Benchmarking operational efficiency in waste collection: Discussion of current approaches and possible alternatives

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Abstract

Purpose: Identify an unbiased performance indicator able to benchmark the degree of optimization of the waste collection service independently to the context.

Methods: review and comment the literature in waste collection service efficiency assessment and benchmarking, in particular for the Portuguese context. The main group of tools reviewed are performance indicators and statistical approaches

Results: proposal and discussion of complementary / alternative absolute and unbiased performance indicators for assessing the operational and service efficiency. The proposed performance indicators were developed considering the framework of the Portuguese regulatory performance indicators system for the waste sector.

Conclusions: most tools are useful to evaluate waste collection performance in absolute terms or track the performance evolution of a utility on time, but for benchmarking purposes the majority is affected by the context in which the utility operates. So, an absolute and almost unbiased performance indicator is proposed for benchmarking operational efficiency of waste collection utilities, collection capacity use (CCU), and performance indicator alternative to percentage of segregate waste collection, segregate waste collection efficiency (SWE), is proposed for benchmarking service efficiency of waste collection utilities.

Keywords: waste collection, operational efficiency, benchmark, performance indicators.

1. Introduction

At a local and region level, waste collection service tends to be a natural monopoly. In practice, despite the possible competition at a national or international level, the common residential waste producer does not have alternative service providers. Furthermore, even the existing competition does not take place on a daily basis since in the cases where the service providers are private the concessions are usually multi-

year contracts. Within this context, assessing efficiency in the waste collection service and benchmarking the utilities performance is a need for the various interested parties, in particular the service regulators, the municipalities, the governments and the public in general.

The two most common approaches to assess efficiency and benchmark performance in waste collection resort to: i) performance indicators systems; or ii) statistical approaches. Depending on the level of development, the former may provide a multidimensional holistic overview of the waste collection service covering economic, environmental and social aspects. Statistical approaches allow assessing the empirical relation between various factors and the performance of the waste management for a particular aspect or group of aspects. The present communication reviews the international use of both approaches and discusses their benefits/advantages and limitations/disadvantages. Taking the Portuguese context as a case study, where the use of performance indicators has been adopted by the waste management regulator (*Entidade Reguladora dos Serviços de Água e Resíduos* - ERSAR), possible alternatives to enhance a more accurate operational efficiency assessment in the waste collection services are proposed, discussed and compared. A particular emphasis will be given to the development of an indicator translating the degree of collection service optimization that is mostly universal and context independent.

2. Literature Review

Performance indicators are one of the most widely used approaches to assess efficiency not only in the waste sector, but also in other sectors (e.g., water – IWA 2016; transportation – Black et al. 2002). The European Environment Agency (EEA 1999, 2003) defines an indicator as an elementary datum or a simple combination of data capable of measuring an observed phenomenon. Regarding the waste sector, several authors have proposed performance indicators (Table 1). Sanjeevi and Shaabudeen (2015) and Zaman (2014) present reviews on the development of performance indicators for the waste sector.

Table 1 – Performance indicator proposed for assessing performance in the waste sector

Author	Indicators	Scope	Context / Application
Cailean and Teodosiu 2016	18	Environmental / Waste management	National - Romania
Teixeira and Neves 2009	167	Global / Waste management	National - Portugal
Desmond 2006	13	Global / Waste management	International - Europe
Teixeira et al. 2014	3	Operational / Waste collection	Regional - Portugal
Bertanza et al. 2018	13	Operational / Waste collection	Regional - Italy
Ferreira et al. 2017	3	Operational / Waste collection	National - Portugal
Vivanco et al. 2012	2	Service / Waste management	Regional - Spain
Passarini et al. 2011	1	Service / waste collection	Regional - Italy
Dahlén et al. 2007	7	Service / Waste collection	Regional - Sweden
Gallardo et al. 2010	5	Operational / Waste collection	Regional – Spain
Karagiannidis et al. 2004	4	Service / Waste collection	Regional - Greece
Huang et al. 2011	5	Service / Waste collection	National - Taiwan
Greene and Tonjes 2014	11	Service / Waste management	Regional – New York
Rigamonti et al. 2016	3	Environmental / Waste management	Regional - Italy

