Environmental sustainability assessment of municipal solid waste management through carbon footprint

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Introduction

One of the most challenging issues for building sustainable cities is the improvement of municipal solid waste management (MSWM), which requires a substantial effort to reduce its production and improve its different stages: collection (or pre-collection/containerization), transport and treatment. Each of these stages has environmental impacts stemming from the use of bags to hold the waste generated by residents in their homes, from the containers placed in public roads for drop-off, from the use of lorries or systems to transport waste to the processing plants, and from the construction and operation of plants to treat each waste fraction. In Europe, the Waste Framework Directive specifies Life Cycle Assessment (LCA) as a necessary policy-making tool, ensuring that impacts are assessed from cradle to grave, and avoiding 'hiding' impacts by moving them to other countries or stages of production/consumption. One of the environmental impacts evaluated is climate change (CC), in which greenhouse gas (GHG) emissions from the whole life cycle are calculated: carbon footprint (CF). This poster shows a methodology, based on LCA standards (ISO 14040 / 14044 / 14067), to calculate CF of MSWM. This methodology was applied to Madrid City.

Case study: Madrid City

In Madrid, 344 kilograms of MSW are produced per inhabitant. They are collected separately in different fractions (F1=mix waste, including organic material, F2=packaging, F3=paper/cardboard and F4=glass). F1 and F2 fractions are managed in Valdemingomez Technology Park (VTP), comprising three sorting plants and material recovery facilities (SP/MRF), one waste-to-energy plant (WtE), one composting complex, two anaerobic digestion plants, one landfill, and one installation to use biogas recovered from a sealed landfill. The remaining fractions are taken to authorized handlers, regardless of whether they are part of integrated management systems (Fig. 1) or not, as is the case with F3 and F4 (the other two significant fractions).

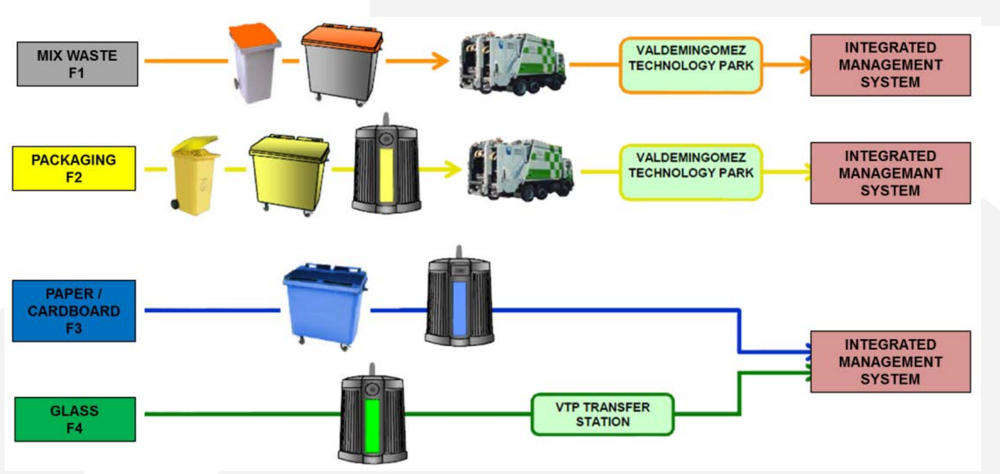

Fig. 1. Basic MSWM scheme for the four main MSW fractions in the city of Madrid

Methodology and results

1- Collection (containerization)

Collection CF is calculated using SimaPro software (v. 8.0.5.13). **System boundaries:** raw materials extraction and processing and container production. **Functional unit:** one ton of MSW collected. **Inventory data:** Ecoinvent 3.1, container manufacturers, Madrid City Council. The collection impact per unit of waste is 3.6 kg CO_2 eq/$t_{MSW\ collected}$. Fig. 2 shows total GHG emissions distribution by MSW fraction collection and type of container (left), and collection CF per district (right)

