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Towards increased recycling of household waste: Documenting cascading effects and material efficiency of commingled recyclables and biowaste collection

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A B S T R A C T

Municipal solid waste (MSW) management remains a challenge, even in Europe where several countries now possess capacity to treat all arising MSW, while others still rely on unsustainable disposal pathways. In the former, strategies to reach higher recycling levels are affecting existing waste-to-energy (WtE) treatment infrastructure, by inducing additional overcapacity and this in turn rebounds as pressure on the waste and recyclable materials markets. This study addresses such situations by documenting the effects, in terms of resource recovery, global warming potential (GWP) and cumulative energy demand (CED), of a transition from a self-sufficient waste management system based on minimal separate collection and efficient WtE, towards a system with extended separate collection of recyclable materials and biowaste. In doing so, it tackles key questions: (1) whether recycling and biological treatment are environmentally better compared to highly efficient WtE, and (2) what are the implications of overcapacity-related cascading effects, namely waste import, when included in the comparison of alternative waste management systems. System changes, such as the implementation of kerbside separate collection of recyclable materials were found to significantly increase material recovery, besides leading to substantial GWP and CED savings in comparison to the WtE-based system. Bio-waste separate collection contributed with additional savings when co-digested with manure, and even more significantly when considering future renewable energy background systems reflecting the benefits induced by the flexible use of biogas. Given the current liberalization of trade in combustible waste in Europe, waste landfilling was identified as a short-to-medium-term European-wide waste management marginal reacting to overcapacity effects induced by the implementation of increased recycling strategies. When waste import and, consequently, avoided landfilling were included in the system boundary, additional savings of up to 700 kg CO_2 eq. and 16 GJ eq. of primary energy per tonne of imported waste were established. Conditions, such as energy recovery efficiency, and thresholds beyond which import-related savings potentially turn into GWP burdens were also determined.

1. Introduction

Comprehensive efforts towards increasing recycling combined with the relatively stable waste generation observed after 2008 across Europe have led to an upsurge in combustion Waste-to-Energy (WtE) overcapacity in countries like Austria, Germany, the Netherlands, Belgium, Sweden and Denmark (Friege and Fendel, 2011; Ingeniøren, 2013; Jofra Sora, 2013; Vos, 2012). By 2012, recycling and biological treatment together accounted for more than 50% of Municipal Solid Waste (MSW) treatment in Germany (65%), Austria (62%), Belgium (57%) and the Netherlands (50%). The UK (46%) and Ireland (45%) were the countries which most dramatically increased recycling from their 2001 levels of 12% and respectively 11% (Eurostat, 2014; Fischer et al., 2013). To encourage high efficiency WtE with regard to remaining residual MSW, but perhaps also in anticipation of overcapacities, the 2008 EU Waste Framework Directive (WFD) introduced some important changes to the European waste market. Most importantly, the evaluation of needs for incineration capacity can now be assessed at the European level, as non-hazardous combustible waste can be traded

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between countries more freely. As a result, shipments of combustible waste from countries with treatment under-capacity towards countries with treatment over-capacity have increased significantly in the last few years and are expected to continue increasing, especially if fuelled by favourable economic conditions created by national authorities (e.g. the UK) (Dubois, 2013). A few countries are even adjusting their national strategies to facilitate waste imports, such as the Netherlands and Sweden (Ringstrom, 2012; Vos, 2012).

Around 110 million tonnes of municipal waste are still being landfilled in Europe (EU-28, Iceland, Norway, Switzerland and Turkey (Eurostat, 2014)), and although waste combustion in countries with incineration overcapacity is, in general, seen as an environmentally preferable option to landfilling, it also raises some concerns. Among them, it is argued that low incineration gate fees, combined with the possibility to export, create unfavourable conditions for recycling and hamper local treatment infrastructure development in exporting countries (Jofra Sora, 2013). Another concern is the impact of transporting the waste. On the other hand, studies such as Dubois (2013) and Sundberg and Bisaillon (2011) suggest that based on previous experience with liberalization of international trade in recyclable waste streams, the more recent and controversial trade in combustible waste has the potential to bring significant societal benefits. Although the topics of WtE overcapacities and combustible waste shipments in Europe have been discussed for some time, their associated environmental implications and connection to waste management system changes, have not been addressed in scientific literature to date. This includes recent life cycle assessment (LCA) studies which propose, evaluate or compare alternative municipal solid waste management systems (MSWMS), as found in Cleary (2009) and Laurent et al. (2014).

