Life-cycle cost analysis of waste collection equipment: The case study of Cascais Municipality

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ABSTRACT

The recent publication of the ISO 55000 standards series provides a guide on asset management. One of the requirements set on the ISO 55001 is the consideration of the asset life cycle, which comes in line with the recent European Directive on public purchasing recommending the awarding based on the life-cost instead of the purchase cost. Focusing on the solid waste sector, there are two major components: i) waste collection; and ii) waste treatment. Regarding waste collection there are several studies on the spatial optimization of collection services (route planning), but, little is found on the time optimization of the collection service, namely definition the equipment maintenance and replacement plans and evaluation of equipment alternatives.

The present communication proposes a methodology for the detailed life cycle cost analysis based on the ISO 15686-5 and presents its application to the waste collection at Cascais municipality with the aim of providing a baseline for the time optimization of the service, namely assisting on decisions regarding equipment operation and replacement. Waste collection in Cascais Municipality is divided into 4 services: i) residual waste; ii) source segregated waste, namely paper, plastic and glass; iii) parks and garden waste; and iv) bulky waste. The containers contribute only 8%, while the vehicles represent 92% of the life-cycle costs of the waste collection. The vehicles operation accounts for the largest share of their life-cycle costs, with up to 82%. Within the operation, labour cost represent up to 88% (72% of the life cycle costs), implying that alternatives on automation to reduce labour needs will have the highest potential for cost reduction.

Keywords: waste collection, vehicles, containers, life-cycle cost, asset management.

1. INTRODUCTION

Nowadays, solid waste management is a high priority for European policy due to its environmental, economic and social relevance, since environmental impacts can be reduced through the efficient natural resources management, it potentiate the creation of new business opportunities and adds value to the waste, creating new jobs and contributing to circular economy [1]. Globally, solid waste management comprises a system of activities that form a chain of circular interaction, including collection, transport, storage, sorting, treatment, recovery and disposal operations, but also the components relating to waste prevention, environmental policies, regulatory frameworks and the regulation of waste management activities [2]. At an operational level, solid waste management comprise of two major components: i) waste collection; and ii) waste treatment. Despite the natural interdependence between both, the challenges in each are distinct. The later deals mostly with optimizing treatment options with little spatial dynamics and indirect relation with the waste producers, while the former deals with improving the collection in a dynamic spatial context and waste producer interaction.

The Portuguese urban waste sector is divided spatially (municipalities and regions) and functionally (collection and final destination), resulting in 282 entities managing the service. In terms of function, there are 259 utilities responsible for waste collection (retail services), usually at the municipal level, and 23 responsible for waste disposal (bulk services). This division promotes advantages in terms of economies of scale, particularly in the waste disposal service, but implied losses in process economies [3]. Complementarily, a service regulator (ERSAR) has been created with the main goal of protecting the interests of the consumers by promoting the quality of the provided service by operator. ERSAR aims to ensure the sustainability of the sector by acting at three levels: i) social sustainability of services; ii) economic, infrastructure and human resources sustainability of management entities; and iii) environmental sustainability in the use of environmental resources and prevention of pollution.

In order to increase the waste collection performance, the available technological solutions and management models need to be carefully assessed and implemented by the waste management utilities. Amongst the management models, the recent publication of the ISO 55000 standards series provides a guide on asset management [4]. One of the requirements set on the ISO 55001 [5] is the consideration of the asset life cycle, which comes in line with the recent European Directive on public purchasing (Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014) recommending the awarding based on the life-cycle cost (LCC) instead of the acquisition cost .

Regarding waste collection, most studies found in the literature focus on the spatial optimization ([6–8]), in particular the definition of routes and location of collection and deposition points. However, little is found on the time optimization of the collection service, namely definition the equipment maintenance and replacement plans and evaluation of equipment alternatives. Considering that the collection services can account for around 40 to 70% of the overall solid waste management costs, it is relevant to explore its optimization both in space and time [9]. The present communication proposes a methodology for the LCC analysis of the waste collection equipment and presents its implementation to Cascais municipality. The goal is to develop a baseline for the time optimization of the collection equipment by identifying the relative weight of the various costs categories and allowing to evaluate the impact of decisions regarding the equipment management.

2. LIFE-CYCLE COST ANALYSIS METHODOLOGY

According to ISO 15686–5 [10], LCC is defined as "a cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements for which it was designed." According to this standard, the LCC is part of the concept of whole life-cycle (WLC) which includes revenues, externalities and costs non-related to the acquisition of the asset. According to the European standard IEC 60300-3-3 [11], the main purpose of life cycle cost is to provide decision-making criteria at all stages of the equipment life cycle. For this, it is important to identify in the LCC model the costs with greater and lesser influence on an equipment life cycle cost.