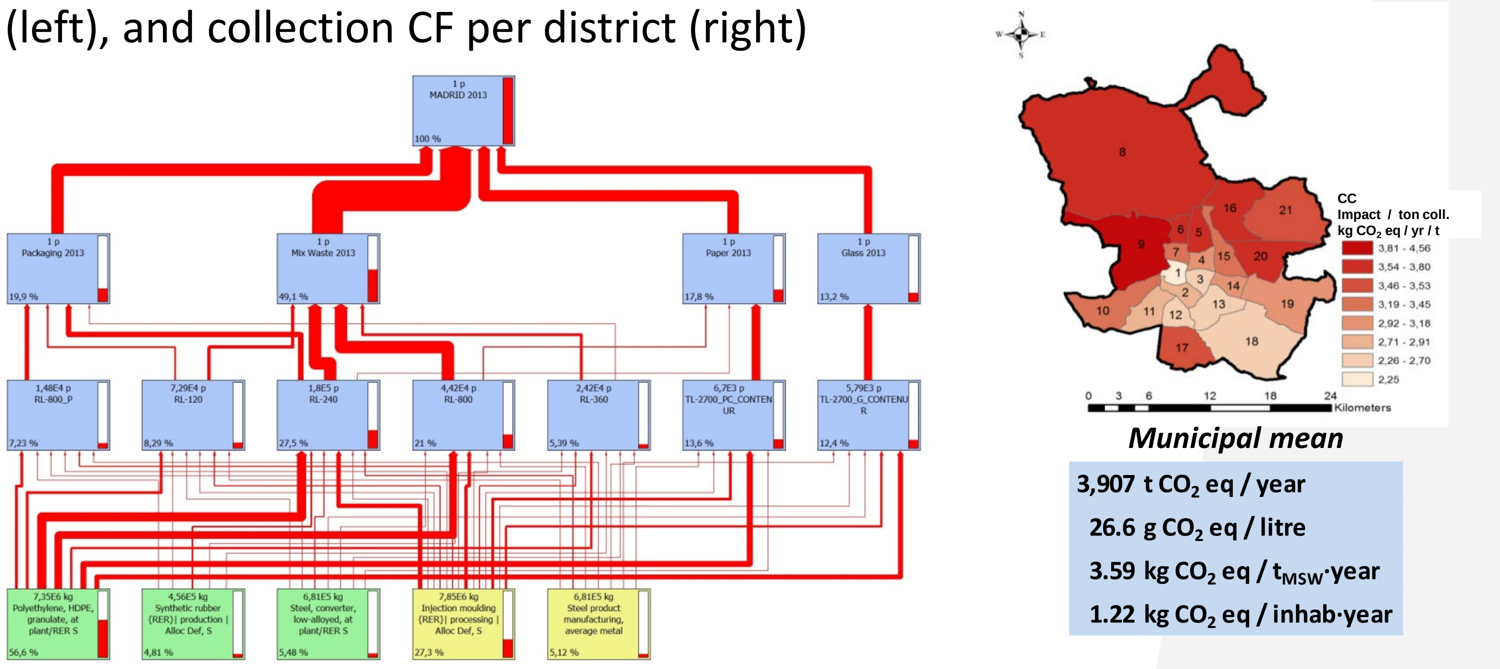

Fig. 2. Collection CF. Distribution of GHG emissions per fraction and type of container (left). Impact per district (right)

2- Transport

The boundaries of the system include both the fuel life cycle (FLC) and the vehicle life cycle (VLC). CF is calculated taking into account actual data about the fleet and fuel consumption, and using Copert 4.11.3 and GlobalTRANS (a tool developed at UPM). In the city of Madrid, MSW transport vehicles run on compressed natural gas (CNG). Fleet's CF is 25 kg CO_2 eq/$t_{MSW\ collected}$, 92% of which stems from FLC and the remaining 8% from the VLC. In terms of FLC, 86% of the impact comes from the Tank-to-Wheel (TtW) stage and 14% from the Well-to-Tank (WtT) stage (Fig. 3). The Madrid case is compared with other Spanish cities and past scenarios in Madrid, when vehicles ran on diesel. It has also been evaluated a possible future where natural gas is replaced by purified biogas from the anaerobic digestion of municipal waste, in order to reduce CF (Fig. 4).

