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A methodology for estimating the carbon footprint of waste collection vehicles under different scenarios: Application to Madrid

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ABSTRACT

This paper proposes a methodology to calculate the impact on climate change associated with the MSW collection and transport fleet, using the Life Cycle Assessment (LCA) methodology. The proposed methodological procedure was applied to the past and present situation in Spain, taking the city of Madrid as a characteristic example. The boundaries of the system include both the fuel life cycle (FLC) and the vehicle life cycle (VLC), the emissions for which are calculated using the GlobalTRANS tool developed at the Technical University of Madrid (UPM).

In the city of Madrid, MSW transport vehicles run solely on compressed natural gas (CNG). The fleet's carbon footprint (CF) is 25.1 kg CO_2 eq/$t_{MSWcollected}$, 92% of which stems from the FLC and the remaining 8% from the VLC. In terms of the FLC, 86% of the impact comes from the Tank-to-Wheel (TtW) stage and 14% from the Well-to-Tank (WtT) stage. The raw material extraction, manufacturing and transport processes account for 67% of total VLC greenhouse gas (GHG) emissions.

The situation in the city of Madrid in 2013 is compared to that in other Spanish cities and to past scenarios in Madrid, when vehicles ran on diesel. The DIESEL scenario yields emissions that are 18.5% higher than those of the CNG scenario, which means the CF would rise to 29.7 kg CO_2 eq/t_{MSW}. A possible future scenario where CNG is replaced by purified biogas from the anaerobic digestion of municipal waste (BIOGAS scenario) was also evaluated. In this case, CF is 92% lower.

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1. Introduction

One of the most challenging issues for building sustainable cities is the improvement of municipal solid waste (MSW) management (UNEP, 2015), which requires a substantial effort to reduce its production and improve its collection, transport and treatment systems (UN, 2013).

In Europe, the Waste Framework Directive (WFD) (EC, 2008) provides the general framework for MSW prevention and management. It specifies life cycle assessment (LCA) as a necessary policy-making tool, ensuring that impacts are assessed from cradle to grave, and avoids 'hiding' impacts by moving them to other countries or stages of production/consumption.

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The LCA methodology makes it possible to objectively, systematically and scientifically assess the environmental and human health impacts associated with a product or service (Finnveden et al., 2009; ISO, 2006a, 2006b). One of the environmental impacts evaluated is climate change (CC), in which greenhouse gas (GHG) emissions from the whole life cycle are calculated. A carbon footprint (ISO, 2013) study is designed when only the impact on climate change is considered.

MSWM is a key sector in the assessment of city's carbon footprint (BSI, 2013; WRI, 2014), in which all of its stages have to be considered (collection, including containerization, transport and final treatment). The transport stage is a relevant contributor to GHG emissions from MSWM (Bernstad and la Cour Jansen, 2012; Jaunich et al., 2016; Cleary, 2009). This contribution varies by the type of collection and transport system in place: pneumatic systems (Teerioja et al., 2012; Punkkinen et al., 2012) or conventional systems that rely on trucks (Erses Yay, 2015; Fernández-Nava et al., 2014; Fontaras et al., 2012; López et al., 2009; Maimoun et al., 2013; Rose et al., 2013; Sandhu et al., 2014). In the second case, the fuel used by collection vehicles has a significant influence on the carbon footprint (Jayaratne et al., 2010; López et al., 2009; Maimoun et al., 2013; Rose et al., 2013) and urban air quality (Fontaras et al., 2012; Lozhkina and Lozhkin, 2016; Sandhu et al., 2014; Suthawaree et al., 2012).