Performance indicators are flexible and easy to interpret, allowing covering a wide range of vectors related to waste management and to convey a message clearly to both informed and less-informed interested parties. Regardless of the distinctions in terms of number, nature, scope and context of the various sets of indicators developed/proposed, they are useful to track the waste management performance evolution in time or against some goal/target. In fact, performance indicators have been used to monitor the effect of policy measures, such as the core set of indicators collected by the Eurostat (e.g., WST 004 - Waste generation, WST 005 - Waste recycling, WST 006 - Diversion of waste from landfill).

A significant limitation of the performance indicators is that they are unidimensional measurements of multidimensional realities. Consequently, the applicability of the majority of these indicators to compare management performance of a waste utility is affected by its context. For instance, segregated waste collection performance may be influenced by management decisions (e.g., infrastructures, type of collection service, education campaigns), individuals' behavior (e.g., awareness and waste separation habits), socio, cultural and economic context (e.g., economic activities, consumption and waste production) and political, legal/regulatory and resources limitations (e.g., pricing system allowed). Some of these context related issues are outside of the waste management utility control, limiting the interpretation and conclusion of the benchmark.

In the scope of waste management performance assessment and benchmarking, the statistical approaches can be divided into two groups: i) regression models; and ii) econometric models. Regression models include the common Ordinary Least Squares (OLS) regression as well as other approaches (e.g., non-parametric regression, logistic regression). Table 2 present some studies using regression models to assess waste management performance and the variables considered. Regression models estimate the "average" performance, so when the identification of the maximum (e.g., amount of waste collected) or minimum (e.g., cost per amount of waste collected) performance is of interest econometric models come into play. Some of the most common tools in this group of models are the parametric stochastic frontier analysis (SFA - stochastic) and the non-parametric data envelopment analysis (DEA - deterministic) or Partial Frontier Analysis (PFA - stochastic). Econometric models focus on efficiency, seeking to relate the optimum output with various context and service related variables (Table 3).

Table 2 – Regression models developed for assessing performance in the waste sector

	Bel and Fageda 2010	Plata-Díaz et al. 2014	Greco et al. 2015	Lombrano 2009
INPUTS[1]				
Demographics				
Percentage of non-residential customers			X	
Population served		X	X	X
Population density			X	
Land				
Location			X	
Area			X	
Topography			X	
Service				
Ownership	X		X	
Waste treatment / disposal	X			X
Service Cost		X		
Waste collected	X		X	X
Staff	X		X	
Collection method				X
Collection frequency	X			
Vehicles			X	
Shifts			X	
Other				
Tourism flows	X			
Fiscal stress		X		
Infrastructure quality		X		
Political aspects		X		
OUTPUT	Cost	Management model	Cost	Cost
REGION	Galicia (Spain)	Spain	Italy	Italy
SAMPLE	65	685	67	18
MODEL	OLS Regression	Logistic regression	OLS / Robust Regression	OLS Regression

1 Each input category may be represented by more than one independent variable in the model

Table 3 – Econometric models developed for assessing performance in the waste sector

