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Source segregation of food waste in office areas: factors affecting waste generation rates and quality

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Abstract

Existing legislation mandates that the amount of waste being recycled should be increased. Among others, in its Resource Strategy Plan, the Danish Government decided that at least 60% of food waste generated by the service sector, including in office areas, should be source-sorted and collected separately by 2018. To assess the achievability of these targets, source-sorted food waste and residual waste from office areas was collected and weighed on a daily basis during 133 working days. Waste composition analyses were conducted every week to investigate the efficiency of the source-sorting campaign and the purity of the source-sorted food waste. The moisture content of source-sorted food waste and residual waste fractions, and potential methane production from source-sorted food waste, was also investigated.

Food waste generation equated to 23 ± 5 kg/employee/year, of which 20 ± 5 kg/employee/year was source-sorted, with a considerably high purity of 99%. Residual waste amounted to 10 ± 5 kg/employee/year and consisted mainly of paper (29 ± 13%), plastic (23 ± 9%) and missorted food waste (24 ± 16%). The moisture content of source-sorted food waste was significantly higher (8%) than missorted food waste, and the methane potential of source-sorted food waste was 463 ± 42 mL CH_4/g VS. These results show that food waste in office areas offers promising potential for relatively easily collectable and pure source-sorted food waste, suggesting that recycling targets for food waste could be achieved with reasonable logistical ease in office areas.

Keywords:

Residual waste

Waste composition

Biochemical methane potential

Sorting efficiency

Impurity

Waste sorting bins

1 Introduction

In the context of the circular economy and resource efficiency, the Danish Government, in 2013, launched its Resource Strategy Plan, mandating that, by 2018, at least 60% of food waste– that cannot be prevented or reduced – generated by the service sector, including in office areas, should be source-sorted and collected separately (Danish Government, 2013). This source-sorted food waste should be treated biologically to produce biogas and to recover nutrients (Danish Government, 2013). Furthermore, numerous public and private companies and businesses as well as institutions in the service sector are increasingly committed to sustainable development through the prevention, reuse and recycling of their waste (European Commission, 2013; Lang et al., 2011; Phillips et al., 1999). In order to assess the current waste situation, and to allow for any evaluation of performance against target indicators, data on solid waste generation and composition are required. While recently many studies have focused on source-sorted food waste at the household level (Bernstad, 2014; Hansen et al., 2007b; Jansen et al., 2004; Vinnerås et al., 2006), waste data from the service sector in general, and especially office areas, are limited (Christensen and Fruergaard, 2010).

Waste from office areas typically consists of paper, packaging (e.g. board, plastics, metals, etc.), waste from electrical and electronic equipment (WEEE), hazardous waste and unsorted waste associated, for example, with food consumption (Christensen and Fruergaard, 2010). The management of waste from office areas may vary according to countries and office cultures; for instance, in Denmark paper, packaging, WEEE and hazardous waste are source-sorted for either special treatment (e.g. batteries, paint products, waste oil, etc.) or recycling (e.g. paper, board, plastic, WEEE, etc.), while unsorted waste currently is incinerated (Danish EPA, 2014a). This unsorted waste, in many cases, may represent a significant – or the most significant – fraction of generated waste. As an example, the proportion of unsorted waste from the service sector that was incinerated in Denmark in 2012 accounted for up to 31% of the total waste (Danish EPA, 2014b).

Numerous studies have quantified and characterised unsorted waste generated in canteens, production kitchens and cafeteria in schools, at universities, hotels, restaurants and catering outlets (Armijo de Vega et al., 2008; Cordingley et al., 2011; Katajajuuri et al., 2014; Marthinsen et al., 2012, Mason et al., 2004; Mbuligwe, 2002; Smyth et al., 2010). Mason et al (2004) analysed source-sorted food waste from canteens, production kitchens and cafeteria at Massey University in New Zealand, but the study did not include office areas. Additionally, the waste generation data were presented as total waste for the university, thus limiting their applicability to other contexts. Composition data on unsorted waste from the service sector, and specifically from office areas, is thus generally very limited, if at all available. In particular, data on source sorting potential and efficiency, as well as the quality (e.g. content of impurities) of food waste generated from employees' lunches, coffee breaks, social events, etc., do not exist, as this waste is often collected and quantified as part of the mixed waste generated by institutions. However, the biologically degradable fraction of this otherwise unsorted waste may represent a valuable source of organic waste. In order to assess whether the collection and specific management of food waste from office areas may contribute significantly to achieving food waste targets, concrete data for waste generation and the quality of the waste are needed. An additional shortfall in many of the abovementioned studies is that the moisture content of waste is rarely measured, even though it represents one of the key parameters affecting, for example, the biological treatment of waste, such as composting (Stentiford and de Bertoldi, 2010), energy recovery (Hulgaard and Vehlow, 2010) and the environmental assessment of waste treatment technology (Clavreul et al., 2012).

The overall aim of this case study was to quantify the potential for source-sorted food waste in office areas, which was done by quantifying food waste generation rates, source sorting efficiencies and the purity of sorted fractions for a selected office area case study. Temporal variations (seasonal and daily) and the influences of a number of employees were investigated. In addition, the moisture content and biochemical methane potential of the collected source-sorted food waste were determined, and the results were then evaluated with respect to how they may contribute to local and national food waste management targets.

2 Materials and methods

2.1 Definitions

In this section, we describe the terminology used in this study. *Food waste* refers to avoidable and unavoidable food waste, including drinks and beverage products (WRAP, 2009), while *residual waste* refers to the remaining unsorted waste when food waste has been taken out; this includes tissue paper, plastic film, food wrapping paper, etc. (see Figure 1). A *source-sorted waste fraction* refers to a waste fraction that is disposed of in the intended waste bin; for instance, source-sorted food waste is food waste disposed of in a food waste bin. A *missorted waste fraction* refers to a waste fraction disposed of in the wrong waste bin; for example, missorted residual waste is residual waste disposed of in a food waste bin, and vice versa.

In the present study, the following waste fractions were not included: source-sorted recyclable waste (see Section 1), WEEE and batteries, hazardous waste and waste from canteens. The results of statistical analyses are given as probability values

(p) and degrees of freedom (df), and the data are presented as mean and standard deviations (Mean ± SD) unless otherwise indicated. The waste generation rates are expressed as mass wet waste per employee at work per working day, or mass wet waste per employee at work per year, assuming 250 working days per year.

2.2 Study area

The study was carried out in the office area of the Department of Environmental Engineering at Technical University of Denmark. The total number of employees was 180 during the waste sampling campaign (DTU Environment, 2013). This office area has four kitchens which are used by the employees for lunch, coffee breaks and social events (e.g. birthdays, breakfast, etc.). The employees can also bring either their food from home or buy from a canteen, supermarket, etc. In general, only hot drinks such as coffee and tea are prepared in the kitchen. The mixed waste generated in this office area is disposed of primarily in the waste bins placed in these kitchens. There are no bins in the corridors for reasons of fire safety. Thus, in the course of this study, two plastic waste bins of 60 L each were placed in each of the four kitchens: (1) food waste bins were used for food leftovers, edible and inedible food, spent coffee grounds with paper filters, tea bags, etc. (see Figure 1); (2) residual waste bins were used to dispose of all other waste fractions (apart from food waste), including tissue papers, plastic film and food packaging, beverage cartons, aluminium wrapping foil, etc. As a result, eight waste bins were used for this sampling campaign, and they had stickers clearly stating the name of the waste fractions (either source-sorted food waste or residual waste) that should be disposed of in the bins. Sorting guidelines were also available on the department website, while pamphlets explaining the waste sorting campaign were delivered to individual offices (see Figure 1).

