 and annually from 2001 onwards. Hence we have to make a number of assumptions in order to calculate BMW generations levels for all other years from 1990-2005. Some of these assumptions include:

- Degradable Organic Carbon (DOC) is created by Municipal Solid Waste (MSW), street cleanings and sludge from municipal wastewater treatment;
- MSW per-capita generation rates from 1995, 1998, 2001 and 2004 in addition to those implied by earlier surveys are used to estimate MSW production in all years;
- The ratio of street cleanings to MSW is estimated based on the figures for 1995, 1998 and 2001-2007;
- MSW is assumed to contain DOC in the following proportions: Organics – 15%, Paper – 40% and Textiles – 40%; and
- The DOC contribution of sludge is determined from information on the Biochemical Oxygen Demand (BOD) content, the BOD removal rate and the proportion of sludge disposed to landfill.

Our calculation of EPA’s projected methane emissions are based upon an EPA publication (Environmental Protection Agency 2009). This report does not explicitly project methane emission levels however it does project greenhouse gas emission levels
from waste. We are assuming that methane emissions stay constant as a proportion of greenhouse gas emissions and therefore grow at the same rate.

This paper estimates Ireland’s BMW generation from 1960-2008 (excluding the years where actual data is available for obvious reasons). A simple constant elasticity demand model for waste disposal is applied, using the number of households, income levels, service sector production levels and commercial price levels to predict waste quantities. Model parameters are drawn from previous research; in particular, the elasticities of waste generation with respect to household disposable income and number of persons in the household are used to estimate of residential waste, while the elasticity of demand with respect to collection charges and service sector value added are used to estimate commercial waste generation. Since these behavioural parameters are drawn from studies that used data from different time periods and jurisdictions, they may not be correct today let alone as far back as 1960. Hence it is necessary to carry out a sensitivity analysis of these parameters as a robustness test.

Using the estimates of waste generated, we then predict methane emissions in Ireland from 1968-2006. We model emissions from waste using the same model as applied by the Irish EPA. We then compare our methane emissions estimates to the EPA’s figures.

The paper continues as follows. Section 2 discusses data and methods. Section 3 presents the results. Section 4 concludes.

**Data and Methodology**

This paper takes the actual observations of waste sent to landfill in 1995, 1998 and 2001-2006 as a staring point to calculate the data for all other years. These figures are taken from the EPA’s National Waste Reports of the relevant years. We assume that residential waste generation, \( RW \), is a function of both the household density elasticity of waste generation \( r \) (the percent change in waste per capita caused by a one percent change in the number of persons per household, \( PPH \)), and the household income elasticity of.
waste generation \( s \) (the percent change in waste generation per household caused by a one percent change in real average disposable income, \( YD \)). For year \( t \), this would be estimated by:

\[
\ln(RW_t) = \alpha + r \ln(PPH_t) + s \ln(YD_t)
\]

The historical household income data is taken from the National Income and Expenditure Accounts which are published by the Central Statistics Office (CSO). The population data is also sourced from the CSO. Future household income data is taken from ESRI forecasts (Bergin et al., 2009).

Commercial waste generation, \( CW \), is assumed to be a function of the price elasticity of demand of waste disposal \( m \), the real price of waste collection \( PC \), the output elasticity of service sector waste demand \( n \) and the value added by the services sector, \( VAS \). Thus, for year \( t \):

\[
\ln(CW_t) = \alpha + m \ln(PC_t) + n \ln(VAS_t)
\]

