A structured methodology to understand waste generation at local level with minimised effort. Development and case of study.

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Abstract

Understanding waste generation is a key requirement for designing and optimizing waste collection services. The present contribution proposes a statistical methodology to identify waste generation patterns in the waste collection records. It was used in a Portuguese neighbourhood to support the implementation of a pilot PAYT.

Keywords: waste generation, waste collection, pattern identification

1 Introduction

In addition to the total generation, the design of modern municipal solid waste (MSW) collection services requires knowing the waste generation pattern of the various waste fluxes, to support both operational as well as financial decisions (e.g., tariff system). Proper assessment of this pattern must be based on a previous thorough collection of the necessary data required for the subsequent analyses. Usually, researchers search for historical records of data on databases provided by statistics agencies – such as Eurostat or its equivalent at country level –, or alternatively obtain them from responsible entities – either municipalities or corresponding governing bodies, or waste management companies. Unfortunately, these sources are not always available or reliable, particularly at local level. Data may not exist for a specific location or might be not consistent – e.g. due to different origins – and, thus not validated for scientific use [1]. For instance, in developing countries the lack of statistical records is a common drawback for research work [1, 2]. While much effort has been dedicated to the development of forecasting models for MSW generation based on more or less complex mathematical tools [3–7] – reviews published in 2008 and 2016 are available [8, 9] –, less attention has been given to the procedures for data collection. There is currently no established consensus for acceptance of a standard for waste characterisation studies, therefore a wide variety of different methodological approaches are found in the literature covering this topic [10–12]. For instance, in three different studies addressing MSW generation in university campuses where no statistical data records were previously available [13–15], the data collection process for determining MSW generation rate were respectively performed, either weighing the collection vehicle before and after the daily collection route, visually checking the filling degree of the waste bins at the studied sites or assuming a fixed volume of waste carried by the collection vehicle in every journey. Unsurprisingly, this variety in methodologies makes studies hardly comparable between them [12]. In the case of studies focusing on household waste, other researchers opted for directly weighing waste generated by randomly selected households [2, 12], but this kind of field surveys are often limited by the availability of personnel, resources and time. In the wake of this issue, no agreement is found regarding the ideal sampling period. Although there exists a consensus to state that the minimum sampling period should cover at least a whole week to take into account the different waste generation in weekdays and weekends [10], it is difficult to assess at which extent the selected sampling period would be representative of a generation pattern, provided that special events – such as holiday activities, local festivities, musical or sporting events, etc. – could alter the otherwise normal waste generation behaviour [11]. Moreover, short sampling periods lasting only several days or weeks will not account the seasonal influence on MSW generation. The effect of yearly seasonal variation in MSW generation has been already assessed [16]; some authors have found it to be especially relevant in touristic locations – Gidarakos *et al* (2006) in their study for the island of Crete [17] –, while others have considered it to be negligible in the context of their study – Miezah *et al* (2015) in their research about household waste generation in Ghana [1] –, or have even decided to exclude this effect from the scope of their work – Edjabou *et al* (2015) in their characterisation of household waste in southern Denmark [12] –. In their methodological proposal, Sahimaa *et al* (2015) [11] recommend to perform sampling at least in two different seasons; if not possible, Dahlén and Lagerkvist (2008) [10] suggested to choose the most representative season.

In view of the context explained, the present contribution proposes a structured methodology to assist on capturing the waste generation patterns while minimizing the resources spent in monitoring and waste characterization campaigns. The methodology is applicable in cases where a waste collection system already exists and the present research effort details its application on the definition of the monitoring campaign. The monitoring campaign was carried out in a specific neighbourhood in the city of Aveiro (Portugal), as part of a pilot experience for the installation of a *pay-as-you-throw* (PAYT) system, within the scope of the LIFE PAYT project[1].