2.3 Waste sampling and analyses

The study was conducted during 133 working days, corresponding to 29 weeks, from 12th February to 31st August 2013. This period covered the winter, spring and summer seasons. The waste was collected separately from each kitchen on a daily basis; however, it was not collected during weekends and public holidays, when the offices were officially closed.

We carried out four analyses. First, we collected and weighed separately the waste from each bin in the four kitchens. This collected waste represented the total mixed waste generated in this office area during the sampling period. However, the food waste that is disposed of via other routes, such as sewer, etc., was not included in this study. Furthermore, we used the existing employee online registration system to obtain data on the number of employees who worked at the office during the study. Second, once a week, we manually sorted the waste generated during a working day, to determine the composition of source-sorted food waste and residual waste. The working day was chosen successively every week to investigate possible daily variations in waste composition. Source-sorted food waste and residual waste were sorted into 30 waste fractions, as classified and described by Edjabou and co-authors (2015). Third, we used the sorted waste samples to measure the moisture content of source-sorted food waste and residual waste fractions throughout the sampling period by drying the samples at 105°C until a constant weight (approximately 24 hours) was attained. We then calculated moisture content according to equation (1) (CEN/TC 335, 2010):

$$WC_j=(W_{j1}-W_{j2})/(W_{j1}-m_j)*100 \qquad (1)$$

where WC_j is the moisture content of the material fraction (*j*) as a percentage of wet waste, Wj_1 is the mass of the waste fraction (*j*) and the container before drying, Wj_2 is the mass of the waste fraction (*j*) and the container after drying, and m_j is the mass of the empty container. Fourth, we measured the biochemical methane potential of source-sorted food waste. For this purpose, source-sorted food waste samples collected during 29 days (total daily source-sorted food waste, about 8 kg) and stored at -20^{o}C were mixed mechanically by core-shredding (ARP SC 2000). To obtain representative samples for the biochemical methane potential test, we reduced the mass of source-sorted food waste (about 232 kg) by laying samples in elongated 1-D multilayer piles and subsequently removing cross-cut portions of the lot, leading to two separate samples. This was repeated until we obtained the necessary sample size about 5 kg. Before the biochemical methane potential test, we determined the volatile solids (VS) content of source-sorted food waste per wet mass in a muffle oven by measuring the loss of volatile solids at 550^{o}C (approximately 2 hours) (Lagerkvist et al., 2010). The remaining fraction was defined as the ash content of the sample. We carried out biochemical methane potential tests using triplicate reactors (total volume of a 1L batch reactor with a working volume of 400 mL, of which 320 mL inoculum) with organic loading rates of 3g VS/L that were incubated at 55^{o}C with 400 mL of inoculum from a thermophilic biogas plant. We measured methane production during 28-day period on a gas chromatograph (Hansen et al., 2004).

Figure 1 about here

2.4 Food waste source sorting evaluation

Based on Christensen and Matsufuji (2010), the following indicators were defined to evaluate the source-sorted food waste campaign. Here SSFW is source-sorted food waste, RW is residual waste and FW is food waste.

- The food waste potential (P_{FW}) is the total amount of food waste generated, consisting of correctly sorted source-sorted food waste (Mc_{SSFW}) and missorted food waste (Mm_{FW}) in the residual waste bins, as shown in Equation (2).

$$P_{FW}=Mc_{SSFW}+Mm_{FW} \quad (2)$$

- The sorting efficiency (E_{FW}) of food waste is the ratio of source-sorted food waste (M_{SSFW}) and the potential of food waste (P_{FW}), as shown in Equation (3):

$$E_{FW}=M_{SSFW}/P_{FW} \quad (3)$$

- Purity may determine the level of organic waste pre-treatment prior to treatment in a biogas plant (Hansen et al., 2007a). The purity of source-sorted food waste source-sorted food waste (Pu_{SSFW}) is the ratio between the wet mass of "correctly" sorted food waste, disposed of in the food waste bin (Mc_{SSFW}), and the total waste disposed of in the food waste bin (M_{SSFW}), as shown in Equation (4). The "correct" sorted food (Mc_{SSFW}) is the difference between the wet mass of source-sorted food waste (M_{SSFW}) and the wet mass of missorted material fractions (Mm_{RW}) found in the food waste bin, as shown in Equation (5).

$$Pu_{SSFW} = Mc_{SSFW} / M_{SSFW} \quad (4)$$

$$Mc_{SSFW} = M_{SSFW} – Mm_{RW} \quad (5)$$

2.5 Statistical analyses

We applied statistical analyses, in order to assess (i) the quality of the waste data obtained and (ii) the influence of weekday, month and season on solid waste generation and its composition as well as moisture content. For this purpose, the relationship between the amount of waste (source-sorted food waste and residual waste) and the number of employees registered during the sampling campaign was analysed by using a simple linear regression (Reimann et al., 2008). Furthermore, we applied bootstrapping regression models (Fox and Weisberg, 2012) to investigate the influence of weekdays and temporal variations (monthly and seasonal variations) on source-sorted food waste and residual waste generation and composition. Finally, we compared the moisture content of source-sorted food waste and missorted food waste (e.g. food waste disposed of in the residual waste bin), using two samples t-test (BEST) (Kruschke, 2012). We assessed the representativeness of the waste sample size (number of sampling days) by comparing three confidence intervals based on (1) bootstrap, (2) t-distribution and (3) normal distribution as a function of sample size, given a fixed standard deviation (Crawley, 2005; Sharma and McBean, 2007). The statistical analyses were modelled in the statistical and graphical programming language R (http://www.r-project.org).

3 Results and discussion

3.1 Waste generation rates and assessment of the waste data and sample size

Table 1 summarises the data on source-sorted food waste and residual waste. The average amount of source-sorted food waste generated in the office area amounted to 8.07 ± 2.34 kg per working day, whereas the residual waste was 4.08 ± 1.69 kg per working day (see Table 1). The average number of employees at work was 99 ± 20, corresponding to 55 ± 11% of the total employees (Table SM 1 and Figure SM 1). The high variation in the number of employees at work during this study was due to the official Danish summer holiday period (from 1st May to 30th September), where employees can take up to three weeks' vacation; for example, in July, up to 61% of the employees were away on holiday and did not therefore attend work.

Usually, the unit generation rates of solid waste in the service sector are expressed as waste generated per employee, per pupil or per student (Christensen and Fruergaard, 2010). The problem is that many studies use the total number of employees officially registered at the workplace to compute this unit generation rate (Cordingley et al., 2011; Mason et al., 2004; Mbuligwe, 2002). In practice, however, the number of employees who generate solid waste may vary substantially during the sampling period, because some employees may leave for holidays, external meetings, business travel, etc. Estimating unit generation rates based on the actual number of employees at work, rather than the total official number of employees, is crucial for the general planning of waste management (e.g. choice of the waste bin size, collection frequency, etc.) and for the assessment of temporal variations.

