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Food waste from Danish households: Generation and composition

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1 Published in Waste Management

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3 **Food waste generation and**
4 **composition from Danish households**

5

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20 **Abstract**

21 Sustainable solutions for reduction of food waste require good
22 understanding of food waste generation and composition,
23 including avoidable and unavoidable food waste. We analysed
24 12 tonnes of residual household waste collected from 1474
25 households, without source segregation of organic waste. Food
26 waste was divided into six fractions according to avoidability,
27 suitability for home composting and whether or not the food
28 waste was cooked, prepared or had been served at within the
29 household. The results showed that the residual household
30 waste generation rate was 434 ± 18 kg per household per year, of
31 which 183 ± 10 kg per year was food waste. Unavoidable food
32 waste amounted to 80 ± 6 kg per household per year, and
33 avoidable food waste was 103 ± 9 kg per household per year.
34 The mass of food waste was influenced significantly by the
35 number of occupants per household (household size) and the
36 housing type. The results also indicated that avoidable food
37 waste occurred in 97% of the households, suggesting that a
38 most of Danish households could avoid or at least reduce food
39 waste generation. Moreover, food waste including avoidable
40 and unavoidable was more likely to be found in houses
41 containing more than one person than households containing
42 only one person.

43

44

45	Keywords:
46	Household food waste
47	Avoidable food waste
48	Unavoidable food waste
49	Food waste generation
50	Bootstrap and confidence interval
51	

52 **1 Introduction**

53 Food production and distribution exert increasing
54 pressure on natural resources such as land, water and energy;
55 however, one-third of the total mass of food produced is either
56 wasted or lost (Gustavsson et al., 2011). Thus, the resolution of
57 the European Parliament on resource efficiency calls on the
58 European Union (EU) Commission (EC) to set a target to
59 reduce by at least 30% the mass of food wastage in EU member
60 states by 2020 (European Parliament, 2015). Food is wasted
61 and lost throughout the food supply chain. In EU member
62 states, food waste from households is relatively higher
63 compared to other parts of the food supply chain (Brautigam et
64 al., 2014; Monier et al., 2010). For this reason, reducing food
65 waste from households may contribute significantly to meeting
66 the reduction target, as well as provide financial and energy
67 savings (Dana, 2012; WRAP, 2009). Initiatives and efforts to
68 change household behaviours related to food waste require a
69 detailed understanding of the quantities and composition of
70 what is discarded. However, although previous studies have
71 measured food waste occurring throughout the food supply
72 chain as well as from households, most of these studies have
73 provided only average data, making the description of the food
74 waste generation between households impossible. Moreover,
75 existing studies have diverse scopes and differ in their
76 definitions, metrics (e.g. mass, calories) and measurement

77 protocols (e.g. sampling) (HLPE, 2014), making the
78 comparison of food waste data between studies challenging.
79 Therefore, there is a need to estimate accurately and
80 consistently the food waste generation and composition from
81 households (Halloran et al., 2014).

82 The lack of a consensus methodology for food waste
83 data collection has led to the development of various food
84 waste estimation methods, such as questionnaire surveys
85 (Abeliotis et al., 2014; Parizeau et al., 2014, Tucker and
86 Farrelly, 2015), kitchen diaries (Langley et al., 2010;
87 Silvennoinen et al., 2014; Williams et al., 2012) and literature
88 reviews based on waste statistics from public authorities
89 (Beretta et al., 2013; Brautigam et al., 2014; Gustavsson et al.,
90 2011; Monier et al., 2010). The reliability and accuracy of data
91 from these methods may be hampered by various limitations
92 and inherent errors (Hallström and Börjesson, 2013). First,
93 kitchen diaries and questionnaire surveys require a good
94 memory and the honesty of the participants, which can hardly
95 be documented (Hallström and Börjesson, 2013). Second, a
96 general ethical consideration associated with food can influence
97 the response of participants (Fessler and Navarrete, 2003). As
98 an example, Parizeau et al. (2014) reported that households in
99 Canada overestimated home cooking because it is less socially
100 acceptable “to be identified as someone who does not cook but

101 relies on pre-packaged foods.” Similarly, Quested et al. (2011)
102 estimated that food waste generation data from kitchen diaries
103 were 40% lower than when based on waste stream analysis in
104 the UK. Third, national waste statistics may be prone to
105 significant uncertainties, due to (i) varying definitions of food
106 waste and (ii) the calculation methods and assumptions applied
107 (Brautigam et al., 2014; HLPE, 2014). Therefore, waste stream
108 analysis is recommended to obtain reliable data on food waste
109 generation and composition (Dahlén and Lagerkvist, 2008;
110 Monier et al., 2010).

111 The disadvantage of the waste stream analysis is that
112 only food waste entering the municipal waste stream is
113 analysed. Thus, the waste stream analysis may exclude the food
114 waste that is fed to animals, home composted or disposed via
115 the sewer system (WRAP, 2009). Langley et al. (2010) argued
116 that the waste stream analysis characterises waste that age
117 could affect the degradation of some food products making
118 their separation and identification awkward. However, several
119 methods for characterisation of municipal solid waste
120 suggested to analyse at least one full week of waste because the
121 waste generation during weekends may differ compared to
122 weekdays (Dahlén and Lagerkvist, 2008). The degradation of
123 waste including food waste is significantly minimised when the
124 waste is sorted within a week from the sampling day (European

125 Commission, 2004; Nordtest, 1995), which has been confirmed
126 by practical experience (Edjabou et al., 2015).

127 An additional limitation of existing food waste studies
128 is that they focus mainly on avoidable food waste (Halloran et
129 al., 2014). To provide a consistent basis for new initiatives
130 targeting households, the detailed relationship between both
131 unavoidable and avoidable food waste needed to be understood
132 (Halloran et al., 2014).

133 A number of studies on this subject have found a
134 correlation between the mass of avoidable food waste and the
135 number of occupants per household. However, these studies
136 had relatively small sample sizes (Langley et al., 2010;
137 Parizeau et al., 2014). Moreover, issues such as uncertainty
138 related to the influence of household size as well as
139 geographical and periodic variations on avoidable and
140 unavoidable food waste have not been systematically
141 investigated. Consequently, the statistical uncertainties related
142 to the generation of food waste and potential influencing
143 factors are poorly documented. The uncertainty related to
144 temporal variation could be reduced by sampling in different
145 periods (Dahlén and Lagerkvist, 2008).

146 The prevention of food waste has the highest
147 environmental benefits (Gentil et al., 2011). However, a
148 biological treatment of food waste (e.g. home composting,

149 central composting, anaerobic digestion) that cannot be reduced
150 or prevented (e.g. unavoidable food waste) generates various
151 benefits, such as: (1) reduction of environmental impacts such
152 as emission of greenhouse gases, surface and groundwater
153 contamination, and soil pollution , (2) generation of nutrients
154 that will be returned to food production system, (3) production
155 of biogas (Andersen et al., 2010; Raven and Gregersen, 2007;
156 WRAP, 2009), and (4) financial incentives due to high taxes on
157 landfilling and incineration (Danish Government, 2013).

158 Currently, one of the challenges facing biogas plants
159 (e.g. in Denmark) is a reliable availability of organic material
160 (Raven and Gregersen, 2007). Therefore, availability of food
161 waste constitutes one of the key parameters for feasible
162 economic operation of biogas plants (Raven and Gregersen,
163 2007). Generally, the availability of waste materials from
164 household are also considered for planning of waste source-
165 segregation systems, and development of collection schemes
166 (Nilsson and Christensen, 2010).The availability of food waste
167 can be estimated by analysing the occurrence of food waste
168 from households (US EPA, 2002). Despite the importance of
169 these data, they were not attempts to analyse food waste
170 occurrence from households, thereby hindering our ability to
171 accurately map resources and develop food waste treatment
172 technologies.

173 The overall objective of this study was to estimate the
174 occurrence, the mass, and composition of discarded food
175 fractions from Danish households. The study also aimed at
176 evaluating and estimating the influence of the following
177 factors: (1) geographical variations (city, municipalities and
178 region), (2) periodic variations, and (3) household size, on the
179 mass and the occurrence of individual food waste fractions.

180 **2-Materials and methods**

181 **2.1 Definitions and classification of food waste**

182 In this study, *food waste* includes food, drinks and
183 beverages that are avoidable and unavoidable (FUSIONS,
184 2014; WRAP, 2009). We applied the food waste classification
185 described by Edjabou et al. (2015), WRAP (2009) and
186 FUSIONS (2014). Initially, food waste was subdivided into
187 animal-derived products and vegetable products. Vegetable
188 food waste estimates the potential mass of food waste from
189 households that could be home composted, provided that in
190 home composting schemes, animal-derived may be, excluded
191 because of the risk of attracting flies, rats and other pests as
192 well as undesired odours (Christensen and Matsufuji, 2010).
193 The two food waste fractions (animal-derived and vegetable)
194 were further grouped into avoidable and unavoidable food
195 waste (FUSIONS, 2014; Koivupuro et al., 2012; Lebersorger
196 and Schneider, 2011; WRAP, 2009). *Unavoidable food waste* is

197 defined as “food that is not and has not been edible under
198 normal circumstances”(WRAP, 2009), e.g. bones, carcasses,
199 egg shells, peels, fruit skin, apple cores, coffee grounds, etc.
200 (Table 1 & Table SM 1), while *avoidable food waste* refers to
201 edible food that could have been eaten but instead is disposed
202 off regardless of the reason (FUSIONS, 2014). Finally,
203 avoidable food waste was split into two further fractions. The
204 first covered “food and drinks that have been cooked, prepared
205 or served in the home”(WRAP, 2009), characterised as
206 *avoidable processed food waste*, while the second covered
207 “purchased food that has been discarded” (WRAP, 2009) such
208 as discarded food that has not been cooked, prepared or served
209 as a meal (*avoidable unprocessed food waste*). As a result, we
210 had six detailed fractions: (1) “avoidable unprocessed vegetable
211 food waste” (AUVFW), (2) “avoidable processed vegetable
212 food waste” (APVFW), (3) “unavoidable vegetable food waste”
213 (UVFW), (4) “avoidable unprocessed animal-derived food
214 waste” (AUAFW), (5) “avoidable processed animal-derived
215 food waste” (APAFW) and (6) “unavoidable animal-derived
216 food waste” (UAFW) (Table 1 and Table SM 1). Table 1
217 provides an overview of what was included in these categories,
218 while Table SM 1 shows how they were grouped. For
219 comparison purposes, these categories were grouped into 11
220 food categories adapted from WRAP (2009) and Lebersorger
221 and Schneider (2011), as shown in Table 1 (2nd column) and in

222 Table SM 2. We differentiated between avoidable food waste
223 and unavoidable food waste based on the general food habit
224 and tradition in this study area. Thus, this classification may
225 change according to the food habit of the area (e.g. country,
226 region) with respect to culture, tradition, and religion. The
227 reason is there are some “food that some people eat and others
228 do not” (Beretta et al., 2013; FUSIONS, 2014; WRAP, 2009)

229 **2.2 Study area**

230 Residual household waste was sampled in five
231 municipalities in Denmark, namely Gladsaxe, Helsingør,
232 Odense, Viborg and Kolding, as shown in Table 2. In these
233 municipalities, food waste was neither source-segregated nor
234 accepted at recycling stations. Instead, along with other residual
235 waste (e.g. tissues papers, nappies, beverage cartons, plastic
236 film, metal cans, etc.), it was disposed of in residual waste bins.
237 However, gardening waste, paper, board, glass, waste electrical
238 and electronic equipment (WEEE) and batteries, household
239 hazardous waste and bulky waste were source-segregated.

240 Residual household waste management and collection
241 varied according to housing type. In single-family house areas,
242 an individual waste bin for each house was used to collect
243 residual waste, whereas, in multi-family areas, people living in
244 the same apartment block used a joint full-service collection
245 point system, with many of them sharing the same waste bin. In

246 single-family house areas, residual waste bins consisted of
247 paper sacks and plastic bags between 110 and 240 L in
248 capacity, whereas in the multi-family house areas, wheeled
249 containers of 400 to 750 L were used. Residual household
250 waste was collected every week in the multi-family house areas
251 and every two weeks in the single-family house areas. This
252 difference between the two types of household explains the
253 waste sampling and sorting procedures applied in this study.

254 To encourage home composting, especially in the
255 single-family house areas, municipal authorities have provided
256 home composting units to those interested in doing it.
257 Additionally, the municipality of Viborg has provided these
258 composters for free, whereas other municipalities charge a fee.

259 **2.3 Sampling of residual household waste**

260 Table 2 provides an overview of the waste sampling
261 campaign in terms of numbers of households and total mass of
262 residual household waste analysed. In total, 1,474 households
263 were included in this study, and the number of households
264 investigated in each area varied between 100 and 200, as
265 recommended by Nordtest (1995). Overall, a total of 12 tonnes
266 of residual household waste was collected and manually sorted.
267 To investigate the effect of periodic variations in food waste
268 generation, residual household waste was sampled repeatedly
269 from the same single-family house area in the municipality of

270 Gladsaxe in May 2011, October 2011 and March 2012.

271 The households involved in this sampling campaign were
272 selected by the municipal authorities responsible for solid waste
273 management, with the aim of ensuring that these homes were
274 representative of the investigated area (Table SM 3). Before
275 sampling began, the selected households were asked if they
276 would like to participate in three waste sampling campaigns in
277 the future, without indicating the exact dates. This was done by
278 telephone and mail. First, the telephone interview was used to
279 obtain the consent of households to participate to waste
280 sampling campaign. After obtaining the consent, a confirmation
281 letter was sent to households that accepted to participate to the
282 waste sampling campaign. Based on this method, we obtained
283 up to 80% of interviewed households that accepted to
284 participate to the sampling campaign. This method was applied
285 in order to comply with Danish waste regulations (Danish EPA,
286 2014) and also to avoid any potential changes in household
287 behaviour, which could hamper the reliability of the results.
288 Thus, one week or two weeks' residual household waste was
289 collected from those households enjoying weekly existing
290 collection schedule. After sampling, the waste was transported
291 using non-compacting tipping trucks to the sorting facility. The
292 residual household waste was sorted within a week from the
293 sampling day to minimise the degradation of food products

294 (Edjabou et al., 2015).

