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Municipal Solid Waste Composition: Sampling methodology, statistical analyses, and case study evaluation

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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 characterization 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.

Key words:

Residual household waste

Waste generation rate

Waste fractions

Statistical analysis

Waste sampling

Waste composition

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. Characterization 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 characterization 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 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 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 other compartment for mixed paper, board, and plastic foil. However, in multi-family house areas, a Molok system and joint full service collection points (joint wheeled container) were used for the collection of RHW and source-sorted materials for recyclables. The waste bins had volumes between 60 to 360 litres in the single-family house area and between 400 to 1000 litres in the multi-family house area.

Collection frequencies for the residual waste were every two weeks in single-family house areas and every week in multi-family house areas. Garden waste, HHW, WEEE and bulky waste from single and multi-family house areas could be disposed of, either at recycling stations or collected from the premises on demand. However, food waste was not separately collected and was disposed of in the RHW bin. This study focused not on the source-segregated materials (bulky waste, garden waste, and other source-segregated materials), but rather on the characterisation of the residual waste consisting of a mixed range of materials of high heterogeneity.

2.3 Waste sampling procedure

The three municipalities were subdivided into sub-areas distinguished by housing type. RHW was sampled directly from households in each of the 10 sub-areas; three sub-areas were from Aabenraa, three from Sønderborg, and four from Haderslev. As such, the sampling campaign focused on the overall waste generation from the individual sub-areas and the associated housing types, rather than the specific waste generated in each household.

To avoid changes of the normal waste collection patterns within the areas (see section 2.2) potentially leading to changes in household waste disposal behaviour, the waste was collected following the existing residual waste collection schedules.

A single RHW collection route was selected in each sub-area by the municipal authorities responsible for the solid waste management. The distribution of households along the selected routes was representative for each sub-area with respect to the volume of RHW bins and the size of the households. The number of selected households in each sub-area was between 100 and 200, as recommended by Nordtest (1995).

Based on these conditions (households samples representativeness and number of households), the number of selected households were computed and reported in Table 1, which also shows the amount of waste collected and sorted from each sub-area. In total, 426 households in Aabenraa, 389 households in Sønderborg and 627 households in Haderslev were selected. Overall, 779 households were distributed in four multi-family house areas, and 663 households in six single-family house areas.

In total, six tonnes of waste was collected and sorted from multi-family house areas and 11 tonnes from single-family house areas (overall 17 tonnes). The waste was sampled during spring 2013. Any effects from seasonal variations on waste composition and generation rates were not investigated in the study.

Table 1 about here

2.4 Sorting procedure

In order to avoid errors from waste splitting, the entire waste sampled from each sub-area was sorted as a "batch" and the waste from the 10 sub-areas was treated each as a "single sample", resulting in 10 individual samples from the three municipalities. This means that as a result of the sorting campaign, waste data (waste composition and waste generation) for 10 individual sub-areas were obtained.

For this reason, the waste was collected separately from each sub-area without compacting (e.g. the waste was not collected by a compaction vehicle). The waste was then transported to a sorting facility, where it was unloaded on a tarpaulin, and filled in paper sacks for weighing and temporary storage. The paper sacks were labelled with ID numbers. Each paper sack was weighed to obtain the "dry mass" before filling in the waste. Thereafter, the filled paper sacks were weighed before and after all sorting activities to quantify mass losses during sorting and storage. The mass loss was calculated as the difference in net mass of waste before and after a process.The errors due to contamination during sorting process and storage, e.g. the migration of moisture from food waste to other components (paper, board, plastic, etc.) and paper sacks, and evaporation was negligible (see Supplementary material D for mass losses). The average mass loss was 1.7%, and thus below 3% (Lebersorger and Schneider, 2011). No adjustments of the waste data from errors due to mass losses were applied in this study.

Figure 1 illustrates the waste sorting procedure and the steps applied. A tiered approach for material fraction sorting was developed as illustrated by Levels I to III in Table 2, to allow comparison between datasets with different needs for sorting and data aggregation. For example, one study may focus on detailed fractionation of food waste (e.g. addressing avoidable and non-avoidable food), while another study may only wish to characterize food waste by a few overall fractions (e.g. vegetable and animal derived food waste). Categorizing the fractions in levels (e.g. Levels I to III) would thereby still allow comparison between such two studies, at an overall level. In the context of the sub-areas, all collected waste from each sub-area was sorted separately. This was done according to Level I in Table 2, corresponding to 10 material fractions. To provide further details, waste from one municipality (Aabenraa) was selected for more detailed sorting according to Level II & III. The waste from Haderslev and Sønderborg was sorted only at Level I. As such, the datasets from these three municipalities represent examples of sorting campaigns carried out at different levels of complexity; nevertheless, the tiered approach allows comparison between the datasets at Level I.

Food packaging containing remaining food was separated as an extra fraction and subsequently sorted separately into the individual material fractions as shown in Table 2. Food waste including beverage was easily removed from the packaging. However, in some cases tools were used e.g. to open containers, or packaging was compressed as much as possible to remove food waste e.g. from tube packaging.

All waste fractions from Aabenraa,including food packaging containing remaining food leftovers were subsequently sorted according to the three levels in Table 2 (Level I, II and III). For instance, plastic waste was sorted by reading the resin identification label on the plastic. Unspecified plastic represented plastic where no resin identification label was present. Metal fractions were sorted into ferrous and non-ferrous using a magnet. As the contents of "special waste" including WEEE and HHW were very low, this fraction was sorted only to Level II.

The waste sampled from each sub-area was sorted under the same conditions, by a professional team, within a week from the sampling day. This sorting time may minimize any physical changes of the samples as recommended by European Commission (2004).