2 Methodology

Domestic waste generation drivers are multiple, complex and inter-dependent, making it difficult to assess the contribution of each to model the amount of waste generated. In the present research, these drivers are classified into: i) external (e.g., economy; types of goods available to purchase; type of community); ii) service related (e.g., tariff system; waste collection system); and iii) internal. The internal drivers can further be divided into seasonal and non-seasonal. Non-seasonal internal drivers encompass aspects such as the level of education, age, gender or wealth of the waste producer, reflecting the average waste production behaviour and degree of awareness to waste reduction and waste separation issues. Seasonal drivers reflect the variation in waste generation due to the differences of the individuals' daily activities along the days of the week (e.g., weekdays versus weekends) and months of the years (e.g., typical vacation months versus typical work months). Considering the difficulty of setting up and calibrating a mechanistic model, waste generation modelling has been researched mostly based on the use of statistical tools.

Waste generation vary over time following the dynamics of the waste producer. Focusing on residential producers, the external, service related and non-seasonal internal waste generation drivers form a group that usually show a slower evolution and are frequently considered as constant over time for modelling purposes. Seasonal internal drivers, on the other hand are intrinsically variable over time. Therefore, it is possible to split the domestic waste generation drivers according to the degree of variability over time into: i) medium to long-term time variability; and ii) short-term time variability.

This organization is not so useful for categorization purposes, but it is interesting for modelling waste generation. Assuming that the effect of the drivers in each category are independent, it is possible to adopt a 2 step modelling approach with a model for the medium to long-term time waste generation and another for the short-term (Figure 1). The principle underlying the modelling approach is that the average waste generation at a yearly or multiyear scale is a function of the external, service related and non-seasonal internal waste generation drivers, while for time scales the waste generation is a function of the seasonal internal waste generation drivers, and both aspects may be modelled separately and the effect added.

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[1] www.life-payt.eu

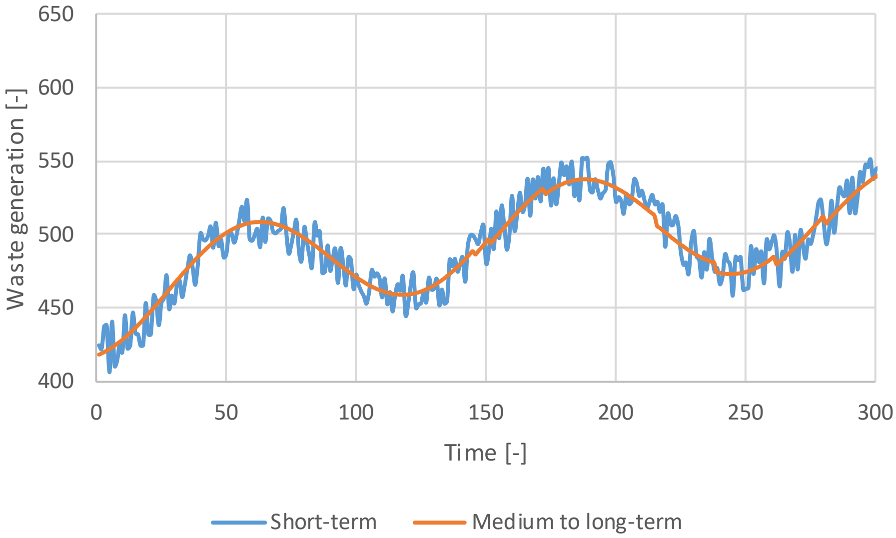


Figure 1. Schematic representation of the waste generation evolution over time

Most authors have focused on modelling the medium to long-term waste and, for Portugal, this was explored in past research efforts using both function-based (Oliveira et al. 2018) and data-based models (Oliveira et al. 2019; Sousa et al. 2019). The present research aims at complementing these waste generation models with the aim of identifying the waste generation patterns driven by the day-to-day behaviour of the waste producers.

Within this scope, it was considered that on a short-term basis, the waste generation vary over a monthly and over a weekly time scales (Figure 2). The former is motivated by aspects such as the weather or vacation periods. The later reflects the influence of working and non-working days. The methodology proposed herein consists in: i) normalize the waste generation; and ii) identify the groups with statistically distinct waste generation pattern.