295 **2.4 Food waste sorting**

296 The residual household waste (Table 2) was sorted into
297 six food waste fractions and other waste material fractions. The
298 six food waste fractions were further sorted into detailed
299 fractions, which in turn were grouped into 11 food categories
300 (Table SM2).

301 Although the six food waste fractions were clearly
302 defined and illustrated by examples, we encountered some
303 difficulties that were overcome by sorting consistently these
304 food products throughout the sorting campaign. A food
305 product naturally composed of inseparable avoidable and
306 unavoidable components was considered as avoidable food
307 waste. For examples, a whole chicken, containing both meat
308 (avoidable) and bones (unavoidable) was sorted as
309 avoidable food waste. Similarly, whole fish, banana, etc.
310 were sorted as avoidable food waste. We differentiated
311 between processed and unprocessed food waste as follow:
312 food waste is unprocessed when the whole food product was
313 disposed with or not packaging, whereas discarded food
314 products that were partly eaten or destroyed was sorted as
315 processed food waste. Skin and peels of fruit and vegetables
316 that were removed prior disposal were sorted as unavoidable

317 food waste..

318 The waste sorting methods involved ‘batching’ sorting for
319 waste from the multi-family house areas and individual waste
320 bin sorting for waste from the single-family house areas.

321 **2.4.1 Single-family house areas**

322 In the single-family house areas, the residual waste was
323 collected separately from each household. Initially, the bins
324 were sealed tightly, to prevent losses and to separate them from
325 other bins. Finally, the waste bins were labelled with the
326 address of the household from where it was collected. The bins
327 were sorted separately, and food waste data were obtained for
328 each household. Information on the number of persons per
329 household was provided by the municipal authorities.

330 The sorting of individual household waste bins enables
331 to investigate differences and distribution (Dahlén and
332 Lagerkvist, 2008), but it is very costly and demands a great
333 deal of effort. Additionally, it is only feasible in single-family
334 house areas.

335 **2.4.2 Multi-family house areas**

336 It was neither economically nor technically feasible to
337 collect and separately sort the waste from each household in
338 these areas. Instead the waste was mixed and transported to the
339 sorting facility, where it was sorted as a ‘batch’ (Edjabou et al.,

340 2015). Here the waste from each area was treated as a “single
341 sample.” As a result, we obtained one dataset from each of the
342 multi-family house area.

343 Batch sorting is less labour intensive and suitable for all
344 housing types. While it may avoid sampling and splitting errors
345 (Edjabou et al., 2015), it does generate data that may not
346 describe waste distribution between households.

347 **2.5 Food waste data and statistical analyses**

348 Given the waste sampling and sorting procedures,
349 distributions of food waste per household were only available
350 from the single-family house areas. However, data from multi-
351 family house areas described differences between
352 municipalities.

353 The average quantities and composition of food waste
354 were calculated as weighted average according to the
355 distribution of the Danish population as shown in Tables SM 4
356 & SM 5 (Statistics Denmark, 2015).

357 We applied permutation tests (Kabacoff, 2011) to
358 compute p-values. A bootstrap, applied on a robust regression,
359 was used to calculate a 95% confidence interval and estimates
360 of measurement precision (Fox and Weisberg, 2012). A
361 permutation test and bootstrap methods were applied, because
362 they do not require distribution assumptions for the data, and
363 they are less sensitive to outliers (Kabacoff, 2011).

364 We investigated whether or not the mass of food waste
365 was influenced by housing type, by comparing the average data
366 from each of the two areas. Furthermore, we analysed factors
367 influencing the mass of food waste in the single-family house
368 areas and compared the relationship between individual food
369 waste fractions. The households' generation of food waste was
370 analysed by means of a permutation test extended to logistic
371 regression. Here, the binary variable was whether a household
372 generated food waste (mass higher than zero) or not (the mass
373 was zero) (Kabacoff, 2011).

374 The effect of the sample size was analysed for each food
375 waste fraction by assessing the relationship between the
376 confidence intervals and the sample size (number of households).
377 The confidence intervals were computed using bootstrapping
378 (Crawley, 2005). This method was chosen because traditional
379 sampling plans assume specific classical probability distribution
380 (typically normal distribution) of either the population or of the
381 parameters of the population to be estimated. However, given the
382 heterogeneity of waste fractions, a very large sample at
383 unacceptable cost should be considered to ensure each fraction is
384 distributed normally. Moreover, the composition studies showed
385 that almost no waste fraction generation and composition is
386 normally distributed (Klee, 1993). For these reasons, traditional
387 sampling theories are not suitable to estimate the required sample

388 size in order to determine the quantity or the composition of solid
389 waste (Klee, 1993) assume specific classical probability
390 distribution (typically normal distribution) of either the
391 population or of the parameters of the population to be estimated.
392 However, given the heterogeneity of waste fractions, a very large
393 sample at unacceptable cost should be considered to ensure each
394 fraction is distributed normally. Moreover, the composition
395 studies showed that almost no waste fraction generation and
396 composition is normally distributed (Klee, 1993). For these
397 reasons, traditional sampling theories are not suitable to estimate
398 the required sample size in order to determine the quantity or the
399 composition of solid waste (Klee, 1993).

400 The data were modelled using the statistical and
401 graphical software R (<http://www.r-project.org>).

402 **3 Results and discussion**

403 **3.1 Analysis of sample size for each municipality**

404 We simulated sample sizes (k : to determine) between 5
405 and 782, and for each sample size we used 10,000 replicates. The
406 results show that the bootstrap 95% confidence intervals for food
407 waste fractions narrowed sufficiently to suggest that a sample
408 size of 100-200 households would produce reliable results. This
409 simulation confirms the sample size recommended by Nordtest
410 (1995).

411 **3.2 Quantities and composition of food waste fractions**

412 Tables 3 & 4 show respectively the weighted average of
413 wet mass and the composition of food waste. Figure 1
414 illustrates the average mass of food waste generated in a Danish
415 household, split into unavoidable and avoidable, which were
416 further split into the six food waste fractions. The mass of
417 vegetable (suitable for home composting) and animal-derived
418 food waste are also provided.

419 The total weighted mass of residual waste generated in
420 an average Danish household amounted to 434 ± 18 kg per year
421 (Figure 1), or 201 ± 13 kg per person per year. Thus, per mass,
422 the largest contribution to residual household waste was from
423 food waste ($43 \pm 1.8\%$) as shown in Table 3. These results are
424 consistent with previous Danish studies, which reported 42%
425 (Edjabou et al., 2015) and 41% (Riber et al., 2009) food waste.

426 Food waste in Danish households consisted of $56.4 \pm 3.8\%$
427 of avoidable food waste and $43.6 \pm 2.2\%$ of unavoidable food
428 waste (Table SM 6). The avoidable food waste amounted to
429 103 ± 9 kg per household per year (Figure 1), or 48 ± 4 kg per
430 person per year. These results differ from those estimated by
431 EUROSTAT at 7 kg per person per year (Monier et al., 2010) and
432 126 kg per household (Brautigam et al., 2014) as shown in Table
433 5. However, Monier et al. (2010) acknowledged their estimates
434 may include high uncertainties, and so they recommended
435 undertaking a waste stream analysis to estimate reliable data. The

436 mass of avoidable food waste from Danish households was also
437 lower than those found in the UK (210 kg per household per year
438 (WRAP, 2011)), the United States (124 kg per person per year
439 (Koester, 2013)) and in Canada (117 kg per person per year
440 (Parizeau et al., 2014)). However, this figure is in the range of
441 those reported in Austria (33 kg per person per year (Lebersorger
442 and Schneider, 2011)) and Finland (23 kg per person per year
443 (Koivupuro et al., 2012)). This discrepancy between countries
444 confirms the difficulty of extrapolating avoidable food waste
445 data.

446 Avoidable processed food waste, which occurs after
447 cooking, serving or preparation (Section 2.1) accounted for 30%
448 of all avoidable food waste (Table 3 and Table SM 6) and was
449 34 ± 5 kg per household per year (Figure 1), or 16 ± 3 kg per person
450 per year. Avoidable unprocessed food waste constituted 67% of
451 all avoidable food waste (Table 3 and Table SM 6) and was
452 estimated at 79 ± 9 kg per household (Figure 1) per year, or 32 ± 4
453 kg per person per year. These results indicate that a high
454 proportion of avoidable food waste was food that had been
455 purchased, stored (or not) and then discarded.

456 On average, 71% of the avoidable food waste consisted
457 of vegetable products, which amounted to 73 ± 8 kg per household
458 per year (Figure 1), or 35 ± 2 kg per person per year. The
459 corresponding 29% of avoidable animal-derived food waste

460 indicates that Danish households discard a relatively small mass
461 avoidable animal-derived food waste compared to avoidable
462 vegetable food waste. Moreover, given that animal-derived food
463 waste consisted of animal products and a mix of animal products
464 and vegetable products, such as salads (Table 1), we could
465 conclude that the mass of avoidable animal products may be
466 smaller than the mass of avoidable animal-derived food waste.

467

468 While the mass of avoidable animal-derived food waste
469 consisted of 50% unprocessed avoidable food waste, avoidable
470 vegetable food waste comprised 74% of avoidable unprocessed
471 food waste (54 ± 6 kg per household per year) and 36% avoidable
472 processed food waste (19 ± 7 kg per household per year), as
473 shown in Figure 1. This result indicates that about 74% of the
474 avoidable vegetable food waste may be food that has been
475 purchased and then thrown away, without having been cooked,
476 prepared or served as a meal. These results could be explained
477 mainly by inefficient purchase planning, causing unnecessary and
478 excessive food that neither could be eaten nor preserved for a
479 longer period (FUSIONS, 2014; Halloran et al., 2014; Parizeau et
480 al., 2014; Silvennoinen et al., 2012). Thus, shopping planning
481 reduce (Silvennoinen et al., 2014; Stefan et al., 2013; WRAP,
482 2009) and the correct storage of vegetables and fruits (WRAP,
483 2009) could reduce substantially the mass of avoidable food

484 waste in the Danish households. Additionally, recipes for food
485 leftovers and cooking planning (WRAP, 2009) should be
486 considered to reduce food waste from household.

487 **3.2 Composition of food categories**

488 Food waste fractions were grouped in food categories
489 (Table 1 and Table SM 2). Each food category was further
490 subdivided into avoidable and unavoidable food waste as
491 shown in Figure 2. Overall, the dominant food products were
492 fresh vegetables and salads (30% of total food waste) and fresh
493 fruit (17% of total food waste), followed by bakery (13% of
494 total food waste), and drink and confectionery and desert (13%
495 of total food waste).

496 The predominant avoidable food categories from
497 Danish houses were fresh vegetables and salads (14% of total
498 food waste) and bakery (13% of total food waste). However,
499 fresh vegetables and salads (16% of total food waste), fresh
500 fruit (12% of total food waste) and drink, confectionery and
501 desert (11% of total food waste) were the dominant
502 unavoidable foods. A relatively high percentage of drink,
503 confectionery and desert in unavoidable food waste was mainly
504 due to spent coffee grounds. These results are comparable to
505 those found by WRAP (2009) for which fresh vegetables and
506 salads, drink, fresh fruit, bakery and meal (home-made and pre-
507 prepared) were dominant in the UK.

508 3.3 Occurrence of food waste

509 We analysed whether a single-family household
510 generated one of the six food waste fractions or not. In this
511 section, occurrence of food waste refers to whether household
512 generated food waste fractions or not. This approach aimed to
513 assess the availability of food waste fractions generated from the
514 single-family house areas. Owing to the waste data for each
515 household, we computed the number of households where “zero
516 mass” of food waste were found in the waste bin. The analysis
517 was done for each of the six food waste fractions.

518 The occurrence of food waste from the Danish
519 households was analysed by assessing how many cases where
520 “zero mass” of food were found in the waste bins. The analysis
521 was done for each of the six food waste fractions. The percentage
522 of households (single-family house areas) that did not generate
523 food waste as function of household size is presented in Table 6.
524 The results show that 97% of households involved in this study
525 generated avoidable food waste, suggesting that this practice
526 occurs in most of Danish households. Avoidable processed food
527 waste was found in 68% of bins. Consequently, initiatives to
528 reduce avoidable food waste could be carried out at national
529 level, even though municipalities have the responsibility for the
530 management and prevention of municipal solid waste (Danish
531 EPA, 2014), as suggested by Halloran et al. (2014). Moreover,

532 98% of household generated unavoidable food waste. These
533 figures suggest that, initiatives to reduce avoidable food waste
534 should be accompanied by other initiatives that enable efficient
535 resource recovery with minimum environmental impacts from
536 food waste that cannot be avoided.

537 Logistic regression was applied to assess the factors
538 influencing food waste generation (Table SM 7). The binary
539 variable was food waste generation (yes/no), where “yes” meant
540 that food waste fraction was found in the bins, and where “no”
541 meant that it was not found. The explanatory variables were
542 regions, municipalities and household size (Table SM 7).

543 The results show that only the variable household size
544 might affect significantly households’ food waste generation
545 (Table 6). This suggests the likelihood that food waste is
546 generated will increase significantly according to the number of
547 occupants in the household. As a result, a house containing two
548 persons may increase this likelihood of generating food waste by
549 a factor of four, and a house containing more than two persons
550 may increase this figure by a factor of five or more.

