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Assessing the environmental sustainability of energy recovery from municipal solid waste in the UK

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ABSTRACT

Even though landfilling of waste is the least favourable option in the waste management hierarchy, the majority of municipal solid waste (MSW) in many countries is still landfilled. This represents waste of valuable resources and could lead to higher environmental impacts compared to energy recovered by incineration, even if the landfill gas is recovered. Using life cycle assessment (LCA) as a tool, this paper aims to find out which of the following two options for MSW disposal is more environmentally sustainable: incineration or recovery of biogas from landfills, each producing either electricity or co-generating heat and electricity. The systems are compared on a life cycle basis for two functional units: 'disposal of 1 tonne of MSW' and 'generation of 1 kWh of electricity'. The results indicate that, if both systems are credited for their respective recovered energy and recyclable materials, energy from incineration has much lower impacts than from landfill biogas across all impact categories, except for human toxicity. The impacts of incineration co-generating heat and electricity are negative for nine out of 11 categories as the avoided impacts for the recovered energy and materials are higher than those caused by incineration. By improving the recovery rate of biogas, some impacts of landfilling, such as global warming, depletion of fossil resources, acidification and photochemical smog, would be significantly reduced. However, most impacts of the landfill gas would still be higher than the impacts of incineration, except for global warming and human toxicity. The analysis on the basis of net electricity produced shows that the LCA impacts of electricity from incineration are several times lower in comparison to the impacts of electricity from landfill biogas. Electricity from incineration has significantly lower global warming and several other impacts than electricity from coal and oil but has higher impacts than electricity from natural gas or UK grid. At the UK level, diverting all MSW currently landfilled to incineration with energy recovery would not only avoid the environmental impacts associated with landfilling but, under the current assumptions, would also meet 2.3% of UK's electricity demand and save 2–2.6 million tonnes of greenhouse gas emissions per year.

1. Introduction

Sustainable management of municipal solid waste (MSW) is a critical issue for municipal authorities around the world. Traditional disposal method by landfill is considered to be the least favourable option in the waste management hierarchy, as that wastes valuable resources and gives rise to methane emissions (DEFRA, 2011). Therefore, policies and regulations in many countries, such as the Landfill Directive in Europe (EC, 1999), discourage landfilling and encourage recycling and resource recovery. With the drive towards circular economy gaining momentum, under current proposals, landfilling of all recyclables will be banned in the EU by 2025, with all disposal by landfill virtually eliminated by 2030 (EC, 2014). In the UK, the landfill tax, which is intended to help the UK meet its targets for reducing the amount of waste being landfilled as stipulated by the EU Landfill Directive, has increased steadily from £7 per tonne of waste in 1996 to £82.6 in 2015, to make landfilling economically unattractive (HM Revenue and Customs, 2015). Owing to these policies, the proportion of MSW disposed of by landfill has decreased in the UK from 70% in 2004 to 34% in 2013 (EC, 2015). However, this is still very high compared to some other EU countries, such as Germany and the Netherlands, where less than 2% of waste is landfilled (EC, 2015). Similarly, the amount of MSW incinerated to recover energy is low: 21% compared to Germany and the Netherlands which incinerate 35% and 49% of their waste, respectively (EC, 2015). One of the main reasons for a low uptake of incineration in the UK is

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the opposition of the public because of the perceived health risks from air emissions, increased local pollution and traffic, aesthetics and other concerns (Azapagic, 2011; DEFRA, 2013a; Nixon et al., 2013). Compared to landfills, incinerators also have higher capital and operational costs (Bozorgirad et al., 2013).

Environmental impacts of MSW management have been studied extensively, including a number of life cycle assessment (LCA) studies (for reviews, see e.g. Laurent et al. (2014) and Astrup et al. (2015)). Several of these focused on MSW management in European cities and elsewhere; for example, London (Al-Salem et al., 2014), Liège (Belboom et al., 2013), Rome (Cherubini et al., 2009), Macau (Song et al., 2013), Irkutsk (Tulokhonova and Ulanova, 2013) and Seoul (Yi et al., 2011). They considered various combinations of waste management options, such as landfilling, incineration, recycling, as well as aerobic and anaerobic digestion, to identify the optimal strategies for MSW management at a city level. In general, all of these studies recommend minimising landfilling, increasing recycling and maximising energy recovery from waste fractions with high calorific values.