The assessment of the representativeness of the sample size (the number of working days covered by the sampling period) showed that confidence intervals declined considerably when the number of working days increased (Figure SM 2 & 3). For both source-sorted food waste and residual waste, confidence intervals narrowed rapidly after 20 working days but more slowly thereafter, and they became nearly constant after 60 working days. We could conclude that 133 working days is a markedly good sample range from which to obtain reliable estimates, whereas less than 20 working days is regarded as a small sample. Furthermore, given the standard deviation obtained in this case study, the results of the confidence interval analyses also indicated that 30 working days could be a sufficient sample size to provide reliable estimates.

Figure 2 shows the relationship between the wet mass of generated source-sorted food waste and residual waste, and the number of employees registered at work during the sampling campaign, which is illustrated by the linear lines of the best fit with a 95% confidence interval region (in grey) We observed some source-sorted food waste and residual waste outliers that showed significant variations in waste generation in the office area. These outliers could be due to the waste generated during celebrations, and so for this reason they were included in data processing. The number of employees at work was highly correlated and statistically significant with discarded source-sorted food waste mass (R^2=0.55, with a 95% confidence interval extending from 0.42 to 0.66); however, there was a small, but still statistically significant, correlation between the number of employees at work and residual waste (R^2=0.30 with a 95% confidence interval from 0.15 to 0.42). This difference in correlation coefficients could be explained by the fact that residual waste consisted mainly of light material fractions, and as a result we chose the unit generation rates as discarded mass per employee (at work) per working day.

Source-sorted food waste amounted to 0.08 ± 0.02 kg per employee at work per working day, while it was 0.04 ± 0.02 kg per employee at work per working day for residual waste (Table 1). Assuming 250 working days per year, solid waste generation was estimated at 20 ± 5 kg of source-sorted food waste per employee per year and 10 ± 5 kg of residual waste per employee per year.

Table 1 about here

Figure 2 about here

3.2 Waste composition of source-sorted food waste in office areas

The amount of source-sorted food waste collected represented 67% of the total waste generated in the office area and consisted primarily of spent coffee grounds (80 - 90%), edible food waste (1-2%), leftovers and tea bags (8-9%). This could explain the strong correlation between food waste and the number of employees at work, since coffee is made according to the number of employees in attendance. Material fractions missorted into food waste were mainly light materials such as plastic film and miscellaneous combustibles, and they amounted barely to 0.5% of the total. This relatively small proportion of missorted material fractions could also be explained by the high moisture content of spent coffee grounds in comparison to the light mass of residual waste such as plastics and foil.

3.3 Waste composition of residual kitchen waste

The amount of residual waste represented 33% of the total waste generated in this office area and consisted predominantly of paper (e.g. 28 ± 13%), missorted food waste (24 ± 16%) and plastic waste (23 ± 9%) (Table 2). Here, the paper waste fraction consisted mainly of tissue paper, which accounted for 23 ± 13% of the total residual waste. The plastic waste fraction consisted primarily of plastic packaging (17 ± 10% of the total residual waste), especially polyethylene terephthalate (PET/PETE, 7 ± 7% of total residual waste) and polypropylene (PP, 4 ± 4% of the residual waste) (Table 2).

Table 2 about here

3.4 Evaluation of the source sorting campaign

Source-sorted food waste sorting efficiency and purity data are shown in Table 3. We calculated these data using source-sorted food waste and residual waste composition (Table 2) and the equations presented in Section 2.4. The sorting efficiency of food waste in the office area was calculated using Eq. (3) and amounted to 89% (wet mass) of the potential food waste. This result indicates that only 11% (wet mass) of the potential food waste was missorted in the residual waste bins, while residual waste missorted in the food waste bins accounted only for 0.5% (wet mass) of source-sorted food waste , indicating extremely high (>99%) source-sorted food waste ´s purity. Consequently, the potential unit generation rate of food waste was calculated as 0.09 ± 0.02 kg per employee per working day, corresponding to 23 ± 5 kg per employee per year.

The food waste sorting efficiency found in this case study was considerably higher than that reported for Scandinavian households, which is at the level of 25 to 50% (Table 4). Furthermore, the level of source-sorted food waste impurity from households was higher in comparison to the office areas in this study, ranging typically from 1 to 9% mass (Bernstad et al., 2013a; Dahlén et al., 2007; Møller et al., 2013). For example, Bernstad et al. (2013a) studied source-sorted food waste in a residential area in Malmö in Sweden in 2009, and they found a sorting efficiency for food waste as low as 25%, with a level of incorrect sorting between 3 and 9%. This sorting efficiency barely increased to 35% after the installation of sorting equipment in households and intensive awareness-raising campaigns (Bernstad, 2014). Consequently, these results confirmed that source-sorted food waste in the office area represents a potential source for the separate collection of high-quality food waste and suggest that a 60% recycling target formulated by the Danish Government for food waste generated by the service sector, including office areas, should be achievable.

Table 3 about here

3.5 Moisture content

The moisture content of source-sorted food waste and residual waste is presented in Table 5. Due to the extremely low content of missorted residual waste in the food waste bins, we only measured the moisture content of source-sorted food waste and 15 fractions from the residual waste.

Moisture content was 73 ± 7% and 67 ± 8% for source-sorted food waste and food waste missorted in the residual waste bins, respectively. The difference in moisture content between source-sorted food waste and missorted food waste was statistically evaluated, and the results indicate that the moisture content of source-sorted food waste was significantly higher than the missorted FW by about 9% (with a 95% confidence interval extending from 4 to 13). These significant differences between missorted food waste and source-sorted food waste are explained by (i) the migration of water content from food waste to light fractions such as paper and board in the residual waste bin (Dahlén and Lagerkvist, 2008) and (ii) very low amounts of missorted residual waste in the food waste bins (Figures SM 4 & 5).

The moisture content of non-ferrous metal, consisting mostly of used aluminium coffee capsules, was 36 ± 10%. This is high compared with the moisture content of other metal fractions found in the residual waste (Table 5) as well as from household waste typically at the level of 8-19% (Riber et al., 2009). This high moisture content of used aluminium coffee capsules is attributed to spent coffee grounds remaining in the capsules. Except for used aluminium coffee capsules, the moisture content of residual waste fractions in office areas was lower than that reported for residual household waste (Riber et al., 2009), which suggests that the source sorting of food waste may reduce the moisture content of residual waste fractions and could increase heating value when residual waste is incinerated with energy recovery.

3.6 Biogas potential

The biochemical methane potential for source-sorted food waste measured in the batch test amounted to 463 ± 42 Nm^3/t VS (Table SM 2), which is similar to the methane potential reported for household source-sorted food waste (Bernstad et al., 2013b; Davidsson et al., 2007; Hansen et al., 2007a). The VS content in the source-sorted food waste was 23%, thereby suggesting a methane potential of 110 Nm^3/t wet mass waste.

Table 4 about here

3.7 Factors influencing unit generation rates

Variations in source-sorted food waste and residual waste unit generation rates as a function of weekdays are shown in Figure 3. The highest source-sorted food waste generation rate (23 ± 4 kg/employee/year) was observed on Mondays, while the lowest (19 ± 5 kg/employee/year) was recorded on Fridays. Similarly, the highest and lowest residual waste generation rates we observed were 12 ± 3 and 9 ± 4 kg/employee/year, recorded on Mondays and Tuesdays, respectively. The statistical analyses confirmed a significant difference in generation rates on weekdays for both source-sorted food waste ($p = 0.02$, $df = 4$) and residual waste ($p = 0.03$, $df = 4$). This significant difference was due to significantly higher amounts of waste collected on Mondays. The underlying explanation is that waste collected on Mondays included anything generated during the weekends and on the subsequent Monday, because although some employees may work during weekends and holidays, there is no waste collection during these periods. There were no significant differences between waste amounts generated Tuesday to Friday ($p = 0.10$; $df = 3$ for source-sorted food waste and $p = 0.48$, $df = 3$ for residual waste) (Table SM 3 & 4).

