



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

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1 2nd revision of manuscript.

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3 **Municipal Solid Waste Composition:**  
4 **Sampling methodology, statistical**  
5 **analyses, and case study evaluation**

6

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21 **Abstract**

22 Sound waste management and optimisation of resource  
23 recovery require reliable data on solid waste generation and  
24 composition. In the absence of standardised and commonly  
25 accepted waste characterization methodologies, various  
26 approaches have been reported in literature. This limits both  
27 comparability and applicability of the results. In this study, a  
28 waste sampling and sorting methodology for efficient and  
29 statistically robust characterisation of solid waste was  
30 introduced. The methodology was applied to residual waste  
31 collected from 1442 households distributed among 10  
32 individual sub-areas in three Danish municipalities (both single  
33 and multi-family house areas). In total 17 tonnes of waste were  
34 sorted into 10-50 waste fractions, organised according to a  
35 three-level (tiered approach) facilitating comparison of the  
36 waste data between individual sub-areas with different  
37 fractionation (waste from one municipality was sorted at "Level  
38 III", e.g. detailed, while the two others were sorted only at  
39 "Level I"). The results showed that residual household waste  
40 mainly contained food waste ( $42\pm 5\%$ , mass per wet basis) and  
41 miscellaneous combustibles ( $18\pm 3\%$ , mass per wet basis). The  
42 residual household waste generation rate in the study areas was  
43 3-4 kg per person per week. Statistical analyses revealed that  
44 the waste composition was independent of variations in the  
45 waste generation rate. Both, waste composition and waste

46 generation rates were statistically similar for each of the three  
47 municipalities. While the waste generation rates were similar  
48 for each of the two housing types (single-family and multi-  
49 family house areas), the individual percentage composition of  
50 food waste, paper, and glass was significantly different between  
51 the housing types. This indicates that housing type is a critical  
52 stratification parameter. Separating food leftovers from food  
53 packaging during manual sorting of the sampled waste did not  
54 have significant influence on the proportions of food waste and  
55 packaging materials, indicating that this step may not be  
56 required.

57 **Key words:**

58 Residual household waste

59 Waste generation rate

60 Waste fractions

61 Statistical analysis

62 Waste sampling

63 Waste composition

64

## 65 **1 Introduction**

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

88       The quality of waste composition data are highly affected  
89 by the sampling procedure (Petersen et al., 2004). Solid waste

90 sampling may often involve direct sampling, either at the  
91 source (e.g. household) (WRAP, 2009) or from a vehicle load  
92 (Steel et al., 1999). Vehicle load sampling is often carried out  
93 by sampling the waste received at waste transfer stations  
94 (Wagland et al., 2012), waste treatment facilities, e.g. waste  
95 incinerators (Petersen, 2005), and landfill sites (Sharma and  
96 McBean, 2009; Chang and Davila, 2008). While logistic  
97 efforts can be reduced by sampling at the point of unloading of  
98 waste collection vehicles, a main drawback of this approach  
99 may be that the sampled waste cannot be accurately attributed  
100 to the geographical areas and/or household types generating  
101 the waste (Dahlén et al., 2009). This limits the applicability of  
102 the obtained composition data. On the other hand, collecting  
103 waste directly from individual households and/or from a  
104 specific area with a certain household type, allow the waste  
105 data to be associated with the specific area (Dahlén et al.,  
106 2009). Additionally, as most modern waste collection trucks  
107 use a compaction mechanism (Nilsson, 2010), waste fractions  
108 sampled from such vehicles have been affected by mechanical  
109 stress and blending, which leads to considerable difficulties in  
110 distinguishing individual material fractions during manual  
111 sorting (European Commission, 2004). Owing to the  
112 mechanical stress and the blending processes from collection  
113 trucks, cross-contamination between individual fractions may  
114 occur, leading to further inaccuracies that can neither be

115 measured nor corrected afterwards.

116 To ensure uniform coverage of the geographical area  
117 under study, stratification sampling is often applied. This  
118 involves dividing the study area into non-overlapping sub-  
119 areas with similar characteristics (Dahlén and Lagerkvist,  
120 2008; Sharma and McBean, 2007; European Commission,  
121 2004).