551 Waste sampled from three different periods from the
552 same households showed that 94-97% generated avoidable food
553 waste, whereas 97-98% generated unavoidable food waste
554 (Figure SM 1). The statistical analysis showed that periodic

555 variations did not significantly affect household food waste
556 generation in this respect. The size of household significantly
557 influenced the generation of food waste from the Danish
558 households (Tables SM 8 & SM 9).

559 These results suggest that an increase in the number of
560 persons per household increases the likelihood of wasting food. A
561 possible explanation for this might be that a person living alone
562 (household containing one person) tends to eat “simplified” or
563 “cold meal” consisting of bread (e.g. rye bread) with cold or fried
564 fish, cold meats, warm meats, etc..., soup, and ready meals. They
565 may also eat at work. As a result, these households may merely
566 generate food waste (Table 6), although they may generate other
567 waste materials such as packaging. However, a house containing
568 more one person may keep “classical” or “traditional” meal habit,
569 especially for dinner where warm meal or prepared food is
570 served. The process of preparing, cooking and serving food at
571 home for more than one person may increase the risk of
572 overestimation during purchasing and cooking, leading to food
573 waste generation. This uncertainty may increase when the size of
574 household increases because it is apparently more difficult to plan
575 efficiently purchasing and cooking of food that satisfy the desire
576 of all the household members. These results suggest that in the
577 single-family house areas, households with one person could
578 affect the availability of food waste for home composting and

579 biogas plants. These plants rely on a continuous availability of
580 organic material

581 **3.4 Factors influencing the quantity of individual food** 582 **waste fraction**

583 First we analysed the significance differences in the quantity of
584 food waste between single-family and multi-family areas.

585 Second, we investigated that may influence the quantity of food
586 waste from the single-family house areas.

587 **3.4.1 Influence of housing type on food waste**

588 The mass of residual household waste per household
589 was significantly higher in single-family house areas (8.7 ± 0.2
590 kg per household per week) than in multi-family house areas
591 (7.8 ± 0.1 kg per household per week) (Table 4). However, this
592 difference was not significant when considering the mass per
593 person. Similarly, single-family house areas generated
594 significantly higher mass of food waste, avoidable food waste
595 and unavoidable food waste per household than multi-family
596 house areas (Table 4). In contrast, considering the mass per
597 person, the mass of total food waste, avoidable and unavoidable
598 food waste was similar between single-family house areas and
599 multi-family house areas. Regardless of factors such as socio-
600 economic differences, these results may suggest that the results of
601 statistical analysis applied to the mass of food waste, depends on
602 the unit generation rates of food waste (mass of food waste per

603 household or mass of food waste per person). This could be
604 explained by the difference in the number of occupants per
605 household, which is 2.4 for single-family house areas and 1.8 for
606 multi-family house areas (Statistics Denmark, 2015).

607 In the following sections (3.4.2 to 3.4.5), we investigated
608 the influence on the quantity of food waste from single-family
609 house areas, based on (1) household size, (2) municipality, (3)
610 region and (4) the difference between municipalities offering a
611 free composter for home composting and those, which do not
612 provide such a service. For the latter factor, we did not assess
613 differences in the numbers of households engaged in home
614 composting; we considered the mass of food waste per household
615 and per person.

616 **3.4.2 Geographical variation**

617 Geographical variations include the influence of regions
618 and municipalities on the generated mass of food waste. The
619 distribution between households of the mass of avoidable and
620 unavoidable food waste as a function of household size in single-
621 family house areas is shown in Figures 3A & 3B for mass per
622 household and Figures 3C & 3D for mass per person. The results
623 show that geographical variations including municipalities (df=3,
624 $p>0.05$) and regions (df=1, $p>0.05$) did not make any significant
625 difference to the mass of avoidable and unavoidable food waste
626 per household and per person. Similarly, we found no significant

627 difference in the mass of the six detailed food waste fractions,
628 respectively, between municipalities and regions in Denmark.
629 These findings indicate that the generation of avoidable food
630 waste, as well the detailed food waste fractions, were not affected
631 by geographical differences such as municipalities or regions.

632 **3.4.3 Household size**

633 We analysed household size as a categorical explanatory
634 variable. The result showed that the mass of food waste (see
635 Table 1 and Table SM 1) per household may increase
636 significantly in line with the size of household. For the mass of
637 avoidable food waste per household, households containing one
638 person generated significantly lower avoidable food waste than
639 those containing two persons (0.66 kg, with a 95% confidence
640 interval of 0.23 to 1.44), three persons, (1.85 kg, with a 95%
641 confidence interval of 1.36 to 2.34) and four or more persons
642 (2.75 kg, with a 95% confidence interval of 2.30 to 3.12), as
643 shown in Table 7. These findings are consistent with those of
644 Parizeau et al. (2014), Silvennoinen et al. (2014) and WRAP
645 (2009). Similarly, the mass of unavoidable food waste was also
646 significantly affected by household size (Table 7).

647 The mass of food waste decreased when household size
648 increased, except for avoidable processed food waste (avoidable
649 processed animal-derived food waste, avoidable processed
650 vegetable food waste and total avoidable processed food waste)

651 (Tables SM 10 & SM 11). For example, households containing
652 one person generated higher avoidable food waste than those
653 containing two persons, three persons and more than three
654 persons as it shown in Table 7. However, this difference was not
655 statistically significant, thereby suggesting that there was no
656 significant difference in the mass of avoidable food waste per
657 persons among households. Although these results differ from
658 those published by Parizeau et al. (2014), who found a negative
659 correlation, they are nevertheless consistent with those of WRAP
660 (2009), Katajajuuri et al.(2014), Koivupuro et al. (2012) and
661 Silvennoinen et al. (2014). In contrast, the mass of unavoidable
662 food waste per person decreased significantly in line with the
663 number of persons per household. Thus, a household containing
664 three or more may generate, respectively, 18 kg (a 95%
665 confidence interval of 8 to 28) per person per year and 22 kg (a
666 95% confidence interval from 14 to 32) per person per year,
667 which is significantly lower than for one person (Table 8). This
668 discrepancy could reflect the difference in the generation of
669 avoidable and unavoidable food waste from the Danish
670 households.

671 The comparison between the mass of avoidable and
672 unavoidable food waste per household showed that on average,
673 Danish households generated 24 kg (95% confidence interval
674 from 15 to 33) per household per year significantly higher

675 avoidable food waste than unavoidable food waste. The results
676 according to household size showed that households containing
677 three or more persons generated 33 kg (95% confidence interval
678 16 to 52) per household per year significantly higher avoidable
679 food waste than unavoidable food waste. However, households
680 containing one and two persons generated comparable mass of
681 avoidable and unavoidable food waste. Figures 4 present the
682 bootstrap 95% confidence interval and mean of unprocessed vs.
683 processed and vegetable vs. animal-derived per household
684 (Figures 4A & 4B) and per person (Figures 4C & 4D). The
685 results also showed that the difference in the mass of food waste
686 generated per household, between (1) avoidable unprocessed
687 food waste and avoidable processed food waste and (2) vegetable
688 and total animal-derived food waste, increased significantly in
689 line with household size.

690 A possible explanation for these results may be that
691 households with one person may only cook food to satisfy their
692 own desire, at least less often than those with more than one
693 person. Furthermore, easy accessibility to shops enables
694 householders to make smaller purchases (Gjerris and Gaiani,
695 2013). Thus, households containing one person could purchase
696 food products that they want for themselves, even though
697 promotions and price discounts could affect the type and mass of
698 what they buy (Jahns et al., 2014).

699 **3.4.4 Free composter for home composting**

700 We analysed the influence of the ‘free composter’ on the
701 mass of food waste discarded in single-family house areas by
702 comparing those municipalities offering free composter and those
703 that do not.

704 The result of the permutation test showed that offering a
705 free composter did not make a significant difference to the mass
706 of food discarded by single-family households. Surprisingly, the
707 mass of vegetable food waste was not significantly influenced
708 either. These results may suggest that municipalities where free
709 composters are offered generated a comparable mass of food
710 waste compared to those that do not offer such a service. Since
711 we did not determine the number of households engaging in
712 home composting as a result of being given a free composter,
713 these results should be interpreted with caution.

714 The results showed that about 145 ± 9 kg per household
715 per year could be home-composted (Figure 1) in Danish
716 households and as a result reduce $33\pm 2\%$ of the total residual
717 household waste. However, the current incentive via free of
718 charge composters has not made any significant differences in
719 this respect, especially for vegetable food waste. Tucker and
720 Speirs (2003) argued that negative perceptions, such as vermin,
721 flies, space, aesthetics, etc., may determine households’ reticence
722 to take composting on board. They also found that factors such as
723 time and effort could influence the issue. Therefore, Tucker and

724 Speirs (2003) suggested awareness programmes focusing on
725 changing perceptions, such as “composting does not necessarily
726 attract flies and vermin” and “composters can be beautiful.”
727 Refsgaard and Magnussen (2009) proposed including
728 institutional and organisational solutions in addition to technical
729 solutions such as providing composters and financial incentives
730 to motivate households. An alternative could be a central
731 composting or combined anaerobic and aerobic treatment plant.

732 **3.4.5 Periodic mass of household food waste**

733 The mass of food waste generated from households
734 during the three periods, and the p-values of the permutation test
735 (Kabacoff, 2011), are presented in Table 8.

736 Overall the results showed that the mass of food waste
737 generated in Danish households was not significantly different
738 between the three periods. However, only the mass of
739 unavoidable animal-derived food waste per household and per
740 person (4 to 6% of total food waste) was significantly different
741 through this time span. These results could be explained by the
742 demand for fresh food through the whole year and the modern
743 food chain that enables retailers to import out of season produce
744 (HLPE, 2014). However, in contrast to these results, another
745 study found significant monthly variations in Canada, which were
746 explained by the increased supply of fresh food in the summer
747 months at more affordable prices (Adhikari et al., 2008).

748 Figures 5 show the distribution of food waste as a
749 function of household size, grouped per period per household
750 (Figures 5A & 5B) and per person (Figures 5C & 5D).
751 Concurrently, the mass of avoidable and unavoidable food waste
752 per household increased in line with the size of the household.
753 Compared to a household containing one person, the mass of
754 avoidable food waste may increase by 1.15 kg (with a 95%
755 confidence interval of 0.76 to 1.53) per week for a household
756 containing two persons, 1.72 kg (with a 95% confidence interval
757 of 0.40 to 2.97) per week for household containing three persons
758 and 2.42 kg (with a 95% confidence interval of 1.52 to 3.31) per
759 week for more than three persons. However, the mass of
760 avoidable food waste per person also increased in line with
761 household size, albeit not significantly.

762 The mass of unavoidable food waste per household
763 increased significantly in line with the number of occupants per
764 household, whereas the mass per person decreased insignificantly
765 in relation to household size (Figures 5A & 5B). These results are
766 consistent with those found for the four municipalities (Section
767 3.4.2).

768 **3.4.6 Influence of household with “zero mass” of food** 769 **waste**

770 The influence of household that did not generate food
771 waste during this sampling period on the outcome of statistical

772 analyses was investigated by comparing two datasets: (1) all
773 households (in single-family house areas) included in the
774 sampling campaign and (2) those that actually generated food
775 waste. This means that households that did not generate anything
776 were excluded in the second datasets for each food waste
777 fraction.

778 We found a significant difference between datasets for the
779 following: avoidable processed food waste avoidable processed
780 vegetable food waste, avoidable processed animal-derived food
781 waste, avoidable unprocessed animal-derived food waste, and
782 unavoidable animal-derived food waste (Table SM 12). For these
783 waste fractions, the mass per person increased in line with the
784 size of household.. However, if we consider only the dataset for
785 households that generated food waste, we found that the mass of
786 food waste per person decreased when the household size
787 increased – as expected.

788 **5 Conclusions and future prospects**

789 In the present study, we provided data for the occurrence,
790 the mass and the composition of food waste from Danish
791 households based on waste stream analysis.

792 The results showed that most of the Danish households
793 generated avoidable (97% of households) and unavoidable (98%
794 of households) food waste independently of regions,
795 municipalities and sampling period. Moreover, the occurrence of

796 food waste generated by households was driven by household
797 size. The results indicate a Danish household containing one
798 person is less likely to generate avoidable food waste compared
799 to other household sizes.

800 We found that avoidable food waste was the predominant
801 food waste fraction, suggesting that a reduction of avoidable food
802 waste could reduce considerably the total mass of Danish residual
803 household waste. However, an efficient treatment of unavoidable
804 food waste could ensure resource recovery.

805 Although, the results showed that the mass per household
806 of food waste fractions increased in line with household size, the
807 statistical analysis revealed that there was no significant
808 difference among household sizes of the aggregated mass per
809 person for individual fractions, avoidable and unavoidable food
810 waste.

811 A combining waste stream analysis based on food
812 categories, households purchasing data, and their consumption
813 patterns-type should be considered to determine the mass of food
814 purchased and the mass of food consumed. These data could
815 provide better insight of the detailed food products that are
816 wasted from households. This information enables to develop
817 efficient and local based solution to reduce food waste from
818 households.

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829 **Supplementary material (SM)**

830 Supplementary materials contain detailed food waste data used
831 for calculations and figures. SMs are divided into tables (Table
832 SM) and figures (Figure SM).

