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The application of life cycle assessment (LCA) in municipal solid waste management: A comparative study on street sweeping services

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ABSTRACT

Street sweeping services are integral to municipal solid waste management systems. The environmental impact of municipal solid waste management has been widely debated in the literature, but the specific impact of street sweeping services has not been fully studied. The aim of this study is to fill this literature gap by applying the life cycle assessment (LCA) methodology to compare the effects of different types of street sweeping services provided in two medium-sized Italian cities. The results show that fuel consumption is by far the largest contributor in all environmental impact categories, followed by the material consumption of the equipment. The study provides managerial and policy implications. The results can enable managers to lessen the environmental impact of sweeping services, and the findings can be applied by policy makers through Green Public Procurement procedures.

1. Introduction

Life cycle assessment (LCA) methodology has been used to assess the environmental impact of products and services in many different sectors, including municipal solid waste management (Geng et al., 2010; Yay, 2015). LCA enables a comparison of different management systems in the sector and, through the identification of the most impactful phases, to provide suggestions for improving environmental performance. Comparative LCA studies of alternative municipal solid waste management systems in the literature include using LCA to compare street and door-to-door waste collection systems (Gilardino et al., 2017) and a comparison of the environmental effects of incineration and landfill as waste disposal scenarios (Nabavi-Pelesaraei et al., 2017).

Street sweeping is an integral part of urban hygiene services and, consequently, of the municipal solid waste management (MSWM) system. In this framework, the service can be considered environmentally relevant from both positive and negative perspectives. On one side, studies have focused on the positive environmental impact of the service, with authors highlighting how it could reduce dust emissions from paved roads and thus contribute to better air quality in urban settings, in terms of concentration of particulate matter (Amato et al., 2010; Karanasiou et al., 2012). On the other side, probably we cannot retain to it as a service with high environmental impact. However, considering how widespread and frequent the service is in most large and medium cities worldwide, its cumulative environmental impact may be particularly significant.

Although scholars have widely discussed the application of LCA to different services in the field of MSWM, few analyses of the environmental impacts of street sweeping services can be found in the academic literature. To the best of our knowledge, no scholars have to date assessed this service by taking an LCA approach. The justification to adopt a LCA perspective in the assessment of this service is also related to the fact that street sweeping is usually assigned through public tenders. Previous scholars in the field of Green Public Procurement (GPP) highlighted that the environmental requirements of public tenders are too often focused on the adoption of an environmental certification of the service provider more than the inclusion of "technical specifications" linked with the most pollutant phase or materials used in the service (Testa et al., 2012).

To fill this gap in the literature, the aim of this study is to apply LCA to a street sweeping service, identify the phases that have the most impact on the environment, and to quantify this impact. We present a comparative case study of the sweeping services in to two

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medium-sized Italian cities: Pisa and Livorno. Although these are similar to many other cities in Italy, the case study is not intended to be representative of all Italian urban contexts. The research allows us to highlight similarities and differences between the environmental impacts of the two street services and identify their strengths and weaknesses. The paper proceeds as follows. The next section briefly illustrates previous studies in the literature. Section 3 describes the applied methodology in conducting the LCA analysis. In Section 4 the results are outlined and discussed. The last section summarizes the main findings of the study.

2. Literature review

2.1. LCA and municipal solid waste management

LCA can be applied in many areas of waste management, as it is able to consider the whole life cycle – and each single phase – of alternative systems, and the related environmental impacts (Ghose et al., 2017; Daddi et al., 2017). The extensive literature concerning LCA confirms it to be a valid instrument for supporting decisions and investments in municipal solid waste management (MSWM) systems (Rigamonti et al., 2010). As Dong et al. (2014) illustrated, LCA combined with a Life Cycle Costing (LCC) analysis can enable the most energy-efficient, environmentally friendly and economically affordable system to be chosen from three different MSW treatment technologies: landfill; landfill with biogas conversion to electricity; and incineration with energy recovery. Evangelisti et al. (2014) also used LCA to compare the environmental impacts of anaerobic digestion in energy and organic fertiliser production with two alternative approaches: incineration for energy production and landfill for electricity production.

Other authors have focused on the methodology of using LCA for integrated MSWM (Finnveden, 1999; Clift et al., 2000; Ekvall et al., 2007), or on the use of LCA as a tool for comparing different waste management systems and selecting the solution with the lowest environmental impact (Cherubini et al., 2009; Manfredi and Christensen, 2009; Iriarte et al., 2009; Zorpas, 2016).

