Compositional analysis of seasonal variation in Danish residual household waste

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

Large public events such as festivals, sports events or national celebrations tend to attract a considerable number of people. While some of the events are important sources of entertainment for the participants, such gatherings create a challenge to organize and maintain a functioning infrastructure. Sound waste management is one of the challenges. Some preliminary results presented here, concern waste material flows at a large public event, illustrated on the example of Roskilde Festival (Denmark). Roskilde Festival is a large annual event, which attracts more than 120,000 participants and generates more than 2000 tonnes of waste over eight days. In 2016, approximately 16% of the total waste generated was either recycled or sent to special treatment, the remaining (approximately 85%) ended up as residual waste and was sent to a waste-to-energy facility. While measures to promote material recycling at the festival have been implemented, our preliminary results suggest that there is currently large potential to recover additional materials for recycling and improve sustainability at large public events.

General information
Compositional data analysis of household waste recycling centres in Denmark

The Danish government has set a target of 50% recycling rates for household waste by 2022. To achieve this goal, the Danish municipalities should increase the source separation of household waste. While significant knowledge and experiences were locally gained, lessons learnt have not been extensively exploited country-wise, an important reason being that the influence of these changes has not been rigorously investigated and quantified, meaning that generalized conclusions could not be drawn so far. One of the reasons is that a consistent calculation method to assess and document the effect of these projects on the recycling rates does not exist. Thus, compositional data analysis technique was applied to analyze consistently waste data. Based on the waste composition obtained from a recycling center in Denmark, we analyzed the composition of waste treatment and disposal options. Zero and non-zero pattern was used to describe historical changes in the definition and components of waste fractions. Variation array was applied to determine the relationship between waste treatment and disposal options. As a result, compositional data analysis technique enables to analyze waste data regardless of the unit (mass or percentage).
Statistical analysis of solid waste composition data: Arithmetic mean, standard deviation and correlation coefficients

Data for fractional solid waste composition provide relative magnitudes of individual waste fractions, the percentages of which always sum to 100, thereby connecting them intrinsically. Due to this sum constraint, waste composition data represent closed data, and their interpretation and analysis require statistical methods, other than classical statistics that are suitable only for non-constrained data such as absolute values. However, the closed characteristics of waste composition data are often ignored when analysed. The results of this study showed, for example, that unavoidable animal-derived food waste amounted to $2.21 \pm 3.12\%$ with a confidence interval of $(-4.03; 8.45)$, which highlights the problem of the biased negative proportions. A Pearson's correlation test, applied to waste fraction generation (kg mass), indicated a positive correlation between avoidable vegetable food waste and plastic packaging. However, correlation tests applied to waste fraction compositions (percentage values) showed a negative association in this regard, thus demonstrating that statistical analyses applied to compositional waste fraction data, without addressing the closed characteristics of these data, have the potential to generate spurious or misleading results. Therefore, compositional data should be transformed adequately prior to any statistical analysis, such as computing mean, standard deviation and correlation coefficients.
Composition of municipal solid waste in Denmark

In response to continuous pressure on resources, and the requirement for secure and sustainable consumption, public authorities are pushing the efficient use of resources. Among other initiatives, the prevention, reduction and recycling of solid waste have been promoted. In this context, reliable data for the material and resource content of waste flows are crucial to establishing baselines, setting targets and tracking progress on waste prevention, reduction and recycling goals. Waste data are also a critical basis for the planning, development and environmental assessment of technologies and waste management. These data are obtained through the characterisation of waste material. In the absence of standardised and commonly accepted waste sampling and sorting procedures, various approaches have been employed, albeit they limit both the comparability and the applicability of results. Thus, waste sampling and sorting procedures, as well as a consistent and transparent waste-naming system, have been developed.

Classical statistics are applied increasingly when analysing waste data, in order to draw conclusions that underpin the...
development of waste legislation and policy. The existing statistical techniques ignore the inherent properties of waste data, which are "closed data," because the percentage or mass of individual fractions are positive and add up to a constant. This constant constraint affects statistical analysis seriously and results in erroneous interpretations. Therefore, compositional analysis techniques have been introduced to analyse waste data more appropriately.

Waste was sampled directly from source, in order to attribute the waste data accurately to the geographical areas and types of household generating the waste. Sampling and contamination errors were minimised by avoiding sieving and the mass reduction of waste before manual sorting. Consequently, the waste was collected without compacting. Additionally, the entire sample was manually sorted into 10-50 waste fractions organised according to a three-level approach. This detailed waste fractions list facilitated the comparison of waste data with various objectives.