Figure 1 about here

2.5 Waste fraction nomenclature

The waste fraction nomenclature was mainly adapted from Riber et al. (2009) and other literature (Steel et al., 1999, Dixon and Langer, 2006), and the Danish National Waste register (Danish EPA, 2014). Naming conventions for the individual material fractions may be affected by local traditions and may be ambiguously defined. Special care was taken here to ensure consistent naming of fractions and avoid potential misleading names. The tiered fraction list is shown in Table 2 and consists of 10 fractions at Level I, 36 fractions at Level II, and 56 fractions at Level III. This nomenclature allowed transparent classification while still facilitating flexible grouping of waste fractions and comparison between the individual areas. For example, we used food waste and gardening waste instead of organic waste, which by definition includes more than food waste and gardening waste. Here, food waste comprises food and beverage products that are intended for human consumption, including edible material (e.g. fruit and vegetables, and meat) and inedible material (e.g. bones from meat, eggshells, and peels) (WRAP, 2009). Paper was divided into advertisements, books & booklets, magazines & journals, newspapers, office paper, phonebooks and miscellaneous paper. Miscellaneous paper was then further subdivided into envelopes, kraft paper, other paper, receipts, self-adhesives, tissue paper, and wrapping paper. Plastic waste was subdivided according to resin type (PET, HDPE, PVC, LDPE, PP, PS, Other resins) (Avella et al., 2001) and unidentified plastic resins for plastic with no resin identification. Special waste was categorised as batteries (single batteries and non-device specific batteries), WEEE and HHW. WEEE and HHW were further split into components defined by the EU directive on WEEE and HHW.

Table 2 about here

2.6 Statistical analysis

The waste generation rate (WGR) and composition of the residual waste were analysed by the Kruskal-Wallis test and the permutation test (Johnson, 2005) to identify significant differences among the three municipalities and between the two housing types. Furthermore, the Kolmogorov-Smirnov test (Johnson, 2005) was applied to identify cases when the proportion of at least one fraction in the overall composition was significantly different between housing types or among municipalities. Based on Spearman´s correlation test (Johnson, 2005) a correlation matrix between the WGR and percentages of individual waste fractions was determined (Crawley, 2007). Correlations between the WGR and individual waste fractions were used to determine whether variations in WGR also influenced the waste composition, while correlations between waste fractions were used to identify potential trends in the households' efficiency in source segregating of recyclables (e.g. based on leftover recyclables in the residual waste). The test of the correlation for significance addressed whether the correlation's coefficients were statistically significant or significantly different from zero (Crawley, 2007).

Waste composition data were reported and discussed based on the relative distribution of fractions in percentages of wet mass (as opposed to the quantity of wet mass of individual waste fraction) to ensure scale invariance and enable comparison of waste composition from different areas (Buccianti and Pawlowsky-Glahn, 2011). Additionally, percentage composition data remove the effects from WGR (since in the study area, the WGR varies according to sub-areas), which could otherwise lead to "false" correlations (Egozcue and Pawlowsky-Glahn, 2011). This approach allows comparison of different waste composition data. However, waste composition data in percentages are “closed datasets” because the proportions of individual fractions are positive and add up to a constant of 100 (Filzmoser and Hron, 2008). As such, these data require special treatment or transformation prior to statistical analyses (Aitchison, 1994; Filzmoser and Hron, 2008; Reimann et al., 2008). Here, log-transformation was applied since “the log-transformation is in the majority of cases advantageous for analysis of environmental data, which are characterised by the existence of data outliers and most often right-skewed data distribution” (Reimann et al., 2008).

Data analysis was carried out with the statistical software R. Data for three municipalities (Sønderborg, Haderslev, and Aabenraa), two housing types (single and multi-family), and two sorting procedures (with and without including food packaging in the food waste component) were investigated. The influence of including food packaging in the food waste fraction was modelled by comparing two waste composition datasets: 1) data from the sorting campaign where food packaging was separated from food waste and added to the relevant material fraction, and 2) a "calculated" dataset where the mass of food packaging was added to the food waste fraction.

Based on the compositional data and the WGR obtained for each sub-area, aggregated waste compositions (corresponding to Level I) were computed for each municipality and each housing type. These waste compositions accounted for the relative distribution of housing types and number of households among sub-areas (Statistics Denmark, 2013).

3 Results and discussion

3.1 Comparison with previous Danish composition data

The detailed composition of the RHW from Aabenraa is shown in Table 3 for Level I & II and in Table 4 mainly for Level III. Food waste (41-45%) was dominating the waste composition, and it consisted of vegetable food waste (31-37%) and animal-derived food waste (8-10%). Plastic film (7-10%) and human hygiene waste (7-11%) were also important RHW fractions. The proportion of miss-sorted material fractions was estimated to be 26% of the total RHW, of which 20 to 22% were recyclable material fractions (see Table 3). These results were comparable with those found in a previous Danish study, which found values of 41% food waste, 31% vegetable food waste and 10% animal-derived food waste (Riber et al., 2009). Although, the households in the previous study did not source segregate board, metal and plastic, the percentages of board (7%), plastic (9%), metal (3%) glass (3%), inert (4%) and special waste (1%) were also similar in the two studies. The main differences between these studies were related to the detailed composition of paper and combustible waste. Despite the fact that paper (advertisement, books, magazines and journals, newspapers, office paper and phonebooks) was source-segregated in both studies, in our study paper contributed with 7-9% of the total waste (4% was tissue paper, see Table 4), while Riber et al. (2009) reported a paper content of 16% (mainly advertisement, newsprints and magazines). Although variations in source-segregation schemes may potentially explain these differences, other factors such as sorting guides, income levels, demographics and developments in general consumption patterns may also affect data.

Table 3 about here

3.2 Comparison between municipalities

RHW compositions for the Level I fractions for each sub-area are shown in Figure 2. For all three areas, food and miscellaneous combustible waste were the largest components of the RHW. Paper, board and plastic constituted individually between 5 and 15% of the total RHW. The proportion of special waste was less than 1% and was the smallest fraction of the total RHW.

The waste generation rates for RHW were expressed in kg per person per week and estimated at 3.4±0.2 in Aabenraa, 3.5±0.2 in Haderslev, and 3.5±1.4 in Sønderborg. Waste composition between municipalities showed minor differences. The highest percentage of food (44±3%) and plastic (15±1%), and the lowest percentage of miscellaneous combustible waste (15±4%) were found in Sønderborg. The highest miscellaneous combustible waste (19 ±4%) was in Haderslev, while the highest inert (4±4%) was in Aabenraa.