Figure 4 shows variations in the source-sorted food waste and residual waste generation rates per working day and per month as a function of months. This graph shows that the highest daily source-sorted food waste generation rate was in June (21 ± 3 kg/employee/year) and the lowest in August (19 ± 4 kg/employee/year). On the other hand, the highest daily residual waste generation rate was in June (11 ± 3 kg/employee/year) and the lowest in August (9 ± 3 kg/employee/year). However, none of these differences was statistically significant ($p = 0.83$, $df = 6$ for SSWF and $p = 0.25$, $df = 6$ for residual waste) (Table SM 5 & 6), which indicates that the source-sorted food waste and residual waste unit generation rates were not significantly influenced by monthly variations.

Given that the office buildings in this case study are located at a university, we also investigated the influence of students' activities on the waste generation rates of the employees. For this reason, we assessed the effect of institutional activities consisting of lecturing, exams and holidays on waste generation. The results suggest that there was no significant effect of institutional activities on source-sorted food waste ($p=0.32$, $df=2$) and residual waste ($p=0.43$, $df=2$) generation rates.

Table 5 about here

Figure 3 about here

3.8 Factor influencing food waste sorting

The composition of missorted residual waste fractions in the food waste bin was about 0.5% of the total source-sorted food waste (see Section 3.2.2). However, we found that the percentage of food waste missorted in the residual waste bin varied according to weekdays and months. We observed the highest percentage of missorted food waste in February (33 ± 19% of the total residual waste), which could be explained by the fact that the sorting campaign started in this month, and therefore it took some time for the employees to get used to the system. Furthermore, the percentage of missorted food waste decreased slightly in March (23 ± 9%), before it increased progressively to reach 30 ± 13% in May, and then dropped to its lowest level in June (18 ± 17%). The low percentage of missorted food waste could be attributed to an information campaign carried out at the beginning of the month, where the preliminary results of the food waste sorting system were presented. However, none of these differences in the percentage of missorted food waste was statistically significant, thus suggesting that the incorrect sorting of food waste could be explained neither by the weekday and monthly variations nor by the awareness-raising campaign.

Figure 4 about here

3.9 Factors influencing moisture content

In this study, we focused on the influence of monthly variations in source-sorted food waste and missorted food waste moisture content. The moisture content of source-sorted food waste varied between 73 ± 5% in February and 62 ± 18% in May, but this difference was not statistically significant ($p > 0.05$, df = 5). Similarly, we found no significant effect of monthly variations in missorted food waste moisture content, which could be explained by the fact that food waste was collected in office areas where the indoor temperature is nearly constant, and there was a great deal of spent coffee grounds, which was not significantly affected by seasonal variations.

3.10 Implications and perspectives of the study

In this study, source-sorted food waste accounted for 67 ± 6% and residual waste 33 ± 6% of the total waste in the office area. Missorted food waste amounted to 24 ± 16% of residual waste. As a result, the potential food wastefood waste accounted for 75 ± 16% of the total waste in the office area and corresponded to 23 ± 5 kg/employee/year.

Both household food waste and methane potential were found in the literature and are presented in Table 4. Potential household food waste was estimated at 75 kg per person per year (Edjabou et al., 2013). Under the assumption that up to 35% of the potential food waste generated in households could be collected separately (Bernstad, 2014), expected household source-sorted food waste amounted to 26 kg/person/year.

A comparison of food waste generation rates (both potential food waste and estimated source-sorted food waste) between office areas and households (see Table 4) suggested that the unit generation rates of source-sorted food waste in office areas may be comparable to households. However, the amount of food waste generated per office area could be considerably higher than for households, because office areas are usually used by more people (on average 73 employees per office area in Denmark (Statistics Denmark, 2015)) than the average household size (2.2 person per household in Denmark (Statistics Denmark, 2015)); for instance, 8.1 ± 2.3 kg food waste was source-sorted and collected per day from the current study area. Considering the Danish conditions, this amount corresponds to potential food waste from about 11 Danish households, meaning that 11 waste bins would be used to collect source-sorted food waste from households. On the other hand, only four waste bins were used to collect food waste in office areas in this case study. These results indicate that significant amounts of food waste could be collected separately with reasonable logistical ease in office areas.

The level of impurity in source-sorted food waste found in this case study was markedly lower than the values reported in the literature from Danish households. This suggests that good-quality source-sorted food waste could be collected in office areas.

Based on the literature review on the methane potential of household source-sorted food waste (see Table 4), and the biochemical methane potential test results, we calculated the total potential of biogas emanating from office areas and households. Here, we used the estimated total number of employees in office areas instead of the number of employees actually at work, because we were estimating the potential of source-sorted food waste and methane that could be generated at the national level. Assuming similar methane potential and unit generation rates for waste generated in office areas across the country, and assuming that the total potential number of employees working in office areas is 1.2 million in Denmark (Statistics Denmark, 2015), we estimated that 2.5 million m^3 methane could be generated per year in Denmark from source-sorted food waste in office areas. Comparatively, 16 million m^3 methane could be generated from source-sorted food waste in Danish households.

Due to the specification and difference of culture in office areas in different countries, these data should be applied based on the definition of office area provided in this study.

4 Conclusions

This study quantified the generation rates and composition of source-sorted food waste generated in office areas, and it investigated potential influential factors. We found that 0.08 ± 0.018 kg/employee/day of source-sorted food waste could be collected separately from office areas, with a very low level of impurity (0.5%). Given the sorting efficiency (89 ± 28% of food waste potential) and the high purity of source-sorted food waste, we can conclude that a 60% recycling target, formulated by the Danish Government for FW generated by the service sector, including office areas, should be achievable.

The amount of source-sorted food waste was not affected significantly by seasonal variations, but missorted food waste contributed considerably to the amount of residual waste, although it represented only 11 ± 9% of the potential food waste. Despite the fact that this study was conducted in office areas located at a university, the amount of waste generated was not affected by the number of students. In the present study, the waste bins were placed in the employee kitchens; however, the implementation of food waste source sorting in office areas may vary considerably according to the structure and office culture. Although the statistical significance of the awareness-raising campaign on reducing the percentage of missorted food waste was not investigated, we found evidence that continuous information campaigns are necessary to maintain the participation of employees in these sorting activities.

The significant difference in moisture content between source-sorted food waste and missorted food waste suggested that the moisture content of food waste migrates to lighter residual waste materials such as paper, board and plastics. The methane potential obtained from biochemical methane potential tests for source-sorted food waste generated in office areas was comparable to the methane potential of household food waste reported in the literature.

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Supplementary materials

Supplementary materials contain detailed waste data used for calculations, boxplots that present the number of employees registered during the waste sampling campaign as a function of months and weekdays, curves that show the results of simulating sample size based on confidence intervals, histograms of the posterior distribution of the difference in mean and standard deviations of the moisture content, detailed results of the biochemical methane potential test and bootstrapping regressions and their confidence intervals. SMs are divided into tables (Table SM) and figures (Figure SM).

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List of Tables

Table 1: Statistical description of solid waste generation from the office area and the percentage of employees at work during the sampling campaign (number of working days is 133).

