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# Techno-economic performance indicators of municipal solid waste collection strategies

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ABSTRACT

Several indicators for the evaluation of the MSW collection systems have been proposed in the literature. These evaluation tools consider only some of the aspects that influence the operational efficiency of the collection service. The aim of this paper is to suggest a set of (easy to calculate) indicators that overcomes this limitation, taking into account both the characteristics of collected waste and the operational - economic performance. The main components of the collection system (labour, vehicles and containers) are separately considered so that it is possible to quantify and compare their role within the whole process. As an example of application, the proposed approach was used for comparing the MSW collection strategies adopted in four towns in Northern Italy. Results are discussed and a comparison with alternative assessment methods available in the scientific literature is reported.



## 1. Introduction

Municipal Solid Waste (MSW) management consists of several activities including: collection, transportation, treatment, material and energy recovery, and disposal, that must be addressed in accordance with the priorities agreed by the European Union (EU) Waste Framework Directive 2008/98/CE (European Parliament and Council, 2008).

For the assessment of MSW management strategies and systems as a whole (e.g. type, number and location of facilities), the multi parameter approach has been frequently adopted. Standardized methods are available, such as Life Cycle Assessment, Life Cycle Costing, Cost-Benefit Analysis, Risk Assessment, Eco-Efficiency analysis, Social Life Cycle Cost (Allesch and Brunner, 2014). This shows that, for the optimization of the overall system (from collection to ultimate disposal) a number of aspects (operational, economic, environmental and social) should be considered. The application of these methodologies requires large databases assembly, systematic data collection and processing procedures (Teixeira et al., 2014). Frequently, the lack of detailed data requires that specific analytical campaigns are carried out or assumptions are made.

Instead, for the techno-economic optimization of single phases of the MSW management system (such as waste collection), a more practice-oriented analysis may be preferable: as pointed out by Gallardo et al. (2015), when either designing a new collection system or tuning an existing one, several markedly site-specific techno-economic factors should be taken into account. For this reason, numerous indicators that consider operational and economic aspects have been proposed in the literature (see Section 2). This demonstrates that waste collection is recognized to play a crucial role in that it influences the subsequent operations of reuse, recycling and disposal and having the most significant cost impact on the whole waste management process, generally accounting for a percentage ranging between 50 and 70% (Nguyen and Wilson, 2010; Tchobanoglous and Kreith, 2010).

MSW collection can be operated in several ways, in short attributable to the following methods: drop-off (bring) collection and door-to-door collection, mixed systems being also often adopted (Seyring et al., 2016): there is not a unique universal model valid for all towns and cities. As mentioned above, the evaluation/comparison of collection strategies can be profitably based on the analysis of specific techno-economic data. An important aspect is that this kind of information is easily accessible and reliable, being attainable from common monitoring protocols of real applications, carried out by local authorities (Lebersorger and Beigl, 2011). Simple efficiency indicators can be calculated and used for comparing different strategies in an objective way (Teixeira et al., 2014b). However, techno-economic indicators proposed in the scientific literature only focus on some aspects (i.e. either the quantity of waste, or the type of equipment, or the labour required, etc.), giving a partial view of the investigated scenario.

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The objective of this paper is to propose a set of indicators which are, at the same time, comprehensive of the many factors involved, and easy to be obtained/calculated. For testing the suitability of the proposed approach, this was used for assessing and comparing the collection strategies adopted in four towns in the North of Italy.

## 2. A selection of performance indicators of MSW collection systems reported in the literature

In this work the authors focused on the waste collection, instead of the whole MSW management system (as done for instance in Simões and Marques, 2012; Laurent et al., 2014; Achillas et al., 2013; Soltani et al., 2015). A literature review was then conducted in order to identify the techno-economic indicators used for evaluating the operational and economic performance of collection strategies, from the view point of the service manager. Only the assessment methods based on simple techno-economic indicators were addressed; in particular those that can be obtained by data and information commonly available in the databases of municipalities and waste management companies. On the contrary, the studies mainly focused on the social (e.g. employment and labour markets, communication, participation and perception of the population) and environmental impacts (Abdelli et al., 2016; Larsen et al., 2009; Lolli et al., 2016) were not considered. Furthermore, assessment tools based on approaches such as Life Cycle Assessment (Bernstad et al., 2011; Iriarte et al., 2009; Liu et al., 2017; Perez et al., 2017; Rives et al., 2010; Yıldız-Geyhan et al., 2016), Cost Benefit Analysis (Feng et al., 2009) and on non-parametric approaches such as Data Enveloped Analysis (De Jaeger and Rogge, 2014; Rogge and De Jaeger, 2013) were disregarded. These procedures are usually characterized by complex computational processes, are time and resource intensive and require a large amount of data with a low level of uncertainty (Greene and Tonjes, 2014), that makes them unsuitable for the aim of the present study.