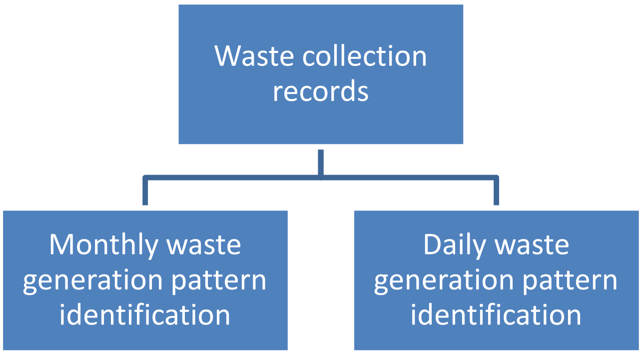


Figure 2. Short-term time scales of the waste generation variability

Since the waste generation between months and between months may be affected by external, service related and non-seasonal internal drivers, to capture the influence of the seasonal internal drivers the influence of the former need to be stripped from the data. For that, we propose the use of normalized values by dividing the daily waste generation amounts by: i) the average daily waste generation of each week (weekly waste generation index); and ii) the average daily waste generation of each year (yearly waste generation index). The weekly waste generation index makes the waste generation of each day of the week of any week of any year to be comparable. This enables looking for the existence of days of the week with different waste generation pattern without the influence of being a period of higher or lower waste generation. The yearly waste generation index day of any year to be comparable. This allows evaluating if the waste generation pattern is distinct for each month of the year.

3 Implementation

3.1 Case study characterization

Under the scope of the LIFE-PAYT project, a neighbourhood (*Forca Vouga*) was selected for a pilot implementation of the PAYT system. The neighbourhood consists on both apartment buildings as well as single-family houses and is mostly inhabitated by young, medium-high income families, totalling around 1200 inhabitants. There are also some offices, bars and shops. The area has been recently developed with new constructions, but still lies on the edge of the urbanised surface and is mostly surrounded by open terrain. This relative isolation from the main urban core poses an advantage for PAYT experimentation, since unwanted deviations out of the area of household waste trying to escape the system are minimised.

The municipality keeps records of the daily mixed MSW collected in the waste collection circuit serving the neighbourhood, measured through weighing of collection vehicles. The data is summarised in Figure 3, showing monthly amounts for the years between 2012 and 2017. However, specific recordings of mixed MSW collected on the area of interest are not available, since the waste collection circuit serving the neighbourhood covers a much broader area, which includes also the city centre.

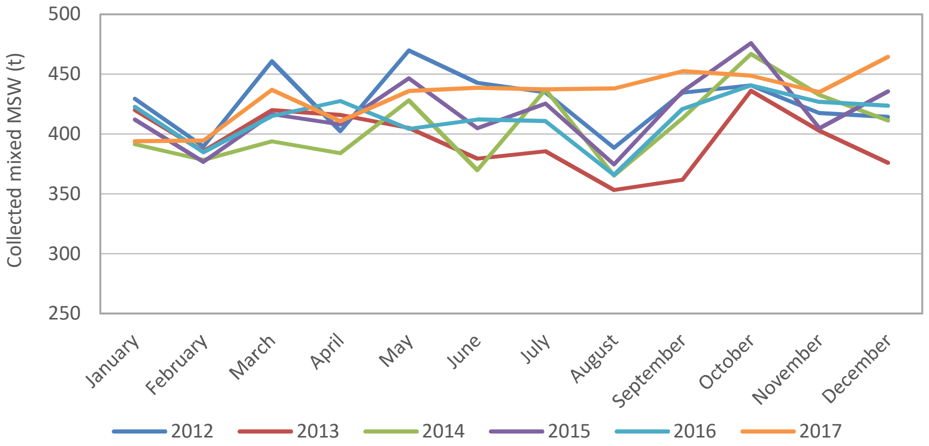


Figure 3. Monthly mixed MSW generation in the whole collection circuit (2012–2017)

To estimate the waste generated in the neighbourhood a monitoring campaign was implemented. The monitoring campaign consisted in allocating a waste collection vehicle to collect and weight the MSW from the street waste containers in the neighbourhood. The goal was to estimate the proportion of waste generated in relation to the full normal waste collection circuit in order to use the existing records based on the assumption that the proportion was and will remain stable.