122 In order to reduce the volume (amount) of waste to be  
123 sorted, the waste sampled from each sub-area is usually coned  
124 and quartered before sorting into individual waste material  
125 fractions (Choi et al., 2008; Martinho et al., 2008). Although  
126 this reduces labour intensity, the approach has shown to  
127 generate poorly representative samples (Gerlach et al., 2002).  
128 Because of the heterogeneity of residual household waste  
129 (RHW), the material in a waste pile (or cone) is unevenly  
130 distributed (Klee, 1993). Instead, sampling from elongated flat  
131 piles and from falling streams at conveyor belts is  
132 recommended to generate more representative samples (De la  
133 Cruz and Barlaz, 2010, Petersen et al., 2005). While elongated  
134 flat piles can be used on most waste materials, sampling from  
135 falling streams at conveyor belts may potentially induce  
136 additional mechanical stress if not appropriately applied.  
137 However, only few studies have applied these mass reduction  
138 principles for solid waste sampling prior to the manual sorting  
139 in fractions. The waste sampled from a specific sub-area could

140 also be split into a desired or calculated number of sub-samples  
141 (European Commission, 2004, Nordtest, 1995). This method  
142 can provide mean and standard deviation for each waste  
143 fraction, and may be argued as cost-effective (Sharma and  
144 McBean, 2007). However, the main drawback is the splitting,  
145 which can introduce a bias. Additionally, the obtained standard  
146 deviations are highly associated with the number of samples  
147 and the size (mass or volume) of the samples, which vary  
148 considerably across literature (Dahlén and Lagerkvist, 2008).  
149 In order to avoid any bias from mass reduction , sorting all the  
150 collected waste from an individual sub-area would be  
151 necessary (Petersen et al., 2004).

152 In addition to the influence from waste sampling, also the  
153 subsequent sorting procedures can influence the results for  
154 household waste composition. The overall material fraction  
155 composition is directly related to the sorting principles applied  
156 for dividing waste materials into individual fractions, e.g. to  
157 which extent is food packaging and food materials separated,  
158 how are composite materials handled, and how detailed  
159 material fractions are included in the study? The influence of  
160 food waste sorting procedures has been investigated by  
161 Lebersorger and Schneider (2011). While the influence of food  
162 packaging on food waste in this particular case was shown to  
163 be insignificant, the influence of food packaging on other  
164 material fractions in the waste (e.g. packaging material) has



165 not been examined.

166       Inconsistencies among existing solid waste  
167 characterisation studies, e.g. definitions of waste fractions,  
168 may cause confusion and limit comparability of waste  
169 composition data between studies (Dahlén and Lagerkvist,  
170 2008). While Riber et al. (2009) published a detailed waste  
171 composition for household waste, including 48 waste material  
172 fractions, more transparent and flexible nomenclature for the  
173 individual waste material fractions is needed to allow full  
174 comparability between studies with varying numbers of  
175 material fractions and sorting objectives. Such classification  
176 principles exist, but only for certain waste types and often  
177 developed for other purposes: e.g. classification of plastics  
178 based on resin type (Avella et al., 2001), the European Union's  
179 directive on Waste Electrical and Electronic Equipment  
180 (WEEE) (European Commission, 2003) and grouping of  
181 Household Hazardous Waste (HHW) (Slack et al., 2004).

182       The overall aim of the paper was to provide a consistent  
183 framework for municipal solid waste characterisation activities  
184 and thereby support the establishment of transparent waste  
185 composition datasets. The specific objectives were to: i)  
186 introduce a waste sampling and sorting methodology involving  
187 a tiered list of waste fractions (e.g. a sequential subdivision of  
188 fractions at three levels), ii) apply this methodology in a  
189 concrete sampling campaign characterising RHW from 10

190 individual sub-areas located in three different municipalities,  
191 iii) evaluate the methodology based on statistical analysis of  
192 the obtained waste datasets for the 10 sub-areas, focusing on  
193 the influence of stratification criteria and sorting procedures  
194 (e.g. the influence of sorting of food waste packaging on other  
195 packaging materials), and iv) identify potential trends among  
196 sub-areas in source-segregation efficiencies.

## 197 **2 Materials and methods**

### 198 **2.1 Definitions**

199 RHW refers to the remaining mixed waste after source  
200 segregation of recyclables and other materials, such as HHW,  
201 WEEE, gardening and bulky waste. Bulky waste refers to  
202 waste such as furniture, refrigerators, television sets, and  
203 household machines (Christensen et al., 2010). Source-  
204 segregated material fractions found in the residual household  
205 waste are considered as miss-sorted waste fractions. Housing  
206 type consists of single-family and multi-family house. Here  
207 single-family house corresponds to households with their own  
208 residual waste bin, while multi-family house corresponds to  
209 households sharing residual waste bins, e.g. common  
210 containers in apartment buildings. Food packaging is  
211 packaging containing food remains or scraps. "Packed food"  
212 waste represents food items inside packaging while "unpacked  
213 food" waste is food discarded without packaging. Within this  
214 paper, the terms "fraction" and "component" was used

215 interchangeably. The data are presented as mean and standard  
216 deviation (Mean $\pm$ SD) unless otherwise indicated.