The composition and the WGRs for each municipality are compared in Table 5 based on the Kruskal-Wallis test. No examples of significant differences in either WGR or waste composition could be observed for the three municipalities. This may indicate that in areas with identical source-segregation systems and similar sorting guides for households, data for individual sub-areas (municipalities) may statistically represent the sub-areas. While this conclusion is only relevant for the specific material composition (Level I) and the socio-economic and geographical context, the results also suggest that the composition data may be applicable to other similar areas (e.g. similar housing types, geography, etc.) in Denmark. In contrast to this, a review of waste composition analyses in Poland (Boer et al., 2010) showed high variability in waste composition and WGR between individual cities. According to Boer et al., 2010, these differences could be attributed to different waste characterisation methods used in each city, and to differences in waste management systems between these cities. Therefore, a consistent waste characterisation methodology was recommended to facilitate any comparison of solid waste composition among these cities.

Table 6 provides an overview of waste compositions corresponding to Level I for a range of studies in literature. Most of these studies found that food waste was the predominant RHW fraction, although the percentage of food waste varied considerably among studies. For instance, food waste accounted for 19% of the total RHW in Canada (Sharma and McBean, 2007), 25% in Wales (Burnley et al., 2007), 30% in Sweden (Bernstad et al., 2012) and 56 % in Spain (Montejo et al., 2011). On the other hand, RHW contained only 12 % of food waste after paper (33%) and wood (24%) in South Korea (Choi et al., 2008). Similarly, in Italy food waste was only 12 % of RHW, which was predominantly made of paper (39%) and plastic (27%) (AMSA, 2008).These differences may be related to: i) socio-economic and geographical factors (consumption patterns, income, climate,) (Khan and Burney, 1989), ii) waste management system (source-segregation, waste collection systems), iii) local regulation (Johnstone, 2004), and iv) waste characterisation methodology (type of waste characterised, terminology as well as waste sampling and characterisation methodologies) (Beigl et al., 2008). The comparison between composition data clearly illustrate the difficulties related to comparison and applicability of aggregated data.

Table 4 about here

3.3 Correlations between waste generation rates and waste fractions

The correlation test identified significant relationships between WGR and composition of RHW as well as among the proportion of individual waste fractions. The correlation test among the proportion of individual waste fractions was carried out to evaluate whether available free space in the RHW bin could influence source-segregation behaviour of the households. The resulting Spearman correlation matrix is shown in Table 7, where both correlation coefficients and their significance levels are provided.

From Table 7, WGR appeared to be negatively correlated with food, gardening waste, plastic, metal and inert waste fractions, and positively correlated with miscellaneous combustibles, board, glass and special waste. However, none of these correlations were statistically significant. This indicated that the percentages of individual waste fractions varied independently of the overall WGR within the study areas. It also suggested that distribution of waste fractions in the RHW might not be estimated based on variations of the overall waste generation rate.

The proportion of glass was negatively and highly significantly correlated with the proportion of food waste (r=-0.81). Likewise, a high negative correlation between miscellaneous combustible waste and gardening waste was observed (r=-0.82). This suggests that when proportions of food waste and miscellaneous combustible waste decreases, the proportions of gardening and glass waste (potentially miss-sorted recyclable glass) increase correspondingly. These results suggest that sorting of glass and gardening waste could be affected by the amounts of food waste and other miscellaneous waste generated by the household.

3.4 Influence of housing type on composition

The weighted composition and WGR for each housing type are presented in Table 8 together with the associated probability values (p-values <0.05 indicate significant difference). RHW from single-family house areas contained significantly higher fractions of food waste than multi-family house areas. On the other hand, RHW from multi-family house areas contained a higher share of paper and glass waste than single-family house areas. However, the p-value (p=0.123) of the Kolmogorov-Smirnov test for the overall difference in waste composition was not significant.

In Austria, Lebersorger and Schneider (2011) found a statistically significant difference between housing types; however, RHW from multi-family house areas had significantly higher percentage of food waste than RHW from single-family house areas. In Poland for example, Boer et al. (2010) showed that the overall household waste composition depended on the type of housing, because of the differences in heating systems of the households.

Figure 2 about here

Table 5 about here

3.5 Influence of sorting practices on composition

Food packaging comprised about 20% of “packed food”, 7% of the total food waste and nearly 3% of the total RHW as shown in Figure 3a. Total food waste consisted of 66% of “unpacked food” waste (30% of the total RHW), 27% of “packed food” waste (12% of the total RHW) and 7% of food packaging.

Table 6 about here

The composition of food packaging is shown in Figure 3b. Food packaging consisted of plastic (50%), paper and board (25%), metal (10%) and glass (13%). These results were comparable to literature data reporting food packaging to represent about 8% of avoidable food waste (Lebersorger and Schneider, 2011), and food packaging consisting of 40% of plastic, 25% of paper, 22% of glass and 13% of metal (Dennison et al., 1996).

Figure 3 about here

Table 9 presents the composition of RHW based on waste sorting and the probability values from the permutation test. For this case study, no statistically significant effect on the percentage of food waste and the overall RHW composition could be observed from sorting practices for food waste (e.g. whether or not packaging was included in the food fraction). This may be explained by the fact that the food packagings were predominently made of plastic only contributing with low mass compared to the food waste and other fractions. Consistently, Lebersorger and Schneider (2011) found that the “packed food” waste had a relative high mass compared to its packagings.

Table 7 about here

Table 8 about here

3.6 Implications for waste characterisation and applicability of composition data

The tiered approach for fractionation of solid waste samples offered sufficient flexibility to organise waste composition data, both at an overall level (e.g. Level I for comparison between municipalities) but also to report more detailed data (for Aabenraa at Level III). The suggested waste fraction list accounted for current European legislation governing the classification of WEEE and HHW, and key characteristics for plastic and metal waste. This type of categorisation enables, to a certain extent, comparison among future and existing studies, and among studies with different focus and need for details. This may potentially increase the applicability of the obtained waste composition data.

