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Greenhouse gas emission factors for recycling of source-segregated waste materials

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ABSTRACT

A key challenge for the waste management sector is to maximise resource efficiency whilst simultaneously reducing its greenhouse gas (GHG) emissions. For stakeholders to better understand the GHG impacts of their waste management activities and identify emissions reduction opportunities, they need to be able to quantify the GHG impacts of material recycling. Whilst previous studies have been undertaken to develop GHG emission factors (EF) for materials recycling, they are generally insufficient to support decision-making due to a lack of transparency or comprehensiveness in the range of materials considered. In this study, we present for the first time a comprehensive, scientifically robust, fully transparent, and clearly documented series of GHG EFs for the recycling of a wide range of source-segregated materials. EFs were derived from a series of partial life cycle assessments (LCA) performed as far as possible in accordance with the ISO 14040 standard. With the exceptions of soil, plasterboard, and paint, the recycling of source-segregated materials resulted in net GHG savings. The majority of calculated GHG EFs were within the range of data presented in the literature. The quality of secondary data used was assessed, with the results highlighting the dearth of high quality life cycle inventory (LCI) data on material reprocessing and primary production currently available. Overall, the results highlight the important contribution that effective source-segregated materials recycling can have in reducing the GHG impacts of waste management.

1. Introduction

Solid waste management contributes less than 5% to global greenhouse gas (GHG) emissions (Bogner et al., 2007). In response to growing concerns about the threat of climate change, international action aimed at reducing greenhouse gas (GHG) emissions is accelerating and the solid waste management sector is expected to contribute. Previous laggards such as the United States of America (USA) have recently committed to a reduction of GHG emissions of 26–28% below 2005 levels by 2025, whilst China aims to peak carbon emissions by 2030 and obtain 20% of its energy from zero-carbon sources (White House, 2014). The European Union (EU) is committed to reducing its GHG emissions by at least 20% of 1990 levels by 2020 (EC, 2009) and 40% by 2030 (EC, 2014). This commitment has translated into Member States developing their own ambitious GHG emissions reduction targets. For example, the United Kingdom (UK) has committed to reducing their GHG emissions by 80% of 1990 levels by 2050 (HMSO, 2008). A key challenge for the waste management sector is to maximise resource efficiency whilst simultaneously reducing its GHG emissions (Turner et al., 2011). Numerous international studies have shown that the recycling of waste materials can result in net savings of GHG emissions (Björklund and Finnveden, 2005; Franchetti and Kilaru, 2012; Manfredi et al., 2011; WRAP, 2006, 2010a). This is because recycling materials into new ("secondary") products can displace production of "primary" products that can require significant inputs of energy and raw materials. In order for stakeholders to better understand the GHG impacts of their waste management activities and identify GHG emissions reduction opportunities to help achieve national GHG emissions reduction targets, they need to be able to quantify the GHG emissions from material recycling.

Typically, GHG emissions are estimated using emission factors (EFs) that relate the quantity of a pollutant emitted to a unit of activity (e.g., kg fossil CO_2 per tonne of material reprocessed). EFs for different GHGs are usually aggregated and expressed as CO_2 equivalent (CO_2e) per activity unit. In the case of waste material recycling, EFs are often expressed per tonne of waste material collected and sent for recycling (kg CO_2e/t). GHG EFs for waste

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material recycling are typically developed using life cycle assessment (LCA), applied either partially (focusing solely on the climate change potential impact indicator) or fully. LCA is a well established and internationally standardised methodology (ISO, 2006a,b) for quantifying emissions from specified products or systems over their entire life cycle. LCA accounts for both the environmental burdens (e.g., GHG emissions from residual waste disposed of in landfill) and benefits (e.g., the recovery of recycling of waste materials to produce secondary products that replace the production of primary products). However, choices regarding system boundaries definition, model parameterisation, and data selection can significantly affect the calculated results (Finnveden, 1999). Furthermore, GHG EFs are generally developed for specific geographical areas and technologies, and their appropriateness to other situations may be questionable. To ensure that appropriate and representative GHG EFs are applied, a thorough examination of background information relating to methodological choices taken and data sources is essential (Brogaard et al., 2014). However, GHG EFs are rarely accompanied by such detailed documentation.

A number of studies have presented GHG emissions factors for materials recycling that may be used to support decision makers. A Carbon Metric has been developed by WRAP (Waste and Resources Action Programme) for the purpose of assisting the Scottish government in evaluating the GHG impacts of its national solid waste management system and to identify areas for improvement (Pratt, 2014; Pratt et al., 2013). The Carbon Metric is used to measure progress towards national waste reduction targets and evaluate the impacts of waste policies on Scotland's GHG impacts. As part of the ongoing study, WRAP have produced a series of GHG emission factors for recycling, incineration, and landfilling of certain waste materials and waste streams based on secondary data from a range of published and unpublished sources. Whilst details of the data sources used are provided, specific documentation regarding the modelling approach and assumptions made to produce the EFs is absent. Furthermore, comprehensive EFs for materials recycling are lacking.