With LCC application all costs of the alternatives are considered over their lifetime, allowing an assessment on a common basis for the defined period of analysis. The proposed methodology comprise 12 steps (Table 1) and was developed for solid waste equipment based on two main documents: i) ISO 15685-5 [10]; and ii) Langdon [12]. It included also contributions from the IEC 60300-3-3 [11] and EN 15643-4 [13].

Table 1 - LCC analysis methodology

Step	Description	Outcome/achievement
1	Identify the purpose of the LCC analysis	Considerations about the objectives of LCC analysis; understand how the analysis can be applied and related outcomes
2	Identify assets requirements/constraints	Statement of constraints; define the asset relevant requirements and information
3	Identify the scope of the analysis	Define scale and stages of application of LCC exercise; understanding of information likely to be relevant
4	Identify the relation with sustainability	Understand the relationship between sustainability assessment and LCC
5	Identify the period of analysis and methods of economic evaluation	Identify the period of analysis and the considerations governing its choice; identify the method of economic evaluation that best fits this LCC analysis; identify the discount and inflation rate
6	Identify the need for additional analysis	Carry out a preliminary risk identification process; identify and develop appropriate risk assessment techniques
7	Assemble cost and time data to be used in LCC analysis	Identify all costs relevant to LCC model; develop calculation methods and estimation of unknown costs (previous / future)
8	Identify options to be included in the LCC analysis	Identify alternative options to evaluate
9	Verify values of financial parameters and period of analysis	Confirm the suitability of the period of analysis; confirm appropriate values for the financial parameters
10	Perform economic evaluation	Drawn together all the data needed for LCC analysis; perform the LCC analysis; record the results for future interpretation
11	Carry out additional analysis	Perform semi-quantitative risk assessment.as described at step 6
12	Present and interpret the results	Review, present and interpret the results on the LCC analysis; identify whether further iterations of the LCC exercise are required

3. CASE STUDY

Cascais municipality, covering an area of almost 100 km^2 and with a population of 206 000 inhabitants, is located in Portugal at approximately 30 km west of the capital city, Lisbon (Figure 1). The municipality is divided into 4 parishes, with 2 of them resulting from the merge of the parishes of Cascais with Estoril and Carcavelos with Parede. The majority of the population is concentrated in the southern parishes (Cascais-Estoril and Carcavelos-Parede) along the coastline. The average total solid waste produced yearly is approximately 120 000 tonnes.

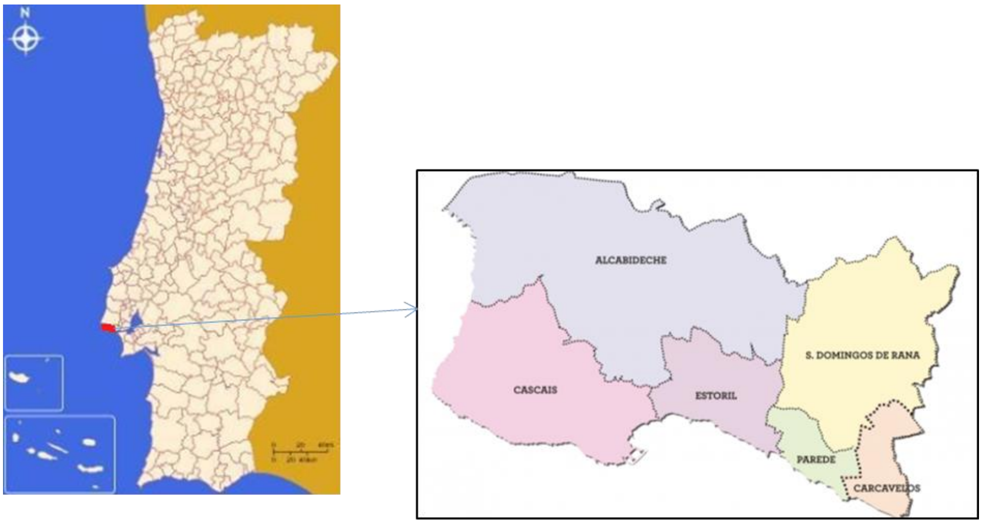

Figure 1 - Map of Cascais Municipality (Source: Cascais Municipality database)

The waste collection is amongst the responsibilities of Cascais Ambiente, who collects the solid waste through 4 collection services: i) residual waste; ii) source segregated waste, namely paper, plastic and glass; iii) parks and garden waste; and iv) bulky waste. In addition to the collection, the residual and segregated waste services include the containerization (Figure 2). The waste collected is deposited at a waste treatment plant managed by TRATOLIXO.