Parameters	Median	Mean	Standard deviation
Waste generation			
Source-sorted food waste (kg ww[a] /working day)[b]	7.99	8.07	2.34
Source-sorted food waste (kg ww[a]/employee[d]/working day)	0.08	0.08	0.02
Residual waste (kg ww[a] /working day)[b]	3.92	4.08	1.69
Residual waste (kg ww[a]/employee[d]/working day)	0.04	0.04	0.02
Employees			
Number of employees per working days	105	99	20
Percentage of employees[c]	58	55	11

[a] *Wet mass*
[b]*:kg wet mass waste per working day for the office area investigated.*
[c]*: Number employees per working days.*
[d]*:Employees at work.*

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Table 2: Detailed composition of the waste generated in the office area in percentage of wet mass.

Waste fraction	SSFW[a] (%w/w[c])		RW[b] (%w/w[c])		Total (%w/w[c])	
	Mean	SD	Mean(%w/w[c])	SD	Mean	SD
Food waste	99.6	0.01	24.0[d]	15.9	74.5	16.1
Gardening waste	-	-	0.0	0.0	0.0	0.0
Paper	-	-	28.6	13.4	9.6	13.4
Tissue paper	-	-	22.8	10.2	7.7	1.5
Other paper	-	-	2.2	2.1	0.7	1.8[f]
Paper (cleaned)[e]	-	-	3.7[4]	7.4	1.2	2.5
Board	-	-	16.1	7.5	5.4	7.5
Folding boxes	-	-	1.9[d]	2.6	0.6	2.0
Miscellaneous board	-	-	14.6	7.4	4.9	1.5[f]
Plastic	-	-	22.9	9.4	7.7	9.4
Foam	-	-	0.7	1.2	0.2	2.1
Composite plastic	-	-	2.5	1.9	0.8	1.5
Pure plastic film	-	-	2.6	2.2	0.9	1.5
Packaging plastic	-	-	17.0	9.5	5.7	1.4[f]
PET/PETE	-	-	7.0	6.8	2.4	1.1
HDPE	-	-	1.2	5.7	0.4	5.0
PVC/V	-	-	0.0	0.0	0.0	0.0
LDPE/LLDPE	-	-	0.0	0.0	0.0	0.0
PP	-	-	3.8	4.1	1.3	1.2
PS	-	-	1.9	1.9	0.6	1.2
Other resins	-	-	0.2	0.6	0.1	3.2
Unspecified	-	-	2.9	2.2	1.0	1.0
Metal	-	-	4.2	3.6	1.4	3.6
Aluminium wrapping foil	-	-	1.3	1.0	0.4	2.8
Metal ferrous	-	-	0.9	1.6	0.3	3.2
metal non ferrous	-	-	1.3	1.3	0.4	2.9
Glass	-	-	1.7[4]	4.7	0.6	4.7
Miscellaneous combustibles	0.4[d]	0.01	1.8	2.2	0.6	2.2
Inert	-	-	0.3	1.2	0.1	1.2
Special waste	-	-	0.5[d]	3.1	0.2	3.1
Total	100.0	-	100.0	-	100.0	-

[a]*: Source-sorted food waste.*
[b]*: Residual waste.*
[c]*: Wet mass.*
[d]*:Misplaced material fractions;*
[e]*: Paper (cleaned) consisted of offices papers, newspapers, magazines and advertisements.*

Table 3: Overview of food waste generation rates, sorting efficiency and purity.

Parameters	Values
Misplaced food waste in residual waste bins (%)	24±16
Purity of food waste (%)	99±0.01
Potential of food waste ww[a] (kg/employee/working day)	0.091±0.02
Sorting efficiency of food waste (%)	89±28
Percentage of misplaced food waste as function of food waste potential (%)	11±9

[a]*: wet mass*

Table 4: Estimated potential of the amount of source-sorted food waste and biogas from office area and households in Denmark.

	Quantities		Percentage (%)	
	Employee´s kitchen	Household	Employee´s kitchen	Household
Potential food waste (kg wet mass per year)	23[a]	75[b]	23	77
Sorting efficiency (%)	89	35[c]	35	
Expected SSFW (wet mass kg per year)	20[a]	26[b]	43-26	57-74
Estimated total waste in Denmark (ton wet mass)	48,838[d]	147,715[e]	-	-
Methane potential (Nm^3/ton wet waste)	110	109[f]	-	-
Estimated total methane potential (Nm^3)	4,542,391	16,100,926	14	86

[a]*: wet mass kg per employee per year.*

[b]*: wet mass kg per person per year* (Edjabou et al., 2013).

[c]: (*Bernstad, 2014*)

[d]*: estimated total source sorted food waste based on 2 million employees working in office areas in Denmark (see section 3.7)* (*Statistics Denmark, 2015*).

[e]*: estimated total source-sorted food waste based on 5.6 million inhabitants in Denmark* (*Statistics Denmark, 2015*).

[f]:(Hansen et al., 2007b)

Table 5: Moisture contents of SSFW and RW fractions collected separately in the office area.

Waste fractions	SSFW(%)[a]		RW(%)[b]	
	Mean	SD[f]	Mean	SD
Food waste	72.5	7.1	66.5[c]	8.4[c]
Paper	-	-		
Tissue paper	-	-	35.8	9.7
Other paper	-	-	14.6	6.6
Paper	-	-	17.8	10.8
Board	-	-		
Folding boxes	-	-	16.9	6.7
Miscellaneous board	-	-	19.7	7.9
Beverage cartons	-	-	24	1.4
Plastic	-	-		
Foam trays	-	-	18.7	13.1
Composite plastic	-	-	7.7	6.4
Pure plastic film	-	-	8.5	7.3
Packaging plastic	-	-	10.4	6.5
Metal	-	-		
Aluminium wrapping foil	-	-	16.9	10.5
Metal ferrous	-	-	4.8	0.8
Metal non-ferrous	-	-	30.6	16.3
Miscellaneous combustible waste	-	-	23.0	16.7