## 217 **2.2 Study area**

218 The sampling campaign covered residual waste collected from  
219 households in three Danish municipalities: Aabenraa,  
220 Haderslev and Sønderborg. These municipalities have the same  
221 waste management system including the same source  
222 segregation scheme. They introduced a waste sorting system  
223 using a two-compartment wheeled waste bin for separate  
224 collection of recyclable materials from single-family house  
225 areas (Dansk Affald, 2013). One compartment was used for  
226 collection of mixed metal, plastic, and glass; the other  
227 compartment for mixed paper, board, and plastic foil. However,  
228 in multi-family house areas, a Molok system and joint full  
229 service collection points (joint wheeled container) were used  
230 for the collection of RHW and source-sorted materials for  
231 recyclables. The waste bins had volumes between 60 to 360  
232 litres in the single-family house area and between 400 to 1000  
233 litres in the multi-family house area.

234           Collection frequencies for the residual waste were every  
235 two weeks in single-family house areas and every week in  
236 multi-family house areas. Garden waste, HHW, WEEE and  
237 bulky waste from single and multi-family house areas could be  
238 disposed of, either at recycling stations or collected from the  
239 premises on demand. However, food waste was not separately

240 collected and was disposed of in the RHW bin. This study  
241 focused not on the source-segregated materials (bulky waste,  
242 garden waste, and other source-segregated materials), but rather  
243 on the characterisation of the residual waste consisting of a  
244 mixed range of materials of high heterogeneity.

### 245 **2.3 Waste sampling procedure**

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

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

259           A single RHW collection route was selected in each  
260 sub-area by the municipal authorities responsible for the solid  
261 waste management. The distribution of households along the  
262 selected routes was representative for each sub-area with  
263 respect to the volume of RHW bins and the size of the  
264 households. The number of selected households in each sub-

265 area was between 100 and 200, as recommended by Nordtest  
266 (1995).

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

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

282           *Table 1 about here*

## 283 **2.4 Sorting procedure**

284 In order to avoid errors from waste splitting, the entire waste  
285 sampled from each sub-area was sorted as a “batch” and the  
286 waste from the 10 sub-areas was treated each as a “single  
287 sample”, resulting in 10 individual samples from the three  
288 municipalities. This means that as a result of the sorting  
289 campaign, waste data (waste composition and waste generation)

290 for 10 individual sub-areas were obtained.

291 For this reason, the waste was collected separately from  
292 each sub-area without compacting (e.g. the waste was not  
293 collected by a compaction vehicle). The waste was then  
294 transported to a sorting facility, where it was unloaded on a  
295 tarpaulin, and filled in paper sacks for weighing and temporary  
296 storage. The paper sacks were labelled with ID numbers. Each  
297 paper sack was weighed to obtain the “dry mass” before filling  
298 in the waste. Thereafter, the filled paper sacks were weighed  
299 before and after all sorting activities to quantify mass losses  
300 during sorting and storage. The mass loss was calculated as the  
301 difference in net mass of waste before and after a process. The  
302 errors due to contamination during sorting process and storage,  
303 e.g. the migration of moisture from food waste to other  
304 components (paper, board, plastic, etc.) and paper sacks, and  
305 evaporation was negligible (see Supplementary material D for  
306 mass losses). The average mass loss was 1.7%, and thus below  
307 3% (Lebersorger and Schneider, 2011). No adjustments of the  
308 waste data from errors due to mass losses were applied in this  
309 study.

310 Figure 1 illustrates the waste sorting procedure and the steps  
311 applied. A tiered approach for material fraction sorting was  
312 developed as illustrated by Levels I to III in Table 2, to allow  
313 comparison between datasets with different needs for sorting  
314 and data aggregation. For example, one study may focus on

315 detailed fractionation of food waste (e.g. addressing avoidable  
316 and non-avoidable food), while another study may only wish to  
317 characterize food waste by a few overall fractions (e.g.  
318 vegetable and animal derived food waste). Categorizing the  
319 fractions in levels (e.g. Levels I to III) would thereby still allow  
320 comparison between such two studies, at an overall level. In the  
321 context of the sub-areas, all collected waste from each sub-area  
322 was sorted separately. This was done according to Level I in  
323 Table 2, corresponding to 10 material fractions. To provide  
324 further details, waste from one municipality (Aabenraa) was  
325 selected for more detailed sorting according to Level II & III.  
326 The waste from Haderslev and Sønderborg was sorted only at  
327 Level I. As such, the datasets from these three municipalities  
328 represent examples of sorting campaigns carried out at different  
329 levels of complexity; nevertheless, the tiered approach allows  
330 comparison between the datasets at Level I.