Analysis revealed that Danish residual household waste constitutes mainly food waste (42 – 45% mass per wet basis). Misplaced recyclable materials in residual waste bins, such as paper, board, glass, metal and plastic, amounted to 20% (mass per wet basis) of residual household waste. Moreover, special waste, such as hazardous waste, batteries and WEEE, was also misplaced in residual household bins, accounting for 0.4-0.8% of the total. Although the proportion of misplaced special waste was relatively small, these material fractions can have dire impacts on the environment when they are not disposed of appropriately.

Statistical analysis indicated that separating food waste residue from packaging during waste sorting was unnecessary, because this separation did not significantly influence overall waste composition, the percentage of food waste or packaging waste fractions. Furthermore, the difference in waste composition between municipalities was not significant. These results suggest that waste composition data obtained from one municipality could be applied to other municipalities in the same area (provided that municipalities share the same source segregation scheme), although socio-economic aspects between municipalities were not analysed.

Food waste consists of avoidable and unavoidable food waste. Here, “avoidable” food waste is defined as food that could be eaten but instead was thrown away regardless of the reason, whereas “unavoidable” food waste is food that would not be edible under normal circumstances (e.g. bones, banana peel, etc.). Food waste was estimated at 183 kg per household per year (86 kg per person per year), of which 103 kg per household (48 kg per person) per year was avoidable food waste and 80 kg per household (38 kg per person) per year was unavoidable food waste. These food waste fractions occurred in most of Danish households, which suggests that initiatives to reduce avoidable food waste should be combined with policies that promote the efficient treatment of unavoidable food waste, to ensure plant nutrient and resource recovery.

Waste analysis from kitchens in office areas showed that food waste generation amounted to 23 kg per employee per year, of which 20 kg per employee was source-segregated. This suggests that only 11% of food waste was misplaced in residual waste, which itself amounted to 10 kg per employee per year and consisted of 29% paper, 23% plastic and 24% misplaced food waste. Thus, sorting efficiency was estimated at 89% of food waste, accompanied by extremely high purity (99%). These results indicate that the 60% recycling target formulated by the Danish Government for food waste generated by the service sector should be achievable.

The mass of avoidable food waste discarded per household increased in line with household size. However, there was no statistical evidence that a household containing one person throws away more avoidable food waste per person than households containing more than one person. This suggests that campaigns and initiatives targeting food waste reduction should particularly aim at households containing more than one person.

Additionally, the mass of avoidable and unavoidable food waste per household and per person discarded in Danish houses was significantly influenced neither by periodic variation nor by geographical variations.

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**Food waste from Danish households: Generation and composition**

Sustainable solutions for reducing food waste require a good understanding of food waste generation and composition, including avoidable and unavoidable food waste. We analysed 12 tonnes of residual household waste collected from 1474 households, without source segregation of organic waste. Food waste was divided into six fractions according to avoidability, suitability for home-composting and whether or not it was cooked, prepared or had been served within the household. The results showed that the residual household waste generation rate was 434 ± 18 kg per household per year, of which 183 ± 10 kg per year was food waste. Unavoidable food waste amounted to 80 ± 6 kg per household per year, and avoidable food waste was 103 ± 9 kg per household per year. Food waste mass was influenced significantly by the number of occupants per household (household size) and the housing type. The results also indicated that avoidable
food waste occurred in 97% of the households, suggesting that most Danish households could avoid or at least reduce how much they generate. Moreover, avoidable and unavoidable food waste was more likely to be found in houses containing more than one person than in households with only one occupant.
Generation of organic waste from institutions in Denmark: case study of the Technical University of Denmark

As a response to the growing pressure on the supply chains, developing a resource-efficient circular economy will be fundamental to satisfy the future demands for material resources. In this context, the Danish Government, in 2013, launched its Resource Strategy Plan, mandating that, by 2018 at least 60% of organic waste – that cannot be prevented or reduced – generated by service sector, should be source-segregated and collected separately. In order to establish the baseline of the current situation, and to allow for any evaluation of performance against target indicators, data on solid waste generation and composition are required.

The overall aim of this study was to quantify the potential for source-segregated organic waste as well as mixed waste from institution.