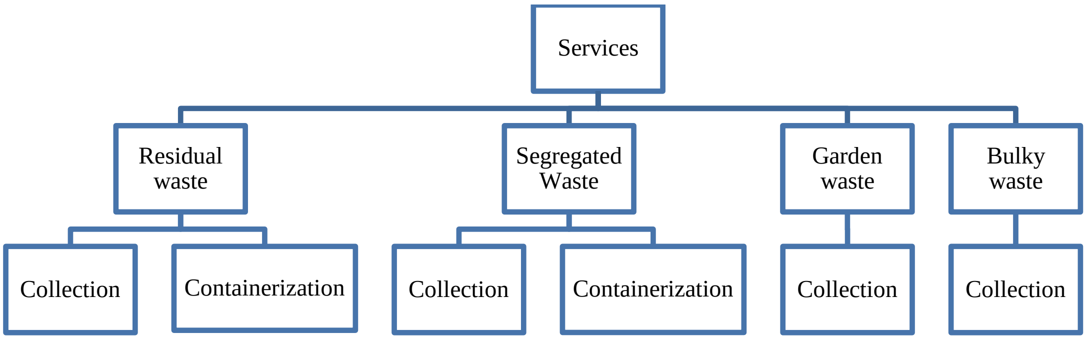

Figure 2 – Organization of the waste containerization and collection services

Some service data are presented in Table 2. The total amount of the waste collected in 2015, by Cascais Ambiente was only 71 000 tonnes and not the 120 000 tonnes reported previously because the data regarding the residual waste collection service is only for part of the municipality. Residual waste collection of roughly half of the total area of the municipality was conceded to a private company. For the remaining parameters, the data is for the whole municipality.

Table 2 - Waste collection service data in 2015

	Residual Waste	**Segregated Waste**	**Garden Waste**	**Bulky Waste**	**Total**
Amount [kg/year]	35.906.703	8.993.195	23.398.000	2.878.500	71.176.398
Amount [%]	50	13	33	4	100
Distance [km/year]	181.656	153.665	321.674	137.833	794.827
Distance [%]	23	19	40	17	100
Vehicles [-]	10	13	11	5	39
Containers [-]	2496 (0.8 m^3) 22 (0.12 m^3)	2232 (2.5 m^3)	-	-	-

The residual waste service has the most number of collection points. Contrariwise, the segregated waste service has fewer containers, but superior distance between collection points. It should also be noted that garden and bulky waste services perform an activity subject to variable constraints, such as public scheduling requests or evidences detected by operators of other types of collection, therefore this service have longer travel distances per vehicle (uncertainty arising from abandonment on public roads).

The waste collected over the months depends on the amount produced. In 2015, the average monthly waste collection amounts were: 2890 ton./month of residual waste; ii) 803 ton./month of segregated waste; iii) 2043 ton./month of garden waste; and iv) 223 ton./month of bulky waste. In addition to the differences in the total amount, the monthly waste collection varies throughout the year in distinct patterns for each waste collection service (Figure 3). On the first three months of the year there is a similar decrease due to smaller number of days in February. The residual waste show the most constant values of waste collection. Segregated and bulky waste collection show a similar pattern, with a gradual increase over the year to a peak in September-October. It is interesting to notice that the peaks in segregate and bulky waste collection are coincident with the months with less residual waste collection. This indicates that behaviour issues may be underpinning this variation and it is possible to assume that the potential to increase the segregate waste collection is at least 30%. However, it is not possible to be conclusive since other factors influence the amounts of waste produced (e.g. seasonality, tourism). Garden waste has an evolution related to the seasons of the year, having a large increase during the autumn season and lower values during summer.

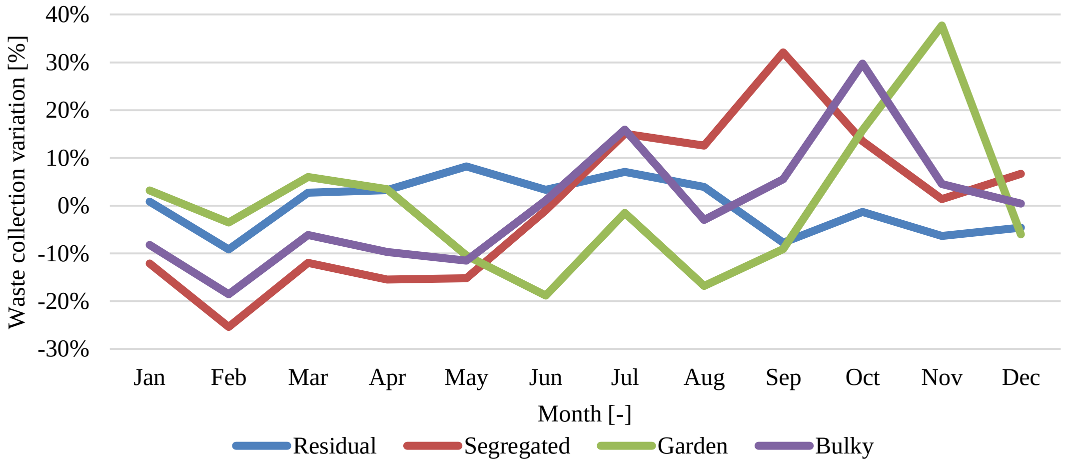

Figure 3 - Variation of waste collection over the months, in 2015

4. APPLICATION OF THE METHODOLOGY TO CASE STUDY

Step 1 - Identify the purpose of LCC analysis

The LCC analysis purpose is to perform an absolute evaluation of the cost associated to the Cascais Ambiente waste collection assets, namely the vehicles and the containers. This enables the identification of the relative weight of the various cost categories and sets a baseline for the evaluation of the effect of possible alternatives on the life-cycle costs of the assets.