An adaptation of the Carbon Metric was produced by WRAP for England (WRAP, 2012). The GHG EFs produced in the study were developed to be used by local authorities in conjunction with data from WasteDataFlow[1] to evaluate waste management performance. No accompanying documentation regarding the development of the EFs is provided. Furthermore, EFs for a number of waste materials are not included due to lack of data.

GHG EFs have also been produced by Defra (Department for Environment, Food & Rural Affairs) in the UK for the purposes of organisational GHG emissions reporting (Defra et al., 2013). However, the EFs are only presented as gross results (i.e., only direct GHG impacts are counted) and 'avoided impacts' (i.e., emissions savings through the substitution of primary energy or material production due to the recovery and production of energy from waste or secondary products) are not included (Hill et al., 2013). Two other studies prepared for Defra by Environmental Resources Management (ERM) have reported GHG EFs for waste materials recycling in the UK. Fisher et al. (2006) undertook a macro-level investigation of the flows of carbon and energy to evaluate the GHG impacts associated with alternative management options for key waste materials in the UK, whilst Fisher (2006) evaluated the GHG impacts of solid waste management policies in the context of the UK waste management system. Both studies provide sufficient documentation and are fully transparent in describing their approach and modelling assumptions. However, both studies are limited in terms of the materials for which GHG EFs are presented, with only the common recyclables covered in the assessments.

The United States Environmental Protection Agency (US EPA) has developed a Waste Reduction Model (WARM) to assist solid waste managers and organisations to measure and report their GHG emissions from solid waste management (US EPA, 2015). For ease of use, the model exists as both a web-based calculator and as a Microsoft Excel spreadsheet. As part of the development of the model, GHG EFs were developed for the recycling of 39 different dry materials. Each EF is well documented, with the modelling approach and assumptions taken clearly reported. Despite the broad range of materials considered, the EFs developed for the US EPA's WARM model do not cover the full range of waste materials reported on in WasteDataFlow. Furthermore, the EFs were developed based on the situation in the USA and lack relevance to European systems and technologies.

Finally, a series of conceptual review papers were published in a special edition of Waste Management & Research that provide a transparent assessment of the GHG impacts associated with the recycling of key materials, including paper (Merrild et al., 2009), metals (Damgaard et al., 2009), plastics (Astrup et al., 2009), glass (Larsen et al., 2009), and wood (Merrild and Christensen, 2009). Each paper provides a description of the relevant material reprocessing technologies involved and an overview of the range of GHG contributions associated with each technology. The GHG contributions were quantified in the geographic context of Northern Europe. Whilst the GHG impacts of materials recycling are transparently documented, the papers are limited in scope to covering only the key recyclable materials.

Although a number of studies have been undertaken to produce GHG EFs for materials recycling (source-segregated or commingled), they are generally insufficient to support national policy makers and local decision makers due to a lack of transparency and clarity in documentation or comprehensiveness in terms of the range of waste materials considered. In this paper, we present for the first time a comprehensive series of GHG EFs for the recycling of a wide range of source-segregated materials based on the results of individual material-specific partial LCA studies. We have focused on source-segregated (aka source-separated) materials as they comprise a large proportion of collected dry recyclables from the municipal solid waste stream in the UK (WYG, 2013) and have been found to produce a higher quality recyclate with lower contamination rates compared to commingled materials collection systems (WRAP, 2008). The purpose of developing the GHG EFs is to assist UK and international decision makers at multiple scales (national/regional governments, local authorities, organisations, and entrepreneurs) in measuring environmental performance and identifying optimal solid waste management solutions with regards to GHG emissions.

2. Methodology

In this study, GHG EFs for recycling of source-segregated materials were derived from a series of partial LCAs undertaken for each recyclable material investigated. The focus of the LCA was on the potential climate change impacts of materials recycling. The LCAs were performed as far as possible in accordance with the ISO 14040 standard (ISO, 2006a,b) and following the technical guidance of the International Reference Life Cycle Data System (ILCD) (EC, 2010, 2011). The LCAs were carried out using EASETECH, a LCA model for the assessment of environmental technologies developed at the Technical University of Denmark (Clavreul et al., 2014). EASETECH was selected as the LCA model as it allows for detailed modelling of heterogonous material flows through complex systems and includes specialised functionality for solid waste management system LCA modelling.

[1] WasteDataFlow is a publically available, web-based data repository system that was established in 2004 to enable local authorities in the UK to report certain municipal waste information to the national government.