833

834

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1 **Tables**

2 Published in Waste Management

3

4 **Food waste generation and composition from Danish**
5 **households**

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Table 1: Food categories and food products included in the six food waste fractions-Last column shows example of food products that is not included

Food waste fractions	Food categories ^a	Included food products	Excluded food products
Avoidable unprocessed vegetable food waste (AUVFW)	Bakery	Bread, cakes (packed or not)	Bread used for sandwiches.
	Drinks and confectionery and desserts	Tea bags, coffee grounds, biscuits, chips, beer, alcohol, etc.	
	Condiments, sauces, herbs and spices	Ketchup, peanut butter, sauces, salt, honey, jam, olives, mayonnaise, salt, sugar, etc.	
	Fresh fruit	Banana, apple, melon, other fruits, etc.	Fruits prepared or served at home -half eaten.
	Fresh vegetables and salads	Carrots, potatoes, other fresh vegetables, etc.	Home cooked or served vegetables, salad.
	Stable food	Breakfast cereal, rice, pasta, flour, etc.	Cooked rice, pasta, etc.
Avoidable processed vegetable food waste (APVFW)	Canned food	Corn, bean, pineapple, other tinned vegetables	
	Other food	Other uncooked vegetable food.	
	Bakery	Vegetable pizza, pizza bread, etc.	Bread used for sandwiches, meat pizza.
	Stable food	Rice, pasta, etc. (cooked or served at home).	
Unavoidable vegetable food waste (UVFW)	Fresh vegetables and salads	Potatoes, yams, vegetables, etc. (cooked or served at home).	
	Other food	Other cooked, prepared or served food at home.	
	Drinks and confectionery and desserts	Spent coffee grounds, tea bags, etc.	Unused tea bag, coffee grounds
	Fresh fruit	Skin (e.g. pineapple), peels (e.g. banana), stones (e.g. avocado), (fruits rinds (e.g. melon).	Half eaten fruit, rotten fruit, etc.
	Fresh vegetables and salads	Skin (e.g. potatoes, carrots, onion), peels (e.g. courgette, cucumber, etc.), etc.	Half eaten vegetables.
Avoidable unprocessed animal derived food waste (AUAFW)	Canned food	Brine from canned vegetables food , etc.	
	Pet food	Vegetable pet food.	
	Other food	Other inedible vegetables and fruits.	
	Dairy and eggs	Eggs, dairy products (milk, yoghurt, cheese, margarine, butter, etc.).	Cooked eggs, opened and served dairy products.
Avoidable processed animal derived food waste (APAFW)	Meat and fish	Meat, fish, packed cold meat, cut meat.	Opened meat package -cooked or served.
	Canned food	Canned meat and fish, canned mixed animal and vegetable products, etc.	Opened canned vegetable.
	Other food	Other mixed of vegetable and animal products.	Opened canned mixed or only animal products.
	Bakery	Bread found in sandwich prepared and served at home.	
Unavoidable animal derived food waste (UAFW)	Dairy and eggs	Cooked or fried eggs, cheese served at home, etc. and edible leftover.	Unopened canned vegetable food.
	Canned food	Opened canned meat and fish food.	
	Meat and fish	Cooked, prepared or served at home (meat, fish, etc.).	Unopened canned mixed or only animal products.
	Other food	Other mixed of vegetable and animal products cooked, prepared or served at home.	
Unavoidable animal derived food waste (UAFW)	Dairy and eggs	Cheese rinds, eggs shells, etc.	Half or leftover eggs and dairy products.
	Meat and fish	Meat and fish (skin, rinds, fat, etc.), fish heads, shellfish shells, etc.	
	Pet food	Animal or mixed animal and vegetable pet food.	
	Other food	Other non-edible mixed of animal and vegetable products.	

^aGrouped food categories were adapted from WRAP (2009) and Lebersorger and Schneider (2011) See Table SM 1 for food categories.

Table 2: Number of household per area and the total amount of residual household waste generated during one week

Housing types	Municipalities	Regions	Number of households per sampling unit	Amount analysed (kg wet mass) ¹
Single-family	Gladsaxe	Zealand	111	1,100
	Gladsaxe	Zealand	98	1,100
	Helsingør	Zealand	189	2,000
	Kolding	Jutland	101	1,000
	Kolding	Jutland	93	1,000
	Viborg	Jutland	108	1,100
	Viborg	Jutland	82	1,000
Multi-family	Gladsaxe	Zealand	319	2,100
	Odense	Jutland	372	1,800
Total	-	-	1,474	12,200

¹Arounded amount of residual household analysed

Table 3: Composition of food waste (in mass per wet basis: w/w)

Composition	SFHA ^a (n=7) ^c		MFHA ^b (n=3) ^c		Denmark (Weighted average) ^d	
	Mean	SD ^e	Mean	SD ^e	Mean	SD ^e
Avoidable food waste						
Avoidable processed food waste						
Avoidable processed animal-derived food waste (% w/w)	7.8	1.1	8.9	3.04	8.2	1.3
Avoidable processed vegetable food waste (% w/w)	8.9	0.9	13.0	4.8	10.5	1.8
Avoidable unprocessed food waste						
Avoidable unprocessed animal-derived food waste (% w/w)	8.3	0.8	7.3	2.3	8.0	1.0
Avoidable unprocessed vegetable food waste (% w/w)	30.6	1.2	28.5	7.7	29.8	2.9
Unavoidable food waste						
Unavoidable animal-derived food waste (% w/w)	3.9	0.8	5.2	1.1	4.4	0.6
Unavoidable vegetable food waste (% w/w)	40.6	1.9	37.0	4.7	39.2	2.1
Total	100		100		100	
Food waste (% w/w of total residual household waste)	41.0	0.8	43	4.7	43	1.8

^a Single-family house areas

^b Multi-family house areas

^c Number of sampling areas (see Table 1)

^d Weighted average was calculated with 60% single-family houses and 40% multi-family houses (Statistics Denmark, 2015).

^e Standard deviation.

Table 4: Generation rate of food waste (in mass per wet basis: w/w)

Composition	SFHA ^a (n=7) ^c		MFHA ^b (n=3) ^c		Denmark (Weighted average) ^d	
	Mean	SD ^e	Mean	SD ^e	Mean	SD ^e
Food waste (kg/household/week)	3.50	0.1	3.8	0.2	3.5	0.1
Food waste (kg/person/week)	1.47	0.04	1.97	0.1	1.6	0.0
Residual household waste (kg/household/week)	8.71	0.2	7.81	0.9	8.4	0.3
Residual household waste (kg /person/week)	3.55	0.2	4.6	0.2	3.9	0.1

^a Single-family house areas

^b Multi-family house areas

^c Number of sampling areas (see Table 1)

^d Weighted average was calculated with 60% single-family houses and 40% multi-family houses (Statistics Denmark, 2015).

^e Standard deviation.

Table 5: Review of household avoidable food waste (wet mass basis)

Countries	Avoidable food waste (wet kg per year)		Methods	Source
	Household	Capita		
Denmark ^a	48	103	WSA ^a	(WRAP, 2009)
UK	210	88	WSA ^a , diary and statistics	
Austria	-	33	WSA ^a	(Lebersorger and Schneider, 2011)
Sweden	60	-	WSA ^a	(Bernstad Sariwa Schott et al., 2013)
EU	-	115	Database	(Brautigam et al., 2014)
DK	-	126	Database	(Brautigam et al., 2014)
Germany	-	7	Questionnaire	(Jörissen et al., 2015)
Italy	-	7	Questionnaire	(Jörissen et al., 2015)
Germany	-	78	Modelling	(Jörissen et al., 2015)
Italy	-	42-104	Modelling	(Jörissen et al., 2015)
US	-	124	Literature review	(Koester, 2013)
UK	-	73	Diary	(Langley et al., 2010)
EU	-	47	Database	(Monier et al., 2010)
Denmark	-	7	Database	(Monier et al., 2010)
Finland	-	23	Diary	(Silvennoinen et al., 2014)
Canada	-	218	WSA ^a	(Parizeau et al., 2014)

^a Current study

^b Waste stream analysis

Table 6: Percentage of households that did not generate food waste (“no”) as function of household size (% n/n)^a in the single-family house area

Household size	1 person	2 persons	3 persons	4+ persons	Total
Number of households	95	304	113	270	782
Avoidable food waste (% n/n)	11	3	0	13	3
Avoidable processed food waste (% n/n)	52	21	8	15	17
Avoidable processed animal-derived food waste (% n/n)	67	41	23	11	32
Avoidable processed vegetable food waste (% n/n)	60	36	25	1	30
Avoidable unprocessed food waste (% n/n)	15	5	2	14	4
Avoidable unprocessed animal-derived food waste	49	28	19	1	25
Avoidable unprocessed vegetable food waste (% n/n)	23	10	2	1	7
Unavoidable food waste (% n/n)	5	2	0	1	2
Unavoidable animal-derived food waste (% n/n)	28	14	12	6	15
Unavoidable vegetable food waste (% n/n)	8	3	1	1	3

^a Number of households that did not generate food waste (n) divided by number of total households for each household size (n)

Table 7: Bootstrap estimates of standard errors and confidence intervals of the difference in amount of food waste (avoidable and unavoidable) as function of household size in single-family house areas

Household size	Coefficients		Standard Errors ^c		Bootstrap Confidence ^a Interval (95%-level) per household		Bootstrap Confidence ^a Interval (95%-level) per person	
	Household	Person	Household	Person	Lower	Upper	Lower	Upper
Avoidable food waste								
1 person	1.03	1.03	0.15	0.16	0.81	1.51	0.81	1.45
2 persons	0.66 ^b	-0.19 ^b	0.18	0.16	0.22	0.96	-0.62	0.05
3 persons	1.85 ^b	-0.07 ^b	0.25	0.17	1.36	2.34	-0.50	0.18
4+ persons	2.75 ^b	-0.15 ^b	0.21	0.16	2.30	3.12	-0.60	0.08
Unavoidable food waste								
1 person	0.96	0.96	0.15	0.08	0.96	1.14	0.81	1.14
2 persons	0.85 ^b	-0.05 ^b	0.18	0.10	0.85	1.14	-0.25	0.14
3 persons	0.91 ^b	-0.34 ^b	0.25	0.10	0.91	1.24	-0.53	-0.16
4+ persons	1.34 ^b	-0.43 ^b	0.21	0.09	1.35	1.58	-0.62	-0.27

^a Confidence interval that excluded zero, and indicating significant difference.

^b Difference between household containing one person and other household size; (-) is lower than household containing one person and (+) means higher than household containing one person. Confidence interval containing zero means that the difference is insignificant, whereas confidence interval excluding zero means the difference is significant.

^c Bootstrap estimate of standard deviation.

Table 8: Generation of food waste and total residual household waste in single-family house area of Gladsaxe as function of period and associated probability values from permutation test (kg wet-waste per week)

Material fractions	Period 1 (n=115) ^a		Period 2 (n=124) ^a		Period 3 (n=124) ^a		P-value ^d	
	HH ^b	PP ^c	HH ^b	PP ^c	HH ^b	PP ^c	HH ^b	PP ^c
Avoidable food waste	2.22±2.13	0.87±0.81	2.6±2.49	1.01±1.34	2.25±2.18	0.84±0.8	0.55	0.37
Avoidable processed food waste	0.66±0.85	0.24±0.29	0.70±0.96	0.24±0.29	0.85±1.03	0.31±0.39	0.12	0.18
Avoidable processed animal-derived food waste [§]	0.32±0.51	0.12±0.2	0.33±0.43	0.11±0.13	0.38±0.54	0.13±0.2	0.34	0.67
Avoidable processed vegetable food waste [§]	0.34±0.52	0.12±0.17	0.37±0.74	0.13±0.24	0.47±0.65	0.18±0.26	0.22	0.13
Avoidable unprocessed food waste	1.56±1.6	0.63±0.68	1.90±2.01	0.77±1.27	1.4±1.49	0.53±0.58	0.07	0.09
Avoidable unprocessed animal-derived food waste [§]	0.3±0.38	0.13±0.21	0.38±0.45	0.15±0.18	0.26±0.57	0.10±0.26	0.18	0.27
Avoidable unprocessed vegetable food waste [§]	1.26±1.41	0.50±0.56	1.52±1.81	0.62±1.24	1.14±1.27	0.43±0.49	0.14	0.16
Unavoidable food waste	2.06±1.58	0.88±0.69	1.90±1.43	0.77±0.53	1.74±1.62	0.68±0.64	0.35	0.04
Unavoidable animal-derived food waste [§]	0.20±0.28	0.08±0.12	0.22±0.29	0.08±0.09	0.13±0.22	0.05±0.09	0.04 ^{§f}	0.04 ^{§f}
Unavoidable vegetable food waste [§]	1.87±1.46	0.80±0.64	1.68±1.34	0.69±0.51	1.60±1.5	0.62±0.58	0.17	0.19
Food waste	4.28±3.05	1.75±1.19	4.49±3.38	1.78±1.54	3.99±3.43	1.51±1.27	0.46	0.39
Residual household waste	8.86±4.64	3.76±2.13	9.38±5.2	3.84±2.3	8.62±5.64	3.47±2.53	0.62	0.84

^a Number of households in the single family house areas

^b mean and standard deviation in kg wet waste per household per week

^c mean and standard deviation in kg wet waste per person per week. Standard deviation describes the variation between single-family houses

^d: p-values for the permutation test based on the amount of FW per households (HH) and per person (PP).

^f: significance level $p < 0.05$

[§]Detailed six food waste fractions

Figures

Figure 1: Weighted generation rate of food waste in Danish households in kg wet mass per household per year.

Figure 2: Weighted average composition of Danish household food waste (% mass per wet basis) based on food categories.

Figure 3: Distribution of the generation of avoidable and unavoidable food waste (box plots are based on wet mass basis) in the single family house areas as function of household size for the four municipalities: kg waste per household (A & B) and waste kg per person per week (C&D).

Figure 4: Comparison of the generation rates for different food waste fractions generated in single-family house areas between (wet mass basis of mean and 95% confidence interval are displayed): 1) unprocessed versus processed food waste fractions (A & C); 2) vegetable and animal-derived food waste fractions (B & D). The data are expressed in kg per household per week (A & B) and kg per person per week (C&D).

