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Compositional analysis of seasonal variation in Danish residual household waste

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ABSTRACT

Seasonal variations are considered one of the key factors affecting the generation and composition of residual waste. Despite this importance, attempts have not been made to characterize residual household waste consistently by accounting for seasonal variations in waste disposal patterns. To assess differences between seasons and within individual households, we collected residual household waste from the same 101 households in summer, autumn and winter. The waste bags were sorted individually, and residual household waste data (mass and composition) were generated for each household. In total, 3 t of waste were collected, weighed and manually sorted into nine (9) waste fractions. The result of mixed linear model indicated that for this study area, seasonal variations may introduce no significant difference to the mass and composition of residual household waste. However, residual waste generation within a household may change significantly between the seasons. The result also showed that while household size may significantly influence the generation of residual household, the difference in residual household waste composition was not significantly different between household sizes.

1. Introduction

In several countries, the approach to managing waste is changing rapidly. In particular, the transition of municipal solid waste management to circular economy and resource efficiency poses unprecedented challenges in terms of waste management planning, which in turn typically requires comprehensive and reliable data about waste generation and composition. Generally, these data are obtained from sampling, sorting and analysing solid waste streams into desired and predefined waste fractions (Edjabou et al., 2015a). To attain reliable data, the seven sampling errors described by Pierre Gy should be avoided: (1) long-range heterogeneity fluctuation, (2) periodic heterogeneity fluctuation, (3) fundamental errors, (4) grouping and segregation, (4) increment and delimitation, (5) increment extraction and (7) preparation errors (Pitard, 1993). Among these errors, tackling periodic heterogeneity fluctuations is particularly challenging, because repeated sampling and analysis is costly and time-consuming (Dahlén and Lagerkvist, 2008).

To address periodic variations (e.g. short-term and seasonal variations), available methods for the determination of waste composition recommend that a waste sample should: (1) cover at least one full week (including weekends), given that the waste generated during weekends may be different to weekdays (Edjabou et al., 2015a), and (2) be stratified based on seasons, which may induce significant variations in the generation and composition of residual household waste (European Commission, 2004). Generally, a full week's data for waste generation and composition are often assumed representative of the whole year (see Edjabou et al., 2015b; Riber et al., 2009). In contrast, a number of other studies have investigated the seasonal generation and composition of household waste (e.g. Denafas et al., 2014; Edjabou et al., 2012; Kamran et al., 2015; Andersen and Larsen, 2012; Aguilar-Virgen et al., 2013). Although these studies concluded that the generation and composition of household waste are affected by seasonal variation, a major drawback of these studies is that the waste was not sampled from the same households for all seasons, thereby introducing inherent uncertainty related to variations in the households' socio-economic situation.

Besides not addressing fluctuations properly, several of the previously mentioned studies did not deal accurately with the fact that waste composition datasets, by nature, are "closed datasets", i.e. the relative contribution of waste fractions should always sum up to 100% (Aitchison, 1986). A major problem with closed datasets is that parts of the composition are linked intrinsically to each other (Edjabou et al., 2015c). Consequently, an increase in the percentage of a waste fraction will lead automatically to a decrease in another fraction and vice versa. This natural property of compositional data biases statistical analysis of

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the relationship between seasonal variations and waste composition. Moreover, results from statistical analysis applied to dataset for waste fraction generation rates (kg waste fraction per week) can neither be necessary generalised nor extrapolated to waste fractional composition dataset (see Edjabou et al., 2017). As a solution, a procedure based on multivariate analysis applied to log-ratio coordinates has been suggested (e.g. Aitchison and Ng, 2005; Egozcue et al., 2003). For this study, an isometric log-ratio transformation (Egozcue et al., 2003) was applied to the waste composition dataset (see SM Table 1), in order to overcome the total sum constraint problem (Aitchison, 1994). Another advantage of the isometric log-ratio transformation is that the same isometric log-ratio coordinates are obtained with either individual waste fraction generation rates (kg waste per week for each waste fraction) or percentage compositions.

The objective of this study was to assess whether the generation and composition of residual household waste are associated with seasonal variations. This was achieved by: (i) collecting waste composition data from 101 households in Denmark, (ii) statistically treating the data using compositional data techniques and (iii) investigating and identifying any significant relationships between seasons and household size.