[a]*: Source-sorted food waste.*

[b]*: Residual waste.*

[c]*: Moisture content of misplaced food waste.*

[f]*:Standard deviation*

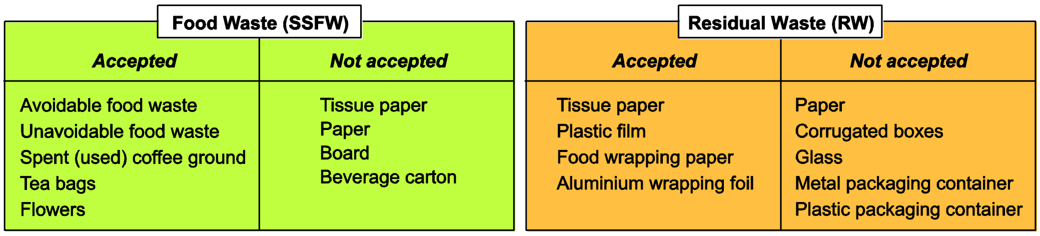

Figure 1: The waste sorting guide provided to employees

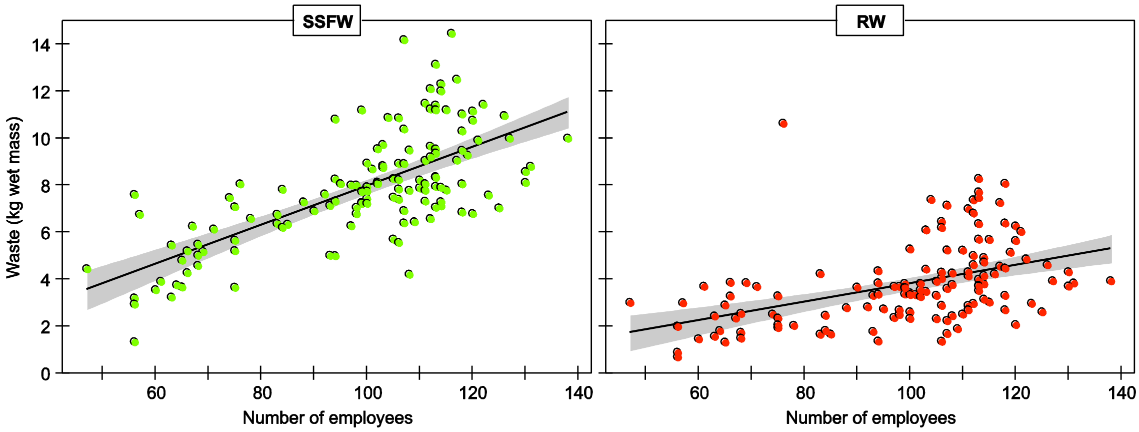

Figure 2: The relationship between the wet mass of waste generated and the number of employees registered at work and the linear lines of best fit with 95% confidence interval region (shown in grey).

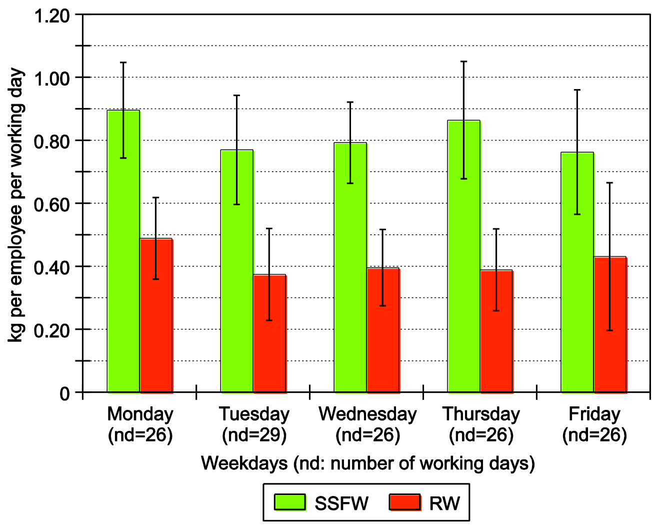

Figure 3: Average unit waste generation rates of source sorted food waste (SSFW) and residual waste (RW) as a function of weekday.

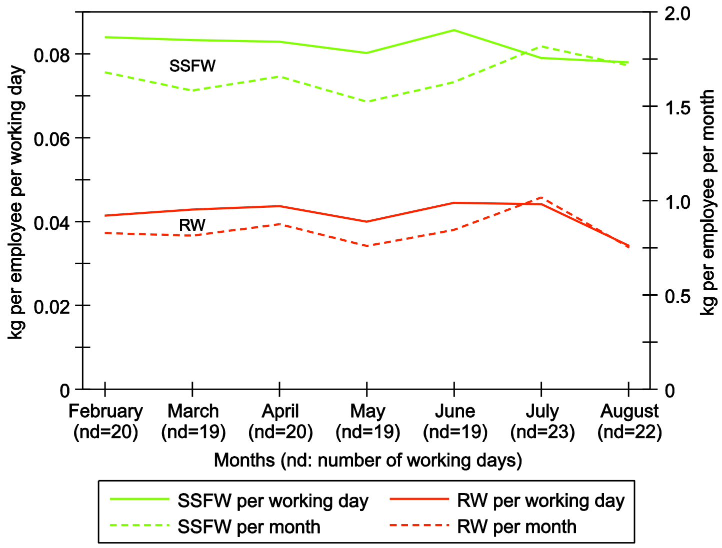

Figure 4: Unit generation rates of source-sorted food waste and residual waste during the waste sampling campaign (kg per employee per working day and kg per employee per month)

Supplementary materials for the paper:

Source segregation of food waste in office areas:

Factors affecting waste generation rates and quality

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Supplementary materials (SM)

Supplementary materials contain detailed waste data used for calculations, boxplots that present the number of employees registered during the waste sampling campaign as a function of months and weekdays, curves that show the results of simulating sample size based on confidence intervals, histograms of the posterior distribution of the difference in mean and standard deviations of the moisture content, detailed results of the BMP test and bootstrapping regressions and their confidence intervals. SMs are divided into tables (Table SM) and figures (Figure SM).

Supplementary materials-Tables

Table SM 1: Overview of the waste sampling campaign showing the sampling period, the number of working days, the total number of employees at work, and amount of waste collected and analysed (wet mass).

Seasons	Months	Number of working days	Total number of employees[a]	Food waste (kg w/w[b])	Residual waste (kg w/w[b])
Winter	February[c]	11	1,269	106	52
	March	19	1,985	165	82
Spring	April	20	2,208	183	96
	May	19	2,061	165	83
	June	19	1,959	168	87
Summer	July	23	1,607	129	71
	August	22	2,064	158	72
Total		133	-	1,073	543

[a]:The total number of employees at office during the whole month.
[b]:Wet mass.
[c]: The waste sampling started on 12 February corresponding to 11working days.

Table SM 2: Statistical description of the results of the Biochemical Methane Potential (BMP) test

Descriptive statistics	TS (% w/w)[a]	VS (% w/w)[b]	BMP ((CH_4 mL/g VS)
Number of samples	12	12	8
Median	32	30	456
Mean	33	29	463
Standard deviation (SD)	6	4	42
Standard error of the mean	2	1	15
Confidence interval of the mean (0.95)	4	3	35

[a] Total solid in percentage of wet mass source-sorted food waste.
[b] Volatile Solid in percentage of wet mass source-sorted food waste.

Table SM 3: Summary of the bootstrapping of the relationship between the amount of residual waste and weekdays using 10,000 bootstrap samples

Variables (Days)	Original[a]	BootBias[b]	BootSE[c]	95% Confidence intervals	
				Lower	Upper
Intercept (Monday)	0.049	0.000	0.003	0.044	0.054
Tuesday	-0.011	0.000	0.004	-0.018	-0.004
Wednesday	-0.009	0.000	0.003	-0.016	-0.002
Thursday	-0.010	0.000	0.004	-0.017	-0.003
Friday	-0.006	0.000	0.005	-0.014	0.009

[a] Original residual waste sample means.
[b] The bootstrapped estimates of bias, which is the difference between the average bootstrapped value of the statistic(residual waste) and the original residual waste sample means .
[c] The bootstrapped estimates of standard error.

