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Review

Physico-chemical characterisation of material fractions in household waste: Overview of data in literature

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ABSTRACT

State-of-the-art environmental assessment of waste management systems rely on data for the physico-chemical composition of individual material fractions comprising the waste in question. To derive the necessary inventory data for different scopes and systems, literature data from different sources and backgrounds are consulted and combined. This study provides an overview of physico-chemical waste characterisation data for individual waste material fractions available in literature and thereby aims to support the selection of data fitting to a specific scope and the selection of uncertainty ranges related to the data selection from literature. Overall, 97 publications were reviewed with respect to employed characterisation method, regional origin of the waste, number of investigated parameters and material fractions and other qualitative aspects. Descriptive statistical analysis of the reported physico-chemical waste composition data was performed to derive value ranges and data distributions for element concentrations (e.g. Cd content) and physical parameters (e.g. heating value). Based on 11,886 individual data entries, median values and percentiles for 47 parameters in 11 individual waste fractions are presented. Exceptional values and publications are identified and discussed. Detailed datasets are attached to this study, allowing further analysis and new applications of the data.

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1. Introduction

State-of-the-art environmental assessment of waste management systems rely on data for the physico-chemical composition of individual material fractions comprising the specific waste (e.g. Laurent et al., 2014; Astrup et al., 2015). Emissions of metals from thermal treatment of waste depend on the metal content of the waste materials received at the waste incinerator (e.g. Brunner and Rechberger, 2014; Astrup et al., 2011; Morf et al., 2000). The composition of compost after aerobic degradation of organic waste is affected by the purity of the input organic waste to the composting facility (Andersen et al., 2010). Similarly, unwanted substances in waste paper collected for recycling may affect the recyclability of the paper (e.g. Pivnenko et al., 2015). Decision support tools like life cycle assessments (LCA), as well as substance flow analysis (SFA) and material flow analysis (MFA), apply waste characterisation data as input for modelling of waste management systems and individual waste technologies, for example, to identify emission hotspots, dissipation of valuable resources, and to assess the environmental consequences of potential new waste management initiatives, e.g. new source-segregation schemes affecting the material composition of existing waste incinerators, additional pre-treatment of organic waste fractions prior to composting, or isolation and removal of potential contaminated material fractions from waste flows. Without data for the physico-chemical composition of these individual material fractions, the environmental consequences of such management initiatives cannot be systematically estimated and evaluated, and emissions from the waste treatment processes cannot be tracked back to individual waste material fractions (Astrup et al., 2011; Manfredi et al., 2010, 2011; Rotter et al., 2004).

Due to the inherent heterogeneity of waste materials as well as temporal and spatial variability, representative sampling and analysis of waste samples is challenging, labour intensive and costly. Consequently, life cycle assessment of waste management technologies and systems are most often based on literature waste characterisation data (e.g. Aye and Widjaya, 2006; Cherubini et al., 2008; Fruergaard and Astrup, 2011; Arena and Di Gregorio, 2014). While selection of these modelling input data may significantly affect the outcome of such studies (e.g. Slagstad and Brattebø, 2013; Clavreul et al., 2014; Laurent et al., 2014), very little attention is devoted to the selection of data and the type of literature sources (e.g. focus and origin of the studies providing the waste characterisation data, sampling and analytical methods applied, data coverage, etc.). As such, little guidance is available for LCA practitioners for selection of waste characterisation data and/or for evaluation of case-specific data in the perspective of data available in literature. An overview of existing characterisation data quantifying data variability for different physico-chemical parameters in individual waste material fractions, and linking critical values to specific publications, sub-fractions, geographical scopes and characterisation methods is important to support LCA practitioners in making an informed choice for their inventory data. Such an overview has not been provided previously.

A variety of waste characterisation methods have been developed, however, no international consensus has been achieved so far (Dahlén and Lagerkvist, 2008). From a more generic perspective, Brunner and Ernst (1986) defined three approaches for waste characterisation: (i) direct waste analysis, (ii) waste product analysis, and (iii) market product analysis. Direct waste analysis examines individual samples of waste materials by chemical analysis. Waste product analysis (also referred to as indirect waste analysis) combines chemical analysis of output materials from waste treatment facilities (e.g. incineration residues, compost or mechanically sorted waste fractions) with mass and substance balance calculations to determine the chemical composition of the input material. A key advantage of waste product analysis over direct analysis is the minimisation of uncertainties associated with sampling as samples of residues from incineration represent larger waste quantities entering the incinerator (e.g. Brunner and Ernst, 1986; Astrup et al., 2011). On the other hand, waste product analysis may provide limited information about individual material fractions within waste flows (i.e. waste product analysis involving waste incinerators may only provide data for the combined waste input flow, rather than the individual materials in the waste), while direct waste analysis may address the specific material fractions within mixed waste flows (e.g. household waste). In both cases, however, high quality characterisation data require considerable attention to sampling and sample handling (e.g. Gy, 1998; Morf and Brunner, 1998; Petersen et al., 2004). Market product analysis estimates the waste composition based on national statistics on production and consumption of goods (Brunner and Ernst, 1986) and is classically used to quantify material and substance flows (MFA/SFA) within a country. As we aimed at directly reported element concentrations and using the later explained search criteria no studies using this approach could be identified, market product analysis is not further addressed in this paper.

Both direct and indirect waste analysis requires considerable efforts for capturing spatial and temporal variation in the physico-chemical properties of waste materials. This may result in limited availability of waste characterisation data suitable for specific assessment purposes. The importance for LCA studies of applying appropriate waste composition data reflecting the spatial and temporal scope of the assessment has been pointed out in several cases (e.g. Clavreul et al., 2012; Fruergaard and Astrup, 2011). However, in a review of LCA studies of waste-to-energy technologies, Astrup et al. (2015) reported that only 44% of studies in literature provided information about the chemical composition of the addressed waste (and only 60% of these specified the origin of the data). Despite the potential challenges related to data quality, data coverage, characterisation approaches, etc., state-of-the-art waste LCA modelling most often involves selection and combination of various data sources for establishment of the needed input data (e.g. Fruergaard and Astrup, 2011). Potentially, this may involve a mixture of datasets from different publications based on a variety of waste characterisation methods as well as varying temporal and regional scopes (e.g. Aye and Widjaya, 2006; Cherubini et al., 2008; Arena and Di Gregorio, 2014). To properly address uncertainties in LCA modelling of waste technologies, a basis for identifying appropriate uncertainty ranges reflecting the choice of physico-chemical waste composition data is needed. A quantitative overview of value ranges and variability of waste characterisation data in literature, including the variations due to involved methods, geographical scopes, waste types, and parameters, is fundamental in this context.

The overall aim of the paper is to provide an overview of available data on the physical and chemical composition of individual