	Marques and Simões 2009	Simões et al. 2010	Simões et al. 2012b	Rogge and De Jaeger 2012	Rogge and De Jaeger 2013	Carvalho and Marques 2014	Pérez-López et al. 2016	Guerrini et al. 2017	Sarra et al. 2017
EXOGENOUS FACTORS									
Demographics									
Percentage of non-residential customers								X	
Population served						X		X	
Population density	X	X						X	
Population dispersion									X
Population demographics					X				
Average household size								X	
Land									
Elevation									X
Area						X			X
Wealth									
Income					X				X
Gross Domestic Product	X	X				X			
Service									
Regulation		X				X			
Ownership		X							
Management model						X	X		
Composting		X							
Incineration		X							
Distance to landfill	X								
Distance to treatment facility		X							
No. of years with curbside collection								X	
Collection method								X	
Collection frequency					X				
Tons of waste collected per load								X	
Pricing method					X				
Other									
Road length									X
Tourism flows								X	X
INPUTS									
Service quality							X		
Service Cost	X	X		X	X	X		X	X
Waste collected composition						X			
Staff			X						
No. of containers						X	X		
Vehicles			X						
OUTPUT	Treated waste	Treated and recycled waste	Waste	Waste fractions	Waste fractions	Separated waste	Cost	Recycled and residual waste	Separated and unsorted waste
REGION	Portugal	Portugal	Portugal	Belgium (Flanders)	Belgium (Flanders)	Portugal	Spain	Italy (Verona)	Italy (Abruzzo)
DMU	29	29	196	293	293	37	771	40	289
Model	DEA	DEA	DEA	DEA	DEA	SFA	PFA	PFA	DEA

Contrarily to performance indicators, statistical model allows context variables in the performance assessment. For benchmarking purposes, this is useful since it provides a means to correct for context bias to some extent. This comes with a cost of complexity, making it more difficult to perform the analysis, interpret some of the results and understand the effective contribution of each input to the output. There may also exist some mathematical issues arising from the sample used (e.g., presence of outliers, heterogeneity of the sample regarding the various explanatory variables considered), the explanatory variables considered (e.g., correlation between explanatory variables) or the mathematical structure (e.g., the model may not be a linear combination of the explanatory variables), amongst others. Consequently, the explanatory variable and mathematical structure will affect the results of the performance assessment. More importantly, statistical approaches report relative and not absolute performance. The performance rating of a waste management utility will depend on the performance of the remaining utilities used in the sample, making it is impossible to know if they are optimal or just the best.

3. The Portuguese System

The Portuguese urban waste sector is divided spatially (municipalities and regions) and functionally (collection and final destination), resulting in a universe of 282 public utilities operating in 2015. In terms of function, there are 259 utilities responsible for waste collection (retail services), usually at a municipality level, and 23 responsible for waste treatment and disposable (bulk services), serving several municipalities. This division resulted in advantages in terms of economies of scale, particularly for the waste disposal, but implied losses in process economies (ERSAR 2016). In addition, the Law n.º 88-A/97, of 25 of July (changed by the Law n.º 35/2013, of 11 of June), set the rules for the private participation in waste management, allowing it through concession contracts with the State or the municipalities. As a result, the existing utilities vary in the degrees of public and private participation and operate in a very wide range of contexts due to variability of the Portuguese territory in terms of population and wealth distribution, topography, infrastructures network, size, land use and main commercial activities of each region, and the culture, behavior and demography of the individuals.

Given the diversity of the waste sector operators and the fact that these services are natural monopolies along with the ever increasing performance demand from the various stockholders, a service regulator (ERSAR) for water and urban waste services was created. Its main goal is the protection of waste sector clients (the public) interests by assessing and promoting the quality of the service provided by the operators. In operational terms, the ERSAR regulatory action has two main vectors, technical and financial. The technical regulation covers the service provided and is based on a set of service quality data and indicators that the utilities have to report yearly. Different goals were set for evaluating the service quality depending if the area covered by the utilities is mainly rural, balanced or mainly urban. The utilities are also required to provide a detailed yearly financial report to ERSAR relating to the service quality data and indicators. The financial report has a detailed record of the acquisition, depreciation and main investments for each asset, but the remaining life cycle costs are recorded as a total sum by cost category (e.g., insurances; fuel; electricity; cleaning, hygiene and comfort; conservation and repair; labor).

The service quality data and performance indicators system developed by ERSAR are presented in Tables 4 and 5, respectively (ERSAR 2013). The information requested is classified according to the performance report categories defined by the ISO 55001:2014. The evaluation of the asset management system provided by the set of data and indicators is limited to the existence of certification. There is still a monitoring gap at the level of the asset management policy or the strategic asset management plan, as well as regarding other key elements of an asset management system.