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

338           All waste fractions from Aabenraa, including food  
339 packaging containing remaining food leftovers were





365 classification while still facilitating flexible grouping of waste  
366 fractions and comparison between the individual areas. For  
367 example, we used food waste and gardening waste instead of  
368 organic waste, which by definition includes more than food  
369 waste and gardening waste. Here, food waste comprises food  
370 and beverage products that are intended for human  
371 consumption, including edible material (e.g. fruit and  
372 vegetables, and meat) and inedible material (e.g. bones from  
373 meat, eggshells, and peels) (WRAP, 2009). Paper was divided  
374 into advertisements, books & booklets, magazines & journals,  
375 newspapers, office paper, phonebooks and miscellaneous paper.  
376 Miscellaneous paper was then further subdivided into  
377 envelopes, kraft paper, other paper, receipts, self-adhesives,  
378 tissue paper, and wrapping paper. Plastic waste was subdivided  
379 according to resin type (PET, HDPE, PVC, LDPE, PP, PS,  
380 Other resins) (Avella et al., 2001) and unidentified plastic  
381 resins for plastic with no resin identification. Special waste was  
382 categorised as batteries (single batteries and non-device specific  
383 batteries), WEEE and HHW. WEEE and HHW were further  
384 split into components defined by the EU directive on WEEE  
385 and HHW.

386 *Table 2 about here*

## 387 **2.6 Statistical analysis**

388 The waste generation rate (WGR) and composition of the  
389 residual waste were analysed by the Kruskal-Wallis test and

390 the permutation test (Johnson, 2005) to identify significant  
391 differences among the three municipalities and between the  
392 two housing types. Furthermore, the Kolmogorov-Smirnov test  
393 (Johnson, 2005) was applied to identify cases when the  
394 proportion of at least one fraction in the overall composition  
395 was significantly different between housing types or among  
396 municipalities. Based on Spearman's correlation test (Johnson,  
397 2005) a correlation matrix between the WGR and percentages  
398 of individual waste fractions was determined (Crawley, 2007).  
399 Correlations between the WGR and individual waste fractions  
400 were used to determine whether variations in WGR also  
401 influenced the waste composition, while correlations between  
402 waste fractions were used to identify potential trends in the  
403 households' efficiency in source segregating of recyclables  
404 (e.g. based on leftover recyclables in the residual waste). The  
405 test of the correlation for significance addressed whether the  
406 correlation's coefficients were statistically significant or  
407 significantly different from zero (Crawley, 2007).

408           Waste composition data were reported and discussed  
409 based on the relative distribution of fractions in percentages of  
410 wet mass (as opposed to the quantity of wet mass of individual  
411 waste fraction) to ensure scale invariance and enable  
412 comparison of waste composition from different areas  
413 (Buccianti and Pawlowsky-Glahn, 2011). Additionally,  
414 percentage composition data remove the effects from WGR

415 (since in the study area, the WGR varies according to sub-  
416 areas), which could otherwise lead to "false" correlations  
417 (Egozcue and Pawlowsky-Glahn, 2011). This approach allows  
418 comparison of different waste composition data. However,  
419 waste composition data in percentages are "closed datasets"  
420 because the proportions of individual fractions are positive and  
421 add up to a constant of 100 (Filzmoser and Hron, 2008). As  
422 such, these data require special treatment or transformation  
423 prior to statistical analyses (Aitchison, 1994; Filzmoser and  
424 Hron, 2008; Reimann et al., 2008). Here, log-transformation  
425 was applied since "the log-transformation is in the majority of  
426 cases advantageous for analysis of environmental data, which  
427 are characterised by the existence of data outliers and most  
428 often right-skewed data distribution" (Reimann et al., 2008).

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

440 fraction.

441           Based on the compositional data and the WGR  
442 obtained for each sub-area, aggregated waste compositions  
443 (corresponding to Level I) were computed for each  
444 municipality and each housing type. These waste compositions  
445 accounted for the relative distribution of housing types and  
446 number of households among sub-areas (Statistics Denmark,  
447 2013).

### 448 **3 Results and discussion**

#### 449 **3.1 Comparison with previous Danish composition** 450 **data**

451 The detailed composition of the RHW from Aabenraa is shown  
452 in Table 3 for Level I & II and in Table 4 mainly for Level III.  
453 Food waste (41-45%) was dominating the waste composition,  
454 and it consisted of vegetable food waste (31-37%) and animal-  
455 derived food waste (8-10%). Plastic film (7-10%) and human  
456 hygiene waste (7-11%) were also important RHW fractions.  
457 The proportion of miss-sorted material fractions was estimated  
458 to be 26% of the total RHW, of which 20 to 22% were  
459 recyclable material fractions (see Table 3). These results were  
460 comparable with those found in a previous Danish study, which  
461 found values of 41% food waste, 31% vegetable food waste  
462 and 10% animal-derived food waste (Riber et al., 2009).  
463 Although, the households in the previous study did not source  
464 segregate board, metal and plastic, the percentages of board  
465 (7%), plastic (9%), metal (3%) glass (3%), inert (4%) and

466 special waste (1%) were also similar in the two studies. The  
467 main differences between these studies were related to the  
468 detailed composition of paper and combustible waste. Despite  
469 the fact that paper (advertisement, books, magazines and  
470 journals, newspapers, office paper and phonebooks) was source-  
471 segregated in both studies, in our study paper contributed with  
472 7-9% of the total waste (4% was tissue paper, see Table 4),  
473 while Riber et al. (2009) reported a paper content of 16%  
474 (mainly advertisement, newsprints and magazines). Although  
475 variations in source-segregation schemes may potentially  
476 explain these differences, other factors such as sorting guides,  
477 income levels, demographics and developments in general  
478 consumption patterns may also affect data.