Table SM 4: Summary of the bootstrapping of the relationship between the amount of source-sorted food waste and weekdays using 10,000 bootstrap samples

Variables (Days)	Original[a]	BootBias[b]	BootSE[c]	95% Confidence intervals	
				Lower	Upper
Intercept (Monday)	0.090	0.000	0.003	0.084	0.096
Tuesday	-0.013	0.000	0.004	-0.021	-0.004
Wednesday	-0.010	0.000	0.004	-0.018	-0.003
Thursday	-0.003	0.000	0.005	-0.012	0.007
Friday	-0.013	0.000	0.005	-0.023	-0.004

[a] *Original source-sorted food waste sample means.*
[b] *The bootstrapped estimates of bias, which is the difference between the average bootstrapped value of the statistic(source-sorted food waste) and the original source-sorted food waste sample means .*
[c] *The bootstrapped estimates of standard error.*

Table SM 5: Summary of the bootstrapping of the relationship between the amount of residual waste and months using 10,000 bootstrap samples

Variables (Months)	Original[a]	BootBias[b]	BootSE[c]	95% Confidence intervals	
				Lower	Upper
Intercept (February)	0.041	0.000	0.005	0.033	0.051
March	0.001	0.000	0.005	-0.009	0.012
April	0.002	0.000	0.006	-0.009	0.013
May	-0.001	0.000	0.006	-0.013	0.011
June	0.003	0.000	0.005	-0.007	0.013
July	0.003	0.000	0.007	-0.009	0.019
August	-0.007	0.000	0.005	-0.018	0.003

[a] *Original residual waste sample means.*
[b] *The bootstrapped estimates of bias, which is the difference between the average bootstrapped value of the statistic(residual waste) and the original residual waste sample means .*
[c] *The bootstrapped estimates of standard error.*

Table SM 6: Summary of the bootstrapping of the relationship between the amount of source-sorted food waste and months using 10,000 bootstrap samples

Variables (Months)	Original[a]	BootBias[b]	BootSE[c]	95% Confidence intervals	
				Lower	Upper
Intercept (February)	0.084	0.000	0.005	0.074	0.093
March	-0.001	0.000	0.007	-0.013	0.013
April	-0.001	0.000	0.006	-0.012	0.011
May	-0.004	0.000	0.007	-0.016	0.010
June	0.002	0.000	0.006	-0.009	0.013
July	-0.005	0.000	0.007	-0.017	0.009
August	-0.006	0.000	0.006	-0.016	0.007

[a] *Original source-sorted food waste sample means.*
[b] *The bootstrapped estimates of bias, which is the difference between the average bootstrapped value of the statistic(source-sorted food waste) and the original source-sorted food waste sample means .*
[c] *The bootstrapped estimates of standard error.*

Supplementary materials- Figures

Figure SM 1: Summary of employees registered during the waste sampling campaign (officially 180 employees were employed at the department during in 2013)

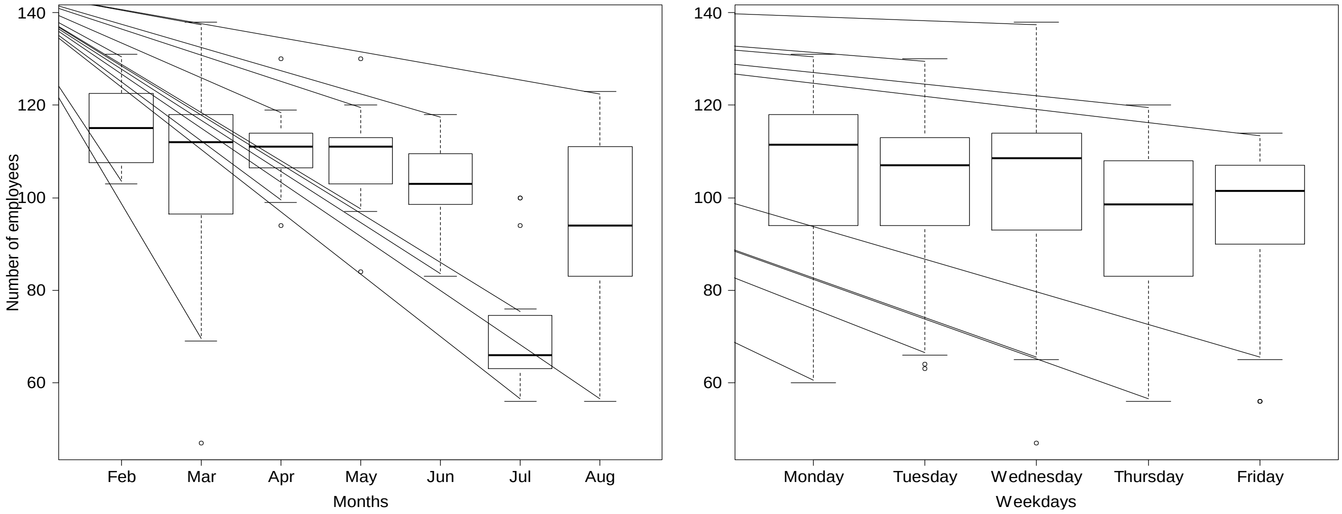

Figure SM 2: Simulation of confidence intervals (CI) of source-sorted food waste (SSFW) as function of sample size (number of working days)

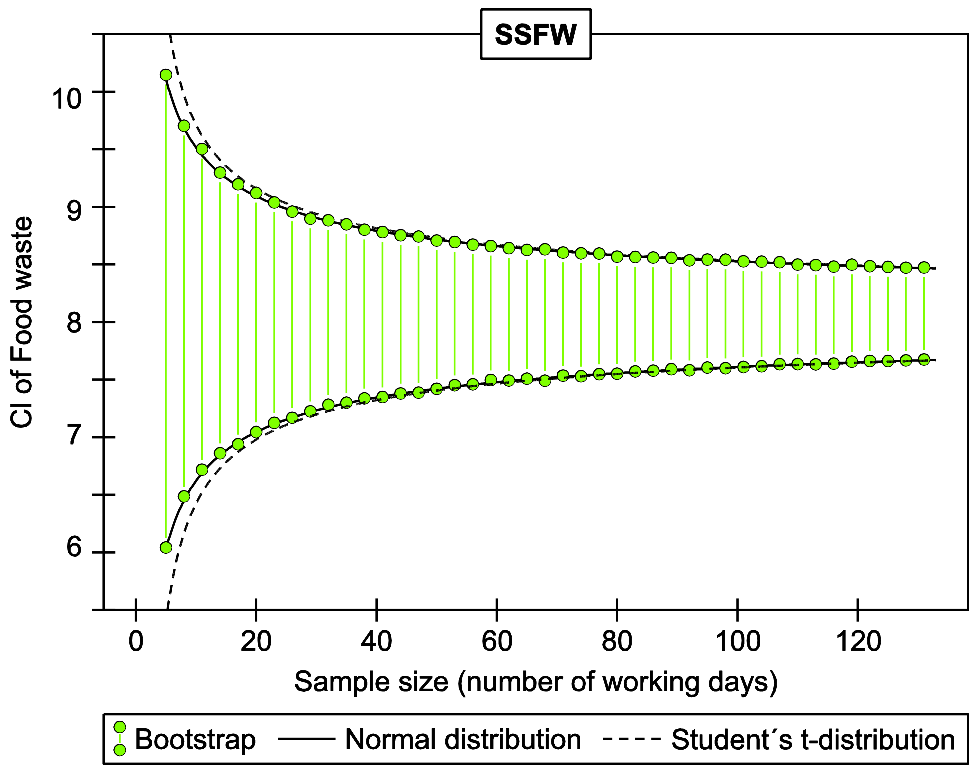

Figure SM 3: Simulation of confidence intervals (CI) of residual waste (RW) as function of sample size (number of working days)