Step 2 - Identify assets requirements/constraints

The assets in the analysis have different requirements and constraints, implying different approaches. Table 3 shows examples of the assets requirements and constraints which were accounted for in the LCC analysis.

Table 3 Examples of asset requirements and constraints

	Constraints	Requirements
Vehicles	Fuel; breakdowns, accidents, damages; location of containers; inclination and width of road and traffic; different operators; brand, model and age of the vehicle	Vehicles capacity; functional reliability; vehicle access to collection points; sufficient number of operators; durability
Containers	Location; amount of waste produced; vandalism and robbery; installation and surrounding space	Containers capacity; container washing; easy maintenance; durability

Step 3 - Identify the scope of the analysis

The LCC analysis includes all the vehicles assigned to the collection operations and all the containers throughout the time span they are within Cascais Ambiente responsibility. Since Cascais Ambiente owns the assets, only the production, commercialization and final disposal costs are excluded from the LCC analysis (Table 4). However, the vehicles production and commercialization is accounted for indirectly through the acquisition costs. The end-of-life phase was not considered in the analysis because Cascais Ambiente has no significant cost or revenue at the end of life of the assets.

Table 4 LCC phases

Acquisition	Vehicles - financed by leasing. The contract does not define any portion related to initial investments, so the acquisition costs are given only by the monthly amortization and financing expenses; Containers - financed by leasing. Depreciated in a single accounting year
Operation	Cascais Ambiente is contractually responsible for the teams of operators performing the services. Teams are not assigned exclusively to a vehicle.
Maintenance	External and internal maintenance

Step 4 - Identify the relation with sustainability

There are several factors and characteristics of the assets that are closely related to sustainability, in their different dimensions: i) environmental (gaseous emissions, solid waste management); ii) social (health and wellness, safety, social equity); and iii) economic (boosting the circular economy, safeguard image-sensitive industries). Usually, LCA is tool used in the evaluation of the environmental impacts, but it is outside of the scope of the present communication. Since fuel consumption will be considered individually in the LCC analysis, it provides an indirect information about resource consumption and gas emissions.

Step 5 - Identify the period of analysis and methods of economic evaluation

The period of analysis is the equipment life cycle, which is distinct for vehicles and containers due to technical and functional differences. For vehicles, the life cycle defined is the economic life. Distinct periods were identified for the vehicles associated with the 4 services based on historical records. For containers, the functional life has been establishing as life cycle. Often the functional life of containers tends to coincide with their physical life, which corresponds to an average of 10 years according to Carvalho et al. [14].

The most appropriate method of economic evaluation for the analysis (different periods and only costs) is the equivalent annual cost (EAC). Nominal discount rates were considered, since different inflation were used to model the cost evolution of various cost components, and 2015 was defined as the reference year.

Step 6 - Identify the need for additional analysis

For the purpose of the present communication, only the sensitivity analysis is present. The full study also included a semi-quantitative risk assessment.

Step 7 - Assemble cost and time data to be used in LCC analysis

The lifecycle cost structure is not the same for vehicles and containers, and different categories of costs were considered for each (Table 5). The data was retrieved from historical records available at Cascais Ambiente and from statistical information available at the Portuguese National Statistics Institute (inflation). Information gaps and/or limitations on the Cascais Ambiente data were solved resorting to expert opinion from the personnel involved in the solid waste management service.

Table 5 – Cost structures for waste collection vehicles and containers

Stage	Cost categories	Collection Vehicles	Containers
Acquisition	Amortizations*	X	
	Financing expenses	X	
	Direct Acquisition*		X
Operation	Operators and managers of the operation	X	
	Fuel	X	
	Insurance	X	
	Single road tax	X	
	Communication / correspondence	X	
	Litigation and notary	X	
	Other expenses	X	
Maintenance	External global maintenance*	X	
	Parts and components	X	X
	Labour	X	X
	Tools and utensils for quick wear	X	X
	Energy and fluids	X	X

Stage	Cost categories	Collection Vehicles	Containers
	Cleaning, hygiene and comfort	X	X
	Specialized works	X	
	Other services	X	
	Fuel*		X
	Subcontracts		X
	Insurance		X
	Rent		X

*Estimates with expert opinion aid

Step 8 - Identify options to be included in the LCC analysis

For the purpose of the present communication, no additional analysis is presented. The full study included the evaluation of acquiring different models and/or brands, change of fuel type (diesel to LPG), install speed limiters and change the maintenance source for the vehicles and replacement of surface with semi-buried or buried containers and resort to automated washing systems.