Table 9 about here

High data quality is facilitated since the methodology follows appropriate sampling procedures proposed by Dahlén and Lagerkvist (2008) to minimize sampling errors as described by Pitard (1993): i) heterogeneity fluctuation errors were addressed by stratification, ii) fundamental sampling errors due to the heterogeneity of RHW were reduced by sampling at household level from a recommended sample size (100-200 households) to obtain representative results (Nordtest, 2005); iii) grouping and segregation errors, and increment delimitation errors were reduced by avoiding sample splitting and instead sorting the entire waste quantity sampled; and iv) increment extraction errors due to contamination and losses of waste materials were minimized by avoiding compacting the sampled waste during transportation, and sieving before sorting.

The case study showed that detailed waste composition of any miss-placed WEEE and HHW required larger sample sizes than was included here (or alternatively that the household source segregation of these waste types was sufficiently efficient to allow only small amounts in the RHW). As both WEEE and HHW should be collected separately, this observation only refers to miss-placed items in the RHW. General characterization of WEEE and HHW should be carried out based on samples specifically from these flows (this was however outside the scope of the study). The manual sorting of plastic waste into resin type was time consuming as resin identification was needed for each individual plastic item; however, the detailed compositional data provided by this effort offer considerably more information that simple categories such as "recyclable plastic" or "clean plastic". This information is indispensable for national or regional waste statistics as basis for estimating the potential of recycling of postconsumer plastics and environmental sound management of non-recyclable plastics. Furthermore, the plastic characterisation based on resin type is needed as input for detailed life cycle assessment and material flow analyses of plastic waste management.

Separation of food packaging from food leftovers, however, was found unnecessary because this division into sub-fractions did not significantly influence the waste composition; this clearly reduces time invested in the sorting campaign, but also improves the hygienic conditions during the sorting process. As the statistical analyses indicated no statistical difference in waste composition between municipalities, waste composition data obtained from one municipality could be applied to other municipalities in the study area (provided the municipalities share source-segregation schemes). This may be used as a basis for reducing the sampling area (and thereby overall waste quantities) in a sampling campaign. However, the statistical differences observed between housing types in relation to food, paper and glass waste indicated that representative sampling of RHW should account for variations in housing types between areas.

The correlation test showed no statistically significant relationship between the percentage of individual waste fractions and the generation rate of RHW. This indicates that for a specific area (with consistent socio-economic and geographical conditions), waste composition data could be extrapolated and scaled up to the entire municipality or down to individual town-level, regardless of the waste generation rate. The correlation analysis among proportions of individual waste fractions showed that the percentages of miss-sorted glass and gardening waste increases when the proportion of food waste (glass) and miscellaneous waste (gardening waste) decrease. Moreover, when the proportion of miss-sorted glass increases, the proportions of miss-sorted board and metal also increase.

4 Conclusions

The study introduced a tiered approach to waste sorting campaigns involving three levels of waste fractions. This allowed comparison of waste datasets at different level of complexity, e.g. involving different numbers of material fractions. This tiered fraction list was applied on a case study involving residual household waste (RHW) from 10 sub-areas within three municipalities. Sub-areas in two municipalities were sorted only at the first level (overall waste fractions), while waste from one municipality was sorted to the third level (e.g. two sub-levels below the overall waste fractions). The obtained waste data (generation rates and composition) for the individual sub-areas were compared for identification of significant differences between the areas. Based on the statistical analysis, it was found that while overall waste composition and generation rates were not significantly different between the three municipalities, the waste composition from single-family and multi-family houses were different. This indicates that while waste composition data may be transferred from one municipality to another (provided the source-segregation schemes are sufficiently similar), differences in housing types cannot be ignored. As opposed to a more "linear" waste fraction catalogue, the three-level fraction list applied in this study allowed a systematic comparison across the datasets of different complexity.

The results of the sorting analysis indicated that food packaging did not significantly influence the overall composition of the waste as well as the proportions of food waste, plastics, board, glass and metal. Specific separation of food packaging from food leftovers during sorting was therefore not critical for determination of the waste composition.

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Supplementary material

Supplementary material contains background information about the data used for calculations and detailed data from the waste characterisation campaign.

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Tables

Table 1: Overview of the sub-areas, number of household per stratum and amount of waste sampled and analysed

Municipalities	Housing type	Number of household per sampling unit	Amount analysed (kg wet
Aabenraa	Single- family	100	1,500
	Multi-family	106	600
	Multi-family	220	1,100
Haderslev	Single- family	94	2,200
	Single- family	100	1,700
	Single- family	100	1,400
	Multi-family	333	3,300
Sønderborg	Single- family	105	2,200
	Single- family	164	2,200
	Multi-family	120	600
Total		1,442	16,800

Table 2: The waste fractions list showing three different levels (Level I, Level II, and Level III)