The proposed methodology was applied to optimize the monitoring a campaign by identifying monthly and weekly waste generation patterns. In order to maximize the accuracy possible with the number of separate collection of the mixed MSW in the neighbourhood available , the methodology was used to identify the months and the days of the week that form groups with similar waste generation patterns. This way, the ten sampling dates were distributed based on waste generation behaviour, instead of choosing and uniform allocation based on time (i.e., the same number of samplings for each day of the week and each month of the year). As a result, a uniform characterization of periods with similar waste generation pattern is achieved and more accurate waste generation estimates are possible.

Since the waste generation pattern was based on the recorded data for the whole circuit, it is implicit in the methodology the assumption that the weekly and monthly waste generation patterns were relatively uniform throughout all the area serviced by the collection circuit. In other words, we assumed that the waste generation pattern in the neighbourhood under analysis it the same of the area covered by the whole municipal waste collection circuit.

3.2 Results and discussion

Three approaches were tested to evaluate if the monthly waste production was distinct: i) using the absolute monthly records of waste collected; ii) using the relative proportion of the waste collected in the month to the total waste collected in the year; and iii) using the average daily waste production in the month. The first option was used to serve as a benchmark. The relative proportion of the waste collected in the month (waste per month/waste per year) was used to correct the variability of the waste collection in absolute values due to differences on waste production throughout the year. The average daily waste production in the month (waste per month/nº days of the month) was use to correct for the fact that the months do not have the same number of days. A fourth approach was also applied combining the second and third options, by using the relative proportion of the average daily waste collected per month.

The ANOVA confirms the existence of months with statistically significant different waste productions independently of the variable used to test. October and August stand out as the months with the highest and lowest waste generation, respectively, using any of the metrics tested. However, the results are distinct. For instance, using the monthly waste and relative monthly waste generated, February was identified as having lower waste generation than November and May, while using the average daily waste and relative average daily it as only a statistically significant higher waste generation than in August.

Table 1.

		Sum of Squares	df	Mean Square	F	Sig.
Waste Monthly	Between Groups	23110275110,000	11	2100934101,000	4,826	,000
	Within Groups	20895289280,000	48	435318526,700		
	Total	44005564390,000	59			
Relative Monthly Waste	Between Groups	9,477	11	,862	7,219	,000
	Within Groups	5,729	48	,119		
	Total	15,205	59			
Average Daily Waste	Between Groups	20852159,500	11	1895650,864	4,146	,000
	Within Groups	21948959,110	48	457269,981		
	Total	42801118,610	59			
Relative Average Daily Waste	Between Groups	,859	11	,078	6,038	,000
	Within Groups	,621	48	,013		
	Total	1,479	59			

Using the relative average daily waste, it is possible to identify three groups of months with statistically distinct waste generation patterns. The months of August and December reveal the lowest waste generation, which is coincident with the most common months of summer and winter vacations in Portugal. Then the months of January, June a July follow, which may be explained by the existence of holidays and several families taking their vacations on these months, particularly after the classes finishing in June. The last group comprise the remaining of the months, but with the exception of the month of October, the waste generated is not statistically distinct from all three months of January, June and July.

Table 2.

			Subset for alfa = 0.05		
	Month	N	1	2	3
Tukey HSD	8,00	5	2,4315		
	12,00	5	2,6698	2,6698	
	1,00	5		2,6812	
	6,00	5		2,7109	
	7,00	5		2,7171	
	4,00	5		2,7300	2,7300
	3,00	5		2,7423	2,7423
	2,00	5		2,7694	2,7694
	9,00	5		2,7941	2,7941
	11,00	5		2,8042	2,8042
	5,00	5		2,8316	2,8316
	10,00	5			2,9647
	Sig.		,068	,524	,076
Ryan-Einot-Gabriel-Welsch	8,00	5	2,4315		
	12,00	5		2,6698	
	1,00	5		2,6812	
	6,00	5		2,7109	
	7,00	5		2,7171	
	4,00	5		2,7300	
	3,00	5		2,7423	
	2,00	5		2,7694	2,7694

9,00	5		2,7941	2,7941
11,00	5		2,8042	2,8042
5,00	5		2,8316	2,8316
10,00	5			2,9647
Sig.		1,000	,500	,152

In order to evaluate if there are statistical significant differences on the waste generated throughout the days of the week two approaches were used: i) using the absolute average daily records of waste collected; and ii) using the relative daily average records of waste collected. An average daily waste collection value was used to account for the fact that the collection is not made at constant intervals of time. The collection on Monday accumulates the waste produced on Sunday, while the remaining only the waste produced in the previous day. The relative values (waste per day/waste per week and waste per day/waste per month) were used to correct the variability of the waste collection in absolute values due to differences on waste production throughout the weeks and months.