Step 9, 10 and 11 - Verify values of financial parameters and period of analysis, perform economic evaluation and additional analysis

The assumptions considered in step 5 were considered adequate in a meeting with the solid waste management team from Cascais Ambiente and the analysis was performed building the cost model on Microsoft excel, creating a tool that is applicable to evaluate the alternatives and easily tailored to different contexts and assets.

Step 12 - Present and interpret the results

i) Global results

Figure 4 presents the LCC cost distribution based on the AEC for the Cascais Ambiente waste collection services. The containerization contributes only 8% to the total LCC of the waste collection service, with the distribution between segregated and residual fairly similar. The collection service accounts for the remaining 92% of the total LCC. The garden waste has the highest proportion of the LCC costs, followed be the residual and segregated waste with similar portions and the bulky is the least significant.

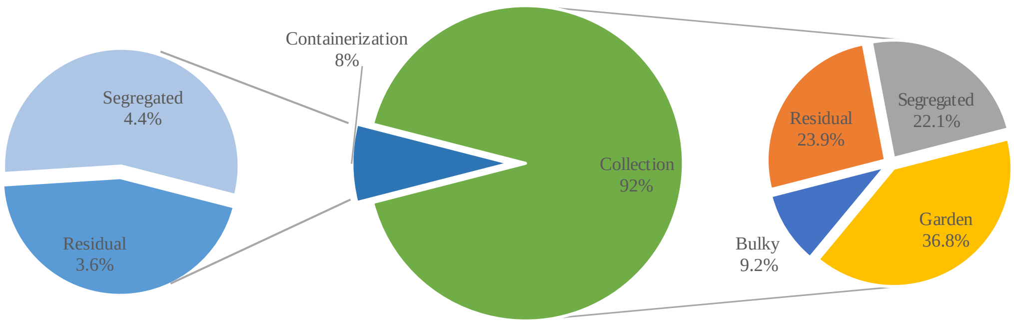

Figure 4 – LCC cost distribution per service

In both containerization services, maintenance costs are higher than acquisition. Amongst the main cost categories within the maintenance of the containers, the labour represents the largest portion of the LCC of both residual and segregate waste containers (Figure 5 and Figure 6). However, the residual containers have a higher weight of the maintenance and labour costs than the segregated, which can be explained mostly by the higher acquisition cost of the latter. Since the residual waste service is carried out in two daily shifts, the collection frequency of all containers is mostly daily, which increases the wear of the containers and can reduce their life cycle. The number of parts and the nature of the operation for transferring the waste from the segregated containers to the vehicles seems to make it more prone to failures. Also, the fact of the segregated containers being grouped influence the consequences of vandalism action, such as fire.

The LCC per number of containers and amount of waste are presented in **Error! Reference source not found.**. The EAC/container and the EAC/amount of waste collected is significantly higher for the segregate waste containerization. This indicate that the capacity for segregate waste collection should be sufficient to face the goals set by the EU in terms of source segregate waste collection but that there is a need for motivating the population to separate further their waste.

Contrary of what occurs with containerization service, the acquisition cost has a marginal influence in the LCC context, with the costs related to the vehicles use (operation and maintenance) representing 90% of the LCC. This allows different approaches in the process of replacement and acquisition of new vehicles. The vehicles performance in terms of fuel costs, which is closely linked to the type of vehicle purchased, and maintenance costs, which will depend also in the use and conservation strategy, have a major impact on the objective of reducing EAC. The biggest share of costs is with the workforce related with the vehicles use, which includes the management support personnel, the operators and the maintenance teams (Figure 7).

