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Impact of the pre-collection phase at different intensities of source segregation of bio-waste: An Italian case study

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ABSTRACT

The contribution of the N_2O and CH_4 emissions generated during pre-collection of the organic fraction of municipal solid waste was investigated for an existing Italian collection district in a life cycle perspective. This district consisted of about 24,000 inhabitants generating 35.6 Mg/day of municipal solid waste, of which 7.27 Mg/day was the organic fraction. Different source segregation intensities and collection frequencies (day^{-1}) were analyzed. The amount of the organic fraction not segregated at source was assumed to be collected commingled with the residual waste. The main findings showed that the lower was the collection frequency, the lower was the fuel consumption of the collection vehicles. For a source segregation intensity of 0%, the amount of fuel consumed ranged from 3.92 L to 1.73 L for each Mg of organic fraction as the collection frequency was decreased from 1 day^{-1} to 14 day^{-1}, respectively. The maximum fuel consumption for the collection of 1 Mg of organic fraction for a source segregation intensity of 50% was from 8.6 L/Mg to 2.07 L/Mg for a collection frequency of 1 day^{-1} and 14 day^{-1}, respectively. On the other hand the lower was the collection frequency, the higher was the amount of greenhouse gas generated during the pre-collection phase. The life cycle analysis showed that these emissions could affect the global warming potential of the scenarios analyzed up to 40%, exceeding the reduction of the emissions due to lower fuel consumption. In any case, as already reported by other authors, the uncertainty analysis confirmed the higher value for the uncertainty associated to the emissions from biological processes compared to those generated by industrial and combustion ones.

1. Introduction

Among the different activities involved in the management of municipal waste, collection is one of the most relevant, due to both the cost and the potential impact on the quality of the urban context. According to Dogan and Duleyman (2003), Ghose et al. (2006) and Tavares et al. (2009), collection can account for up to 70% of the whole waste management costs, ranging from about 70 €/Mg to about 140 €/Mg. Furthermore, as reported by Di Maria and Micale (2013), collection costs are also greatly affected both by the level of source segregation (SS) intensity and the optimization of loads of the waste collection vehicles (WCV). Rada (2013) analyzed the effect that selective collection had on waste-to-energy facilities as a consequence of the reduced calorific value. Ragazzi and Rada (2008) analyzed the consequences of increased selective collection on the suitability of different processes and technology for the treatment of residual and bio-waste.

Johansson (2006) reported that due to low average speed, frequent starts and stops and loading and unloading operations, WCV accounted for 10–15% of the total urban freight transportation in Malmoe, Sweden, along with related emissions. Consequently noise and gaseous emissions arising both from WCV engines and fuel consumption contribute to seriously affecting urban environmental quality (Larsen et al., 2009). In general, the major concern for the impact of waste collection has focused on fuel consumption. Tavares et al. (2009) proposed methods to optimize collection routes aimed at minimizing this aspect. Larsen et al. (2009) showed that the impact due to fuel consumption of WCV has decreased in the last years due to implementation of European emission standards for diesel trucks and that in many cases the net savings due to recyclables exceeds the use of fuel. Similar results were also obtained by Di Maria and Micale (2014, 2015) in analyzing different waste management options for Italian districts. In a Life Cycle Assessment (LCA) perspective, Iriarte et al. (2009) investigated three different selective collection systems

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based on mobile pneumatic, multi-container and door-to-door systems. Also in this case, the impact was evaluated on the basis of materials and energy/fuel consumption. Rives et al. (2010) carried out a LCA of containers of different sizes and materials used for waste collection and showed that larger size steel containers had lower impact than those made with HDPE.

All of this demonstrates that there is a lack of information about another important source of impact associated with the collection system, that is, the emissions generated during storage of the waste in domestic, curbside and/or road containers before collection *i.e.* pre-collection. Concerning this aspect, preliminary results proposed by Boardman et al. (2015) indicate daily emissions of 15 mg of CH_4 from a 240 L bin used for the collection of RMSW. Gaseous emissions characterized by high greenhouse gas (GHG) potential such as CH_4 and N_2O could be generated during the pre-collection phase mainly as a consequence of the spontaneous biodegradation of the organic fraction (OF). In analyzing home composting of bio-waste, Andersen et al. (2010) found CH_4 emissions ranging from 0.4 to 0.42 kg CH_4/Mg and N_2O emissions ranging from 0.3 to 0.55 kg N_2O/Mg. In a similar study concerning home composting of vegetable waste, Colon et al. (2010) reported the generation of 0.32 kg VOC/Mg. Different data were reported by Martinez-Blanco et al. (2010) for each Mg of OF composted at home: 0.158 kg CH_4; 0.559 kg VOC; 0.676 kg N_2O; 0.842 kg NH_3.