This study was carried at the Department of Environmental Engineering at Technical University of Denmark. In the course of this study, two plastic waste bins of 60 L each were placed in the kitchens: organic waste bins and mixed waste bins. Organic waste and mixed waste from these kitchens were collected and weighed separately, on a daily basis, during 133 working days (29 weeks). However, waste was not sampled during weekends and public holidays, when the offices were officially closed. Furthermore, the composition of source-segregated organic waste was analysed to investigate its purity. During the sampling period, the number of employees coming to work at the department was recorded. These data were used to investigate any relationship between mass of discarded waste (source-segregated organic and mixed waste) and the number of employee coming to work at the department.

The result showed that 20 to 60 days (e.g. working days) should be considered to obtain reliable data when sampling waste from an institution.

We found a significant correlation between mass of source-segregated organic waste and the number of employees coming to work at the department (0.70 with 95% HDI 0.6 and 0.78). Similarly, there was a significant correlation between mixed waste and number of employees (0.49 with 95% HDI 0.3 and 0.62).

The generate rates of source-segregated organic waste amounted to 23 ± 5 kg/employee/year, of which 20 ± 5 kg/employee/year was source-segregated, with a considerably high purity of 99%. Mixed waste amounted to 10 ± 5 kg/employee/year.

These results show that source-segregated organic waste from institutions offers promising potential. They also suggest that recycling target for source-segregated organic waste might be achievable with reasonable logistical ease in institution areas.
Compositional data analysis of household food waste in Denmark

Food waste is a growing public concern because the food production and distribution exert enormous pressure on natural resources such as land, water and energy, and leads to significant environmental, societal and economic impacts. Thus, the European Commission has aimed to reduce to 50% the total amount of discarded edible food waste by 2020 within the European Union (EU) Member States. Reliable data on food waste and a better understanding of the food waste generation patterns are crucial for planning the avoidable food waste reduction and an environmental sound treatment of unavoidable food waste. Although, food waste composition carries relative information, no attempt was made to analysis food waste composition as compositional data. Thus the relationship between food waste fractions has been analysed by mean of Pearson correlation test and log-ratio analysis. The food waste data was collected by sampling and sorting residual household waste in Denmark. The food waste was subdivided into three fractions: (1) avoidable vegetable food waste, (2) avoidable animal-derive food waste, and (3) avoidable food waste. The correlation was carried out using: (a) the amount of food waste (kg per household per week), (b) percentage composition of food waste based on the total food waste, and (c) percentage composition of food waste based on the total residual household waste. The Pearson correlation test showed different results when different datasets are used, whereas the log-ratio analysis showed the same results for all the three datasets.

Food waste generation in office areas at DTU

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Food waste generation in office areas at DTU

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

Sound waste management and optimisation of resource recovery require reliable data on solid waste generation and composition. In the absence of standardised and commonly accepted waste characterisation methodologies, various approaches have been reported in literature. This limits both comparability and applicability of the results. In this study, a waste sampling and sorting methodology for efficient and statistically robust characterisation of solid waste was introduced. The methodology was applied to residual waste collected from 1442 households distributed among 10 individual sub-areas in three Danish municipalities (both single and multi-family house areas). In total 17 tonnes of waste were sorted into 10-50 waste fractions, organised according to a three-level (tiered approach) facilitating comparison of the waste data between individual sub-areas with different fractionation (waste from one municipality was sorted at "Level III", e.g. detailed, while the two others were sorted only at "Level I"). The results showed that residual household waste mainly contained food waste (42 +/- 5%, mass per wet basis) and miscellaneous combustibles (18 +/- 3%, mass per wet basis). The residual household waste generation rate in the study areas was 3-4 kg per person per week. Statistical analyses revealed that the waste composition was independent of variations in the waste generation rate. Both, waste composition and waste generation rates were statistically similar for each of the three municipalities. While the waste generation rates were similar for each of the two housing types (single-family and multi-family house areas), the individual percentage composition of food waste, paper, and glass was significantly different between the housing types. This indicates that housing type is a critical stratification parameter. Separating food leftovers from food packaging during manual sorting of the sampled waste did not have significant influence on the proportions of food waste and packaging materials, indicating that this step may not be required. (C) 2014 Elsevier Ltd. All rights reserved.
Occurrence and temporal variation of danish household food waste

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Seasonal variation of household food waste in Denmark
This paper analysed the influence of seasonal variation in the generation of the Danish household food waste. Residual household waste was sampled and manually sorted into six food waste fractions. Vegetable food wastes were the main fraction contributing to the household food waste. Statistical analysis showed a significant relationship between avoidable food waste and household size. However, there were no significant seasonal differences in the amount of avoidable food waste.

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Source segregation of food waste in office areas: Factors affecting waste generation rates and quality
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 CH4/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.