Level I	**Level II**	**Level III**
1-Food waste	1.1 Vegetable food waste; 1.2 Animal-derived food waste	-
2-Gardening waste	2.1 Dead animal and animal excrements (excluding cat litter); 2.2 Garden waste	2.1.1 Dead animals; 2.1.2 Animal excrement bags from animal excrement 2.2.1 Humid soil; 2.2.2 Plant material; 2.2.3 Woody plant material; 2.2.4 Animal straw.
3-Paper	3.1 Advertisements; 3.2 Books & booklets; 3.3 Magazines & Journals; 3.4 Newspapers; 3.5 Office paper; 3.6 Phonebooks; 3.7 Miscellaneous paper.	3.7.1 Envelopes; 3.7.2 Kraft paper; 3.7.3 Other paper; 3.7.4 Receipts; 3.7.5 Self-Adhesives; 3.7.6 Tissue paper; 3.7.7 Wrapping paper
4-Board	4.1 Corrugated boxes; 4.2 Folding boxes; 4.3 Cartons/plates/cups; 4.4 Miscellaneous board.	4.4.1 Beverage cartons; 4.4.2 Paper plates & cups; 4.4.3 Cards & labels; 4.4.4 Egg boxes & alike; 4.4.5 Other board; 4.4.6 Tubes.
5-Plastic	5.1 Packaging plastic; 5.2 Non-packaging plastic; 5.3 Plastic film.	5.i.1 PET/PETE [a]; 5.i.2 HDPE[b]; 5.i.3 PVC/V[c]; 5.i.4 LDPE/LLDPE[d]; 5.i.5 PP[e]; 5.i.6 PS[f]; 5.i.7 Other plastic resins labelled with[1-19] ABS[g]; 5.i.8 Unidentified plastic resin; 5.3.1 Pure plastic film; 5.3.2 Composite plastic + metal coating.
6-Metal	6.1 Metal packaging containers; 6.2 Non-packaging metals; 6.3 Aluminium wrapping foil	6.i.1 Ferrous; 6.i.2 Non-ferrous (with i=1&2).
7-Glass	7.1 Packaging container glass; 7.2 Table and kitchen ware glass; 7.3 Other/special glass.	7.i.1 Clear; 7.i.2 Brown; 7.i.3 Green.
8-Miscellaneous combustibles	8.1 Composites, human hygiene waste (Diapers, tampons, condoms, etc.); 8.2 textiles, leather and rubber; 8.3 Vacuum cleaner bags; 8.4 Untreated wood; 8.5 Other combustible waste.	8.1.1 Diapers; 8.1.2 Tampons; 8.1.1 Condoms; 8.2.1 Textiles; 8.2.2 Leather; 8.2.3 Rubber;
9-Inert	9.1 Ashes from households; 9.2 Cat litter; 9.3 Ceramics, gravel; 9.4 Stones and sand; 9.5 Household constructions & demolition waste.	-
10-Special waste	10.1 Single Batteries/ non-device specific Batteries; 10.2 WEEE; 10.3 Other household hazardous waste.	10.3.1Large household appliances; 10.3.2 Small household appliances; 10.3.3 IT and telecommunication equipment; 10.3.4 Consumer equipment and photovoltaic panels; 10.3.5 Lighting equipment; 10.3.6 Electrical and electronic tool (no large-scale stationary tools), 10.3.7 Toys, leisure and sports equipment; 10.3.8 Medical devices (except implanted and infected products); 10.3.9 Monitoring and control instruments; 10.3.10 Automatic dispensers.

[a] Polyethylene terephthalate; [b] density polyethylene; [c] Polyvinyl-chloride; [d] Low density polyethylene; [e]: Polypropylene; [f]: Polystyrene; [g]: Acrylonitrile/butadiene/styrene
Numbering of waste fractions: n- fractions included in Level I, n.n fractions included in Level II, n.n.n fractions included in Level III;

Table 3: Waste composition (% mass per wet basis) of RWH from Aabenraa-Level I & II

Fractions (Level II)	**SF**[d] (%w/w[a])	**MF** (%w/w[a])
Food waste		
Vegetable food waste	36.5	31.3
Animal-derived food waste	8.1	9.5
Gardening waste		
Dead animal and animal excrements (exclude cat litter)	0.5	0.3
Garden waste etc.	4.8	3.1
Paper		
Advertisements[a]	0.9	2.8
Books & booklets[a]	0.1	0.4
Magazines & Journals[a]	0.3	0.5
Newspapers[a]	0.5	0.8
Office paper[a]	0.7	0.4
Phonebooks[a]	0.0	0.0
Miscellaneous paper	4.6	4.2
Board		
Corrugated boxes[a]	0.4	0.7
Folding boxes[a]	1.5	2.0
Beverage cartons	4.6	3.3
Miscellaneous board	0.8	0.6
Plastic		
Non-packaging plastic	0.5	0.9
Packaging plastic[a]	5.1	4.5
Plastic film	9.8	6.6
Metal		
Metal packaging containers[a]	1.3	1.9
Aluminium wrapping foil	0.0	0.0
Non-packaging metals	0.6	0.7
Glass		
Packaging container glass[a]	1.8	2.2
Table and kitchen ware glass[a]	0.2	0.0
Other/special glass[a]	0.1	0.1
Miscellaneous combustible		
Human hygiene waste (Diapers, tampons, condoms, etc.)	7.3	10.8
Wood untreated	0.6	0.3
Textiles, leather and rubber	2.8	2.4
Vacuum cleaner bags	1.1	0.4
Other combustible waste	2.4	5.6
Inert		
Ashes from households	0.0	0.0
Cat litter	0.8	2.3
Ceramics	0.2	0.3
Gravel, stones and sand	0.3	0.6
Household construction & demolition waste[b]	0.1	0.1
Special waste[b]		
Single Batteries/ non device specific Batteries	0,1	0.1
WEEE	0,3	0,1
Other household hazardous waste	0,3	0.2
Total	100	100

[a]Miss-sorted recyclable material fractions; [b]Miss-sorted other material fractions; [c] Composition of single-family as% wet weight;
[d] Composition of multi-family as (% mass per wet basis)

Table 4: Detailed waste composition (% mass per wet basis) of RWH from Aabenraa focusing on Level III