These results indicate that the spontaneous biodegradation of the OF during pre-collection could generate a non-negligible amount of GHG able to affect significantly the whole emissions associated with waste collection.

The goal of the present study was to assess in a LCA perspective the contribution of the emissions generated by the organic fraction of municipal waste during the pre-collection phase to the whole emissions generated by the collection system. The study was performed starting from an existing Italian collection area consisting of about 24,000 inhabitants. Three different source segregation intensities of 0%, 50% and 80% of the organic fraction were analyzed, combined with different collection frequencies ranging from 1 day^{-1} to 14 day^{-1}. A determinist time/space model was adopted to simulate the collection system in the different scenarios (Di Maria and Micale, 2015). All the main equipment for the collection activity was also considered. Further treatments and/or processes aimed at recycling, recovery and or/disposal were out of the scope of the present study.

2. Material and methods

2.1. Collection area

The collection area considered was a large subdivision of a medium-sized Italian city, consisting of a typical city center, mainly with apartment buildings and with a rather high population density. The resident population was about 24,000 inhabitants, representing about 15% of the entire population of the city, which encompasses an area of about 1.7 km^2.

Municipal Solid Waste (MSW) collection was organized with daily service on 7 routes dedicated to this area (Table 1) by the local collection company. Currently the OF is collected commingled with RMSW (*i.e.* SSOF = 0%) with a frequency of 1 day^{-1}. Road containers of different sizes were positioned in different collection points (CP) along each route; 24 m^3 and 18 m^3 rear loading WCV were used. After collection the WCV transported the waste directly to the transfer center from where it was successively moved to recycling and disposal plants. WCV garages and maintenance service areas were located in the same area as the transfer center. WCV routes can be divided into two main components:

(1) Transport distance (TD), which is the component from the transfer center to the first collection point CP_1 (Fig. 1) (Table 1) of the route (*i.e.* empty vehicles) and then back to the transfer center after the last CP_n (*i.e.* with loaded vehicles);
(2) Collection distance (TD), which is the distance between the first and last CP. During this phase the amount of waste loaded into a vehicle increases during the distance driven.

Other data necessary for the analysis such as fuel consumption and collection time were supplied by the local collection company.

2.2. Waste characterization

The amount of MSW generated in the area considered and the related compositions (Tables 1 and 2) were determined on the basis of analysis performed on a yearly basis.

The rather high concentration of paper was mainly a consequence of the high number of bars and restaurants in the area considered.

The density of the waste was evaluated by measuring the increase in weight of empty containers of 1000 L and 120 L once filled with RMSW and SSOF, respectively (Table 3).

2.3. Calculation model

The effects of different SS intensities on the size and number of collection equipment (*e.g.* WCV, containers, fuel consumption) were evaluated by the aid of a simulation model. This model was already described in Di Maria and Micale (2013). Briefly, it operates according to a space/time correlation and the amount of waste collected (Mg), the amount of fuel consumed (L) and the time (sec) required to cover a given collection route (km) is able to be calculated (Fig. 1).

The input data for the calculation model were represented by the following definitions:

(1) The TD and CD for each collection route on the basis of the SS intensity scenario;
(2) The number and respective distances (d_i) of CP along each collection route (Fig. 1);
(3) The number of bins and their respective size (L) positioned at each CP along with the waste collected;
(4) The WCV size (m^3) used along each collection route on the basis of the SS intensity and collection method (*i.e.* Road, Curbside, Door-to-Door).

Vehicle acceleration (a) and deceleration between two consecutive CP were simulated according to Wang (2001), using the same value a = 2.8 km/h/sec.

The pick-up time required for loading the waste from each bin into the WCV (t_l) was fixed at 60 sec as the average value obtained from observing several (*i.e.* 20) real collection operations on the routes considered and on other collection routes. In this way the total time required for this operation for each CP_i (t_{CPi}) can be calculated.

Two different average speeds (km/h) and fuel consumption values (L/km) for each WCV size (m^3) were used, respectively, for transport and collection operations (Table 4). These values were determined on the basis of 3 different series of direct measurements of collection operations along the routes for the base scenario.

Likewise, different maximum compaction ratios (*i.e.* WCV Volume/Maximum Collectable Waste Volume) were fixed for each WCV on the basis of vehicle size (m^3) and the waste material collected (Tavares et al., 2009) (Table 4).

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