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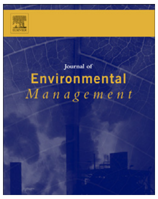

Life cycle assessment of resource recovery from municipal solid waste incineration bottom ash

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ABSTRACT

Bottom ash, the main solid output from municipal solid waste incineration (MSWI), has significant potential for the recovery of resources such as scrap metals and aggregates. The utilisation of these resources ideally enables natural resources to be saved. However, the quality of the recovered scrap metals may limit recycling potential, and the utilisation of aggregates may cause the release of toxic substances into the natural environment through leaching. A life cycle assessment (LCA) was applied to a full-scale MSWI bottom ash management and recovery system to identify environmental breakeven points beyond which the burdens of the recovery processes outweigh the environmental benefits from valorising metals and mineral aggregates. Experimental data for the quantity and quality of individual material fractions were used as a basis for LCA modelling. For the aggregates, three disposal routes were compared: landfilling, road sub-base and aggregate in concrete, while specific leaching data were used as the basis for evaluating toxic impacts. The recovery and recycling of aluminium, ferrous, stainless steel and copper scrap were considered, and the importance of aluminium scrap quality, choice of marginal energy technologies and substitution rates between primary and secondary aluminium, stainless steel and ferrous products, were assessed and discussed. The modelling resulted in burdens to toxic impacts associated with metal recycling and leaching from aggregates during utilisation, while large savings were obtained in terms of non-toxic impacts. However, by varying the substitution rate for aluminium recycling between 0.35 and 0.05 (on the basis of aluminium scrap and secondary aluminium alloy market value), it was found that the current recovery system might reach a breakeven point between the benefits of recycling and energy expended on sorting and upgrading the scrap.

1. Introduction

The current waste management system in Europe generates approximately 35,000,000 Mg of municipal solid waste incineration (MSWI) bottom ash (BA) annually (Eurostat, 2011). The management of this ash varies from country to country, though landfilling, the recovery of valuable metals, treatment and its utilisation as a construction material are among the possible options (Crillesen and Skaarup, 2006). However, increasing pressure on natural resources and concerns about possible losses of valuable resources in waste management have led to growing attention on waste flows such as MSWI BA, which bears potential from a resource perspective (Allegrini et al., 2014; Morf et al., 2013). Scrap metals can be recovered from BA, thereby avoiding mining and the production of primary metals, while the mineral fraction can be utilised within the construction industry, substituting natural aggregates and other natural materials.

Ferrous (Fe) and non-ferrous (NFe) scrap metals are found in MSWI BA in different grain size fractions (Allegrini et al., 2014; Biganzoli and Grosso, 2013; Hu and Rem, 2009; Hu et al., 2011b) and quality (Biganzoli and Grosso, 2013); in fact, scrap metals can be affected by loss of quality (e.g. due to oxidation, corrosion processes), which varies from metal to metal and between different grain sizes

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List of abbreviations: ADm, Depletion of abiotic ineral resource; Al scrap, Aluminium scrap; BA, Bottom ash; CF, Characterisation factor; ECS, Eddy current separator; ET, Ecotoxicity to freshwater; Fe, Ferrous metals; GWP, Global warming potential; HNFe, Heavy non-ferrous metals; HTc, Carcinogenic human toxicity; HTnc, Non-carcinogenic human toxicity; ISS, Inductive sorting system; LCA, Life cycle assessment; LCI, Life cycle inventory; LCIA, Life cycle impact assessment; L/S, Liquid to solid ratio; L/V, Liquid to volume ratio; MSWI, Municipal solid waste incineration; NFe, Non-ferrous metals; SS, Stainless steel; TA, Acidification; WtE, Waste-to-Energy; XSS, X-ray sorting system.

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of the same metal type. The recovery of these metals at various levels is becoming common practice (Allegrini et al., 2014; Crillesen and Skaarup, 2006; Grosso et al., 2011; Heinrichs et al., 2012), and advanced recovery systems have been developed to reach high recovery efficiencies (De Vries et al., 2012; Muchová and Rem, 2006; ZAR, 2014). Enhanced metal recovery favours better utilisation of the mineral fraction in construction works and concrete production, for example by reducing swelling problems due to the oxidation of metallic aluminium residual content (Pecqueur et al., 2001). However, the low quality of scrap metals recovered after incineration affects the recycling phase and lowers the potential environmental benefits from recycling. Furthermore, the use of the mineral residues in more advanced applications could lead to increased demand for other materials (e.g. cement) to comply with structural requirements and potential release into the environment of toxic substances. Thus, a breakeven point, where benefits from resource recovery due to savings of natural resources outbalance the burdens of sorting, upgrading and utilising MSWI BA, might exist.