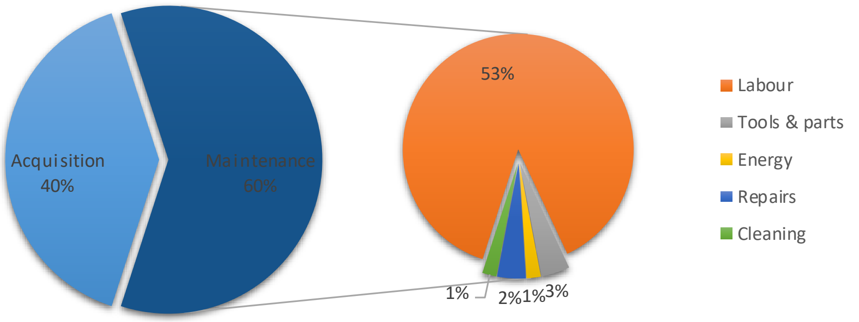

Figure 5 - Cost distribution of residual waste containers

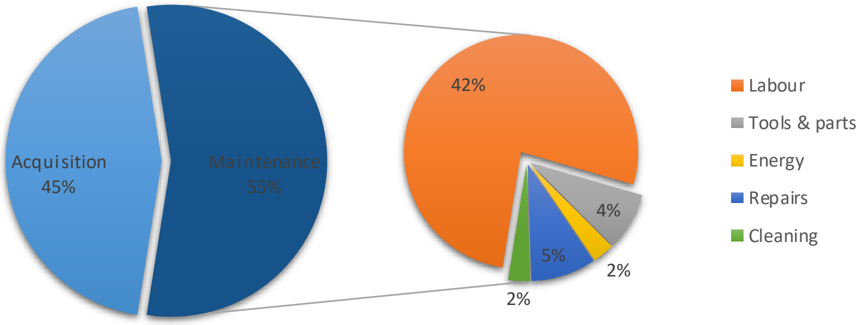

Figure 6 - Cost distribution of segregated waste containers

Table 6 - Costs of waste containerization services

LCC	Residual	Segregated
EAC/container [€/container]	81	110
EAC/amount of waste collected [€/ton]	6	26

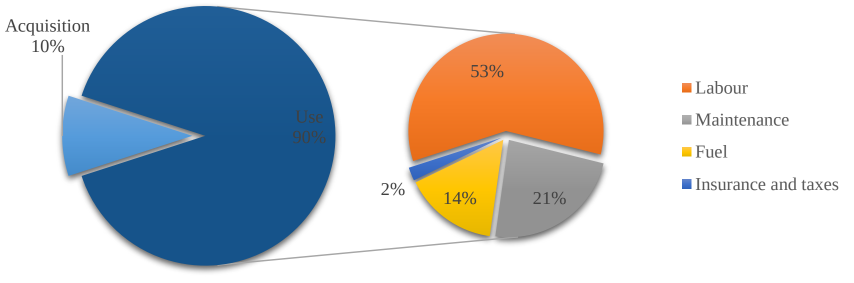

Figure 7 - Collection vehicles average LCC distribution (%)

The vehicles assigned to residual and segregated collection have identical acquisition costs, however in the other cost categories the residual waste service is more expensive, justified by the characteristics of the collection circuits, namely kilometres travelled, distance between collection points and amount of waste collected, that affects fuel consumption, maintenance and the number of operators required to perform the service. There is a similarity in the residual and segregated collection cost breakdown, distinguishing itself from the others, mainly, by the weight of the acquisition cost. However, segregated collection has the peculiarity of collecting three different types of waste (paper, plastic and glass), with the glass assuming a different weight from the rest, since the collection flow is smaller and the vehicles used are less expensive. The cost of operators and managers of the operation constitutes the most relevant cost in all LCC collection services, particularly on gardens and bulk collection where this cost acquires extreme importance, being a category that greatly inflates the global values of these services. Maintenance costs are highly dependent on collection activity and cumulative wear and tear, making it the second most costly category in all collection services life cycle cost. Figure 8 present a percentage distribution of costs for each collection service life cycle phase.

The service with more impact in overall collection services costs is the garden waste. Despite having higher costs of acquisition, fuel or maintenance the residual and segregated waste services have proportionally lower costs of labour. The vehicles of garden and bulk waste have a superior life cycle. Since the equivalent annual value is updated to the year 2015, the values for vehicles with older acquisition date will be inevitably higher. Bulk collection are the least costly service, which can be explained by the fact that there are only 5 vehicles assigned to this service which have lower overall costs than the others.

