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Wood waste decomposition in landfills: An assessment of current knowledge and implications for emissions reporting

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ABSTRACT

Large quantities of wood products have historically been disposed of in landfills. The fate of this vast pool of carbon plays an important role in national carbon balances and accurate emission reporting. The Republic of Ireland, like many EU countries, utilises the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines for greenhouse gas reporting in the waste sector, which provides default factors for emissions estimation. For wood products, the release of carbon is directly proportional to the decomposition of the degradable organic carbon fraction of the product, for which the IPCC provides a value of 0.5 (50%). However, in situ analytic results of the decomposition rates of carbon in landfilled wood do not corroborate this figure; suggesting that carbon emissions are likely overestimated. To assess the impact of this overestimation on emission reporting, carbon decomposition values obtained from literature and the IPCC default factor were applied to the Irish wood fraction of landfilled waste for the years 1957–2016 and compared. Univariate analysis found a statistically significant difference between carbon (methane) emissions calculated using the IPCC default factor and decomposition factors from direct measurements for softwoods ($F = 45.362$, $p = <.001$), hardwoods ($F = 20.691$, $p = <.001$) and engineered wood products ($U = 4.726$, $p = <.001$). However, there was no significant difference between emissions calculated using only the in situ analytic decomposition factors, regardless of time in landfill, location or subsequently, climate. This suggests that methane emissions from the wood fraction of landfilled waste in Ireland could be drastically overestimated; potentially by a factor of 56. The results of this study highlight the implications of emission reporting at a lower tier and prompts further research into the decomposition of wood products in landfills at a national level.

1. Introduction

With an ever-growing global focus on climate change mitigation, incentive has been placed on the accurate accounting and reporting of greenhouse gas (GHG) emissions to facilitate in setting goals for future abatement strategies. GHG accounting in the waste sector, which has historically been reliant on the disposal of solid waste in landfills, is often challenging as direct emissions are not measured, but rather calculated using emission modelling. In accordance with the Kyoto protocol, the majority of European countries use the 2006 IPCC Guidelines for National GHG Inventories (Eggleston et al., 2006) to estimate GHG emissions from the waste sector, including emissions from landfills. This estimation is based on tiered accounting methods. Tier 1 provides IPCC default data to countries with little data available and is the most inaccurate. Tier 2 includes first-order decay (FOD) equations with some default parameters defined by the IPCC, while Tier 3 is based on FOD equations with nationally developed parameters, such as the degradable organic content (DOC) of the waste and the fraction of the DOC that decomposes (DOC_f). In Ireland, and many other EU countries, emissions from landfills are calculated at the Tier 2 level (Duffy et al., 2011, Donlan et al., 2012) where IPCC default factors are employed and thus the accuracy of the results are reduced (IPCC, 2001). For methane (CH_4 emissions from landfills, the CH_4 generation potential is estimated from the amount of DOC in a solid waste landfill (by waste stream), the DOC_f, the CH_4 correction factor (MCF), and the fraction of CH_4 in generated landfill gas (F). The DOCf factor plays an important role the amount of CH_4 emitted, however this value is highly uncertain, particularly for wood products (Barlaz, 2004).

The major biodegradable components of wood products are cellulose and hemicellulose and under anaerobic conditions in landfills, their decomposition results in the generation of approximately equal volumes of biogenic CO_2 and CH_4 (Barlaz, 2006). However, the presence of lignin can interfere greatly with

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cellulose and hemicellulose degradation and research has shown that wood is very resistant to decay in landfills because its cellulose and hemicellulose is embedded in a matrix of lignin (Ham et al., 1993, Wang et al., 1994); the extent of which is highly variable. Consequently, the IPCC allocated DOC_f factor of 0.5 (50%) for wood products in landfilled waste, is potentially a gross overestimation. Early studies on carbon loss, suggest that 56% ($DOC_{f,}$ 0.56) of the C in wood would be lost in landfills (Bingemer and Crutzen, 1987); providing an estimate similar to that provided by the IPCC. However, these measurements were based on stoichiometric calculations as opposed to direct analysis. In contrast, Bogner (1992) observed that CH_4 generation data from laboratory-based experiments under optimised conditions often overestimate actual CH_4 production in landfills as a whole. In corroboration of this, research by Micales and Skog (1997) reviewed estimated CH_4 yields from processes involved in anaerobic decomposition of forest products in landfills and suggested much lower levels of carbon decay (0–3%) than proposed by the IPCC. This suggests that a significant portion of the biogenic C in wood products does not decompose, and therefore represents a sink of C storage in landfills (Eleazer et al., 1997, Wang et al., 2011a,b, Barlaz, 2004, Barlaz, 1998). This decomposition, or lack thereof, will not only have an effect on the landfill C balance (Christensen et al., 2009), but may also have an impact of emission reporting at a national level.

