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Edjabou, Maklawe Essonanawe; Martín-Fernández, J. A.; Boldrin, Alessio; Astrup, Thomas Fruergaard

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Compositional data analysis of household waste recycling centres in Denmark

V.M.E. Edjabou[1], J. A. Martín-Fernández[2], A. Boldrin[1], and T.F. Astrup[1]
[1]Department of Environmental Engineering, Technical University of Denmark, UK; vine@env.dtu.dk
[2] Dept. Computer Science, Applied Mathematics and Statistics, University of Girona, Girona, Spain

Abstract

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).

Key words: geometric mean, recycling center, variation array, waste treatments.

1 Introduction

Over the last decade, about 80% of Danish waste is incinerated to produce 20% of all district heating and 5% of the electricity consumption (Fruergaard et al., 2010). In addition, the bottom ash from incineration plants are primarily used for construction purpose after recovery of scrap metal (Allegrini, 2014). However, mounting pressure on resource supply, to satisfy future societal needs, requires an effective use of available resources (European Commission, 2013).

To ensure a sustainable resource management, and the transition to the circular economy, the Danish Government, in 2013, launched its Resource Strategy Plan. This plan mandates that, by 2022, at least 50% of the following waste fractions: (1) paper, (2) board, (3) plastic, (4) metal, (5) wood, (6) glass and (7) food waste should be source-sorted and collected separately and recycled (Danish Government, 2013).

Generally, the Danish citizens increasingly dispose their waste at recycling centers (Toft et al., 2015). Recently, researchers showed that an increased amount of recyclable waste fractions (paper, board, plastic, metal, wood, glass and food waste) was misplaced in the containers intended for small combustible waste, which is currently incinerated (Edjabou et al., 2015). To motivate citizens to source separate their waste disposed at the recycling centers, numerous Danish municipalities and waste companies managing the recycling centers implemented various relevant legislations and initiatives to increase recycling rates.

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.

Data handling is a particularly critical issue because using different metrics on the same data can provide contradicting results (Martín-Fernández et al., 2015). For example, when choosing the waste composition for traditional statistical analysis, using either a percentage composition or a mass composition is highly critical and may generate different and often contradictory results. Consequently, the interpretation of the results appears inconsistent, while comparison with other studies is not possible.

The overall objective of this study is to develop a comprehensive procedure for analysis of waste data set that reflect the inherent properties of the waste data set. This paper also aims at providing practitioners within solid waste management and planning with a systematic and easy way to analyze their data to effectively develop a consistent public awareness campaign and for future planning of recycling centers.

2 Methods and materials

2.1 Solid waste data

We analyzed yearly data for solid waste fractions from a recycling center in the suburb of Copenhagen in Denmark. The waste data were collected over the period 2010 – 2016.

In this recycling center, the solid waste was source-separated into 52 waste fractions.

For this study, we grouped the waste fractions into waste treatment and disposal options consisting of (1) incineration, (2) recycling, (3) landfill and (4) other treatments (Fischer, 2014). Here, other treatments are primary, special treatment of hazardous waste such as batteries, preservative treated wood, and polyvinylchloride (PVC).

2.2 Data analysis

We use zPatterns function from zCompositions package (Palarea-Albaladejo and Martín-Fernández, 2015) to describe the historical changes in the number, definition and components of waste fractions at this recycling center.

The geometric mean barplot (Martín-Fernández et al., 2015) was used to describe differences in waste

treatment and disposal options between years from 2010 to 2016. A compositional variation array was used to explore the center and the variability of the waste data set (Pawlowsky-Glahn and Egozcue, 2011).
Modelling and analysis of data were carried out using the open source R statistical programming language (R Core Team, 2017) and the freeware CoDaPack (Thió-Henestrosa and Comas-Cufi, 2011).

3 Historical changes in the number of waste fractions

Figure 1 presents the zero and non-zero of total mass per year of individual waste fractions recorded at the recycling center. We identified 14 zero patterns, and their percentage distribution is presented as horizontal bars. These zero patterns represent the number of combinations of zero values in each year and for each waste fractions. For this study, zero patterns is used to describe historical changes in the number of waste fractions at the recycling center.
The data presented in Figure 1 show that the mass of about 35% of the mass of waste fractions was continuously recorded over the period 2010-2016, suggesting that the definition and the components of these fractions remained unchanged during this period. These fractions include glass packaging, gardening waste, paper, board, metal, soil, combustible, impregnated wood, PVC, tires, hazardous waste and oil, large household appliances, asbestos, etc. However, the definition and components of 65% of waste fractions changed during the same period, of which of 29% of waste fractions was never disposed of at this recycling center.
The highest number of waste fractions at this recycling center was reported in 2010 and 2015, whereas the lowest was found in 2012.
These results suggest various waste sorting guidelines and container signage were implemented during this period.
Among the focus fractions defined by the Danish Resource Strategy Plan, the definition and components of wood and plastic waste varied during this period. In 2010, wood was segregated into two fractions consisting of cleaned wood, semi-cleaned wood. From 2011 to 2014, wood was collected as combustible and incinerated. However, in 2015 cleaned-wood waste fraction was established again at the recycling center.

