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Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation

Maklawe Essonanawe Edjabou [a,*], Morten Bang Jensen [a], Ramona Götze [a], Kostyantyn Pivnenko [a], Claus Petersen [b], Charlotte Scheutz [a], Thomas Fruergaard Astrup [a]

[a] Department of Environmental Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
[b] Econet AS, Omøgade 8, 2.sal, 2100 Copenhagen, Denmark

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ABSTRACT

Sound waste management and optimisation of resource recovery require reliable data on solid waste generation and composition. In the absence of standardised and commonly accepted waste characterisation methodologies, various approaches have been reported in literature. This limits both comparability and applicability of the results. In this study, a waste sampling and sorting methodology for efficient and statistically robust characterisation of solid waste was introduced. The methodology was applied to residual waste collected from 1442 households distributed among 10 individual sub-areas in three Danish municipalities (both single and multi-family house areas). In total 17 tonnes of waste were sorted into 10–50 waste fractions, organised according to a three-level (tiered approach) facilitating comparison of the waste data between individual sub-areas with different fractionation (waste from one municipality was sorted at "Level III", e.g. detailed, while the two others were sorted only at "Level I"). The results showed that residual household waste mainly contained food waste (42 ± 5%, mass per wet basis) and miscellaneous combustibles (18 ± 3%, mass per wet basis). The residual household waste generation rate in the study areas was 3–4 kg per person per week. Statistical analyses revealed that the waste composition was independent of variations in the waste generation rate. Both, waste composition and waste generation rates were statistically similar for each of the three municipalities. While the waste generation rates were similar for each of the two housing types (single-family and multi-family house areas), the individual percentage composition of food waste, paper, and glass was significantly different between the housing types. This indicates that housing type is a critical stratification parameter. Separating food leftovers from food packaging during manual sorting of the sampled waste did not have significant influence on the proportions of food waste and packaging materials, indicating that this step may not be required.

1. Introduction

Accurate and reliable data on waste composition are crucial both for planning and environmental assessment of waste management as well as for improvement of resource recovery in society. To develop the waste system and improve technologies, detailed data for the material characteristics of the waste involved are needed. Characterisation of waste material composition typically consists of three phases: first sampling of the waste itself, then sorting the waste into the desired number of material fractions (e.g. paper, plastic, organics, combustibles, etc.), and finally handling, interpretation and application of the obtained data. The sampling and sorting activities themselves are critical for obtaining appropriate waste composition data. The absence of international standards for solid waste characterisation has led to a variety of sampling and sorting approaches, making a comparison of results between studies challenging (Dahlén and Lagerkvist, 2008). Due to the high heterogeneity of solid waste, the influence of local conditions (e.g. source-segregation systems, local sorting guides, collection equipment and systems), and the variability of sampling methodologies generally limits the applicability of waste compositional data in situations outside the original context.

The quality of waste composition data are highly affected by the sampling procedure (Petersen et al., 2004). Solid waste sampling may often involve direct sampling, either at the source (e.g. household) (WRAP, 2009) or from a vehicle load (Steel et al., 1999). Vehicle load sampling is often carried out by sampling the waste

* Corresponding author. Tel.: +45 4525 1498.
E-mail address: vine@env.dtu.dk (M.E. Edjabou).

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received at waste transfer stations (Wagland et al., 2012), waste treatment facilities, e.g. waste incinerators (Petersen, 2005), and landfill sites (Sharma and McBean, 2009; Chang and Davila, 2008). While logistic efforts can be reduced by sampling at the point of unloading of waste collection vehicles, a main drawback of this approach may be that the sampled waste cannot be accurately attributed to the geographical areas and/or household types generating the waste (Dahlén et al., 2009). This limits the applicability of the obtained composition data. On the other hand, collecting waste directly from individual households and/or from a specific area with a certain household type, allow the waste data to be associated with the specific area (Dahlén et al., 2009). Additionally, as most modern waste collection trucks use a compaction mechanism (Nilsson, 2010), waste fractions sampled from such vehicles have been affected by mechanical stress and blending, which leads to considerable difficulties in distinguishing individual material fractions during manual sorting (European Commission, 2004). Owing to the mechanical stress and the blending processes from collection trucks, cross-contamination between individual fractions may occur, leading to further inaccuracies that can neither be measured nor corrected afterwards.

To ensure uniform coverage of the geographical area under study, stratification sampling is often applied. This involves dividing the study area into non-overlapping sub-areas with similar characteristics (Dahlén and Lagerkvist, 2008; Sharma and McBean, 2007; European Commission, 2004).