479 *Table 3 about here*

### 480 **3.2 Comparison between municipalities**

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

488 The waste generation rates for RHW were expressed in  
489 kg per person per week and estimated at  $3.4 \pm 0.2$  in Aabenraa,  
490  $3.5 \pm 0.2$  in Haderslev, and  $3.5 \pm 1.4$  in Sønderborg. Waste

491 composition between municipalities showed minor differences.  
492 The highest percentage of food ( $44\pm 3\%$ ) and plastic ( $15\pm 1\%$ ),  
493 and the lowest percentage of miscellaneous combustible waste  
494 ( $15\pm 4\%$ ) were found in Sønderborg. The highest miscellaneous  
495 combustible waste ( $19\pm 4\%$ ) was in Haderslev, while the  
496 highest inert ( $4\pm 4\%$ ) was in Aabenraa.

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



541 **3.3 Correlations between waste generation rates and**  
542 **waste fractions**

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

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

562 The proportion of glass was negatively and highly  
563 significantly correlated with the proportion of food waste ( $r=-$   
564 0.81). Likewise, a high negative correlation between  
565 miscellaneous combustible waste and gardening waste was



566 observed ( $r=-0.82$ ). This suggests that when proportions of  
567 food waste and miscellaneous combustible waste decreases, the  
568 proportions of gardening and glass waste (potentially miss-  
569 sorted recyclable glass) increase correspondingly. These results  
570 suggest that sorting of glass and gardening waste could be  
571 affected by the amounts of food waste and other miscellaneous  
572 waste generated by the household.

### 573 **3.4 Influence of housing type on composition**

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

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

591 of the households.

592 *Figure 2 about here*

593 *Table 5 about here*

### 594 **3.5 Influence of sorting practices on composition**

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

600 *Table 6 about here*

601 The composition of food packaging is shown in Figure  
602 3b. Food packaging consisted of plastic (50%), paper and board  
603 (25%), metal (10%) and glass (13%). These results were  
604 comparable to literature data reporting food packaging to  
605 represent about 8% of avoidable food waste (Lebersorger and  
606 Schneider, 2011), and food packaging consisting of 40% of  
607 plastic, 25% of paper, 22% of glass and 13% of metal  
608 (Dennison et al., 1996).

609 *Figure 3 about here*

610 Table 9 presents the composition of RHW based on  
611 waste sorting and the probability values from the permutation  
612 test. For this case study, no statistically significant effect on the  
613 percentage of food waste and the overall RHW composition

614 could be observed from sorting practices for food waste (e.g.  
615 whether or not packaging was included in the food fraction).  
616 This may be explained by the fact that the food packagings  
617 were predominantly made of plastic only contributing with low  
618 mass compared to the food waste and other fractions.  
619 Consistently, Lebersorger and Schneider (2011) found that the  
620 “packed food” waste had a relative high mass compared to its  
621 packagings.

622 *Table 7 about here*

623 *Table 8 about here*

### 624 **3.6 Implications for waste characterisation and** 625 **applicability of composition data**

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

638

*Table 9 about here*

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

653           The case study showed that detailed waste composition  
654 of any miss-placed WEEE and HHW required larger sample  
655 sizes than was included here (or alternatively that the  
656 household source segregation of these waste types was  
657 sufficiently efficient to allow only small amounts in the RHW).  
658 As both WEEE and HHW should be collected separately, this  
659 observation only refers to miss-placed items in the RHW.  
660 General characterization of WEEE and HHW should be carried  
661 out based on samples specifically from these flows (this was  
662 however outside the scope of the study). The manual sorting of

663 plastic waste into resin type was time consuming as resin  
664 identification was needed for each individual plastic item;  
665 however, the detailed compositional data provided by this  
666 effort offer considerably more information than simple  
667 categories such as "recyclable plastic" or "clean plastic". This  
668 information is indispensable for national or regional waste  
669 statistics as basis for estimating the potential of recycling of  
670 postconsumer plastics and environmental sound management of  
671 non-recyclable plastics. Furthermore, the plastic  
672 characterisation based on resin type is needed as input for  
673 detailed life cycle assessment and material flow analyses of  
674 plastic waste management.

675           Separation of food packaging from food leftovers,  
676 however, was found unnecessary because this division into sub-  
677 fractions did not significantly influence the waste composition;  
678 this clearly reduces time invested in the sorting campaign, but  
679 also improves the hygienic conditions during the sorting  
680 process. As the statistical analyses indicated no statistical  
681 difference in waste composition between municipalities, waste  
682 composition data obtained from one municipality could be  
683 applied to other municipalities in the study area (provided the  
684 municipalities share source-segregation schemes). This may be  
685 used as a basis for reducing the sampling area (and thereby  
686 overall waste quantities) in a sampling campaign. However, the  
687 statistical differences observed between housing types in

688 relation to food, paper and glass waste indicated that  
689 representative sampling of RHW should account for variations  
690 in housing types between areas.