Unfortunately the CSO does not produce a wholesale price index for refuse disposal. The CSO has however produced a Consumer Price Index for refuse since 1983. We take this to be a proxy for the commercial price of refuse disposal. In the absence of other data, we assume that the real price stayed constant for the period 1960-1983. This series reports a large drop in 1997 due to the abolition of domestic water charges. As this change does not apply to waste charges and has a large effect on the results, the series is adjusted to remove the impact of the abolition of water charges. For future predictions, we assume that the real price of refuse collection is constant from 2008-2020. The level of commercial production is taken from the National Accounts, again published by the CSO. This figure is however only available from 1970-2008.. Previous to this year, the ratio of commercial waste generation to GDP within the economy is assumed constant and the actual figure is deflated for the relevant lower GDP over the 1960-1969 period. Gross Domestic Product (GDP) figures for this early period are sourced from the World Resources Institute. Post 2008 figures for VAS are taken from forecasts by the ESRI (Bergin et al., 2009).
The main waste parameter values are from a variety of previous papers. The household income elasticity of waste generation is taken from Curtis et al. (2009). This paper analysed panel data from 2003-2006 across the local authorities of Ireland. The data shows a household income elasticity of waste generation of 1.08. Although this figure is well above previous international studies, we feel it is more relevant as the figure is calculated on Irish data. The sensitivity analysis below does consider different parameter values. Choe and Fraser (1998) report income elasticities of waste generation from several US studies and do not find a level higher than 0.6, so testing a lower figure than the unit elasticity estimated from Irish data seems appropriate. We choose a value of 0.5. The commercial price elasticity of demand parameter is taken from Jenkins (1993) who carried out a study on nine American communities and found a result of -0.27. Another study of American data carried out by Wertz (1976) found a result of -0.15 and other experts have argued that the absolute cost of refuse disposal is so low that the commercial price elasticity of demand for waste generation is effectively zero. A sensitivity analysis of the model to price elasticity changes is undertaken below by setting the price elasticity to zero. The parameter pertaining to household economies of scale is taken from Scott and Watson (2006). They carry out a study on the imposition of waste charges in Ireland and use household numbers as a control variable. From the coefficient of this variable the household elasticity of waste generation figure can be formed. This figure is 0.486. In the sensitivity analysis, the household density elasticity of waste generation is set to 0. Finally, we assume that commercial waste has a unit elasticity with respect to the sector’s value added. This represents a default position, since no direct estimates were available for Ireland.

Once the waste levels have been estimated, we predict the related methane emissions. The DOC in MSW, MSW, MSW to Landfill, Sludge and Street Cleaning figures are taken from McGettigan et al (2009). For predictive purposes, the future levels of management of DOC and the DOC in MSW are assumed to stay constant at 2008 levels (95% of DOC managed and DOC comprising approximately 20% of MSW). It is assumed that 0.6 of the DOC is dissimilated and that half of the methane remains in the landfill (i.e. does not enter the atmosphere). The methane correction factor (MCF)
managed level is assumed to be 1 and the MCF unmanaged level is assumed to be 0.4. The transformation from DOC to methane is taken to be 1.33 (but see the sensitivity analysis). These parameters are taken from the National Inventory Report 2009. So while this paper uses quite a different methodology to calculate waste generation, given that level of waste generation the approach to calculate methane emissions is identical to the approach used by the EPA. Using these assumptions, it is possible to estimate the total managed and unmanaged methane emissions over the period.

Results
Table A1 shows the actual and estimated waste generation figures for Ireland from 1960-2008 using the parameters as described above. Throughout the period, total waste (BMW and non-BMW) followed an upward trend. Over the entire time period, total waste increased by 369% from its 1960 base.

The following graphs show the sensitivity of the models to changes in selected parameters. For each sensitivity test, the model was run varying a single parameter of interest. Table 1 shows the parameter values of each of the adjusted models. Model YED shows the effect of reducing the assumed elasticity of household waste demand with respect to income from the baseline level of 1.08 to 0.5. Model PED reduces the price elasticity of commercial waste demand equal to 0. This change would imply that commercial waste generation is solely a function of the level of value added by the services sector. Model Econ_Scale reduces the household economies of scale parameter to zero. Model Trans_Ratio adjusts the transformation ratio of Dissolved Organic Carbon to Methane to 1.

Figure 1 shows the total waste generation as predicted by the baseline and adjusted models and the Irish Environmental Protection Agency (EPA). The Trans_Ratio model is not included in this graph as the adjusted parameter has no influence upon the waste generated (hence the values would have been identical to the baseline model). Because the model is based on recent data and predicts earlier values, the baseline and adjusted
figures converge in recent times. Although there is some divergence in the past, this is not particularly large considering the timeframe involved. The baseline and adjusted models are lower than the EPA estimates from 1990 onwards.