Fractions (Level I)	Fractions (Level II&III)	SF[d] (%w/w[a])	MF[c] (%w/w[a])
Food waste		44.6	40.8
Gardening waste			
	Dead animal and animal excrements (exclude cat litter)	0.5	0.3
	Garden waste etc.		
	Humid soil	0.8	0.2
	Plant material	3.5	2.4
	Woody plant material	0.5	0.0
Paper			
	Other paper[e]	2.5	4.9
	Miscellaneous paper		
	Tissue paper	4.1	3.8
	Envelopes[a]	0.1	0.2
	Kraft paper	0.1	0.0
	Wrapping paper	0.1	0.0
	Other paper	0.2	0.1
Board			
	Other board[f]	6.5	6.0
	Corrugated boxes[a]		
	Egg boxes&alike[a]	0.1	0.1
	Cards&labels[a]	0.1	0.1
	Board tubes[a]	0.3	0.3
	Other board	0.2	0.1
Plastic			
	Non-packaging plastic		
	1-PET	0.0	0.0
	2-HDPE	0.0	0.0
	3-PVC	0.0	0.0
	4-LDPE	0.0	0.0
	5-PP	0.1	0.2
	6 PS	0.0	0.5
	7-19	0.0	0.0
	Unspecified	0.4	0.3
	Packaging plastic[a]		
	1-PET	1.1	0.6
	2-HDPE	0.9	1.1
	3-PVC	0.0	0.5
	4-LDPE	0.0	0.0
	5-PP	1.4	0.4
	6 PS	0.4	1.2
	7-19	0.0	0.0
	Unspecified	1.4	0.8
	Plastic film		
	Pure plastic film	9.0	6.1
	Composite plastic + metal coating	0.8	0.6
Metal			
	Metal packaging containers[a]		
	Ferrous	0.8	1.1
	Non-ferrous	0.5	0.8
	Aluminium wrapping foil	0.0	0.0
	Non-packaging metals		
	Ferrous	0.3	0.4
	Non-ferrous	0.3	0.3
Glass			
	Packaging container glass[a]		
	Clear	0.0	0.3
	Brown	1.8	1.7
	Green	0.0	0.2
	Table and kitchen ware glass[a]	0.2	0.0
	Other/special glass[a]	0.1	0.1
Miscellaneous combustible		14.1	19.5
Inert		1.3	3.2
Special waste[a]		0.7	0.5

Total	100	100

[a] Miss-sorted recyclable material fractions; [b]Miss-sorted other material fractions; [c] Composition of single-family houses areas as% wet weight; [d] Composition of multi-family houses areas as (% mass per wet basis);[e] Advertisements, books & booklet, magazines & journals, newspaper, office paper, phonebook; [f]Corrugated boxes, folding boxes, beverage cartons

Table 5: Composition (% mass per wet basis) of RHW as function of municipality and associated probability values from the Kruskal-Wallis test. The last row shows the WGR (kg/per/week)

Fractions (Level1)	Aabenraa (%w/w[a])	Haderslev (%w/w[a])	Sønderborg (%w/w[a])	p-value
Food waste	42.8 ± 5.2	41.7 ± 6.4	43.8 ± 3	0.999
Gardening waste	3.8 ± 1.0	2.6 ± 1.0	5 ± 1.7	0.565
Paper	8.3 ± 1.0	8.9 ± 2.4	7.6 ± 1.2	0.993
Board	7.1 ± 1.0	8.1 ± 1.6	7.1 ± 0	0.387
Plastic	12.6 ± 1.2	11.7 ± 0.5	14.8 ± 0.6	0.457
Metal	2.3 ± 0.6	2.2 ± 0	2.0 ± 0.6	0.984
Glass	1.7 ± 0.6	2.3 ± 1.3	2.1 ± 2	0.387
Miscellaneous combustible	17.6 ± 3.5	19 ± 3.6	15.2 ± 3.5	0.812
Inert	3.5 ± 3.5	2.5 ± 1.5	1.7 ± 1.5	0.731
Special waste	0.4 ± 0.6	1.0 ± 0.8	0.7 ± 0.6	0.314
WGR (kg per person per week)	3.4 ± 0.2	4.3 ± 1.5	3.5 ± 1.4	0.689

Data are presented as Mean ± Standard deviation; Significant level: $p<0.05$; a: (mass per wet basis)

Table 6: Review of household solid waste composition (% mass per wet basis)

Country	Organic/ Food waste	Gardening waste	Paper & board	Glass	Metal	Plastic	Miscellaneous combustible	Inert	Special waste	Fines	Total
DK1[a]	42.2	3.5	15.8	12.6	2.3	2.1	17.6	3.3	0.7	-	100
DK2[b]	41	4.1	23.2	9.2	3.3	2.9	12.2	3.5	0.7	-	100
ES[c]	56.2	1.84	19.04	3.3	2.96	10.67	4.927	0.69	0.12		100
FI[d]	23.9	-	15.3	2.5	3.8	21.4	19.9	10.4	1.7	-	100
IT1[e]	30.1	3.9	23.2	5.7	3.3	10.8	4.5	1.3	8.7	9.4	100
IT2[f]	12.6	-	39.2	5.9	2.4	27.6	14.2				100
PL[g]	23.7		14.1	9.2	2.1	10.8	10.6	4.5	1	24.1	100
SE1[h]	33	9.4	24	2.4	2.2	11.7	9.6	7	0.6	-	100
UK[i]	32.8	-	21.5	10.6	4.8	6.9	9.3	12.5	1.5	-	100
UK[j]	20.2	-	33.2	9.3	7.3	10.2	12	1.8		6.8	100
TR[k]	67	0	10.1	2.5	1.3	5.6	9.7	3.9	-	-	100
KR[l]	12	-	33	-	-	17	32	6	-	-	100
CA[m]	18.8	5.6	32.3	3.1	3.4	13.1	14.0	2.9	5.9		100
MA[n]	44.8		16	3	3.3	15	9.5	8.4	-	-	100

[a] *Current study*
[b] *Denmark (Riber et al., 2009)*
[c]. *Spain (Montejo et al.,2011)*
[d]. *Finland (Horttanainen et al., 2013)*
[e]. *Italy (Arena et al., 2003)*
[f]. *Italy (AMSA, 2008)*
[g]. *Poland (Boer et al., 2010)*
[h]. *Sweden (Petersen, 2005)*
[i]. *United Kingdom (Burnley, 2007)*
[j]. *United Kingdom (Wales) (Burnley et al., 2007)*
[k]. *Turkey (Banar et al., 2009)*
[l]. *Korea (Choi et al., 2008)*
[m]. *Canada (Sharma and McBean, 2007)*
[n]. *Malaysia (Moh and Abd Manaf, 2014)*