691           The correlation test showed no statistically significant  
692 relationship between the percentage of individual waste  
693 fractions and the generation rate of RHW. This indicates that  
694 for a specific area (with consistent socio-economic and  
695 geographical conditions), waste composition data could be  
696 extrapolated and scaled up to the entire municipality or down to  
697 individual town-level, regardless of the waste generation rate.

698 The correlation analysis among proportions of individual waste  
699 fractions showed that the percentages of miss-sorted glass and  
700 gardening waste increases when the proportion of food waste  
701 (glass) and miscellaneous waste (gardening waste) decrease.  
702 Moreover, when the proportion of miss-sorted glass increases,  
703 the proportions of miss-sorted board and metal also increase.

#### 704 **4 Conclusions**

705 The study introduced a tiered approach to waste sorting  
706 campaigns involving three levels of waste fractions. This  
707 allowed comparison of waste datasets at different level of  
708 complexity, e.g. involving different numbers of material  
709 fractions. This tiered fraction list was applied on a case study  
710 involving residual household waste (RHW) from 10 sub-areas  
711 within three municipalities. Sub-areas in two municipalities  
712 were sorted only at the first level (overall waste fractions),

713 while waste from one municipality was sorted to the third level  
714 (e.g. two sub-levels below the overall waste fractions). The  
715 obtained waste data (generation rates and composition) for the  
716 individual sub-areas were compared for identification of  
717 significant differences between the areas. Based on the  
718 statistical analysis, it was found that while overall waste  
719 composition and generation rates were not significantly  
720 different between the three municipalities, the waste  
721 composition from single-family and multi-family houses were  
722 different. This indicates that while waste composition data may  
723 be transferred from one municipality to another (provided the  
724 source-segregation schemes are sufficiently similar),  
725 differences in housing types cannot be ignored. As opposed to a  
726 more "linear" waste fraction catalogue, the three-level fraction  
727 list applied in this study allowed a systematic comparison  
728 across the datasets of different complexity.

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

735

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741 campaign.

742

### 743 **Supplementary material**

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

747



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910 **Tables**

911 Table 1: Overview of the sub-areas, number of household per

912 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

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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 <sup>a</sup> ; 5.i.2 HDPE <sup>b</sup> ; 5.i.3 PVC/V <sup>c</sup> ; 5.i.4 LDPE/LLDPE <sup>d</sup> ; 5.i.5 PP <sup>e</sup> ; 5.i.6 PS <sup>f</sup> ; 5.i.7 Other plastic resins labelled with[1-19] ABS <sup>g</sup> ; 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.	10.3.1 Large 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.

<sup>a</sup> Polyethylene terephthalate; <sup>b</sup> density polyethylene; <sup>c</sup> Polyvinyl-chloride; <sup>d</sup> Low density polyethylene; <sup>e</sup> Polypropylene; <sup>f</sup> Polystyrene; <sup>g</sup> 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;



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

Fractions (Level II)	SF <sup>d</sup> (% w/w <sup>a</sup> )	MF (% w/w <sup>a</sup> )
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 <sup>a</sup>	0.9	2.8
Books & booklets <sup>a</sup>	0.1	0.4
Magazines & Journals <sup>a</sup>	0.3	0.5
Newspapers <sup>a</sup>	0.5	0.8
Office paper <sup>a</sup>	0.7	0.4
Phonebooks <sup>a</sup>	0.0	0.0
Miscellaneous paper	4.6	4.2
Board		
Corrugated boxes <sup>a</sup>	0.4	0.7
Folding boxes <sup>a</sup>	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 <sup>a</sup>	5.1	4.5
Plastic film	9.8	6.6
Metal		
Metal packaging containers <sup>a</sup>	1.3	1.9
Aluminium wrapping foil	0.0	0.0
Non-packaging metals	0.6	0.7
Glass		
Packaging container glass <sup>a</sup>	1.8	2.2
Table and kitchen ware glass <sup>a</sup>	0.2	0.0
Other/special glass <sup>a</sup>	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 <sup>b</sup>	0.1	0.1
Special waste <sup>b</sup>		
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

3 <sup>a</sup>Miss-sorted recyclable material fractions; <sup>b</sup>Miss-sorted other material fractions; <sup>c</sup>

4 <sup>c</sup>Composition of single-family as % wet weight;

5 <sup>d</sup>Composition of multi-family as (% mass per wet basis)