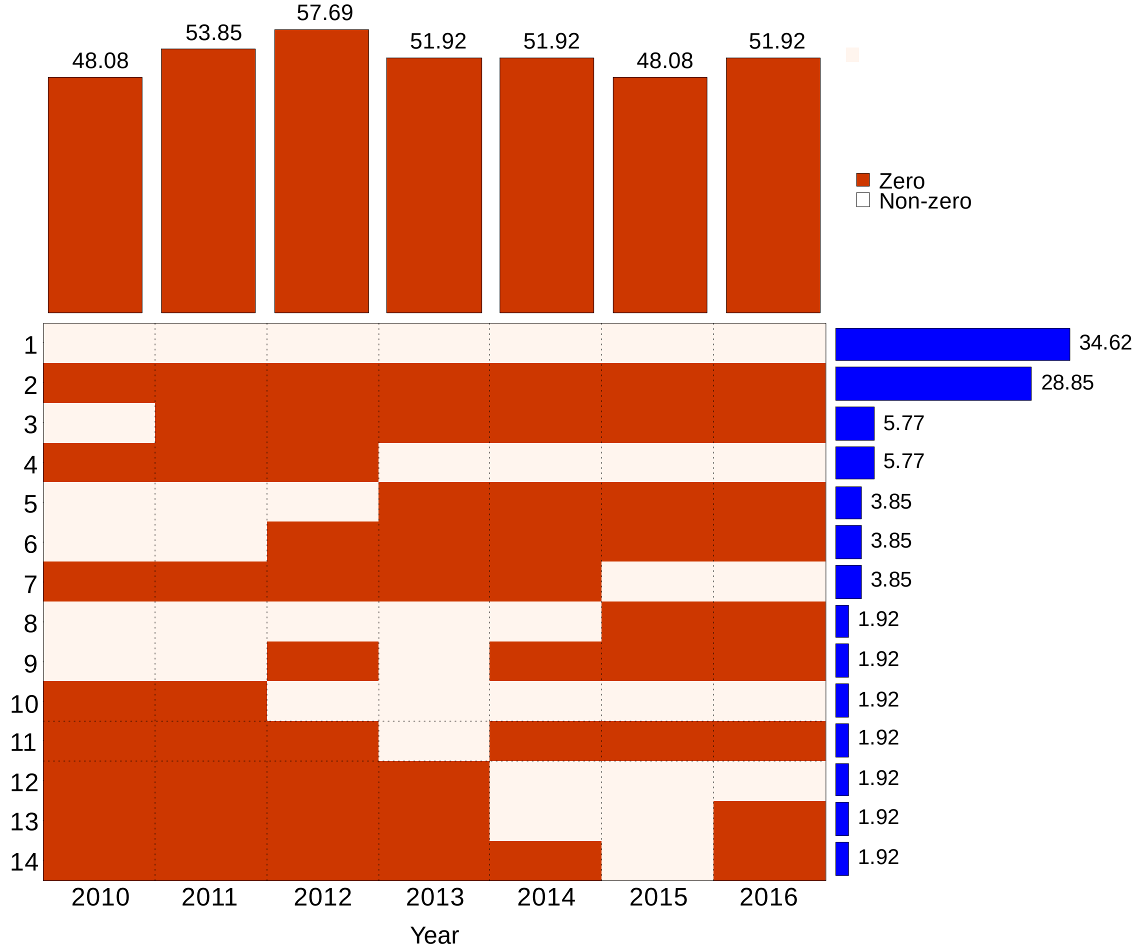

Figure 1: Patterns of zero and non-zero mass of individual waste fractions recorded at the recycling center in the suburb of Copenhagen in the period 2010-2016.

4 Compositional descriptive statistics

For this study, we considered waste treatment and disposal options. This means that 52 waste fractions were grouped according their treatment and disposal options. Thus, we analyzed the composition of waste treatment and disposal options consisting of landfill, other treatments, incineration and Recycling. We computed the center of the whole data set taking into consideration the Aitchison geometry (Martín-Fernández et al., 2015). For individual year, the composition was computed based on the total mass of the whole year.
The data in Table 1 show that recycling waste was the predominant waste fraction collected at the recycling center. On the other hand, solid waste intended for the other treatments was the smallest proportion of total waste disposed of at the study recycling center.

Table 1: Center in the whole period (2010-2016) and the composition for each year.