Figure 5: Periodic generation of avoidable and unavoidable food waste (box plots are based on wet mass basis) in the single-family house areas of Gladsaxe as function of household size: kg per household (A & B) and kg per person(C & D).

Figure 1

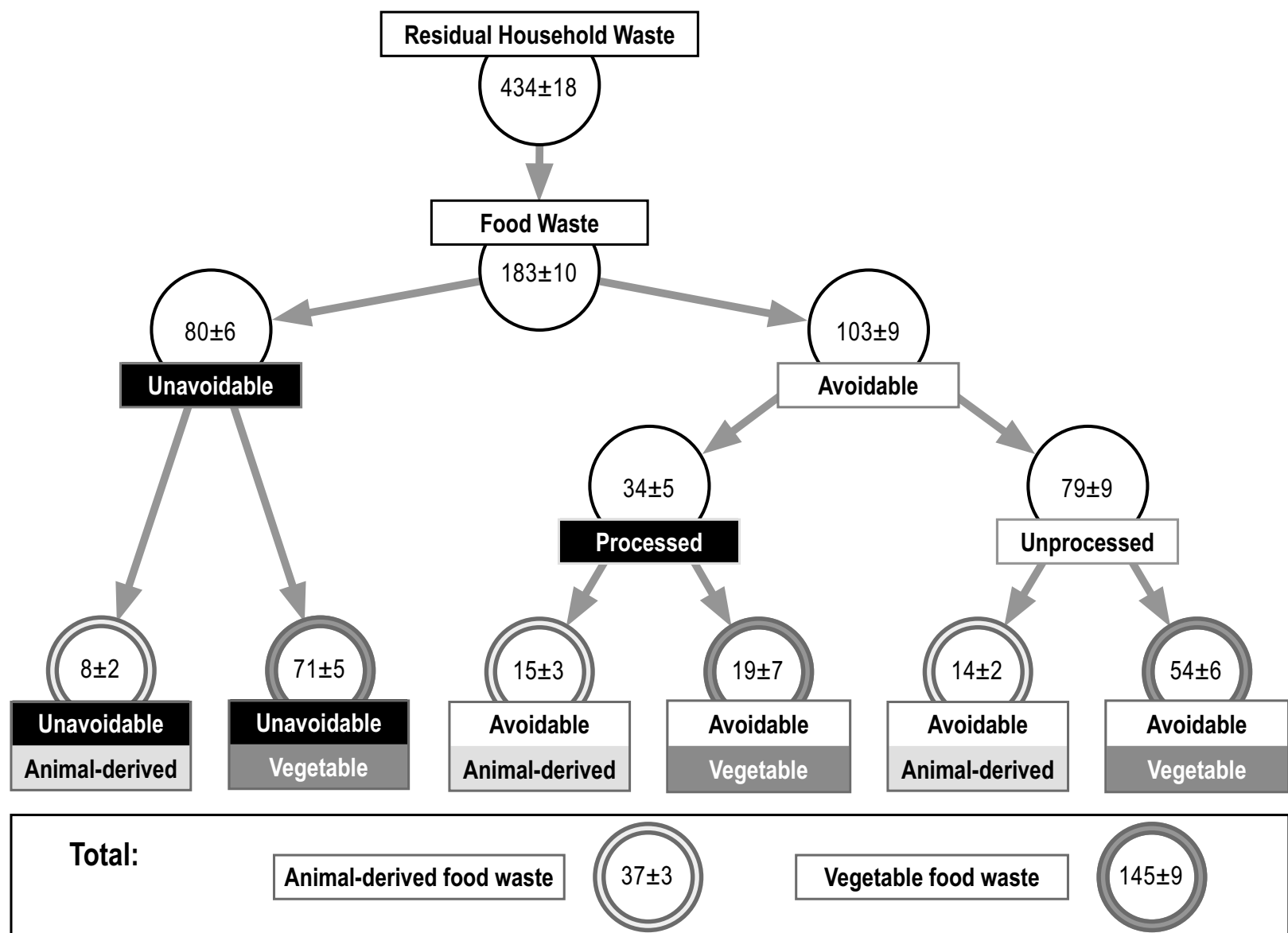


Figure 2

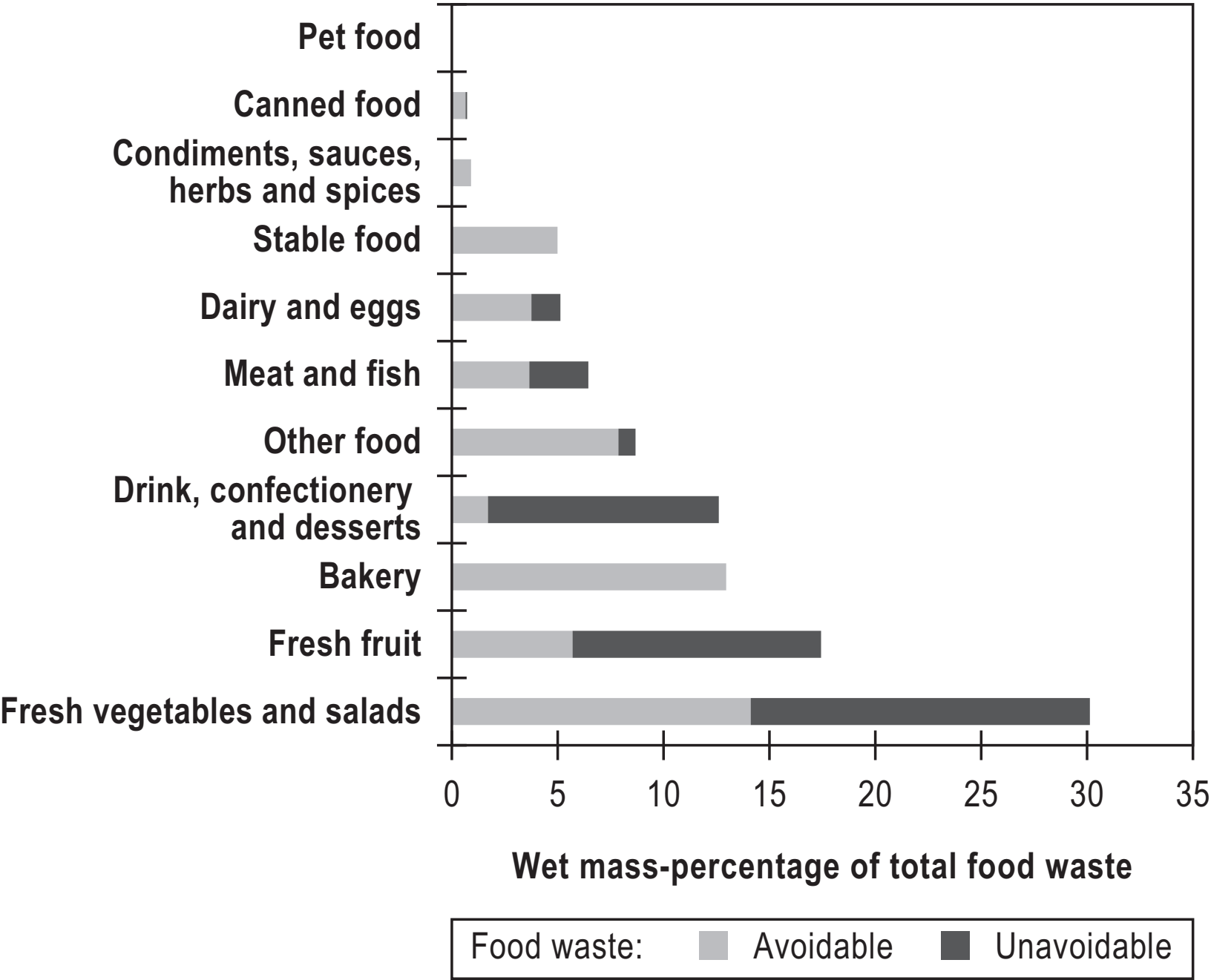


Figure 3

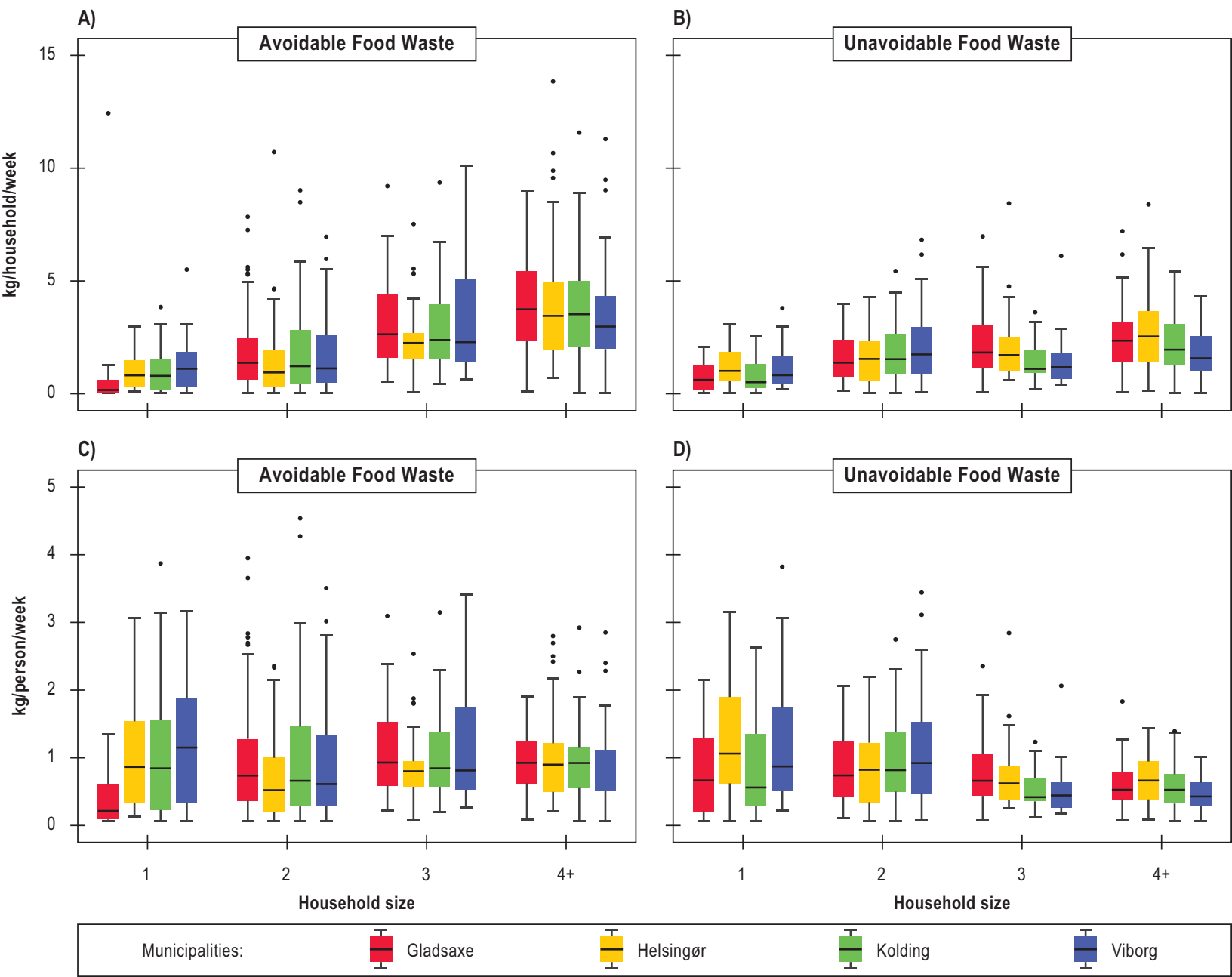


Figure 4

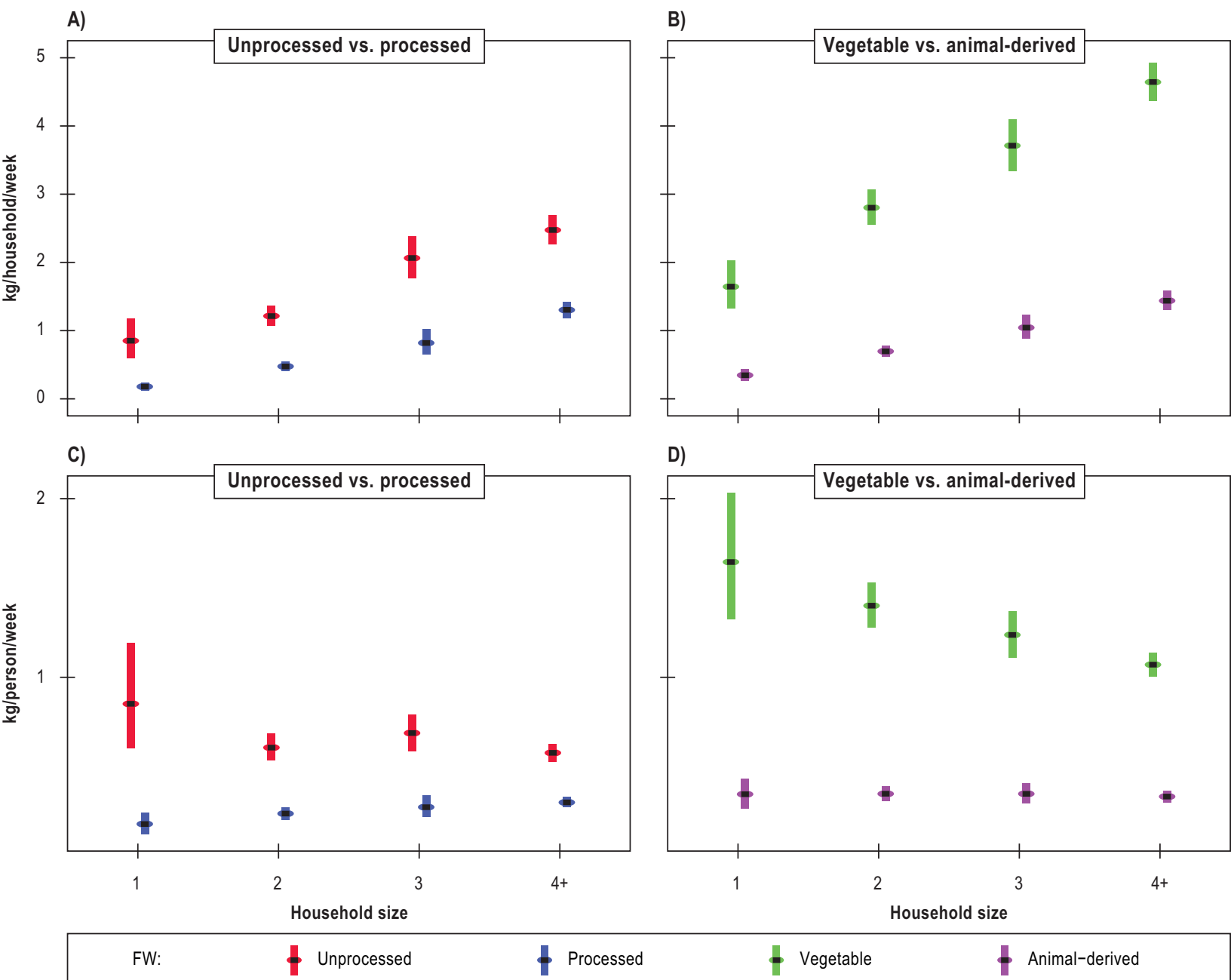
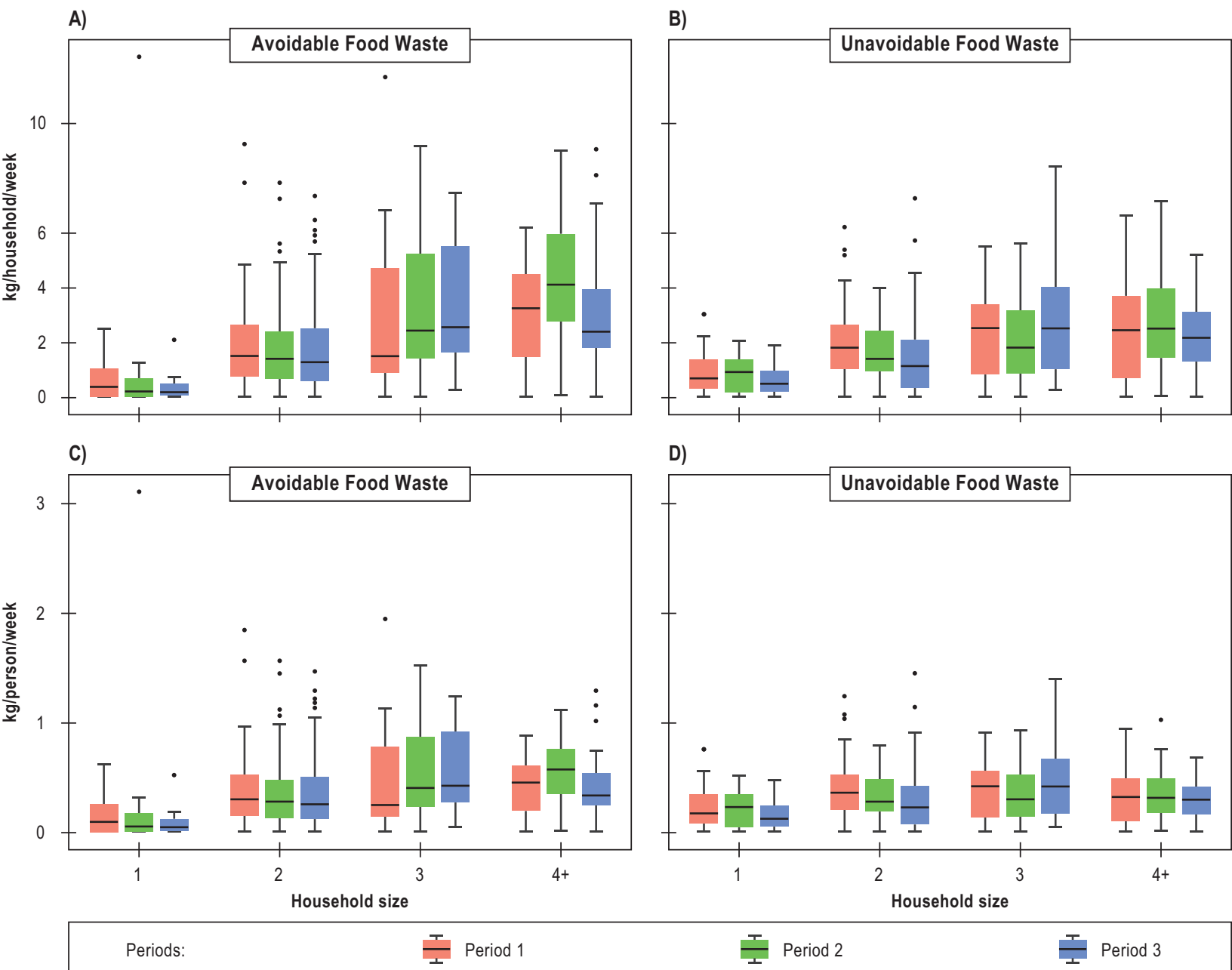


Figure 5



1 Supplementary materials for the paper:

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3 **Food waste generation and composition fom Danish households**

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16 **Supplementary materials (SM)**

17 Supplementary materials contain detailed food waste data used for calculations. SMs are divided into
18 tables (Table SM) and figures (Figure SM).

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20 **Supplementary materials (SM) –Tables**

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22

23 **Table SM1: Grouping of food waste fractions**

Food waste sub-fractions	APAFW ^a	AUAFW ^b	UAFW ^c	APVFW ^d	AUVFW ^e	UVFW ^f
Avoidable food waste	X	X		X	X	
Unavoidable food waste			X			X
Animal derived food waste	X	X	X			
Vegetable food waste				X	X	X
Avoidable processed food waste	X			X		
Avoidable unprocessed food waste		X			X	
Food waste	X	X	X	X	X	X

24 ^a *Avoidable processed animal derived food waste.*
 25 ^b *Avoidable unprocessed animal derived food waste.*
 26 ^c *Unavoidable processed animal derived food waste.*
 27 ^e *Avoidable processed vegetable food waste.*
 28 ^f *Avoidable unprocessed vegetable food waste.*
 29

30 Table SM 2: Food waste categories and fractions included

Grouped food categories	What it includes
Bakery	Bread found in sandwich prepared and served at home Bread, cakes (packed or not) Vegetable pizza, pizza bread, etc.
Canned food	Brine from canned vegetables food , etc. Canned meat and fish, Canned mixed animal and vegetable products, etc. Corn, bean, pineapple, other tinned vegetables Opened canned meat and fish food
Condiments, sauces, herbs and spices	Honey, jam, olives, etc. Mayonnaise, Ketchup, Peanut butter, sauces, salt, sugar
Dairy and eggs	Cheese rinds, eggs shells, etc., Cooked or fried eggs, cheese served at home, etc. and edible leftover, Dairy products (milk, yoghurt, cheese, margarine, butter, etc.) Eggs,
Drinks and confectionery and desserts	Biscuits, chips, beer, alcohol, etc Spent coffee grounds, tea bags, etc. Tea bags, coffee grounds
Fresh fruit	Banana, apple, melon, other fruits, etc. Skin (e.g. pineapple), peels (e.g. banana), Stones (e.g. avocado), (fruits rinds (e.g. melon)
Fresh vegetables and salads	Carrots, potatoes, other fresh vegetables, etc. Peels (e.g. courgette, cucumber, etc.), etc. potatoes, yams, vegetables, etc. (cooked or served at home) Skin (e.g. potatoes, carrots, onion)
Meat and fish	Cooked, prepared or served at home (meat, fish, etc.) Fish heads, shellfish shells, etc. Meat and fish (skin, rinds, fat, etc.), Meat, fish, packed cold meat, cut meat,
Other food	Other cooked, prepared or served food at home, Other inedible vegetables and fruits Other mixed of vegetable and animal products Other mixed of vegetable and animal products cooked, prepared or served at home Other uncooked vegetable food
Pet food	Animal or mixed animal and vegetable pet food Vegetable pet food
Stable food	Breakfast cereal, rice, pasta, flour, etc. Rice, pasta, etc. (cooked or served at home)

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32 Table SM 3: Distribution of household size of both households sampled and population for the four
33 municipalities

Municipalities	Type of population	Household size (in %)				Total
		1	2	3	4+	
Gladsaxe	Sample	12	36	16	35	100
	Population	22	33	16	29	100
Helsingør	Sample	9	42	16	33	100
	Population	23	36	15	26	100
Kolding	Sample	16	35	15	34	100
	Population	24	38	14	25	100
Viborg	Sample	11	43	10	36	100
	Population	26	37	13	24	100

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35 Table SM 4: Household size and distribution of Danish households per housing type