Table 4 – Service quality data relation to monitoring requirements of ISO 55001:2014

DATA		PERFORMANCE		
		Asset	**Management**	**System**
Identification				
dRU01ab	Identification of the utility			
dRU02ab	Governance model		X	
dRU03b	System user			
dRU04ab	Type of area			
dRU05ab	Shareholders positions			
dRU06ab	Contract period			
Households				
dRU07b	Households with waste collection		X	
dRU08ab	Households with selective waste collection		X	
dRU09ab	Existing households			
Complaints				
dRU10ab	Complaints and suggestions		X	x
dRU11ab	Replies to complaints and suggestions		X	x
Waste amount				
dRU12ab	Total waste collected		X	
dRU16ab	Packages selectively collected		X	
dRU17b	Waste collected conveyed for recycling		X	
dRU24b	Unseparated waste collected		X	
dRU26b	Package collection goal		X	
Vehicles, equipment and their use				
dRU28ab	Distance covered by the vehicles	X	x	
dRU29ab	Number of waste collection vehicles	X		
dRU30b	Installed waste collection vehicles capacity	X		
dRU31ab	Waste collection vehicles CO2 emissions	x	X	
dRU32ab	Number of containers washed	X	x	
dRU33ab	Number of containers	X		
Energy				
dRU36b	Fuel consumed	x	X	
Economy				
dRU39b	Average cost of the waste management service		X	
dRU40ab	Average family income			
dRU41ab	Total revenue			
dRU42ab	Total expenditure		X	
Human resources				
dRU44ab	Waste management service in-house personnel		X	
dRU45ab	Waste management service outsourcing personnel		X	
Infrastructures				
dRU46ab	Number of ecopoints (i.e. bring-banks)	X		
dRU47ab	Number of ecocenters	X		
dRU52ab	Number of transfer stations	X		
dRU54b	Installed container capacity	X		
Certifications				
dRU55ab	Environmental management system certification			X
dRU56ab	Quality management system certification			X
dRU57ab	Health and safety management system certification			X
dRU58ab	Other certification			X

Analysing the performance indicators listed in Table 5 it is possible to conclude that they are all context dependent. For instance, in terms of management (service) performance, the service coverage is not independent from the cost of the service (affecting the affordability and coverage of total costs) and will be affected by how the population is distributed over the territory. One should bear in mind that the population density used in several statistical approaches is not a good indicator. In fact, the population density of two regions may be the same and in one case the population is all located in few cities living mostly in multifamily buildings while in the other the population is spread all over the region in single-family houses. These two scenarios will demand very distinct efforts in terms of infrastructure for the same coverage (measured by distance of the houses to the waste collection points) and also in terms of

the distance required to cover by the waste collection vehicles. In addition to the population distribution, the energy use and gas emissions will also be affected by the topography and the roads characteristics.

Table 5 - Service quality indicators link to monitoring requirements of ISO 55001:2014

INDICATOR		DATA	PERFORMANCE		
			Assets	Management	System
Costumer relation adequacy					
Service accessibility					
RU01b	Service coverage	dRU07b / dRU09ab		X	
RU02ab	Selective collection coverage	dRU08ab / dRU09ab		X	
RU03b	Affordability to the service	dRU39a / dRU40ab			
Service Quality					
RU04ab	Waste containers cleaning	dRU32ab / dRU33ab	X		
RU05ab	Replies to written complaints	dRU11ab / dRU10ab		X	x
Service Sustainability					
Economic					
RU06ab	Coverage of total costs	dRU41ab / dRU42ab		X	
Infrastructure					
RU07b	Waste packaging recycling	dRU16ab / dRU26b		X	
RU11ab	Waste collection vehicles renewal	dRU28ab / dRU29ab	x	X	
RU12b	Waste collection vehicles efficient use	dRU24b / dRU30b	x	X	
Human resources production					
RU13b	Adequacy of human resources	(dRU44ab + dRU45ab) / dRU12ab		X	
Environmental sustainability					
Natural resources use efficiency					
RU14b	Efficient energy use	dRU36b / dRU24b	x	X	
Pollution prevention					
RU16b	Greenhouse gas emissions	dRU31ab / dRU24b	x	X	

Despite the focus of the discussion presented herein on the regulatory performance indicators defined by ERSAR for the Portuguese waste sector, the same arguments apply to the majority of the performance indicators proposed in the literature.