In order to reduce the volume (amount) of waste to be sorted, the waste sampled from each sub-area is usually coned and quartered before sorting into individual waste material fractions (Choi et al., 2008; Martinho et al., 2008). Although this reduces labour intensity, the approach has shown to generate poorly representative samples (Gerlach et al., 2002). Because of the heterogeneity of residual household waste (RHW), the material in a waste pile (or cone) is unevenly distributed (Klee, 1993). Instead, sampling from elongated flat piles and from falling streams at conveyor belts is recommended to generate more representative samples (De la Cruz and Barlaz, 2010; Petersen et al., 2005). While elongated flat piles can be used on most waste materials, sampling from falling streams at conveyor belts may potentially induce additional mechanical stress if not appropriately applied. However, only few studies have applied these mass reduction principles for solid waste sampling prior to the manual sorting in fractions. The waste sampled from a specific sub-area could also be split into a desired or calculated number of sub-samples (European Commission, 2004; Nordtest, 1995). This method can provide mean and standard deviation for each waste fraction, and may be argued as cost-effective (Sharma and McBean, 2007). However, the main drawback is the splitting, which can introduce a bias. Additionally, the obtained standard deviations are highly associated with the number of samples and the size (mass or volume) of the samples, which vary considerably across the literature (Dahlén and Lagerkvist, 2008). In order to avoid any bias from mass reduction, sorting all the collected waste from an individual sub-area would be necessary (Petersen et al., 2004).

In addition to the influence from waste sampling, also the subsequent sorting procedures can influence the results for household waste composition. The overall material fraction composition is directly related to the sorting principles applied for dividing waste materials into individual fractions, e.g. to which extent is food packaging and food materials separated, how are composite materials handled, and how detailed material fractions are included in the study? The influence of food waste sorting procedures has been investigated by Lebersorger and Schneider (2011). While the influence of food packaging on food waste in this particular case was shown to be insignificant, the influence of food packaging on other material fractions in the waste (e.g. packaging material) has not been examined.

Inconsistencies among existing solid waste characterisation studies, e.g. definitions of waste fractions, may cause confusion and limit comparability of waste composition data between studies (Dahlén and Lagerkvist, 2008). While Riber et al. (2009) published a detailed waste composition for household waste, including 48 waste material fractions, more transparent and flexible nomenclature for the individual waste material fractions is needed to allow full comparability between studies with varying numbers of material fractions and sorting objectives. Such classification principles exist, but only for certain waste types and often developed for other purposes: e.g. classification of plastics based on resin type (Avella et al., 2001), the European Union's directive on Waste Electrical and Electronic Equipment (WEEE) (European Commission, 2003) and grouping of Household Hazardous Waste (HHW) (Slack et al., 2004).

The overall aim of the paper was to provide a consistent framework for municipal solid waste characterisation activities and thereby support the establishment of transparent waste composition datasets. The specific objectives were to: (i) introduce a waste sampling and sorting methodology involving a tiered list of waste fractions (e.g. a sequential subdivision of fractions at three levels), (ii) apply this methodology in a concrete sampling campaign characterising RHW from 10 individual sub-areas located in three different municipalities, (iii) evaluate the methodology based on statistical analysis of the obtained waste datasets for the 10 sub-areas, focusing on the influence of stratification criteria and sorting procedures (e.g. the influence of sorting of food waste packaging on other packaging materials), and (iv) identify potential trends among sub-areas in source-segregation efficiencies.

2. Materials and methods

2.1. Definitions

RHW refers to the remaining mixed waste after source segregation of recyclables and other materials, such as HHW, WEEE, gardening and bulky waste. Bulky waste refers to waste such as furniture, refrigerators, television sets, and household machines (Christensen et al., 2010). Source-segregated material fractions found in the residual household waste are considered as miss-sorted waste fractions. Housing type consists of single-family and multi-family house. Here single-family house corresponds to households with their own residual waste bin, while multi-family house corresponds to households sharing residual waste bins, e.g. common containers in apartment buildings. Food packaging is packaging containing food remains or scraps. "Packed food" waste represents food items inside packaging while "unpacked food" waste is food discarded without packaging. Within this paper, the terms "fraction" and "component" was used interchangeably. The data are presented as mean and standard deviation (Mean ± SD) unless otherwise indicated.

2.2. Study area

The sampling campaign covered residual waste collected from households in three Danish municipalities: Aabenraa, Haderslev and Sønderborg. These municipalities have the same waste management system including the same source segregation scheme. They introduced a waste sorting system using a two-compartment wheeled waste bin for separate collection of recyclable materials from single-family house areas (Dansk Affald, 2013). One compartment was used for collection of mixed metal, plastic, and glass; the

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