Interest in techno-economic performance indicators for MSW collection is long standing. In some case studies, the collection systems were compared using only simple key indicators, as the annual collection rate and the rate of separate collection (Ağdağ, 2009; Chung and Poon, 1998; Passarini et al., 2011). An assessment tool that considers only these indicators, however, is incomplete. For this reason, more complete evaluation methods including operational, technical and economic aspects were proposed. Dahlén et al. (2007) suggested an assessment approach based on the description of waste material flow and the composition of residual waste. The residual waste produced by six municipalities in southern Sweden was divided into four categories: dry recyclables (newsprint and packaging materials), biodegradable, combustibles, and inorganics. The different collection systems were evaluated using the following six indicators: (1) source sorting ratio, (2) specific waste generation rate, (3) ratio of dry recyclables in the residual waste, (4) ratio of biodegradable matter in the residual waste, (5) ratio of remaining combustibles in the residual waste (recyclable and bio-waste excluded), and (6) ratio of remaining inorganics in the residual waste (recyclable excluded). Similarly, Gallardo et al. (2010) proposed four indicators that describe the quality and quantity of collected MSW: annual collection rate (ACR), fractioning rate (FR), separation rate (SR), and quality in container rate (QCR). Dalla Zanna and Fernandes (2013) suggested a set of indicators based on previous division of household waste into three categories: recyclable (rec), refuse (rej) and organics (org). The proposed indicators are the following: mean daily mass collected, collection composition, selective collection deflection (DC), selective collection effectiveness indicator (SWEI). DC is the amount of a specific type of waste that was introduced in the wrong collection container. The SWEI summarizes the previous indicator, calculated for each waste category, in one single score (1):

$$SWEI = \frac{3 - DCorg - DCrec - DCrej}{3} \quad (1)$$

The solid waste collection costs are influenced by multiple factors: the municipality's features (i.e. the size and density of the population), the characteristics of the area where the activity is being carried out (distances, altitude, roads network), the quantity and quality of the solid waste collected, the technical arrangements used (Greco et al., 2014). For including some of these aspects in the assessment, many studies suggest efficiency indices that consider also the economic performance. Gamberini et al. (2009) suggested a set of indicators for the evaluation of the operational efficiency of the collection service. These indicators consider the performance of vehicles, operators and bins. The proposed indices are: Indicator $R_{d\%}$ (percentage of recyclable collected waste), Indicator $Q_v$ (quantity of waste collected per hour of used vehicles), Indicator $Q_{op}$ (quantity of waste collected per hour of required operators), Indicator $T_b$ (time spent for collecting each bin), Indicator $Q_b$ (average quantity of waste collected in each container). For taking into account also the costs generated by the service, these indicators were subsequently integrated with the following indices (Gamberini et al., 2013): Indicator 5 (annual amount of collected waste per inhabitant), Indicator 6 (incidence of selective collection respect to the whole set of collected waste), Indicator 7 (annual cost for waste management). Karagiannidis et al. (2004) proposed a set of four indicators that consider both operational and economic aspects. The performance of collection services was evaluated with the following indicators: Indicator A (quantity of MSW collected per collection hour), Indicator B (number of served households per collection hour), Indicator C (collection cost per unit mass of collected waste), Indicator D (collection cost per served household in a time period). Huang et al. (2011) suggested an aggregate indicator (AI) to assess the MSW collection efficiency based on multiple factors. The five selected Key Performance Indicators (KPIs) are: Cost-MQ (cost per unit volume of MSW collected), MQ-Time (quantity of MSW collected per unit collection time), MQ-Veh (quantity of MSW collected per collection vehicle), SP-Collector (the population served per collector), MQ-Mile (quantity of MSW collected per vehicle-mile covered). The five KPIs must be aggregated into an AI for assessing the MSW collection performance.

Transportation is the stage with the most significant impact on the MSW collection cost (Teixeira et al., 2014b). Radoičić and Radisavljević (2011) proposed a set of indicators for evaluating the performance of waste transportation that considers the fuel consumption, the distance covered and the travel time. The suggested indicators are: quantity of MSW collected per consumed amount of fuel, quantity of MSW collected per travelled distance, quantity of MSW collected per vehicle-hour.

Although the approaches proposed in the above studies are interesting and respond to the specific aim they were developed for, they do not allow a comprehensive assessment of the waste collection strategy from the viewpoint of the service manager. In fact, the indicators proposed by Dahlén et al. (2007), Gallardo et al. (2010) and Dalla Zanna and Fernandes (2013) are focused only on the characterization of collected waste, whereas the approaches suggested by Karagiannidis et al. (2004), Huang et al. (2011) and Gamberini et al. (2009) consider only operational and economic performance of the service. An assessment tool based only on the description of quantity and quality of material flows fails to take into account the efficiency of technologies used for reaching the final result; vice versa, by considering only the techno-economic performance, the results obtained cannot be related to the characteristics of the collected materials. Moreover,