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Composition of municipal solid waste in Denmark

Data for the composition of municipal solid waste is a critical basis for any assessment of waste technologies and waste management systems. The detailed quantification of waste fractions is absolutely needed for a better technological development of waste treatment. The current waste composition data in Denmark are among the most detailed in the world. However, these data are more than 10 years old, and the following issues remain very important: (1) sampling approach, (2) representativeness of samples, (3) data uncertainties, (4) time and geographical variation. Moreover, in the absence of standardised and commonly accepted waste characterization methodologies, various approaches have been reported in literature. This limits both comparability and applicability of the results. The purpose of this study was to introduce a consistent methodology that reduces uncertainties and ensures data comparability to characterize municipal solid waste. This methodology was applied to residual waste collected from 1,442 households in three municipalities in Denmark. The main fractions contributing to the residual household waste were food waste and miscellaneous waste. Statistical analysis suggested that housing type is a critical stratification parameter for characterization of residual household waste.

Estimating household food waste in Denmark: case study of single family households

Food waste prevention remains the first priority in the European Waste Framework Directive, which aimed to halve the amount of food wasted within the EU Member States by 2025. Thus, reliable data on food waste composition and quantity are crucial for assessing the current food waste situation and determine potential improvements. In Denmark, although many sorting campaigns involving household waste has been conducted, little attention has been placed on food waste. Comparison of recent studies made for examples in Austria, and the UK suggests that quantity and material composition of food waste vary significantly among the studies and differ from one country to another. Here, we provide a consistent methodology for characterization of household food waste, so that data comparability and source information are ensured. In this study, residual household waste was sampled and manually sorted from more than 211 single-family houses in Denmark. The residual waste from each household was collected and sorted separately to obtain a representative variation of the quantity and composition of food waste among households. The main fractions contributing to the household food waste were avoidable vegetable food waste and non-avoidable vegetable food waste. Furthermore, avoidable vegetable and animal food waste were the primary source of household food waste. Statistical analysis found a positive linear relationship between household size and the amount of the household food waste suggesting the amount of household food waste increases with the number of occupants per household.
Characterization of household food waste in Denmark
This paper presents a methodology and the results of compositional analysis of food waste from Danish families living in single-family houses. Residual household waste was sampled and manually sorted from 211 single-family houses in the suburb of Copenhagen. The main fractions contributing to the household food waste were avoidable vegetable food waste and non-avoidable vegetable food waste. Statistical analysis found a positive linear relationship between household size and the amount of the household food waste.

Integrated resource management and recovery (IRMAR): a new Danish initiative
DTU Environment has launched the IRMAR initiative in collaboration with internationally leading partners to improve the scientific basis for integrated assessment of both the quality of resources in waste and the environmental aspects of resource recovery. Today, the basis for prioritization between individual resources is not available: which resources should be recovered from waste and which waste streams should be prioritised for this recovery? Which final resource quality should be achieved? The answers to these questions are less simple than they may appear. With IRMAR, we offer a critical analysis of existing resource assessment approaches (e.g. exergy, statistical entropy, resource indicators, criticality, etc.). On this basis, we develop a consistent framework for integrated assessment of resource recovery and implement this in our EASETECH waste LCA model. The entire concept is demonstrated based on a range of full-scale case studies in collaboration with the waste industry.

Solid waste characterization in Kétao, a rural town in Togo, West Africa
In Africa the majority of solid waste data is for big cities. Small and rural towns are generally neglected and waste data from these areas are often unavailable, which makes planning a proper solid waste management difficult. This paper presents the results from two waste characterization projects conducted in Kétao, a rural town in Togo during the rainy season and the dry season in 2010. The seasonal variation has a significant impact on the waste stream. The household waste generation rate was estimated at 0.22 kg person−1 day−1 in the dry season and 0.42 in the rainy season. Likewise, the waste moisture content was 4% in the dry season while it was 33–63% in the rainy season. The waste consisted mainly of soil and dirt characterized as ‘other’ (41%), vegetables and putrescibles (38%) and plastic (11%). In addition to these fractions, considerable amounts of material are either recycled or reused locally and do not enter the waste stream.
The study suggests that additional recycling is not feasible, but further examination of the degradability of the organic fraction is needed in order to assess whether the residual waste should be composted or landfilled.
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Astrup, T. F., Main Supervisor, Department of Environmental Engineering
Scheutz, C., Supervisor, Department of Environmental Engineering
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Department of Environmental Engineering
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