Parameters	Single-family house (SFHA)	Multi-family house (MFSA)	Denmark (DK)
Distribution (%)	60 ^{aj}	40 ^{aj}	100
Average household size (Number of person per household)	1.89	1.66	1.70 ^b

36 *Source:* (Statistics Denmark, 2015)

37 *The average amount per household in Denmark is: $M_{DK}(\text{Household}) = aiM_{SFHA} + ajM_{MFHA}$; $M_{DK}(\text{Person}) = bM_{DK}(\text{Household})$*

38

39 Table SM 5: Distribution of Danish household's size in the single-family household area

Household size (Number of person per households)	1	2	3	4+
Single-family households (SFHA)	27 ^{aj}	38 ^{aj}	14 ^{aj}	22 ^{aj}

40 *Source:* (Statistics Denmark, 2015)

41 *The average amount per household in Denmark is: $M_{SFHA} = \sum_{k=1}^n c_k m_{SFHA(k)}$*

42 *Where c_k is the distribution according to housing size, and m_{SFHA} is the mass for each housing size.*

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45 Table SM 6: Average food waste composition (wet mass basis) for each housing type and the weighted average
46 for Denmark

Food waste	SFHA ^a (n=4) ^c		MFHA ^b (n=3) ^c		Denmark (Weighted Average) ^d	
	Mean	SD ^e	Mean	SD ^e	Mean	SD ^e
Avoidable food waste	55.6	2.0	57.8	9.8	56.4	3.8
Avoidable processed food waste	16.7	1.4	22.0	5.7	18.7	2.2
Avoidable processed animal-derived food waste	7.8	1.1	8.9	3.0	8.2	1.3
Avoidable processed vegetable food waste	8.9	0.9	13.0	4.8	10.5	1.8
Avoidable unprocessed food waste	38.9	1.4	35.9	8.0	37.7	3.0
Avoidable unprocessed animal-derived food waste	8.3	0.8	7.3	2.3	8.0	1.0
Avoidable unprocessed vegetable food waste	30.6	1.2	28.5	7.7	29.8	2.9
Unavoidable food waste	44.4	2.1	42.2	4.8	43.6	2.2
Unavoidable animal-derived food waste	3.9	0.8	5.2	1.1	4.4	0.6
Unavoidable vegetable food waste	40.6	1.9	37.0	4.7	39.2	2.1
Animal-derived food waste	20.0	1.6	21.4	4.0	20.5	1.7
Vegetable food waste	80.0	2.4	21.4	10.2	79.5	4.0
Avoidable vegetable food waste	38.9	1.5	35.9	9.1	37.7	3.4
Avoidable animal-derived food waste	16.7	1.4	22.0	3.8	18.7	1.6

47 ^a *Single-family house areas*

48 ^b *Multi-family house areas*

49 ^c *Number of sampling areas (see Table 1)*

50 ^d *Weighted average was calculated with 60% single-family houses and 40% multi-family houses (Statistics Denmark, 2015).*

51 ^e *Standard deviation quantifies the amount of dispersion of data set, which consists of the average waste values of the municipalities.*

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53 Table SM 7: Names of variables and description for logistic regression model

Response variable (Y)	Influencing factors (explanatory)	Description
Y=0 (FWs was not found in the RHW waste bin)	Region (categorical n=2)	Jutland, Zealand
Y=1 (FWs was found in the RHW waste bin)	Municipalities (categorical n=4)	Gladsaxe, Helsingør, Kolding and Viborg
	Household size (categorical n=2)	1 person, 1+persons
	Household size (continuous)	Number of person per household

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56 Table SM 8: Overview of the result from the logistic regression model assessing factors that influence whether
 57 a Danish household generate

Potential influential factors	Municipalities	Regions	Composting	Household size	Household size
Type of variables	Categorical	Categorical	Categorical	Categorical	Continuous
Degree of freedom	3	1	1	1	1
Avoidable food waste	Not(Sig)	Not(Sig)	Not(Sig)	Sig***	Sig***
Avoidable processed food waste	Not(Sig)	-	Not(Sig)	Sig*	Sig*
Avoidable processed animal-derived food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Avoidable processed vegetable food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Avoidable unprocessed FW	Not(Sig)	Not(Sig)	Not(Sig)	Sig***	Sig***
Avoidable unprocessed animal-derived food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Avoidable unprocessed vegetable food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Unavoidable food waste	Not(Sig)	Not(Sig)	Not(Sig)	Sig*	Sig*
Unavoidable animal-derived food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Unavoidable vegetable food waste	Not(Sig)	Not(Sig)	Sig*	Sig*	Sig*