2. Methods and materials

2.1. Study area

Residual household waste generated in a Copenhagen suburb was sampled and characterized. In this area, paper, board, metal, garden waste, hazardous waste, waste electrical and electronic equipment (WEEE) as well as bulky items were source-segregated. However, some of these fractions are often misplaced in the residual household bins. Thus, misplaced waste fractions are waste fractions that should have been source-sorted by households for recycling purposes. Therefore, residual household waste included food waste, miscellaneous combustible (e.g. diapers, textiles, etc.) plastic packaging and film, tissue paper, wrapping paper and misplaced source-segregated waste (Table 1).

In this study area, the waste bins had volumes of 180–360 l. They are equipped with a throwback lid, which is always closed to protect the waste from weather exposure (rain, snow, sun, etc.). Thus, the weather and seasonal variation cannot influence the physical characteristics of the waste during the storage and the collection from households. As result, any significant changes in generation and composition of waste can be attributed to the households.

2.2. Experimental design

The waste was sampled from the same group of households in autumn, summer and winter, in 2011–2012. Samples from individual households were taken from waste generated during a full week in each of the three seasons, in compliance with existing guidelines, such as European Commission (2004), Nordtest, (1995) and US EPA, (2002). The waste samples were retrieved as part of the ordinary waste collection schedule, to prevent any changes in household waste generation that may lead to biased results. Thus, the municipality department responsible for waste management selected the waste collection route in collaboration with the waste collection company in the study area. The households located in this collection route are assumed to be representative for the study area with regard to the volume of waste bins, household size and socio-economic patterns (e.g. population distribution) (see Edjabou et al., 2015).

In total, 101 randomly selected households were involved in the study. An additional nine households, initially part of the project, were discarded because they missed one or more sampling campaigns. The exclusion was necessary to ensure it was possible to identify any changes in composition and generation rates within individual houses. For each household, the number of occupants for the three seasons was obtained from the local council authorities.

Residual household waste was collected prior to any compaction and sorted into (1) food waste (Food), (2) gardening waste (Garden), (3) paper, (4) board, (5) metal, (6) plastic packaging, (7) plastic films, (8) inert materials and (9) miscellaneous combustible waste (Table 1). Here, the paper fraction included all types of paper, such as kitchen tissue, newsprints, etc. For this study, gardening waste, paper, board, metal and plastic packaging are misplaced waste, whereas food waste, miscellaneous combustible waste are residual household waste.

Waste sorting was conducted within a week after sampling. Neither sieving nor mass reduction was applied prior to waste sorting. Furthermore, waste from individual households was sorted separately, and the data were then recorded and analysed.

The total amount of residual household waste sampled was 3 t, corresponding to about 1 t per season (Table 2). The numbers of households as a function of household size (number of occupants per households) and per sampling period are provided in Table 2. For this study, households were split into four groups, according to the number of occupants, namely one person (1p), two persons (2p), three persons (3p) and more than three persons (4p +) (Edjabou et al., 2016).

2.3. Statistical analysis

2.3.1. Geometric mean bar plot

We computed geometric mean of data for a fractional solid waste composition as follows:

$$g_{mi}(x) = exp\left[{}^{1}\!/_{n} \sum_{i=1}^{D} ln(x_i) \right] \tag{1}$$

where $g_{mi}(x)$ is the geometric mean of a waste fraction m for the individual subgroup i (e.g. autumn, winter and summer), n is the number

Table 1
List of residual household waste fractions and components included (based on Edjabou et al., 2015b).

Waste fractions	Components
Food waste (Food)	Vegetable and animal derived food waste: Fresh fruit, fresh carrots and potatoes, bread, cereals, residues from fruits, vegetables, coffee grounds, rest of food containing meat
Gardening waste (Garden)	Flowers,
Paper	Advertisements, books & booklets, magazines & Journals, newspapers office paper, phonebooks, miscellaneous paper
Board	Corrugated boxes, beverage cartons, folding boxes, miscellaneous board
Plastic packaging (Plastic)	Packaging plastics, PET/PETE (1), HDPE (2), PVC/V (3), LDPE/LLDPE (4), PP (5) PS (6) non-foamed, PS (6) foamed, Other plastic resins labelled with [1–19] (7), or ABS, Unidentified plastic resin
Plastic film (Plastic foil)	Pure plastic film, composite plastics
Metal packaging (Metal)	Metal packaging containers (ferrous, non-ferrous), and composites
Inert	WEEE, Household hazardous waste, batteries, glass, ashes, cat litter, ceramics, gravel, etc.
Miscellaneous combustible waste	Human hygiene waste, other combustible waste, textile, leather, rubber, vacuum cleaner bags