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Eco-efficiency assessment of options for metal recovery from incineration residues: A conceptual framework

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ABSTRACT

Residues from municipal solid waste (MSW) incineration in Switzerland have been a hot topic in recent years, both in the research and practice communities. Regarded by many as an economically and environmentally sound solution to this issue, technological retrofitting of existing grate incinerators has the dual purpose of enhancing the metal recovery of bottom and fly ashes and improving the inertization of residues to be landfilled. How does context influence the economic and environmental performance of this particular technological option? Under which conditions would this technological option be implemented nationwide in the future? What are stakeholders' views on sustainable transitions of MSW incineration? We propose a three-stage methodological procedure to address these questions.

1. Introduction

Switzerland's municipal solid waste (MSW) management history is characterized by environmental problem shifting (Laurent et al., 2012; Raadschelders et al., 2003; Saner et al., 2011; Spoerri, 2009; Venkatesh and Brattebo, 2009). At the turn of the 20th century, uncontrolled dumping and soaring waste volumes brought about massive surface water pollution that threatened drinking water supplies and aquatic ecosystems as well as malodorous emanations that often reached inhabited areas in the vicinity of dumps. Surface water protection legislation was instrumental in the implementation of three alternative forms of waste treatment: composting, controlled landfilling, and incineration. However, composting quickly became obsolete due to the changing composition of residual waste (i.e., increasing shares of metals and plastics). As for controlled landfilling, the issue of waste volumes was obviously not solved and became more acute in a country with a paucity of land resources. At the same time, tougher landfill construction regulations led to higher landfill prices, which led to incineration getting the upper hand in the eighties. Yet this was not the panacea, as in addition to traffic and industry, grate incinerators with rudimentary filter technology became major emitters of specific air pollutants (e.g., heavy metals) in Switzerland. This time, new air pollution regulations forced operators to upgrade flue gas treatment (e.g., denitrification and acid washing systems) and a minimal energetic yield was imposed upon MSW incineration. With respect to metals, water- and airborne pollutants became incineration residues landfilled onto or into engineered compartments in Switzerland and abroad.

Today, with such practice, Swiss MSW management is facing a new, two-faced problem: first, a resource problem, as prices rise slowly yet steadily in world metal markets, and second, an environmental and human health problem, because of the long-term risk of heavy metal leaching from landfills. Two incineration residue types are targeted by retrofitting of existing incinerators: (i) bottom ash through dry (instead of wet) discharge followed by a series of magnets and Eddy currents (Morf et al., 2012), and (ii) fly ash through acid washing (Nagib and Inoue, 2000; Pan et al., 2008; Youcai et al., 2002). Today, of the 28 incinerators Switzerland counts, two have already implemented and are further developing dry discharge of bottom ash with enhanced metal recovery (e.g., Fe, Cu, Al, precious metals), while 13 others have different variants of acid washing of fly ash to recover various metals (Cd, Cu, Pb, Zn). There is a large consensus among key stakeholders and policy-makers of Swiss waste management that dry discharge of bottom ash and acid washing of fly ash are the best available technologies (BAT) with respect to Swiss conditions and context. However, an objective assessment of the performance of these two technologies in the Swiss context is yet to be conducted.

Based on our experience gathered on the case of disposal of waste glass-packaging in Switzerland (Meylan et al., 2013, submitted for publication, in preparation), we identify three reasons that

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might lead directly or indirectly to further problem shifting if assessments of waste management systems are conducted in their present form. We exemplify these reasons with the case described above.

First, in such assessments, the performance of waste management technologies is given on a unit level, e.g., the disposal of one kilogram of MSW. In reality, a single technology is unlikely to fit best an entire country. On the contrary, a mix of technologies, each corresponding to different local economic, geographic, political, and social conditions, characterizes most MSW management systems. For instance, household organic waste is either collected separately prior to composting or anaerobic digestion or co-incinerated with other household wastes as a result of various factors. There is a need to assess systems at their real scale, i.e., the scale of total waste quantities to deliver credible policy support (Ekvall et al., 2007).

Second, most assessments lack an explicitly prospective nature that makes the anticipation of future trade-offs possible. Practitioners of life cycle assessment (LCA) tend to focus more on the uncertainty of data representing present systems than the uncertainty arising from future developments (Höjer et al., 2008; Spielmann et al., 2005). This contradicts the reality of growing waste amounts and the changing demand for energy and secondary raw materials, i.e., structural change, whose extent depends in turn on various factors. Over the last 20 years, Switzerland experienced a major restructuring of its metal industry with a shift to processing stages generating high added value (e.g., watch industry), while smelting activities were left to neighboring or distant countries. The impacts of further possible structural change on the performance of waste management should thus be part of the scope of an assessment of options for MSW incineration.

The need for prospective and integrative assessments, as described above, was already acknowledged by waste experts and policy-makers almost 30 years ago in the Guidelines for Swiss Waste Management (FOEN, 1986): (i) explicit modeling of upstream and downstream economic sectors linked to waste management processes (e.g., energy production) as well as imports of goods, services, and waste; and (ii) consideration of material flows in quantity and quality.