58 *** *Very high significance probability ($p < 0.001$).*

59 ** *High significance probability ($0.001 < p < 0.1$).*

60 * *significance probability ($0.05 < p < 0.001$).*

61 *Not(Sig) no significance probability ($p > 0.05$).*

62 Table SM 9: Estimated coefficients, 95% confidence interval and statistically significant of the logistic
 63 regression that predict the probability of generating food waste in Danish single-family home

Food waste fractions	Household size	OR ^a	Std. error ^b	Confidence interval (95%)		P-value
				Lower	Upper	
Avoidable food waste	Intercept (1 person)	8.5	1.4	4.64	17.45	< 0.001
	2 persons	3.46	1.59	1.38	8.7	0.00747
	<2 persons	22.41	2.19	5.78	147.55	< 0.001
Avoidable processed food waste	Intercept (1 person)	0.94	1.23	0.63	1.4	0.758
	2 persons	3.92	1.28	2.41	6.4	<0.001
	<2 persons	19.33	1.36	10.73	36.06	<0.001
Avoidable animal-derived food waste	Intercept (1 person)	0.48	1.24	0.31	0.74	<0.001
	2 persons	3	1.28	1.86	4.92	<0.001
	<2 persons	10.9	1.3	6.61	18.33	<0.001
Avoidable vegetable processed food waste	Intercept (1 person)	0.67	1.23	0.44	1	0.0529
	2 persons	2.65	1.27	1.66	4.27	<0.001
	<2 persons	7.2	1.28	4.44	11.83	<0.001
NPropck	Intercept (1 person)	5.79	1.34	3.39	10.65	< 0.001
	2 persons	3.58	1.49	1.63	7.88	0.00136
	<2 persons	16.38	1.79	5.71	58.94	< 0.001
AnNPkr	Intercept (1 person)	1.02	1.23	0.68	1.53	0.918
	2 persons	2.52	1.27	1.57	4.06	<0.001
	<2 persons	4.97	1.28	3.07	8.1	<0.001
VeNPkr	Intercept (1 person)	3.32	1.28	2.1	5.47	<0.001
	2 persons	2.86	1.37	1.54	5.26	<0.001
	<2 persons	28.55	1.75	10.56	99.8	<0.001
UAVoidkr	Intercept (1 person)	18	1.58	8.11	51.09	< 0.001
	2 persons	2.36	1.82	0.68	7.56	0.15146
	<2 persons	10.58	2.33	2.24	74.73	0.00523
AnUkr	Intercept (1 person)	2.52	1.26	1.63	4	< 0.001
	2 persons	2.48	1.33	1.42	4.29	0.00128
	<2 persons	2.98	1.32	1.72	5.12	< 0.001
VeUkr	Intercept (1 person)	10.88	1.45	5.62	24.38	<0.001
	2 persons	2.7	1.63	1	7.06	0.0423
	<2 persons	6.95	1.79	2.26	23.49	<0.001
AnAVoidkr	Intercept (1 person)	1.38	1.23	0.92	2.08	0.125
	2 persons	3.37	1.29	2.04	5.57	<0.001
	<2 persons	10.41	1.34	5.91	18.72	<0.001
VeAVoidkr	Intercept (1 person)	4.94	1.32	2.97	8.76	< 0.001
	2 persons	2.47	1.42	1.23	4.88	0.00955
	<2 persons	25.65	1.9	8.31	112.18	< 0.001
Ankr	Intercept (1 person)	6.92	1.36	3.93	13.34	<0.001
	2 persons	7.18	1.67	2.7	21.16	<0.001
	<2 persons	6.01	1.58	2.46	15.17	<0.001
Vekr	Intercept (1 person)	46.5	2.04	14.73	282.22	<0.001
	2 persons	1.61	2.4	0.22	8.4	0.5845
	<2 persons	8.22	3.42	0.78	177.89	0.0869

64 ^a:The estimate of the odds ratios.
 65 ^b:The estimate of the standard error
 66 ^c: Transformed (exponential) 95% confidence interval
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68 Table SM 10: Uncertainty analysis for food waste generation (wet mass basis): Bootstrapping regression results
 69 for dataset including only household that generated food waste (mass of food waste is higher than zero)

Food waste	Household size	Statistical parameters							
		Wet mass per household per week				Wet mass per person per week			
		original	bootSE ^b	95% CI ^a		original	bootSE ^b	95% CI ^a	
Lower	Upper			Lower	Upper				
Processed FW	(Intercept)	0.356	0.045	0.265	0.446	0.319	0.041	0.240	0.397
	pers2	0.181	0.058	0.064	0.296	-0.066	0.043	-0.148	0.016
	pers3	0.348	0.085	0.183	0.511	-0.076	0.046	-0.164	0.012
	pers4+	0.861	0.077	0.709	1.015	-0.025	0.042	-0.107	0.056
Avoidable animal-derived processed FW	(Intercept)	0.295	0.049	0.201	0.394	0.235	0.049	0.135	0.329
	pers2	-0.014	0.051	-0.116	0.088	-0.106	0.049	-0.200	-0.005
	pers3	0.109	0.065	-0.021	0.234	-0.099	0.051	-0.197	0.005
	pers4+	0.298	0.057	0.182	0.411	-0.090	0.049	-0.184	0.011
Avoidable vegetable processed FW	(Intercept)	0.182	0.024	0.136	0.228	0.168	0.022	0.125	0.210
	pers2	0.195	0.036	0.123	0.263	0.008	0.024	-0.038	0.055
	pers3	0.260	0.053	0.152	0.362	-0.018	0.027	-0.068	0.033
	pers4+	0.468	0.046	0.373	0.557	-0.006	0.023	-0.050	0.040
Avoidable vegetable unprocessed FW	(Intercept)	0.320	0.037	0.246	0.393	0.274	0.037	0.196	0.345
	pers2	0.037	0.042	-0.044	0.122	-0.110	0.039	-0.185	-0.028
	pers3	0.122	0.049	0.026	0.221	-0.125	0.039	-0.200	-0.044
	pers4+	0.144	0.046	0.057	0.235	-0.156	0.038	-0.230	-0.076

70 ^a:Confidence interval.

71 ^b The bootstrapped estimates of standard error

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73 Table SM 11: Uncertainty analysis for food waste generation (wet mass basis): Bootstrapping regression results
 74 for dataset including both households that generated and not food waste (raw data)

Food waste	Household size	Statistical parameters							
		Wet mass per household per week				Wet mass per person per week			
		original	bootSE ^b	95% CI ^a		original	bootSE ^b	95% CI ^a	
Lower	Upper			Lower	Upper				
Processed FW	(Intercept)	0.168	0.028	0.114	0.221	0.125	0.024	0.076	0.172
	pers2	0.233	0.040	0.155	0.314	0.060	0.025	0.011	0.110
	pers3	0.455	0.069	0.325	0.586	0.089	0.029	0.031	0.146
	pers4+	0.988	0.071	0.853	1.123	0.151	0.026	0.101	0.204
Avoidable animal-derived processed FW	(Intercept)	0.067	0.015	0.036	0.096	0.045	0.010	0.026	0.063
	pers2	0.063	0.018	0.028	0.099	0.020	0.010	0.001	0.040
	pers3	0.166	0.032	0.100	0.227	0.046	0.013	0.019	0.074
	pers4+	0.408	0.037	0.338	0.481	0.073	0.011	0.051	0.096
Avoidable vegetable processed FW	(Intercept)	0.071	0.012	0.046	0.097	0.059	0.011	0.038	0.080
	pers2	0.140	0.024	0.091	0.188	0.044	0.013	0.018	0.070
	pers3	0.220	0.036	0.150	0.291	0.048	0.016	0.016	0.080
	pers4+	0.438	0.040	0.356	0.517	0.077	0.013	0.052	0.103
Avoidable vegetable unprocessed FW	(Intercept)	0.149	0.024	0.103	0.195	0.111	0.020	0.073	0.151
	pers2	0.090	0.028	0.033	0.144	0.005	0.019	-0.034	0.043
	pers3	0.187	0.039	0.109	0.262	0.009	0.021	-0.034	0.049
	pers4+	0.219	0.034	0.149	0.285	-0.009	0.019	-0.048	0.027

75 ^a:Confidence interval.

76 ^bThe bootstrapped estimates of standard error

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78 Table SM 12: Comparison between datasets containing or not households that generated food. Difference is
 79 between dataset (raw dataset, including household with zero food waste) and dataset including only households
 80 that generated food waste.

Food waste fractions	Difference	Bias	5%	95%	Significance
Food waste	-0.022	0.005	-0.289	0.232	
Avoidable food waste	-0.071	0.002	-0.262	0.105	
Avoidable processed food waste	-0.161	-0.001	-0.241	-0.072	*
Avoidable processed animal-derived food waste	-0.168	0.000	-0.215	-0.121	*
Avoidable processed vegetable food waste	-0.176	0.000	-0.232	-0.121	*
Avoidable unprocessed food waste	-0.072	0.002	-0.202	0.074	
Avoidable unprocessed animal-derived food waste	-0.130	0.000	-0.188	-0.074	*
Avoidable unprocessed vegetable food waste	-0.101	0.000	-0.220	0.032	
Unavoidable food waste	-0.035	-0.001	-0.158	0.089	
Unavoidable animal-derived food waste	-0.036	-0.001	-0.065	-0.006	*
Unavoidable vegetable food waste	-0.016	-0.001	-0.138	0.098	

81 *significance probability ($0.05 < p < 0.001$).

82 Not(Sig) no significance probability ($p > 0.05$).

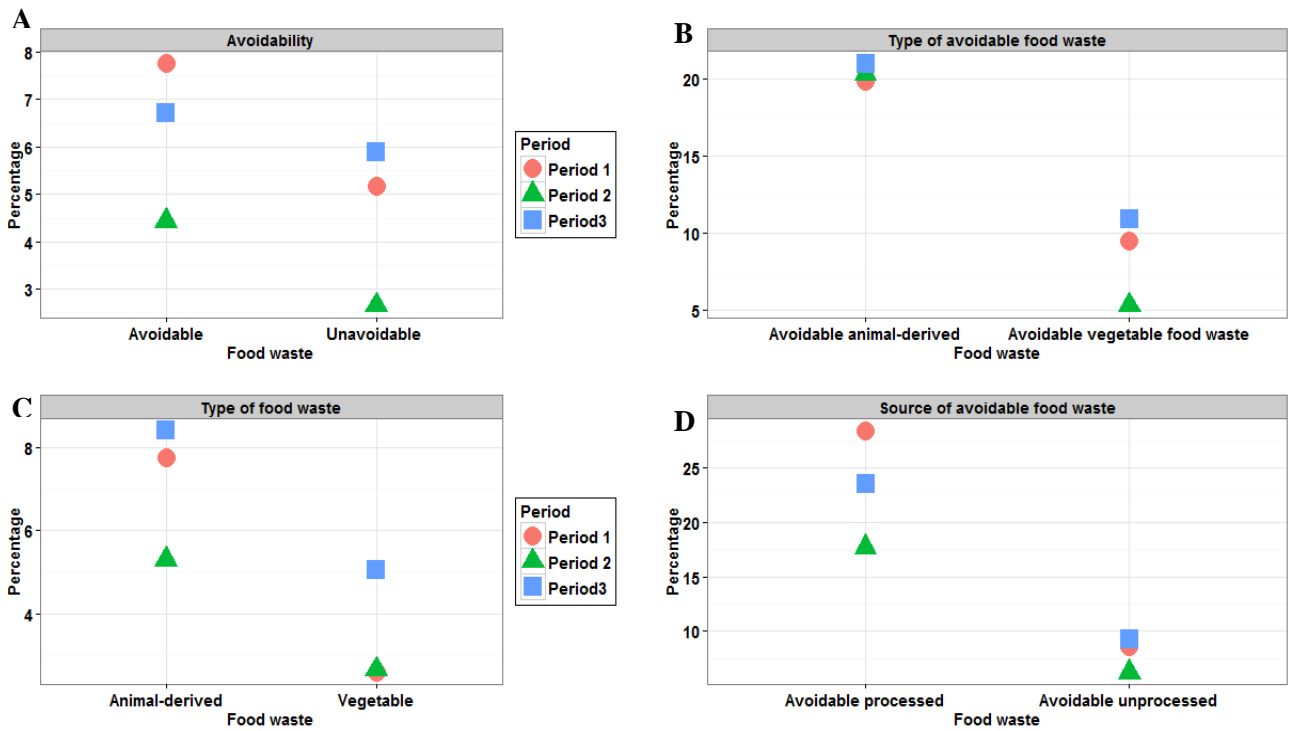
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84 **Supplementary materials- Figures**

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87 Figure SM 1: Percentage of households that did not generate food waste (“no”) in the single-family house area
88 (% n/n) A: Avoidable and unavoidable; B Avoidable animal-derived and avoidable vegetable;
89 C: Animal derived and vegetable food waste; D: Avoidable processed and avoidable unprocessed.