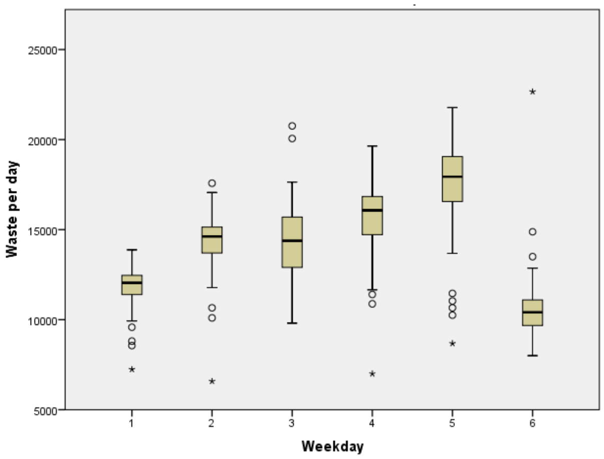
Since the variance is not homogeneous between the groups, the Welch and Brown-Forsythe tests where used instead of the F test. Both tests reveal that there is at least one day of the week with a statistically significant different mean waste generation in absolute and relative terms.

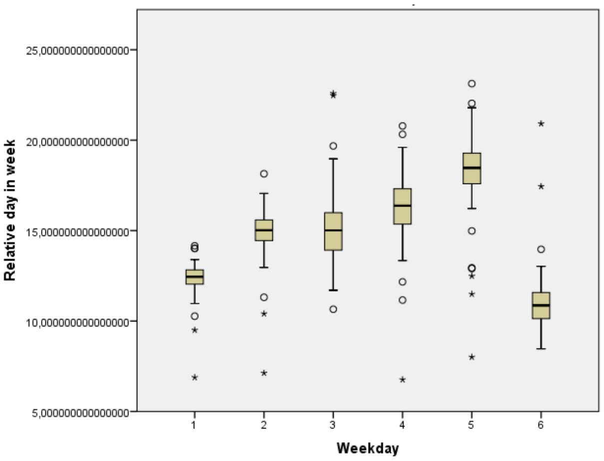
Table 3.

		Test Statistic	df1	df2	Sig.
Waste per day	Welch	143,692	5	217,786	,000
	Brown-Forsythe	148,009	5	403,225	,000
Relative day in week	Welch	180,773	5	216,875	,000
	Brown-Forsythe	177,799	5	403,430	,000
Relative day in month	Welch	150,661	5	217,864	,000
	Brown-Forsythe	154,534	5	393,314	,000

Since the variance is not homogeneous, the Games-Howell post-hoc test was used to compare the waste generated in each day of the week. The waste generation per day in absolute and relative terms was found to be statistically different for every day, except between Tuesdays (weekday=2) and Wednesdays (weekday=3).

Despite the robustness of the ANOVA to the normality of the residuals and the existence of alternative tests post-hoc for the case of heterogeneity of the variance, a non-parametric test (Kruskal-Wallis) was also conducted. As with the ANOVA, there are statistically significant different waste collection amounts in absolute and relative terms between weekdays. However, performing the pairwise comparison between weekdays and considering the significance adjusted by the Bonferroni correction, the waste collection between Saturdays and Mondays, Tuesdays and Wednesdays and Tuesdays and Thursdays are not statistically different. So, three groups of days are possible to identify in terms of waste generation: i) Saturday, Sunday and Monday; ii) Tuesday, Wednesday and Thursday; and iii) Friday.