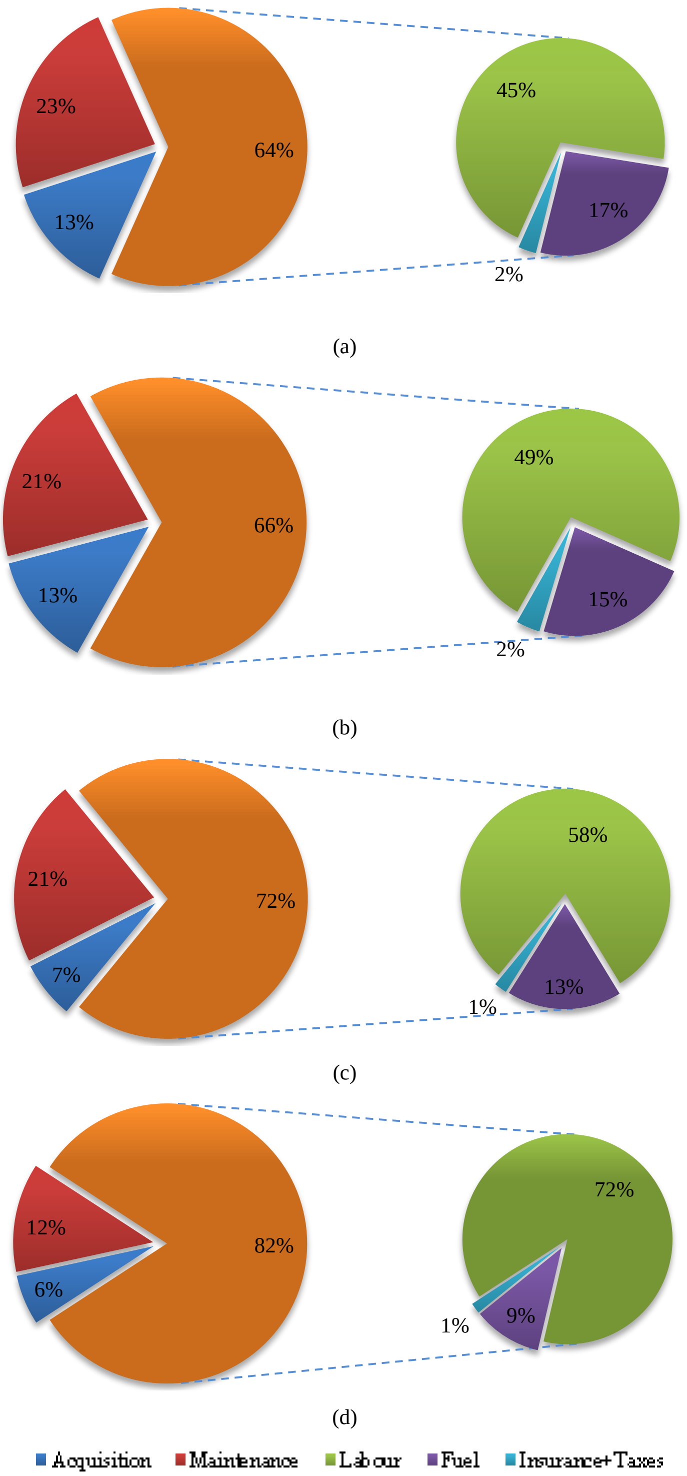

Figure 8 - Relative cost distribution of (a) residual, (b) segregate, (c) garden and (d) bulky waste collection services

Error! Reference source not found. shows some indicators which allow to evaluate the significance of the LCC of the various waste collection services from different perspective. Residual and garden waste have the highest overall and per vehicle cost, but since the amounts of waste collected in these services is significantly higher the LCC per unit weight are the lowest. Residual and segregated waste collection vehicles have similar LCC per distance travelled, indicating that the higher LCC with the segregated waste collection is compensated by relatively longer distances covered. The segregated waste collection presents the lowest LCC due to relatively high number of vehicles when compared to the other services. The collection of bulk waste has the highest cost per unit weight and distance travelled due to the characteristics of the service, namely large volume-low density waste and variable point concentrated collection.**Error! Reference source not found.**

Table 7 - Costs of waste collection services

LCC	Residual	Segregated	Garden	Bulk
EAC/vehicle [€/vehicle]	148.550	95.070	188.340	104.620
EAC/amount of waste collected [€/ton]	49	141	95	180
EAC/distance traveled [€/km]	8	8	6	4

ii) Sensitivity analysis

A preliminary sensitivity analysis was performed on vehicles LCC due to the inflation used for estimating the maintenance costs, the fuel cost and the discount rate. Figure 9**Error! Reference source not found.** shows the results for an average collection vehicle. The discount rate presents a steeper slope for negative variation values of parameter, however for positive variation values of maintenance inflation the EAC is very sensitive, reaching high values. These are the parameters with more sensitive variation. The variation of parameters and EAC is directly proportional, the higher the parameter the higher the EAC.

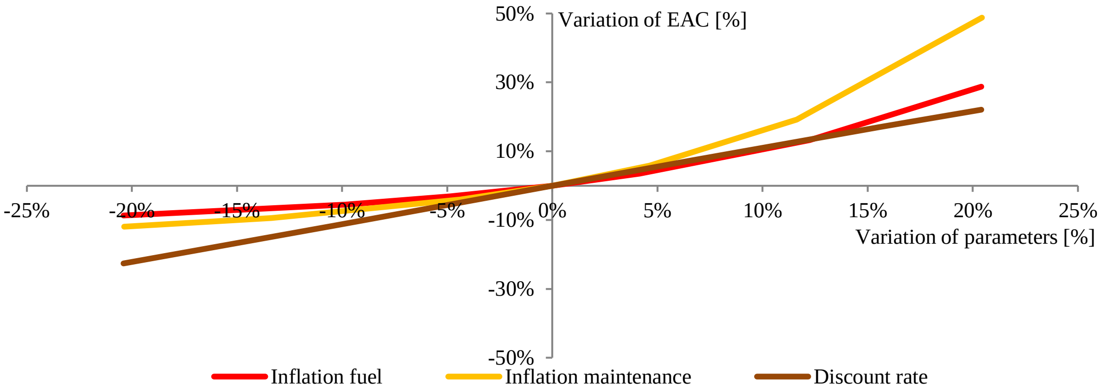

Figure 9 – Sensitivity analysis on average collection vehicle

iii) LCC detailed analysis

The LCC of each vehicle in all waste collection services was calculated, however due to space limitations only an average cost distribution with time is presented in Figure 10.