Table 7: Correlation matrix from Spearman´s correlation test (r: range =-1.00 - + 1.00)

	Food	Gardening waste	Paper	Board	Plastic	Metal	Glass	M. combustible[a]	Inert	Special waste	WGR[b]
Food	1						**				
Gardening waste	0.03	1			*			**			
Paper	-0.44	-0.21	1								
Board	-0.49	0.09	0.08	1			*			*	
Plastic	-0.32	0.77	-0.19	0.19	1			+			
Metal	-0.54	-0.35	0.07	0.49	0.03	1	*				
Glass	-0.81	-0.15	0.43	0.67	0.04	0.7	1			+	
M. combustible[a]	-0.24	-0.82	0.36	-0.07	-0.58	0.09	0.15	1			+
Inert	-0.24	0.28	0.08	0.1	0.36	0.3	0.12	-0.52	1		
Special waste	-0.47	0.21	0.07	0.73	0.38	0.22	0.6	-0.08	0.1	1	
WGR[b]	-0.36	-0.28	0.38	0.31	-0.21	-0.26	0.24	0.64	-0.49	0.33	1

(**) high significance probability between 0.001 and 0.01; (*) medium significance, probability between 0.01 and 0.05; (+) weak significance-probability between 0.05 and 0.10; () no significance-probability higher than 0.1

[a] Miscellaneous combustible; [b] waste generation rate (kg RHW per person per week)

Table 8: Composition (% mass per wet basis) of RHW as function of housing type and associated probability values from the permutation test

Fractions (Level1)	Single-family (%w/w[a])	Multi-family (%w/w[a])	p-value
Food waste**	45 ± 1.3	36.2 ± 3.9	0.003
Gardening waste	3.9 ± 1.2	3.7 ± 1.7	0.799
Paper*	7.6 ± 1.4	10.0 ± 1.0	0.030
Board	7.0 ± 0.9	8.4 ± 1.4	0.375
Plastic	13.1 ± 0.5	12.9 ± 0.5	0.931
Metal	1.9 ± 0	2.8 ± 0.6	0.065
Glass*	1.7 ± 1.6	2.8 ± 1.0	0.042
Miscellaneous combustible	17.3 ± 3.1	17.2 ± 3.8	0.638
Inert	1.9 ± 1.9	4.9 ± 2.8	0.286
Special waste	0.5 ± 0.5	1.0 ± 0.8	0.353
WGR (kg per person per week)	3.7 ± 0.8	4.0 ± 1.5	0.652

Data are presented as Mean ± Standard deviation; Significant level: (*) 0.05, (**) 0.01; a.: (% mass per wet basis)

Table 9: Waste composition (% mass per wet basis) based on food packaging sorting procedure and the associated probability values from the permutation test.

Fractions	Not Included[a] (% w/w[c])	Included[b] (% w/w[c])	P-value
Food waste	45.1 ± 2.8	42.1 ± 2.7	0.50
Gardening waste	4.1 ± 2.2	4.1 ± 2.2	1.00
Paper	8.4 ± 1.1	8.4 ± 1.1	1.00
Cardboard	6.1 ± 0.4	6.8 ± 0.4	0.30
Glass	1.9 ± 0.3	2.2 ± 0.3	0.30
Metal	2.1 ± 1	2.4 ± 0.9	0.50
Plastic	11.5 ± 1.9	13.2 ± 2.2	0.60
Miscellaneous combustible	17.7 ± 3.3	17.7 ± 3.3	1.00
Inert	2.6 ± 1.5	2.6 ± 1.5	1.00
Special waste	0.6 ± 0.2	0.6 ± 0.2	1.00

Sample size (Number of household) 426; Data are presented as Mean ± Standard deviation; Significant level: $p<0.05$;
a.: food and its packaging were sorted as food waste; b.: food packaging was separated from food; c.: % mass per wet basis;"

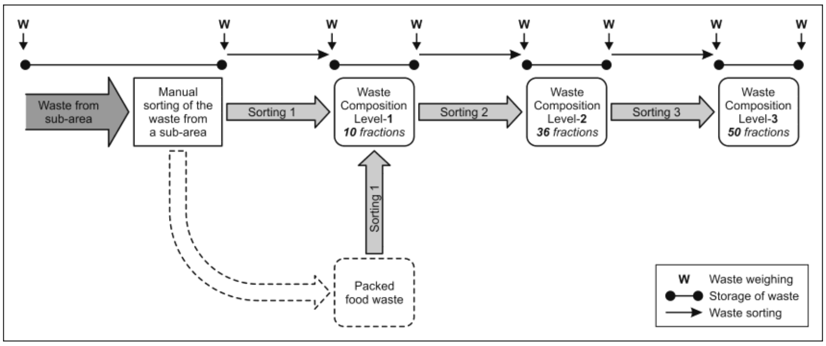

Fig. 1. Schema of waste sorting procedure

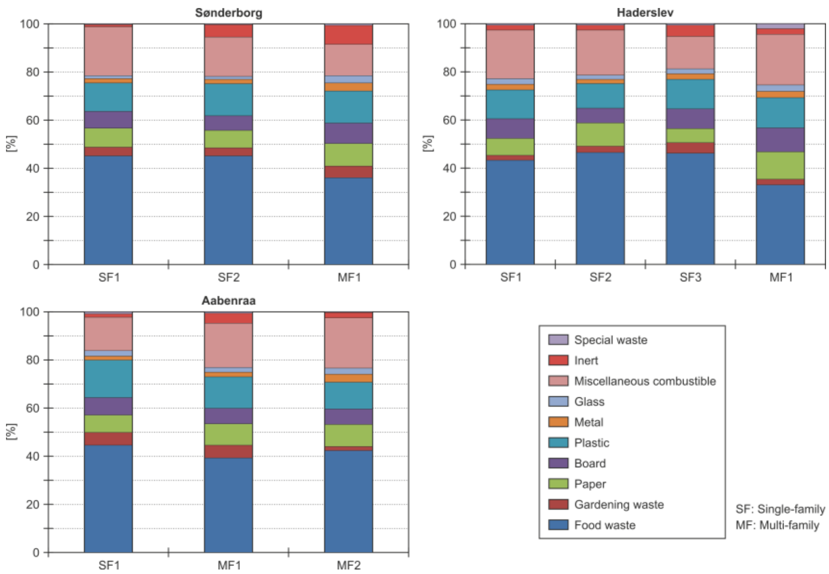

Fig. 2. Composition of residual household waste (% of wet mass) per municipality according to housing types.