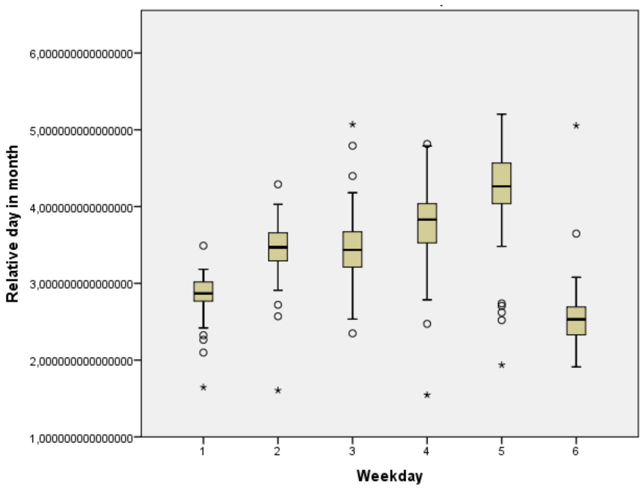


Figure 4.

4 Conclusions

The pattern obtained as a result of the proposed methodology, it was possible to distribute the sampling days along a period reaching one year more efficiently. It was decided: i) to split the 12 sampling days evenly between the two groups of months that have been detected; and ii) assign at least one sampling day to every statistically significant month, which meant in total 10 days. Therefore, the two days left were assigned respectively to the months of minimum and maximum generation (August and October, respectively), thus ensuring better coverage of these extreme situations.

Regarding days of the week, counting on six sampling days for every group of months, it was decided that every group should have at least one sampling for every of the statistically relevant group of days of the week detected. That is: one sampling day on Monday, one on Tuesday or Wednesday, one on Thursday, one on Friday and one on Saturday, thus covering the whole week – keeping in mind that collection takes place six days per week (every day except Sunday). The remaining sampling day was assigned to the day of the week with maximum production observed, i.e. again on Friday. Furthermore, for assigning days of the week to the particular months, it was established that samplings in the months of extreme MSW generation (August and October) should be performed on days of the week with also extreme generation: one Friday (maximum) and one Saturday or Sunday/Monday (minimum) for each month.

The rest of days should be distributed throughout the remaining months. Given that searching for patterns on a weekly basis showed no relevant conclusions, the choice of the actual dates for the sampling was left at convenience of the collection company. According to the previous explanations, the final distribution of sampling days is detailed in Table 4.

Table 4. Distribution of sampling days

Months	Jan	Feb	Mar & Apr	May	Jun & Jul	Aug	Sep	Oct	Nov	Dec
High generation		Mon		Fri			Thu	Fri & Sat	Tue or Wed	
Low generation	Thu		Tue or Wed		Mon	Fri & Sat				Fri

Based on the sampling distribution of Table 4 – which was put into practice between June 2017 and June 2018 –, the weightings of daily MSW collected within the neighbourhood were compared with the value collected for the same dates in the whole collection circuit. The percentage obtained represents the "weight" of MSW generation of the neighbourhood respective to the whole circuit. An average value of this percentage was obtained for each representative cluster of days of the week, as shown in Table 5.

Assuming the percentage is always the same for the same cluster of days of week, daily MSW in the neighbourhood was calculated from the daily recordings of the circuit. The annual generation was finally obtained by adding all single day values, resulting in 468 tonnes generated during the sampling period of one year. Actually, this result is not far than simply multiplying the average amount collected on the neighbourhood by 365 days: 462 tonnes; this closeness may be taken as an indicative of robustness of the method used. Thus, the whole methodology explained in this paper shows its usefulness to be applied in other similar case studies.

Table 5. Percentage of MSW collection within neighbourhood relative to whole circuit

Cluster of days	Average MSW collected on the neighbourhood	Average MSW collected on the whole circuit	Percentage of the neighbourhood on the whole circuit
Monday + Saturday + Sunday	1245 t	12020 t	10.36
Tuesday + Wednesday	1100 t	13455 t	8.18
Thursday	1310 t	13360 t	9.81
Friday	1410 t	19000 t	7.42

The proposed methodology was developed to identify possible waste generation patterns of residential waste producers to optimize the resources available in monitoring campaigns. However, understanding waste generation patterns is useful for several decisions related to waste collection services.

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