A number of studies also compared life cycle impacts of waste incineration and landfilling in different countries. For example, Beylot and Villeneuve (2013) considered the environmental performance of 110 incinerators in France and found that, owing to a difference in energy recovery rates, the global warming potential (GWP) varied from −58 to 408 kg CO_2 eq./t MSW. Kourkoumpas et al. (2015) also studied the GWP of MSW incineration in France but compared it to incineration in Greece, reporting that the impact of the latter is much lower (−326 kg CO_2 eq./t MSW) than in France (172 kg CO_2 eq./t MSW). This is due to the higher credits for the avoided greenhouse gas (GHG) emissions for the electricity mix in Greece, which is predominantly lignite based, than for the French grid, which has a high share of nuclear power and thus a lower GWP. In addition to the system credits, in their study of MSW incineration in Italy and Denmark, Turconi et al. (2011) found that factors such as waste composition and incineration technology also affect the environmental performance. Another study in Denmark (Damgaard et al., 2010) found that incineration is an attractive option because of significant developments in air pollution control technologies and energy recovery systems. Liamsanguan and Gheewala (2007) also concluded that the use of air pollution control, such as removal of nitrogen oxides and dioxins, could lead to incinerators in Thailand having comparable or lower impacts than conventional power plants. In a subsequent study, the authors compared the life cycle impacts of landfilling (without energy recovery) and incineration (with energy recovery) in Thailand, finding that incineration was superior to landfilling (Liamsanguan and Gheewala, 2008). However, the latter was a better option if methane was recovered and used for electricity generation. The study by Assamoi et al. (2012) also compared landfilling and incineration but in Canada, focusing on global warming, acidification and eutrophication, while Habib et al. (2013) and Wittmaier et al. (2009) compared the GWP of these two options in Denmark and Germany, respectively.

However, LCA studies of MSW management in the UK are scarce, with only four found in the literature. Two of these (Papageorgiou et al., 2009; Jeswani et al., 2013) focused on the GWP of energy recovery from incineration in a combined heat and power (CHP) plant; in addition, the latter study also considered heat and electricity generation from landfill biogas in comparison to incineration. The remaining two studies (Tunesi, 2011; Al-Salem et al., 2014) assessed LCA impacts of local waste management strategies in England and Greater London, respectively. In addition to the GWP, the former study considered only two other impacts (depletion of resources and acidification) and the latter three categories (acidification, eutrophication and photochemical smog). In this paper, we go beyond the previous studies to estimate and compare 11 life cycle impacts of MSW incineration and landfilling in the UK, considering both CHP and electricity-only plants. Using the latest waste composition data, the study is first carried out at the level of different waste-to-energy technologies and then extrapolated to estimate the impacts at the national level. As far as we are aware, this is the first study of its kind for the UK.

2. Methods

The LCA has been carried out following the attributional approach and the ISO 14040/44 guidelines (ISO, 2006a,b). The goal of the study, data sources and the assumptions are detailed in the following sections.

2.1. Goal and scope of the study

The goal of the study is to estimate and compare the environmental impacts of MSW disposal by incineration and landfill for the UK conditions, with both systems recovering energy. Two options for energy recovery are considered for each system: generation of electricity only and co-generation of heat and power. To explore how the impacts may be affected by the definition of the functional unit, the options are compared for two units of analysis:

(i) disposal of 1 tonne of MSW; and
(ii) generation of 1 kWh of electricity from MSW.

The incineration and landfilling systems considered in the study are described in turn below.

2.1.1. Incineration

There are currently 25 MSW incinerators with energy recovery in the UK, 80% of which generate electricity and the rest recover both heat and electricity (DEFRA, 2013a; Nixon et al., 2013). Although CHP generation is the most efficient option for utilising energy recovered from waste, it requires infrastructure to supply the heat, such as district heating, which is not common in the UK.

The majority of MSW incinerators in the UK are moving-grate plants and are designed to handle large volumes of MSW without any pre-treatment (DEFRA, 2013a). Fig. 1 shows the life cycle diagram of a typical incineration plant with energy recovery. The system boundary considered here includes the following life cycle stages:

- transport of waste to the incinerator;
- construction of the incinerator;
- incineration of waste;
- flue gas treatment;
- transport and disposal of air pollution control (APC) residue, including fly ash;
- energy recovery and associated energy credits;
- recycling of ferrous metals and the related credit for the avoidance of virgin metals; and
- processing of bottom ash into a road aggregate and the credit for the avoidance of virgin aggregates.

The average composition of MSW in the UK is given in Table 1, with the average lower heating value of 9950 MJ/t (Veolia, 2014a). The waste is assumed to be transported for 45 km to the plant where it is stored in a bunker before being transferred to the incineration chamber. The waste is combusted at temperatures >850 °C; either natural gas or fuel oil is used for the initial start-up and to maintain the high combustion temperatures. To control the emissions of nitrogen oxides, acid gases, heavy metals and dioxins, urea or ammonia, hydrated lime and activated carbon are injected into

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