Third and last, the main output of assessments is usually a set of recommendations to policy-makers, e.g., the ban of a packaging material or the adaptation on a national level of heavy metal thresholds of incineration residues. Based on our own experience, we feel a structured and inclusive process that allows for a societally robust translation of assessment results to policies (Fan, 2012; Kruetli et al., 2012), e.g., avoiding further problem-shifting, is lacking. This can result in misunderstanding/rejection by one or more waste management stakeholders of the assessment results e.g., due to an insufficient transparency of assumptions, or of policies based on these results. Ultimately, the policy might fail to yield desired impacts due to opposition by powerful stakeholders. Further, the scientific community dealing with waste management itself recognizes that it must go beyond recommendations and enter decision-making processes as a prerequisite to establish sustainable waste management systems (Hering, 2012).

In this paper, we present a three-step methodological procedure to meet these needs. First, a prospective analysis of MSW management systems by means of scenario analysis serves to construct possible, future MSW management systems. Second, these possible, future systems are assessed with a novel variant of LCA. Third, a method for conveying assessment results to stakeholders and identifying their views on sustainable transitions of MSW management is proposed. Before presenting this methodological procedure, we detail the two Swiss BATs at stake.

2. Best available technologies

2.1. Dry discharge of bottom ash and enhanced metal recovery

Wet discharge of bottom ash assumes two functions. First, it allows the incineration residue to cool down. Second, the furnace is airtight so that no tertiary air can penetrate into it. However, such a procedure presents the major inconvenience of agglutinating bottom ash, thus obstructing metal recovery. With dry discharge, the potential for metal recovery is significantly increased. Tertiary air cools down the ashes and improves the burning processes, i.e., enhances the afterburning of organic compounds, whereas an equivalent amount of secondary air is retrieved from incineration. Furthermore, a study commissioned by the Swiss EPA and other organizations investigated the quality of bottom ash at a Swiss MSW incineration plant equipped with dry discharge (Fierz and Bunge, 2007). One finding was that, despite longer cooling times, concentrations of asbestos and dioxin in fine bottom ash not conveyed back to the furnace by tertiary air (where it ends up as fly ash) are negligible.

Fig. 1 details the process diagram of bottom ash treatment at one of the two plants implementing this technology, a grate incinerator in Hinwil in the Canton of Zurich (Boeni, 2011; Buechi et al., 2012). Coarse bottom ash (>0.5 mm) is treated conventionally prior to landfilling, i.e., undergoes off-site metal recovery through magnetic separation (Morf et al., 2012). Fine bottom ash (<0.5 mm) is led to a conveyor where it cools down. At its end, a first magnet recovers ferrous metals. The remaining ash is then collected in a silo prior to being separated on a screen into two fractions: fine (0.7–5.0 mm) and finest ash (0.1–0.7 mm). The fine fraction goes through a second magnet before non-ferrous metals (NE) are recovered through a series of two Eddy currents and sent to a new screen. The resulting fractions then land on a separating table, where copper- and aluminum-rich fractions are recovered. As for the finest fraction, it directly undergoes a second screen and is then processed through a series of three Eddy currents. Then, copper- and aluminum-rich fractions are recovered on a separating table. For the fine fraction, whose recovery has taken place since 2008 in Hinwil, a separation rate of 90% is achieved for metals such as Al, Cu, Pb, Sn, and Zn. The content of non-ferrous metals in fine ash (0.7–5.0 mm) amounts to more than 5%. Finally, the NE metals recovered from this fine fraction present minimal mineral contents.

2.2. Acid washing of fly ash

Fly ash accumulates in the boiler pipework and at the various downstream dust filters (electrostatic precipitators, fabric filters, etc.). In most MSW incinerators of Switzerland, fly ash is either exported to underground deposits in Germany or cemented prior to its disposal into domestic residual landfills. This results in a loss of 2200 tons of zinc per year (Schlumberger, 2011). In 13 other plants, 1800 tons of zinc per year are recycled thanks to the FLUWA process (FLUWA: Flugaschenwäsche or washing of fly ash). Table 1 gives a detailed chemical analysis of fly ash.

FLUWA produces a filtrate and, after wastewater treatment, hydroxide sludge, from which cadmium, copper, lead, and zinc are recovered in foreign zinc smelters. As a retrofitting of the FLUWA process, FLUREC is currently being implemented in one of these MSW incinerators (FLUREC: Flugaschenrecycling or fly ash recycling). There, the FLUWA filtrate is processed to three products: (i) pure zinc that is directly purchased by the domestic zinc processing industry, (ii) a cementate containing cadmium, copper, and lead as well as (iii) gypsum sludge. It is estimated that FLUWA/FLUREC could serve to substitute 25–30% of imports to Switzerland of zinc as raw material (Schlumberger, 2011).