Year	Landfill	Other treatments	Incineration	Recycling
2010	6.6	1.5	26.3	62.4
2011	6.5	2.3	24.9	65.5
2012	5.6	1.4	24.5	67.4
2013	3.7	1.4	23.4	69.8
2014	4	0.8	25.4	68.9
2015	3.4	0.6	22.8	72.1
2016	3.8	0.7	22.3	72.7
2010-2016	4.6	1.1	24.2	68.3

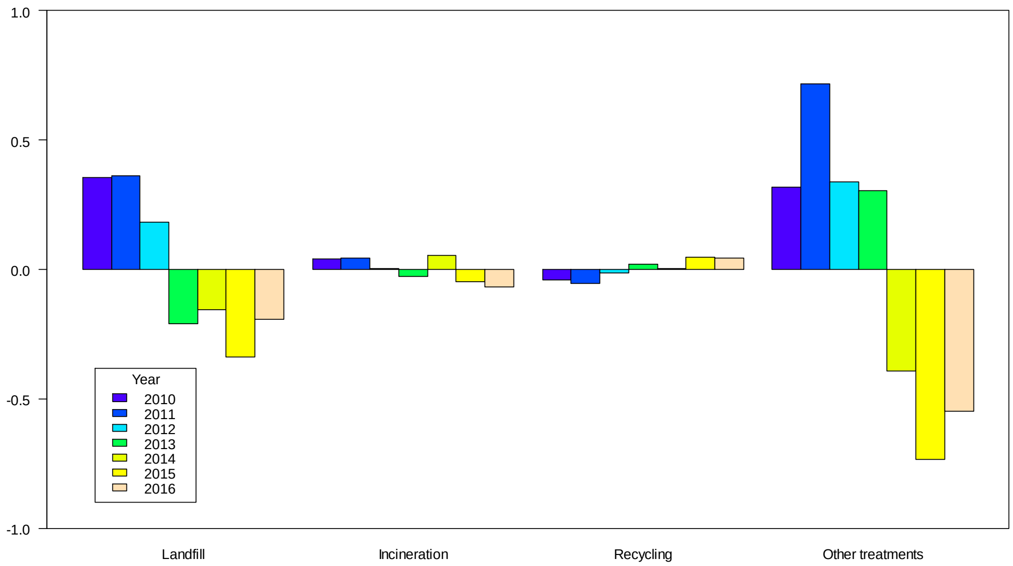

Figure 2: Geometric mean barplot showing the difference in the composition of waste treatment and disposal options over the period 2010-2016.

While data in Table 1 highlight considerably increased in the percentage of recyclables waste from 2010 to 2016, Figure 1 show that for incineration and recycling waste treatments, the differences between the groups (years) and the whole period are minor. However, the difference between groups (years) and the whole period are important for landfill and other treatments. Additionally, the proportion of these waste treatments options (landfill and special treatments) was lower than the whole period from 2013 to 2016 for landfill and from 2014 to 2016 for other treatments. The results may suggest that the changes in the number of waste fractions and the Danish Resource Strategy Plan launched in 2013 contributed to reduce the volume of misplaced waste in the containers intended for landfill and other treatments.

5 Variation array

The variation array is shown in Table 2 and it is divided into two rectangles. The upper rectangle presents ratio between waste treatment and disposal options as a pairwise log-ratio variances (variance $\ln(X_i/X_j)$).

The lower triangle shows the pairwise log-ratio means. Here, the numerator is by column (X_i) and the denominator (X_j) is by row. Furthermore, the sign (+ or -) of log-ratio mean values refer to the direction of the ratio between the two relevant waste treatment options. For example, the ratio between incineration and recycling can be calculated as: recycling/incineration = exp(1.12).

The percentages of centered log-ratio (clr) variances indicate that the largest single contributor to total variation in the waste treatment options from 2010 to 2016 is other treatments, which amounted 55% of the total variation. Recycling was the second predominant contributor to the total variation (24%).

The data from Table 1 indicate a proportional relationship between recycling and incineration because their log-ratio variance is small and closed to zero (colored in blue). These results suggest that a reduction in the amount of misplaced materials in the containers intended for combustible may considerably increase the recycling rates of the study recycling center. In contrast, the results showed that there was no relationship between other treatments and both incineration and recycling.

Table 2: Variation array of the composition of waste fractions grouped per treatment options.

				Variance ln(Xi/Xj)	
Xi\Xj	Landfill	Incineration	Recycling	Other treatments	clr variances (%)
Landfill		0.06	0.09	0.10	8
Incineration	1.62		0.00	0.23	13
Recycling	2.74	1.12		0.29	24
Other treatments	-1.41	-3.03	-4.15		55
	Mean ln(Xi/Xj)				100

6 Conclusions

This study attempts to address the problem associated with analysis of data for of waste fractional composition. Based on zero pattern we found that the definition and components of 64% of waste fractions changed during the period from 2010 to 2016. The geometric mean barplot showed a considerable difference in the proportion of waste being landfilled and those treated and disposed of by means of other treatments options from 2010 to 2016. In contrast, a minor difference was observed in the proportion of incinerated and recycled waste during the same period. The variation array revealed a relationship between the proportions of waste incinerated and recycled.

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