4. Proposed Performance Indicators

In order to assess the management performance in terms of the level of spatial optimization of the collection service we propose using a new indicator, the collection capacity use (CCU), given by:

$$CCU = \frac{WaC}{WCC} \quad (1)$$

where, WaC is the waste collected; and WCC is the waste collection capacity. The waste collected is the amount of waste collected in a period of time. Usually the period of time for reporting purposes in most contexts is 1 year, but others can also be used. The waste collection capacity is given by the capacity of the waste collection vehicles multiplied by the number of discharges in the transfer station, waste treatment plant or landfill, depending on the system configuration. The indicator can be calculated for each type of waste stream individually or for the total waste collection service. Depending on the waste stream, the WaC and WCC may be in volume or weight, depending on which is the limiting unit for the waste collection vehicles. Considering the capacity of the waste collection vehicles usually used and the waste characteristics in Portugal, for low density waste (e.g., packaging) the volume limits the capacity of the waste collection vehicles, whereas for high density waste (e.g. glass) the weight may become the limiting factor.

If the same units are used for WaC and WCC (volume or weight), the CCU is an absolute and almost unbiased indicator ranging from 0 to 1. It is absolute indicator in the sense that the performance rating of

an utility can be assessed directly and not in comparison with others. In fact, a value of CCU=1 will always indicate that the collection routes and frequency balance perfectly the waste produced with the capacity of the waste collection vehicles. For instance, indicators such as greenhouse gas emissions used by ERSAR do not share this property because it is possible to identify if the performance is better or worse in relative terms, but it is impossible to know if it is the best achievable performance. It is also an almost unbiased indicator since there can may exist different combinations of waste collection vehicles capacity and routes/frequency leading to the same CCU, but the indicator is insensible to any other context or service variables.

In addition to CCU, the segregate waste collection efficiency (SWE) is another indicator proposed in this work to assess the environmental performance of the collection service (as an alternative to the usual segregate waste collection percentage), given by:

$$SWE = \frac{SWC}{SWC + SWM} \quad (2)$$

where SWC is the amount of segregate waste collected; and SWM is the amount of waste that could be source-segregated but is currently disposed as unsorted waste. As before, the amount of segregate waste collected reports to a defined period of time, usually 1 year. The indicator can be calculated globally or for each segregated waste stream individually and requires the evaluation of the unsorted waste composition periodically. However, it is an absolute indicator (a value of 1 means that all waste possible to collect separately is conveyed to the segregate collection) and is unbiased to the differences in waste composition between regions.

5. Conclusions

Performance assessment in the waste sector has been carried out resorting to performance indicators and statistical approaches. The later include regression and econometric models and enable the evaluation of the performance in a single output considering the complexity of the context. However, they provide a relative performance assessment, difficult to perform and to interpret for less-informed interested parties. Performance indicators tend to be used in practice more often due to their simplicity in terms of both calculation and interpretation and the flexibility to cover a wide range of vectors of interest (e.g., economic, environmental, social). However, they tend to lack the capability of providing context independent performance evaluations. As such, benchmarking utilities operating in a strict regulatory framework but with variable regional and local contexts, such as the Portuguese case, results in a biased assessment.

The present communication provides a set of complementary / alternative indicators, the collection capacity use (CCU) and the segregate waste collection efficiency (SWE), that could be used to better assess the performance of the waste collection services in terms of operational and service efficiency. The indicators proposed were developed considering the Portuguese regulatory performance indicators system, but are possible to apply universally. Also, the information required for their calculation is not difficult to obtain.

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