The evolution of costs and indicators over the years is similar between the vehicles of the different collection services. In first 5 years of the vehicle's life, costs are superior due to the annual value paid for amortization. After these initial years, there is a decrease in annual costs since there are only maintenance and operation costs. As the vehicles approach their end-of-life, the costs increase motivated by the increase in the maintenance costs. The need for extensive repairs and severe breakdowns determine the end of economic life of the vehicles, but the policy in Cascais Ambiente is to replace before these events to avoid the indirect costs due to service disruption.

The main differentiating factors between the vehicles of the various waste collection services are the costs magnitude and the economic life length. The residual waste service vehicles present the shortest average life (average of 10 years) and the bulky waste service vehicles present the longest (average of 15 years). The differences are explained mostly by the intensity of the residual waste service that has two shifts of waste collection every day.

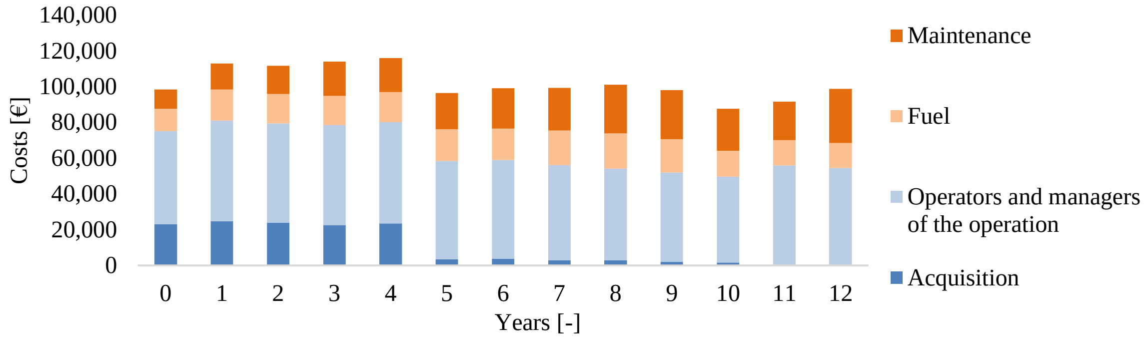

Figure 10 – Average evolution of vehicle costs

5. CONCLUSIONS

The LCC methodology presented is consistent with the European standard for buildings and includes contributions from other sources in the process of tailoring it for waste management context. Its application to the Cascais Ambiente case study allowed to test its applicability. Furthermore, the exercise of applying the methodology was used as a starting point for the certification of Cascais Ambiente waste collection service according to the ISO 55000. Furthermore, the exercise of capturing the detailed cost structure of the waste collection equipment LCC revealed improvement opportunities in the cost record system used, namely linking the maintenance costs with each vehicle.

The results presented constitute a baseline for directing the optimization efforts and for evaluating the performance of potential alternatives with a high level of detail. The collection vehicles represent the biggest parcel of costs with 92% of overall costs. Analysing the results further, it is possible to conclude that the most relevant phase of collection vehicles LCC cost is the operation, in particular the labour representing more than 50% of the LCC. The collection vehicles end-of-life was determined by their economic life, which was defined by the moment when the maintenance costs become higher than annual amortization value of the vehicle. Additionally, the LCC of the various waste collection services (residual, segregated, garden and bulk) are also different and their raking changes depending on the indicator used (€; €/vehicle; €/ton.; €/km). The garden waste collection is the service with the highest EAC, which can be explained by the number of operators required, but is only the third in cost per weight of waste collected, due to the high amount of waste collected. The fact of using some of the oldest vehicles has also some impact due to the inflation of the acquisition cost based on the discount rate used. Despite operating only in a fraction of the Cascais Municipality territory, residual collection constitutes the service that collect the highest amount of waste. Thus, an intensive service with high cost but resulting in the lowest cost per weight.

Future work will involve increasing the accuracy of the estimates at a vehicle level in order to identify and understand the determinants underlying the differences between the collection services and between the vehicles within each service. Also, the results revealed a higher cost with the segregate waste collection compared with the residual waste collection. A scale effect may explain part of the difference, because the existing infrastructure and resources are capable of managing higher amounts of segregate waste. An analysis including collection and treatment and evaluating also the environmental component (through a LCA) are required to correctly compare residual and segregate waste collection performance. Another topic of improvement is the definition of the end-of-life of the equipment. Containers annual replacement data will be used to estimate their durability and the indirect costs due to vehicles breakdown and service disruption should be included in the vehicles replacement decision.

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