Total European emissions from waste are estimated to be approximately 2% of total GHG emissions per year and in 2014 alone approximately 460,000 tonnes of wood waste was diverted to landfills (EUROSTAT, 2014). In the Republic of Ireland, the waste sector accounts for 2.5% of national emissions (above the EU average); with landfills contributing approximately 80% of this total (EPA, 2014). Consequently, the potential inconsistency between decomposition factors of wood products in landfills is an area of warranted investigation and its importance in both national and global C balances should not be overlooked.

The objective of this paper was to identify research on the decomposition of lignin containing wastes, particularly wood, in landfills and consolidate the calculated C decomposition rates for emission modelling. Using the Republic of Ireland landfill data for the years 1957–2014, a CH_4 emission inventory was established and statistical analysis was undertaken to elucidate differences in CH_4 emissions under differentiated decomposition factors from literature and the IPCC. This research aims to solidify the importance of accurate C reporting with high quality specific data (higher tier) and provides support for future research into the decomposition of wood products in landfills.

2. Methods

2.1. Systematic literature review

To identify wood product decomposition rates within the literature, a review protocol was developed where the pre-defined inclusion criteria were as follows: (1) direct results from defined landfill sampling sites, (2) comparative analysis of waste fractions in landfills, (3) laboratory simulations of wood products in landfills and (4) studies published in the English language from January 1st, 1990 to January 1st, 2016, inclusive. Studies were limited to full articles published in peer-reviewed journals and national reports by governmental agencies. Unpublished work, defined as master's theses, dissertations and abstracts from conference proceedings were not included. The rationale for this decision was based on the work of Van Driel et al. (2009) who concluded that (1) the difficulty in retrieving unpublished work could lead to selection bias, (2) many unpublished studies are eventually published, (3) the methodological quality of such studies are poorer than those that are published, and (4) the effort and resources required to obtain unpublished work may not be warranted. This approach is consistent with recent practice. Literature for inclusion was identified using four bibliographic databases (PubMed, Science Direct, Scopus and Google Scholar) using combinations of key terms (i.e. Wood(s), Forest(s), Waste(s), Landfill, Carbon, Greenhouse Gases, Decomposition). All literature scans were undertaken using Boolean positional operators ("AND", "OR", "SAME", "WITH") to focus literature searches. The research assessed was screened by assessing each publication (year, title, abstract) based on the explicit eligibility criteria. The systematic flow of the employed review process and quantification of studies across the flow chain is shown in Fig. 1.

2.2. Wood data collection

Total landfill waste tonnages were obtained from the Irish Environmental Protection Agency (EPA) Landfill gas survey upon request. Data were extracted for all licensed landfills in Ireland between the years 1957–2014. For quantification of the wood fraction of the waste, an estimation of 6.6% was applied based on an a European Commissioned report examining Waste (Villanueva et al., 2010); accurate waste characterisation of landfilled waste is not available for Ireland, particularly prior to the introduction of the European Landfill Directive in 1999.

2.3. Methane emissions inventory

For comparison of derived GHG emissions under different DOC_f values, the IPCC waste model (excel) was utilised to quantify CH_4 emissions, specifically. Within the model, CH_4 emissions from landfills for a single year are derived using the following equation:

$$\mathrm{CH_4\ emissions} = \left[\sum_x CH_4\ generated_{x,T} - R_T\right] \times (1 - OX_T), \qquad (1)$$

where

CH_4 emission = CH_4 emissions in year T, Gg;
T = inventory year
x = Waste category or material (Wood fraction);
R_T = Recovered CH_4 in year T, Gg; and
OX_T = oxidation factor in year T (Fraction).

The OX is the amount of CH_4 from the landfill that is oxidized in the soil or other material covering the waste. The amount of CH_4 generated from decomposable material in year T is estimated using the First Order Decay (FOD) of the mass of decomposable organic carbon (=DDOCm, Gg) in each waste category or type/material as follows:

$$\mathrm{CH_4\ generated}_T = \mathrm{DDOCm\ decomp_T} \times F \times 16/12 \qquad (2)$$

where

$\mathrm{DDOCm\ decomp_T}$ = DDOCm decomposed in year T, Gg;
F = fraction of CH_4 by volume in generated landfill gas (fraction); and
16/12 = molecular weight ratio between methane and carbon (ratio).

$$\mathrm{DDOCm\ decompT} = \mathrm{DDOCma_{T-1}} \times (1 - e^{-k}) \qquad (3)$$

$$\mathrm{DDOCmaT} = \mathrm{DDOCmdT} + (\mathrm{DDOCma_{T-1}} \times e^{-k}) \qquad (4)$$

where

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