The study reported here builds on a full scale comparison of MSWMS, by including and evaluating effects on existing treatment infrastructure occurring in the transition from a waste management system predominantly based on combustion WtE to systems with increasing levels of recycling. The concrete case of a municipality in Denmark (Sønderborg) is used to support with documented evidence the effects of such a transition, including observed separate collection efficiencies, changes in waste flows and developments in managing existing WtE capacity. The study has two main dimensions:

(1) A system comparison, in terms of climate, energy and material efficiency, of waste management involving minimal separate collection coupled with efficient WtE and alternatives based on comprehensive commingled kerbside collection of dry recyclables and collection of biowaste.
(2) A methodological basis which is advocated for dealing with the cascading effects related to waste management system changes when increased recycling leads waste-to-energy overcapacity.

The study endeavours to support decision-making related to planning of strategies to achieve stricter EU waste related targets, by illustrating measured changes in waste flows when implementing comprehensive kerbside collection which includes the effects on other types of collection and how these changes impact the treatment of remaining residual waste. Furthermore, the study identifies framework conditions under which: (1) increased recycling of organic waste fractions leads to environmental benefits; and (2) waste shipments for thermal treatment bring climate benefits, considering aspects such as waste characteristics, energy recovery efficiency and different methods of waste disposal.

2. Materials and methods

2.1. Assessment approach

This study assesses the underlying implications of waste management system changes, evaluated on the basis of system analysis and consequential life cycle assessment methodology (LCA) (Clift et al., 2000; Ekvall and Weidema, 2004; Ekvall et al., 2007). All material and energy flows, as well as system burdens and savings, are thus related to a functional unit (FU), here defined as management of 1 tonne (wet weight) of generated household domestic waste. In this study, domestic household waste encompassed all waste materials discarded daily by households which can be collected in a kerbside collection scheme. This definition excludes bulky and hazardous household waste from the analysis, but includes all recyclable waste streams affected by the system changes (further explained in Supplementary Data (SD) file). The temporal scope under which the results are valid is short-to-medium term, i.e. 10 years, based on the range of technologies modelled, lifetime of current infrastructure and background conditions considered.

The metrics used to compare the systems are global warming potential (GWP100) and cumulative energy demand (CED). CED factors were calculated using the method described by Hischier et al. (2010), while GWP100 (kg CO_2 eq., aggregated over 100y) was calculated on the basis of the latest Assessment Report of the Intergovernmental Panel for Climate Change, IPCC (IPCC, 2013). Biogenic and fossil C were distinctly accounted, however, their contribution to GWP100 was considered equal. The assessed systems were modelled in a mass flow transfer model using Microsoft Excel, complemented by CED and GWP100 factors facilitated with the LCA software SimaPro 8.0.2. Background (or generic) life cycle inventory LCI data was retrieved from the Ecoinvent v.3 database, whereas foreground (or system specific) LCI data was compiled from multiple sources, including the municipality's own accounting system (Sønderborg Affald, 2013), interviews with downstream waste operators and several waste characterization investigations.

2.2. System boundary and marginal suppliers

Based on the consequential LCA rationale, only processes reacting to the changes implemented in the management system were included, i.e. processes reacting in both the foreground systems and background systems of energy and materials production. This implies that so-called marginal supplies/marginal data was used. Thus, any up-stream activities prior to waste generation were not included in the system boundary (Ekvall et al., 2007). Based on the time scope of the study (10 y), short-to-medium-term marginals were considered for energy production, (avoided) primary material production and mineral fertilizers, biomass utilization and, lastly, a waste management marginal was defined.

Marginal electricity production was assumed to be from coal condensing power plants (coal PP), whereas the heat production marginal is specific to the local distribution network (district heating), which in the case area, is based on utilization of natural gas. The marginal nitrogen, phosphorus and potassium fertilizers were identified as calcium ammonium nitrate, diammonium phosphate and potassium chloride, on the basis of Hamelin (2013). The biomass marginal for wood pulp production, i.e. tropical plantations, was considered based on the work of Reinhard et al. (2010). Lastly, marginals for primary material production (for metals, plastics and glass) could not be specifically identified and are based on generic Ecoinvent v.3 data, representing European average production.