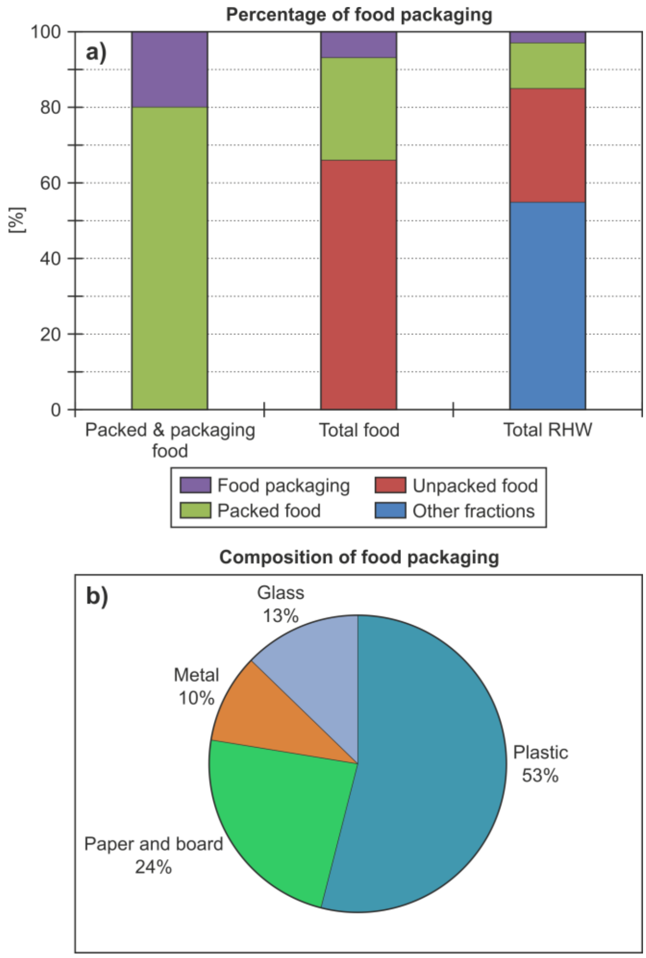

Fig. 3. Percentage of food packaging (% wet mass) in different waste types (a) and composition of packaging (%wet mass) from food waste (b).

Supplementary materials

Supplementary material contain background information used for calculation and detailed data from the waste sampling campaign.

A: Overall composition of household based on housing type in the study area-Unit is percentage of household

Municipalities	Housing type	SF (%)	MF (%)
Sønderborg	Single- family SF1	30	-
	Single-family SF2	9	-
	Multi-family MF1	-	42
Haderslev	Single- family SF1	11	-
	Single- family SF2	11	-
	Single- family SF3	5	
	Multi-family MF1	-	33
Aabenraa	Single- family SF1	33	-
	Multi- family MF1	-	12
	Multi-family MF2	-	12
Total		100	100

Source: Calculated based on data from Statistics Denmark

B: Overall composition of household based on housing type and municipalities in the study area-Unit: percentage of households

Housing type	Sønderborg (%)	Haderslev (%)	Aabenraa(%)
Single-family SF1	56	29	80
Single-family SF2	17	29	-
Single-family SF3	0	14	-
Multi-family MF1	27	28	10
Multi-family MF2	0	0	10
Total	100	100	100

Source: Calculated based on data from Statistics Denmark

C: Overview of total waste sampled and sorted- Unit: mass per wet basis in kg

Municipalities	Dwelling type	APH[a]	Food waste	Gardening waste	Paper	Board	Plastic	Metal	Glass	MC[b]	Inert	Special waste	TotalW[c].
Sønderborg	SF1	2.3	996	75	177	149	263	41	27	442	23	6	2,200
Sønderborg	SF2	2.3	990	77	158	131	295	42	23	361	112	10	2,200
Sønderborg	MF1	1.6	217	29	56	51	80	20	18	79	47	4	600
Harderslev	SF1	2.4	950	50	154	177	262	50	53	448	40	15	2,200
Harderslev	SF2	2.4	792	41	165	106	171	31	32	317	37	8	1,700
Harderslev	SF3	2.4	649	61	79	115	174	34	28	186	67	8	1,400
Harderslev	MF1	1.6	1,088	77	379	324	422	80	95	687	81	67	3,300
Aabenraa	SF1	2.3	668	80	108	109	232	28	31	212	20	11	1,500
Aabenraa	MF1	1.6	236	32	52	40	78	11	12	110	26	3	600
Aabenraa	MF2	1.6	466	17	102	72	122	37	29	228	23	4	1,100

[a.]Average persons per household; [b.]Miscellaneous combustible waste; [c] total waste sorted;

D: Summary of the mass loss during waste sorting process

Descriptive statistics	Loss(%)	W1(mass per wet basis in kg)	W2(mass per wet basis in kg)
N*	76	76	76
Mean	1.7	16.4	16.1
Median	1.3	12.5	12.3
10% Trimmed Mean	1.6	13.4	13.2
1st Quartile	0.8	10.3	10.1
3rd Quartile	2.3	17.4	17.1
Standard Deviation	1.1	16.9	16.6
Interquartile Range	1.5	7.1	7.0
Median Absolute Deviation	1.0	4.5	4.6

N*: number of paper sacks;
Loss (%) is mass loss during the waste sorting and storage processes;: Loss=((W1-W2)/W1)*100, with W1=net wet mass of waste before sorting, W2: net wet mass of waste after sorting;
The average mass loss due to evaporation is 1.7%, which is below 3%.