Figure 2 shows the baseline and adjusted models’ predicted methane emissions versus the EPA’s methane estimates. The base model produces estimates quite similar to three of the sensitivity test models: YED, PED and Econ_Scale. Predicted methane emissions are not very sensitive to changes in these parameters. The EPA’s estimates are lower than our model up until the early 1990s and higher after this point. There are substantial differences between annual methane predictions from our model and the EPA series, reaching more than 15,000 tonnes in some years.

The scenario that tests a unit value for the Transformation Ratio ("Trans_Ratio") leads to significantly lower predicted methane emissions. Methane emissions are highly sensitive to changes in the assumed value of the Transformation Ratio parameter.

Figure 3 shows the percentage difference between the estimated level of methane emissions from 1990-2020 and the target level of methane emissions for 2020 (20% below 1990 emission levels). There is no Trans-Ratio series in this graph as the series is identical to the baseline series. In all cases, estimated emissions exceed the target. The EPA estimates are generally higher than our baseline estimates. That is, the EPA overestimates the required emission reduction effort, because the EPA overestimates the amount of waste in the past. In 2020, our estimate of the distance to target almost coincides with the EPA estimate. This is because we project a faster increase in waste than the EPA does (consistent with our faster increase in the past). In the short- and medium term, the EPA overstates the methane-from-waste problem, but it understates it in the long term.

Our baseline projection of the distance to target is very similar to the three alternative projections (Econ_Scale, PED, YED). The alternative parameter values do not have a large influence on the policy required to achieve the commitments.
Conclusion
This paper set out to estimate the levels of waste generated by Ireland from 1960-2008 in the years where actual observations were unavailable, as a means of estimating related methane emissions. Using assumed demand functions and behaviour parameters we estimated the total quantities of municipal waste produced in Ireland from 1960-2008 and methane emitted from 1968-2006.

We carried out sensitivity tests on selected parameters in the model. There was little change in the absolute waste generation levels due to changes in any parameter. The predicted methane emissions are also quite insensitive to changes in all the parameters with the exception of the Transformation Ratio. The value used for this parameter in the baseline model is in line with international standards, so its sensitivity is not a matter for concern *per se*. However, if future research were to indicate that a different value was more appropriate, it is important that this information be taken into account in emission prediction models. Overall, these sensitivity tests provide some comfort as to the robustness of the model. However, other aspects of the model such as the functional form assumed for each source of demand, is less amenable to sensitivity testing. Further research should help cast light of the sensitivity of predicted landfill methane emissions to such model design decisions.

The levels of waste generation and methane emissions estimated by our model are different from the EPA’s estimates; in particular, our estimates suggest that methane emissions from landfill are significantly lower than figures reported by the EPA. This suggests that the distance to Kyoto targets may be less than currently thought, at least in the medium term. However, such variations are to be expected given the uncertainty about past waste emissions, as previously highlighted by Ramirez *et al.* (2008) and Winiwarter and Rypder (2001).
References


Appendix A

Table A1: Waste Generation in Ireland 1960-2008 (Figures in Bold are Official EPA Recordings) – Baseline Parameters

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Table 1 – Parameter Values

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Figure 1 - Total Waste Estimates
Figure 2 - Methane Emissions from landfill 1990 – 2006

Figure 3 - Difference Between Methane Emissions and 2020 Target
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<td>A Hedonic Analysis of the Value of Parks and&lt;br&gt; Green Spaces in the Dublin Area&lt;br&gt; Karen Mayor, Seán Lyons, David Duffy and Richard S.J. Tol</td>
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<td>Measuring International Technology Spillovers and Progress Towards the European Research Area&lt;br&gt; Iulia Siedschlag</td>
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<td>The EU 20/20/2020 Targets: An Overview of the EMF22 Assessment&lt;br&gt; Christoph Böhringer, Thomas F. Rutherford, and Richard S.J. Tol</td>
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<td>Counting Only the Hits? The Risk of Underestimating the Costs of Stringent Climate Policy&lt;br&gt; Massimo Tavoni, Richard S.J. Tol</td>
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