The comprehensive scope of assessment methodologies such as life cycle assessment (LCA) is suitable for identifying environmental benefits, problem shifting and breakeven points, and criticality related to the management of MSWI BA. Several studies have applied LCAs to analyse specific aspects of MSWI BA valorisation as a support for the implementation of new sorting systems or utilisation options (Barberio et al., 2010; Birgisdóttir et al., 2007; Boesch et al., 2014; Margallo et al., 2014; Meylan and Spoerri, 2014; Muchova, 2010; Toller et al., 2009) or to compare waste management systems where incineration and MSWI BA management are included (Georgeson, 2006; Kuusiola et al., 2012). However, so far, critical aspects such as the influence of recovered metal quality have not been addressed in LCA studies, and often impacts related to pollutants released into the environment during BA utilisation have been disregarded.

The objective of the present study was to assess the environmental impacts of an MSWI BA management system and identify critical aspects thereof, thus providing an improved basis for addressing the environmental assessment of waste-to-energy (WtE) systems. This was done by: i) collecting primary data at a full-scale MSWI BA recovery facility; ii) defining existing and alternative configurations of the plant with increasing metal recovery efficiencies; iii) characterising MSWI BA samples and concrete specimens with MSWI BA as aggregate, to estimate the potential release of pollutants into the environment; iv) evaluating toxic and non-toxic impacts of different recovery scenarios using LCA and v) identify critical parameters relating to resource quality and quantifying their impact on the environmental performance of the system.

2. Material and methods

2.1. The MSWI BA recovery system

A Danish MSWI BA recovery system was used as a case study, a detailed description and analysis of the system is reported in Allegrini et al. (2014) and a simplified scheme of the system is reported in Fig. A.1 in the appendix. The system included the temporary storage of MSWI BA delivered from six MSWI plants, the recovery of Fe metals and upgrading before recycling, outdoor storage for ageing the BA to improve leaching behaviour, the recovery of NFe metals and upgrading of the scrap prior to recycling, the transportation of the mineral residue and metal scrap to utilisation/recycling sites and the utilisation of the treated BA as aggregate in a road sub-base. The average composition of the BA treated in the system was determined in a previous study (i.e. Allegrini et al., 2014) and is summarised in Table 1.

Primary data were collected at the plant during measuring campaigns designed for this study. Electricity and diesel consumption for the sorting units at the recovery facility is reported in Table 2. The individual scrap metal types were transported to specific plants for secondary metal production, while the treated BA fraction was transported to road construction sites within Denmark to be used as aggregate in sub-bases. Data on transportation are reported in Table A.1 in Appendix A.

2.2. LCA

2.2.1. Goal and scope definition

The LCA was carried out following the guidelines reported in EC-JRC (2010). The goal of the LCA was to assess the environmental benefits and burdens of a MSWI BA recovery system with respect to the current treatment and disposal of MSWI BA and alternative configurations of the system in which higher metal recovery is expected to be achieved and alternative utilisation options for the treated BA are considered. The geographical scope was Denmark and the temporal scope for the future technology scenarios was within 10 years from the current situation. The time horizon for the life cycle inventory (LCI) analysis and impact assessment (LCIA) was 100 years (e.g. global warming potential at 100 years). The zero-burden assumption was applied, i.e. the burdens of MSWI BA generation were disregarded, and the FU was defined as “the treatment and management of one Mg of MSWI BA in Denmark”. The LCA was carried out with the SimaPro v.8.0.2. LCA model (http://www.pre-sustainability.com/simapro) and an LCI of activities such as transportation, primary and secondary metal production, electricity production and diesel provision were retrieved from the Ecoinvent v.2.2 LCI database (http://www.ecoinvent.org/). System expansion, based on a consequential approach, was applied, and marginal technologies were therefore identified and used to account for multi-functionality (EC-JRC, 2010; Weidema et al., 1999).

2.2.2. Scenarios

Fig. 1 schematically presents activities included within the system boundaries, while Table 3 summarises the ten scenarios included in this study. Detailed information about energy consumption in each scenario is reported in Table A.2 in Appendix A.

The same recovery of Fe scrap was assumed for all scenarios (except for scenario K), while the recovery efficiency of NFe scrap was varied from 0% up to a hypothetical efficiency equal or larger than 95%. Scenario A was the reference scenario in which NFe scrap was not recovered and the mineral fraction was disposed of in a landfill site.

For scenarios D, E and F, MSWI BA is used as aggregate in concrete and three types of concrete specimen (type 1, 2 and 3) were

Table 1
Composition of MSWI BA delivered to the recovery system and recovery efficiencies for a Danish state-of-the-art system (based on Allegrini et al., 2014).

Material fraction	Content on a wet basis %	Recovery efficiency %
Mineral fraction (with average moisture content of 12%)	90	
Combustible materials	0.11	
Ferrous scrap (Fe)	7.2	85
Non-Ferrous scrap (NFe)	2.2	61
Aluminium scrap (Al scrap)	1.4	62
Heavy NFe (HNFe) scrap (Cu, Pb, Zn etc.)	0.49	43
Stainless Steel (SS)	0.29	85
Total	100	