This paper presents a methodology for calculating the carbon footprint of a fleet of MSW collection and transport vehicles, and applies it to Spain. It also compares the current situation with other scenarios that are representative of past conditions in some cities, and others that could be commonplace in the near future. It does so by first analyzing the national situation in Spain and then considering the city of Madrid as a typical example. In Madrid, MSW collection and transport vehicles are part of the city's management fleets. GHG emissions from municipal fleets and their variation over time (Habib et al., 2013; Pastorello et al., 2011) have been conditioned by the policies and measures implemented at the local (AM, 2014d, 2012) and regional levels (CM, 2014, 2006; GC, 2012, 2008), where promoting the use of alternative fuels has been a priority. Therefore, the increased use of compressed natural gas (CNG), liquefied petroleum gases (LPG) and electric/hybrid technologies, rather than diesel, has succeeded in reducing the emissions from the taxi fleet (Vedrenne et al., 2014), municipal buses (García et al., 2012) and MSW collection vehicles (López et al., 2009).

The current situation in the city involves the use of trucks that consume CNG, as detailed in AM (2014a, 2015a, 2015b). In the past, the vehicles ran on diesel, as in other cities in Spain (Bovea et al., 2010; Fernández-Nava et al., 2014; Martínez-Blanco et al., 2010), in Europe (Al-Salem et al., 2014; Buratti et al., 2015; Erses Yay, 2015; Parkes et al., 2015; Yildiz-Geyhan et al., 2016), and in other continents (Maimoun et al., 2013; Rose et al., 2013; Vergara et al., 2011). And in the near future, they could run on purified biogas resulting from the anaerobic digestion of the organic fraction of the MSW (Budzianowski, 2016), as is the case in cities such as Berlin (BE, 2013). In addition to curbing the demand for fossil fuels, the use of biogas produced by the MSW itself is consistent with the concept of a circular economy, in which waste is leveraged as a resource. This is a central idea in Europe for coming years (EEA, 2016).

Unlike the approach taken in other studies (Erses Yay, 2015; Habib et al., 2013; Iriarte et al., 2009; Parkes et al., 2015), our calculation for the carbon footprint takes into account actual data from the vehicle fleet and its consumption, and is not based on average or generic data contained in LCA programs (GaBi, 2014; PRé, 2015). The main actual data are: number, type and weight of trucks, annual mileage, fuel consumption, mass of collected waste and specific WtT emission factor for each fuel consumed in Madrid City. We also considered the emissions associated both with the fuel life cycle (FLC) and the vehicle life cycle (VLC) to determine their respective contribution, as considered by Rose et al. (2013). VLC is not considered in a large number of studies, which only consider FLC (Erses Yay, 2015; Iriarte et al., 2009; Maimoun et al., 2013; Punkkinen et al., 2012). Those studies that take FLC into account primarily deal with the tank-to-wheel stage (TtW) (Al-Salem et al., 2014; Bovea et al., 2010; Buratti et al., 2015; Fernández-Nava et al., 2014; Habib et al., 2013; Parkes et al., 2015; Pastorello et al., 2011).

As presented in Gentil et al. (2010) and Laurent et al. (2014), the results of the LCA depend on local conditions, which is why this study includes a comparison with the results obtained by other authors for other geographic areas.

In summary, the main purpose of this work is to propose a simple methodology for the estimation of the carbon footprint of a fleet of waste collection vehicles which takes account of all the life cycle stages using actual data about the fleet, fuel consumption, journeys, and collected waste mass without the need of relying estimations or average data. The methodology will be validated for a specific case study with no previous precedents in literature for the city of Madrid (Spain), in which a comparison of a base case with two alternative scenarios is made: one reflecting a past situation and a future hypothetic one. This work will also highlight the importance of using data that reflects the local conditions as much as possible in LCA, by carrying out a comparison with other works.

2. Methodology

2.1. Case study

We conducted a review of the types of trucks and fuels used to collect and transport MSW in the main Spanish cities. According to INE (2015a), there are 44 cities in Spain (0.5% of all municipalities) with over 150,000 inhabitants, accounting for 35% of the national population. These cities, either directly or through the MSW management agencies of which they are a part, provide public information on their websites (checked over the course of 2015), which states that all of the trucks used to collect MSW are powered either by diesel or CNG.

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