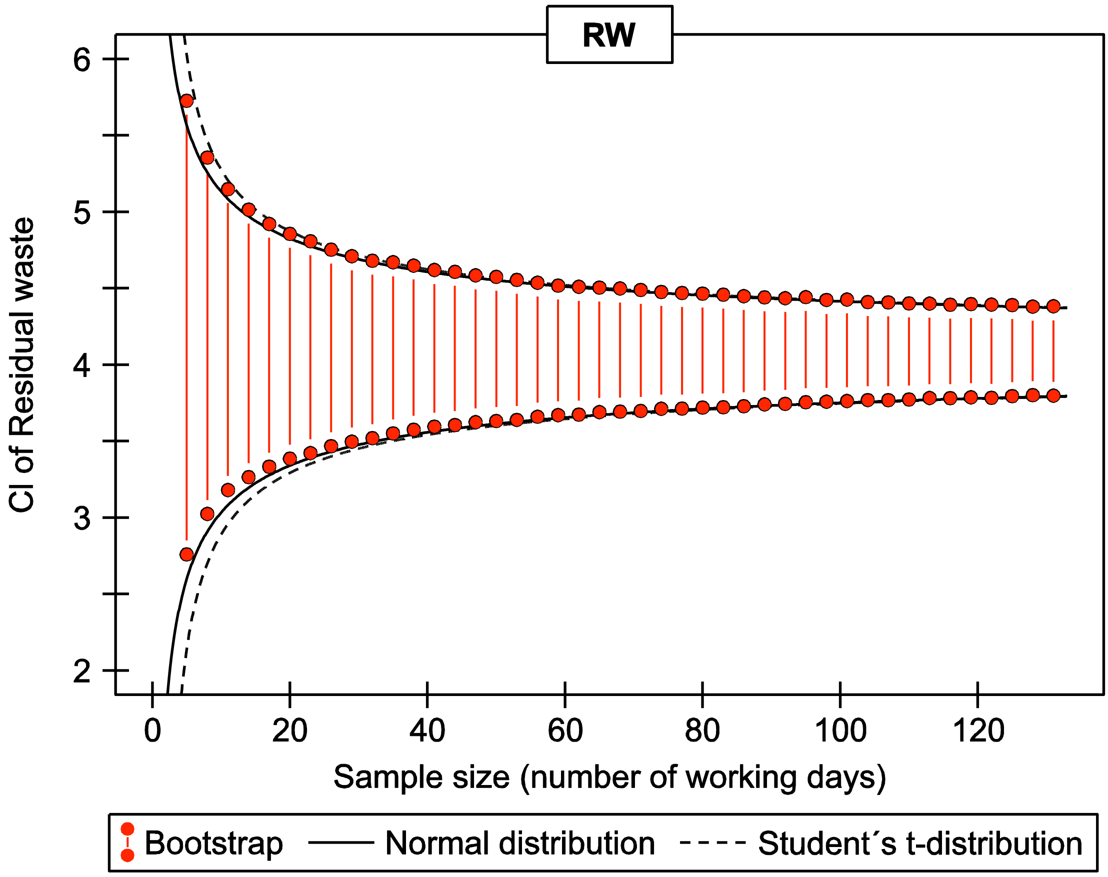

Figure SM 4: Histogram descripting the distribution of the difference in means values between source sorted food waste (SSFW) and misplaced food waste in residual waste bins

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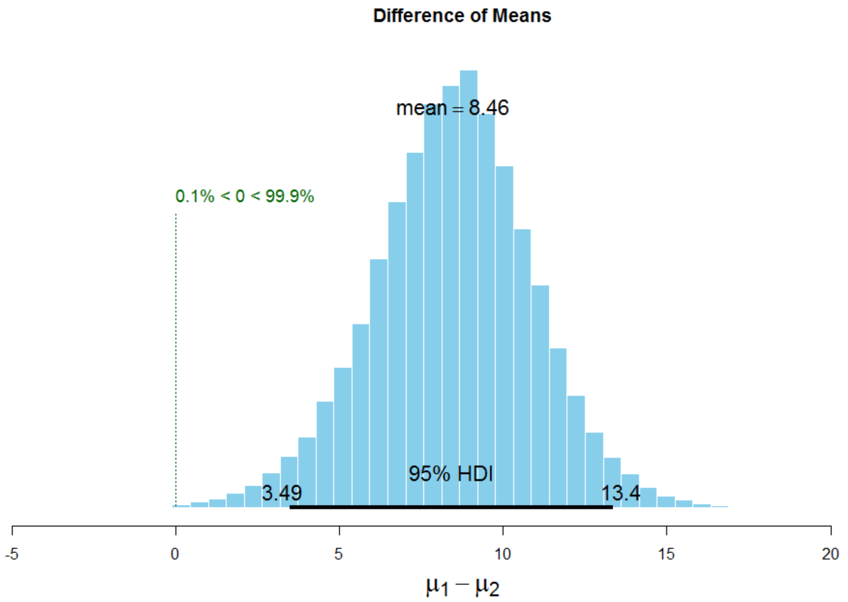
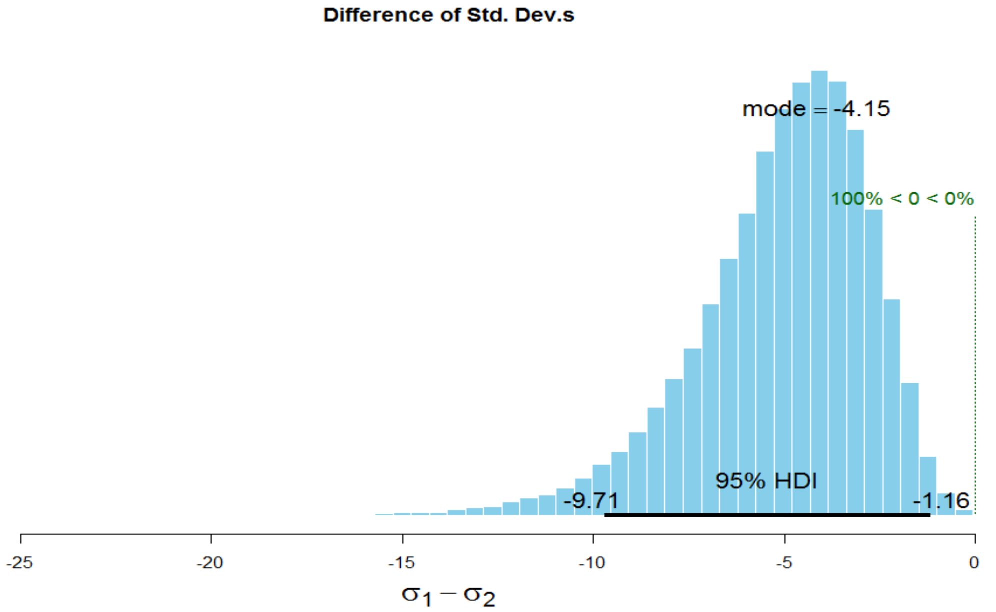


Figure SM 5: Histogram descripting the distribution of the difference in standard deviations between source sorted food waste (SSFW) and misplaced food waste in residual waste bins



(1)

(2) HDI: Highest density interval.

(3) μ_1: means of moisture content of source-sorted food waste.

(4) μ_2: means of moisture content of misplaced food waste.

(5) Std. Dev.s: standard deviation.

(6) σ_1: standard deviation of moisture content of source-sorted food waste.

(7) σ_2*: standard deviation of moisture content of misplaced food waste.*