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

Fractions (Level I)	Fractions (Level II&III)	SF <sup>d</sup> (% w/w <sup>a</sup> )	MF <sup>e</sup> (% w/w <sup>a</sup> )
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 <sup>e</sup>	2.5	4.9
	Miscellaneous paper		
	Tissue paper	4.1	3.8
	Envelopes <sup>a</sup>	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 <sup>f</sup>	6.5	6.0
	Corrugated boxes <sup>a</sup>		
	Egg boxes&alike <sup>a</sup>	0.1	0.1
	Cards&labels <sup>a</sup>	0.1	0.1
	Board tubes <sup>a</sup>	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 <sup>a</sup>		
	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 <sup>a</sup>		
	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 <sup>a</sup>		
	Clear	0.0	0.3
	Brown	1.8	1.7
	Green	0.0	0.2
	Table and kitchen ware glass <sup>a</sup>	0.2	0.0
	Other/special glass <sup>a</sup>	0.1	0.1
Miscellaneous combustible		14.1	19.5
Inert		1.3	3.2
Special waste <sup>a</sup>		0.7	0.5

8	Total	100	100
9	<sup>a</sup> Miss-sorted recyclable material fractions; <sup>b</sup> Miss-sorted other material fractions; <sup>c</sup>		
10	Composition of single-family houses areas as% wet weight; <sup>d</sup> Composition of multi-		
11	family houses areas as (% mass per wet basis); <sup>e</sup> Advertisements, books & booklet,		
12	magazines & journals, newspaper, office paper, phonebook; <sup>f</sup> Corrugated boxes, folding boxes,		
	beverage cartons		

13

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

Fractions (Level1)	Aabenraa (% w/w <sup>a</sup> )	Haderslev (% w/w <sup>a</sup> )	Sønderborg (% w/w <sup>a</sup> )	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

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

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

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

24 <sup>a</sup> Current study

25 <sup>b</sup> Denmark (Riber et al., 2009)

26 <sup>c</sup> Spain (Montejo et al., 2011)

27 <sup>d</sup> Finland (Horttanainen et al., 2013)

28 <sup>e</sup> Italy (Arena et al., 2003)

29 <sup>f</sup> Italy (AMSA, 2008)

30 <sup>g</sup> Poland (Boer et al., 2010)

31 <sup>h</sup> Sweden (Petersen, 2005)

32 <sup>i</sup> United Kingdom (Burnley, 2007)

33 <sup>j</sup> United Kingdom (Wales) (Burnley et al., 2007)

34 <sup>k</sup> Turkey (Banar et al., 2009)

35 <sup>l</sup> Korea (Choi et al., 2008)

36 <sup>m</sup> Canada (Sharma and McBean, 2007)

37 <sup>n</sup> Malaysia (Moh and Abd Manaf, 2014)

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

	Food	Gardening waste	Paper	Board	Plastic	Metal	Glass	M. combustible <sup>a</sup>	Inert	Special waste	WGR <sup>b</sup>
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 <sup>a</sup>	-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 <sup>b</sup>	-0.36	-0.28	0.38	0.31	-0.21	-0.26	0.24	0.64	-0.49	0.33	1

42 (\*\*) high significance probability between 0.001 and 0.01; (\*) medium significance,  
43 probability between 0.01 and 0.05; (+) weak significance-probability between 0.05  
44 and 0.10; () no significance-probability higher than 0.1  
45 <sup>a</sup> Miscellaneous combustible; <sup>b</sup> waste generation rate (kg RHW per person per week)

46

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

Fractions (Level1)	Single-family (%w/w <sup>a</sup> )	Multi-family (%w/w <sup>a</sup> )	P-value
Food waste**	45 ± 1.3	36.2 ± 3.9	0.03
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

50 Data are presented as Mean ± Standard deviation; Significant level: (\*) 0.05, (\*\*)  
51 0.01; a.: (% mass per wet basis)

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53

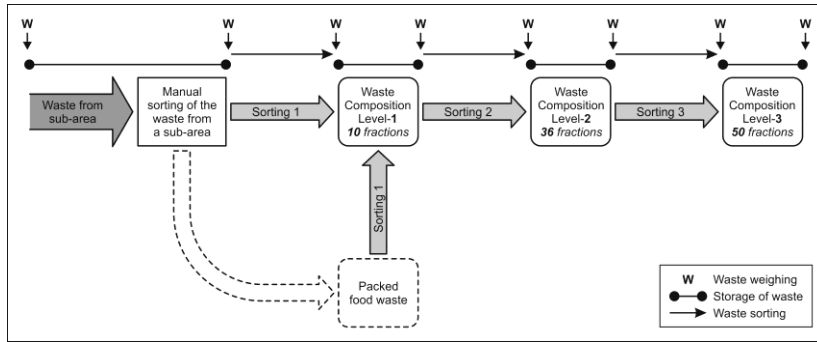
54 Table 9: Waste composition (% mass per wet basis) based on  
 55 food packaging sorting procedure and the associated  
 56 probability values from the permutation test.