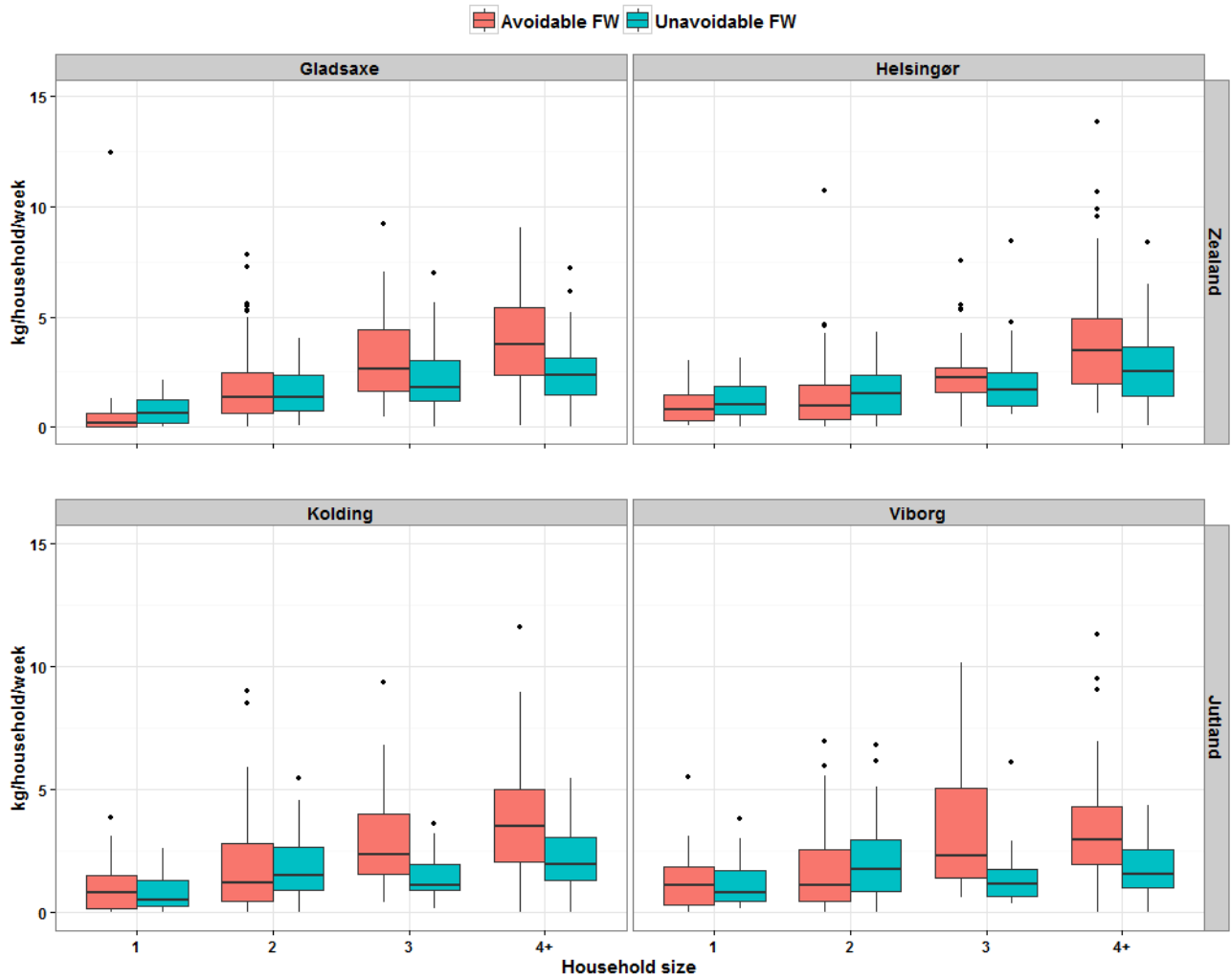


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93 Figure SM 2: Summary of the distribution of total food waste (wet mass basis) among single-family houses as
94 function of household size based on kg per household per week and kg per person per week



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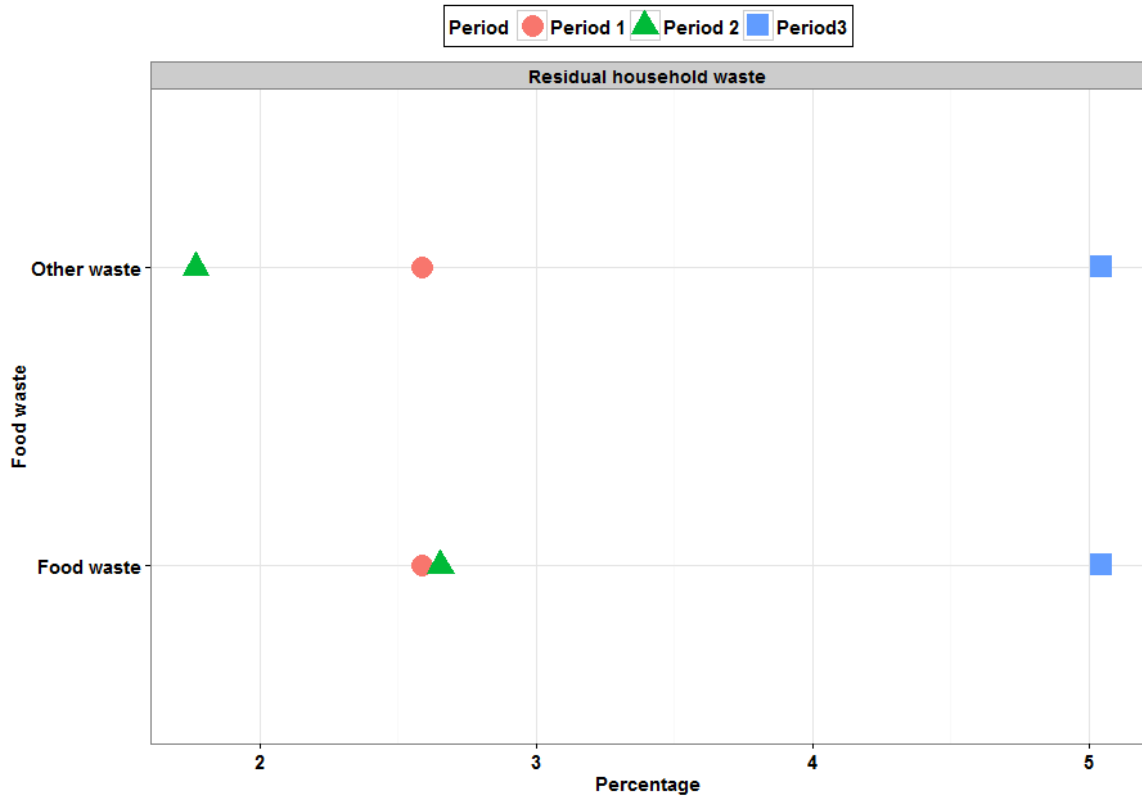
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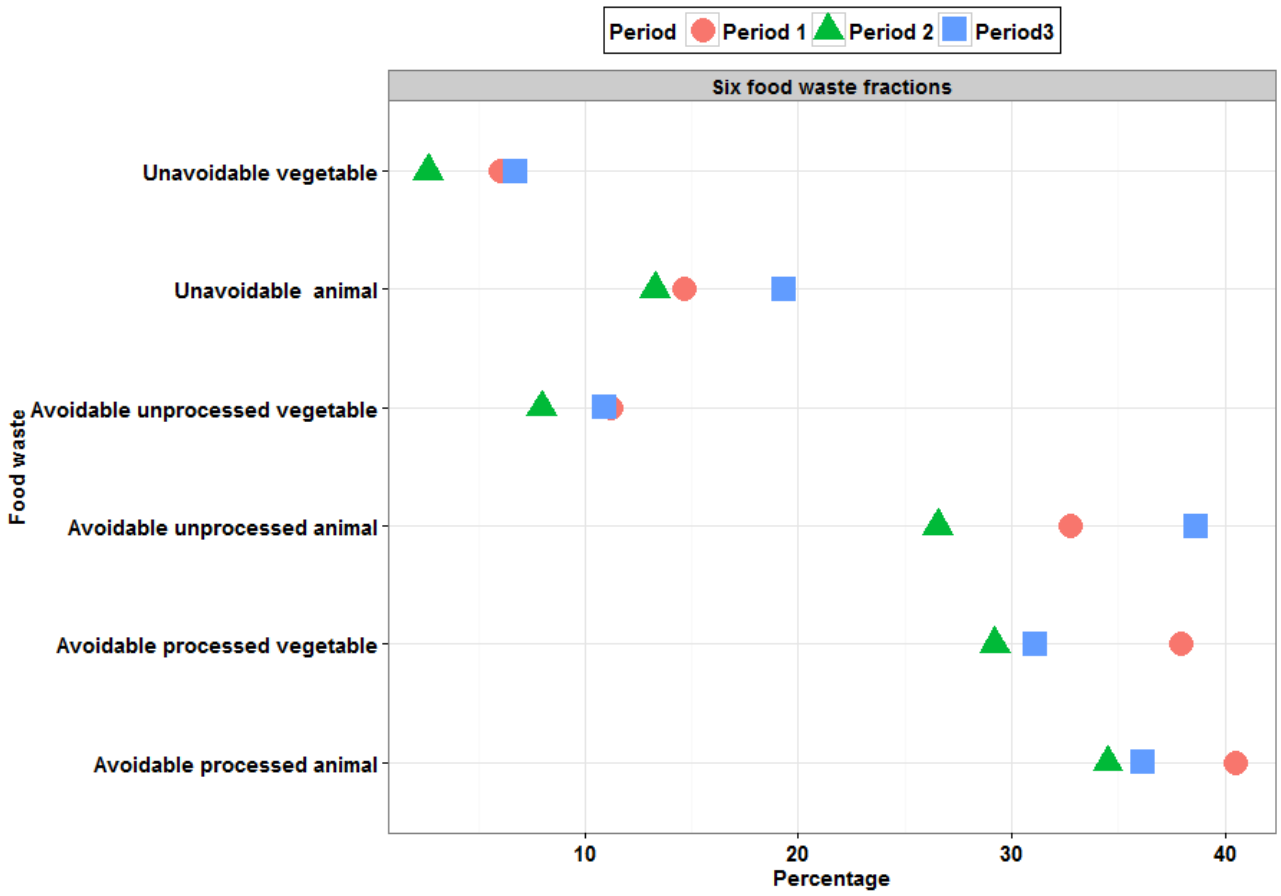
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Figure SM 3: Percentage of households that did not generate food waste (“no”) in the single-family house area
(% n/n): total food waste and other residual household waste



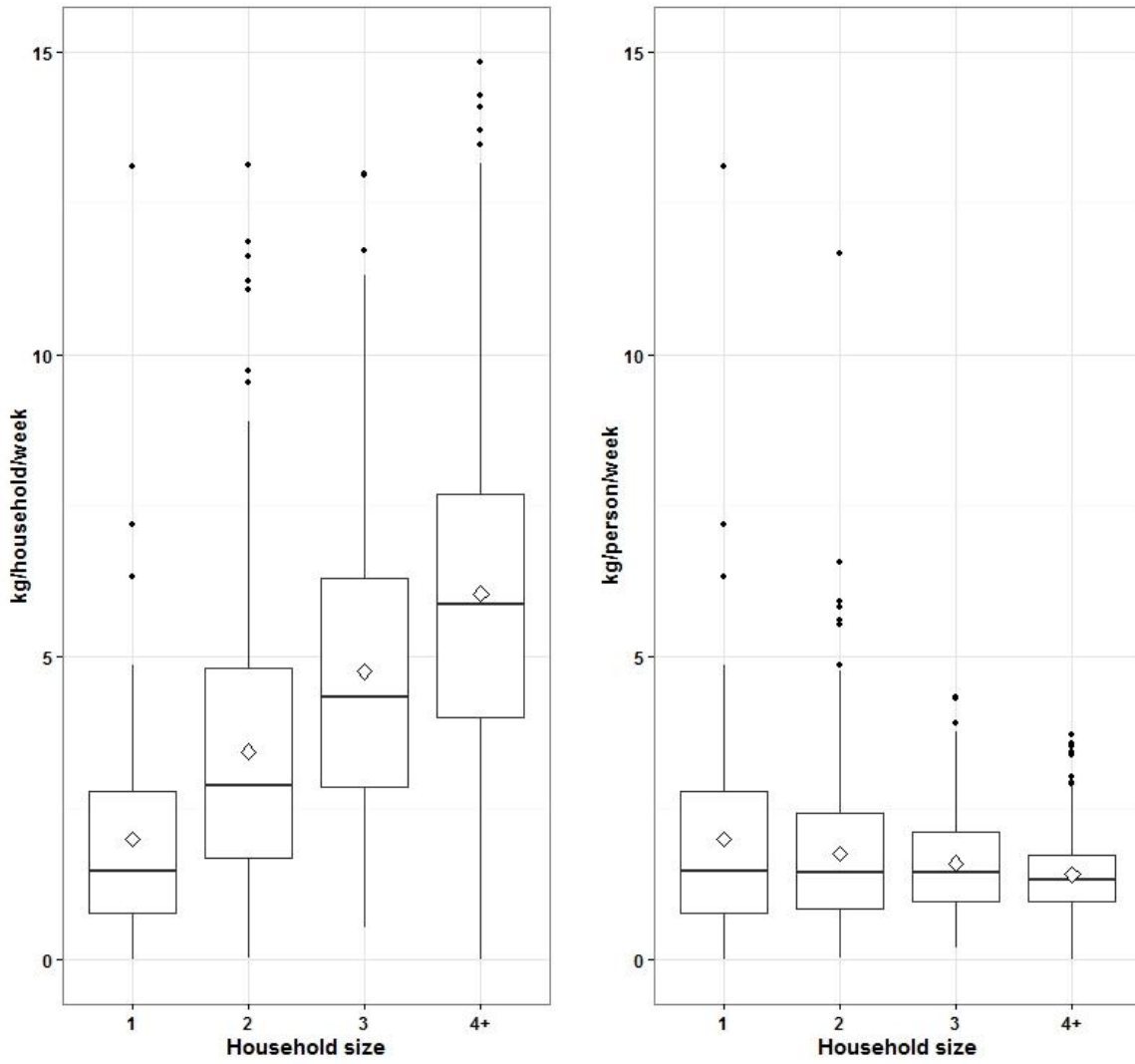
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115 Figure SM 4: Percentage of households that did not generate food waste (“no”) in the single-family house area
116 (% n/n) for the six food waste fractions



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120 Figure SM 5: Summary of the distribution of total food waste (wet mass basis) among households as function
121 of household size based on kg per household per week and kg per person per week



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