LCA has been used as a tool to compare alternative MSWM systems in specific urban areas. For example, Mendes et al. (2004) used LCA to compare three incineration scenarios with different ash treatment systems in the city of São Paulo, Brazil, and two landfilling scenarios, with and without energy recovery. They concluded that incineration with ash disposal in a landfill site has the lowest impact value of all categories.

According to Buttol et al. (2007), LCA is not widely used as a tool in the planning of integrated MSWM in Italy, but they demonstrated its potential by applying it to a case study of Bologna District, in which it supported the development of a new waste management plan. Similarly, Liamsanguan and Gheewala (2008) utilized a life cycle perspective to compare two methods used for MSWM in Phuket, a province of Thailand: landfilling without energy recovery and incineration with energy recovery. Their results, which were focused on energy consumption and greenhouse gas emission, demonstrated that incineration performed better. LCA has also been used to compare alternative scenarios in the field of MSWM (Zhao et al., 2009; Erses Yay, 2015; Liu et al., 2017).

The environmental impact of food waste has recently been evaluated using LCA, enabling the most sustainable options to be identified (Righi et al., 2013; Abeliotis et al., 2016; Brancoli et al., 2017; Zorpas et al., 2018). The anaerobic co-digestion of dewatered sewage sludge in small plants and home composting were found to be most effective. In other studies LCA has been applied to waste water treatments, to quantify and compare their environmental impact, and to identify potential methods of improvement (Ortiz et al., 2007; Pasqualino et al., 2009). Focusing on waste collection activities, Pérez et al. (2017) applied LCA to compare the carbon footprints of waste collection vehicles under different scenarios, and revealed the impact of different fuels in MSWM vehicles on climate change.

2.2. Street sweeping waste service studies

Street sweeping waste services are generally examined from a technological point of view. One branch of the literature focuses on the service's effectiveness in reducing dust emissions, particularly concentrations of particulate matter, in urban areas through cleaning the roads, (Chow et al., 1990; Fitz and Bumiller, 2000; Tobin and Brinkmann, 2002). As mentioned in the introduction, these studies highlight the beneficial effect of street sweeping services on the air quality of urban areas, and their contributions to reductions in the emissions that originate from vehicles circulating on paved roads (Amato et al., 2010; Karanasiou et al., 2012).

Other studies deal with the technical features of street sweepers. Abdel-Wahab et al. (2011) conducted experimental tests to determine the ability of road sweeping gutter brushes to remove various debris types. Similarly, Vanegas-Useche et al. (2015) investigated the performances of two oscillatory gutter brushes in removing street sweeping waste, and Wang et al. (2015) developed a model to analyse brush deformation and predict brush characteristics with the aim of improving sweeping efficiency and assisting the controller design. Besides focusing on technological aspects, few studies address the environmental impacts of street sweeping waste services. The pollutants in the waste collected by the service have been analysed (Jang et al., 2009) and possible waste recovery actions have been explored (Zamhöfer and Schmidt, 2001). This review of the theoretical framework highlights that although LCA is widely used in the field of municipal waste management studies, the literature still lacks research into the overall environmental impact of street sweeping waste services, and no authors have studied the service with an LCA approach.

3. Method

As defined by the International Organization for Standardization, LCA is a methodology to better understand and assess the potential environmental impacts associated with a product or a service throughout its life cycle. The International Standards EN ISO 14040-14044 of 2006 require a definition of the functional unit and system boundaries (goal and scope definition), an input-output inventory (inventory analysis), an evaluation of the associated potential impacts (impact assessment) and ultimately an explanation of the results (impact interpretation) (EN ISO 14040-14044, 2006). Through LCA it is possible to compare different alternatives and guide companies and public institutions towards more environmentally sustainable decisions (Daddi et al., 2015). The results of LCA enable the most significant environmental indicators to be selected, which can then inform consumers by means of green marketing tools.

3.1. Case study profile: AVR street sweeping services in Pisa and Livorno

AVR is an Italian multitasking company operating in street maintenance and environmental sectors.

In the environmental sector, AVR provides MSWM integrated services. The main activities are separate waste collection, waste transportation, street sweeping and cleaning, and management of collection centres. In this case study we applied a life cycle