Fractions	Not Included <sup>a</sup> (% w/w <sup>c</sup> )	Included <sup>b</sup> (% w/w <sup>c</sup> )	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

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

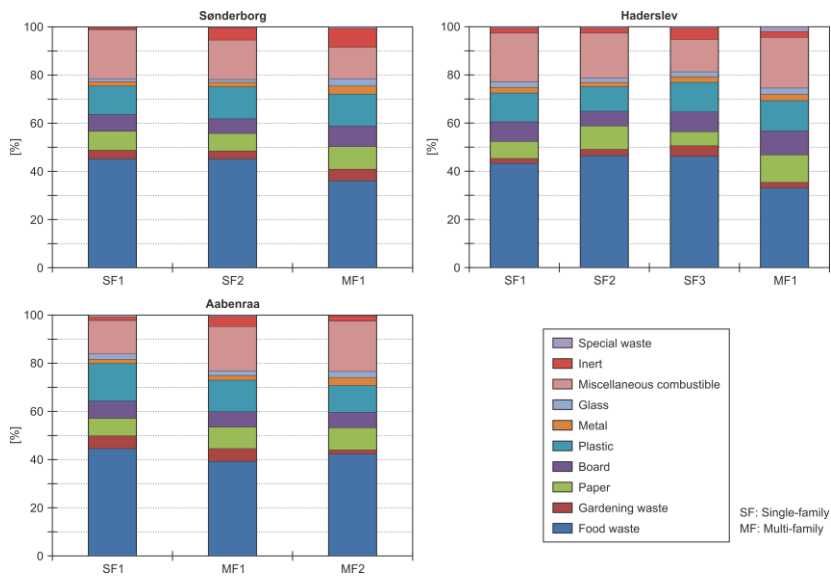
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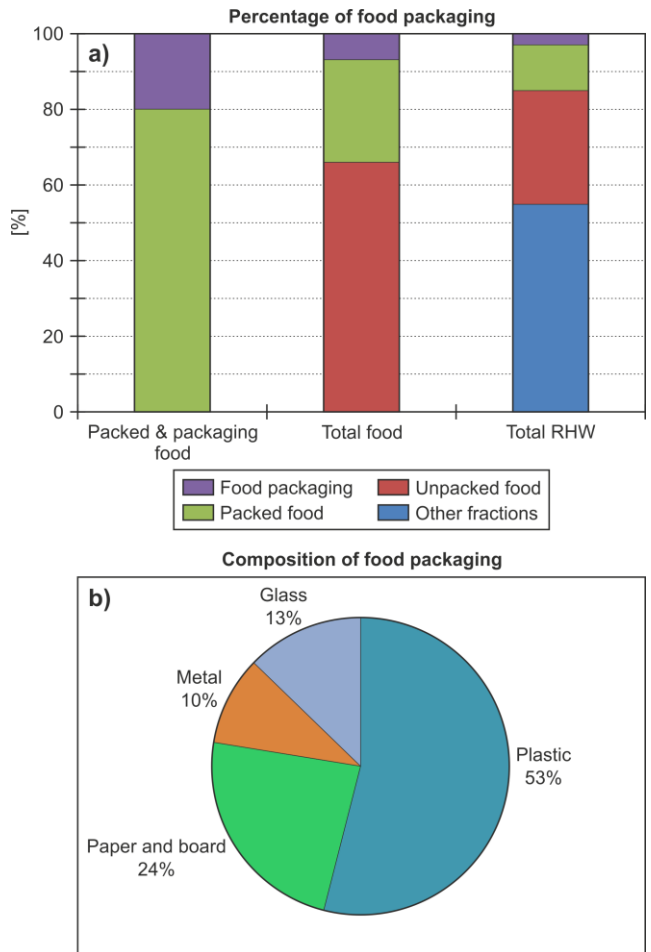
64 Fig. 1. Schema of waste sorting procedure

65



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

69



70

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

74



75 **Supplementary materials**

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

79 A: Overall composition of household based on housing type in  
 80 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

81 *Source: Calculated based on data from Statistics Denmark*

82

83

84 B: Overall composition of household based on housing type  
 85 and municipalities in the study area-Unit: percentage of  
 86 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

87 *Source: Calculated based on data from Statistics Denmark*

88

89

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

Municipalities	Dwelling type	APH <sup>a</sup>	Food waste	Gardening waste	Paper	Board	Plastic	Metal	Glass	MC <sup>b</sup>	Inert	Special waste	TotalW <sup>c</sup>
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

92 <sup>a</sup>Average persons per household; <sup>b</sup>Miscellaneous combustible waste; <sup>c</sup> total waste  
 93 sorted;  
 94

95 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

96 N\*: number of paper sacks;  
 97 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  
 98 waste after sorting;  
 99  
 100 The average mass loss due to evaporation is 1.7%, which is below 3%.

101