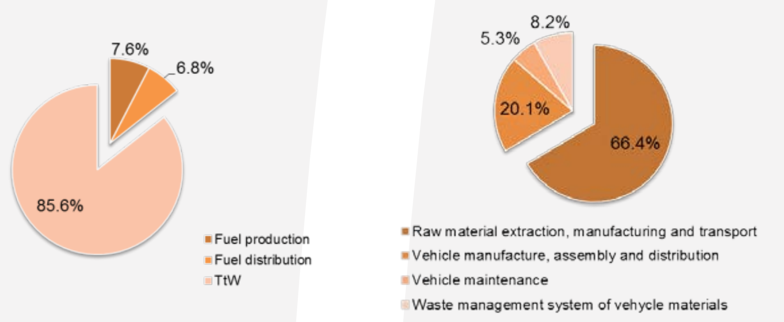

Fig. 3. FLC (left) and VLC (right) GHG emissions distribution

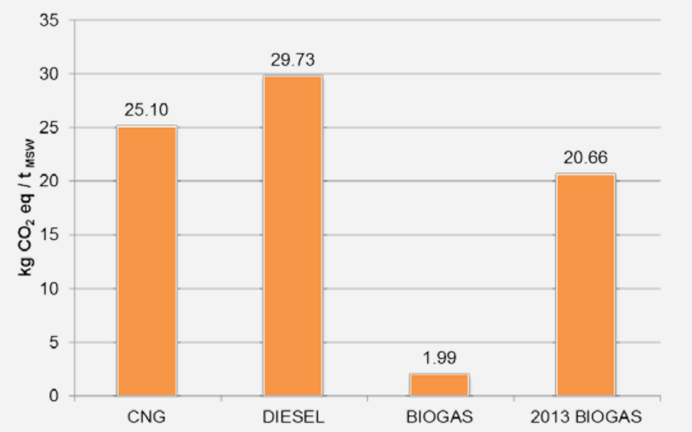

Fig. 4. Comparison between transport scenarios

3- Treatment

The CF of the waste treatment amounts 224 kg CO_2 eq/$t_{MSW\ collected}$. It has been calculated taking into account direct and indirect GHG emissions, and burden avoided. The distribution of GHG emissions per individual treatment is shown at Fig. 5 (2013 scenario).

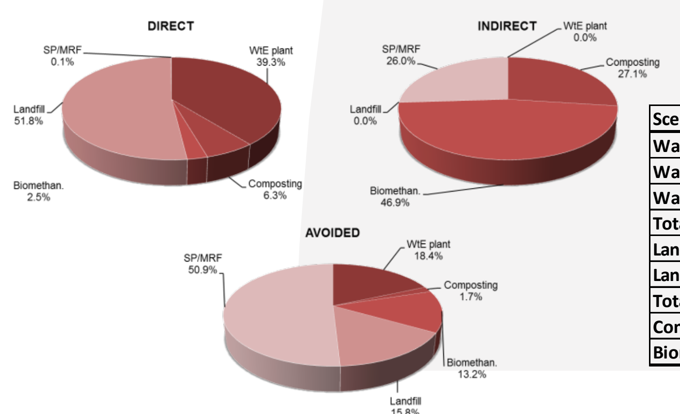

Fig. 5. Direct, indirect & avoided GHG emissions distribution per treatment in the 2013 scenario

This situation was compared with nine alternative scenarios (*Table 1*), which describe hypothetical management routes (among those already implemented in the city) for the different MSW fractions. Results obtained show that scenarios based on a total recovery of valuable materials and WtE or anaerobic digestion treatments present the lowest CF (*Fig. 6*).

Table 1. Proposed alternative scenarios to compare with 2013 scenario

Scenario	Acronym	Organic Matter in F1	Organic matter in F2	Packaging in F1	Packaging in F2	Rest from F1 and F2	F3	F4
Waste-to-energy	WtE	Waste-to-energy	Waste-to-energy	Waste-to-energy	Waste-to-energy	Waste-to-energy	Waste-to-energy	Recycling
Waste-to-energy + Recycling	WtE+R	Waste-to-energy	Waste-to-energy	Waste-to-energy	Recycling	Waste-to-energy	Recycling	Recycling
Waste-to-energy + All Recycling	WtE+aR	Waste-to-energy	Waste-to-energy	Recycling	Recycling	Waste-to-energy	Recycling	Recycling
Total disposal	L	Landfilling	Landfilling	Landfilling	Landfilling	Landfilling	Landfilling	Landfilling
Landfilling	L+R	Landfilling	Landfilling	Landfilling	Recycling	Landfilling	Recycling	Recycling
Landfilling + All Recycling	L+aR	Landfilling	Landfilling	Recycling	Recycling	Landfilling	Recycling	Recycling
Total disposal without biogas recovery	LwBr	Landfilling	Landfilling	Landfilling	Landfilling	Landfilling	Landfilling	Landfilling
Composting	C+aR	Composting	Composting	Recycling	Recycling	Landfilling	Recycling	Recycling
Biomethanation/Composting	B+C+aR	Biomethanation/Composting	Biomethanation/Composting	Recycling	Recycling	Landfilling	Recycling	Recycling

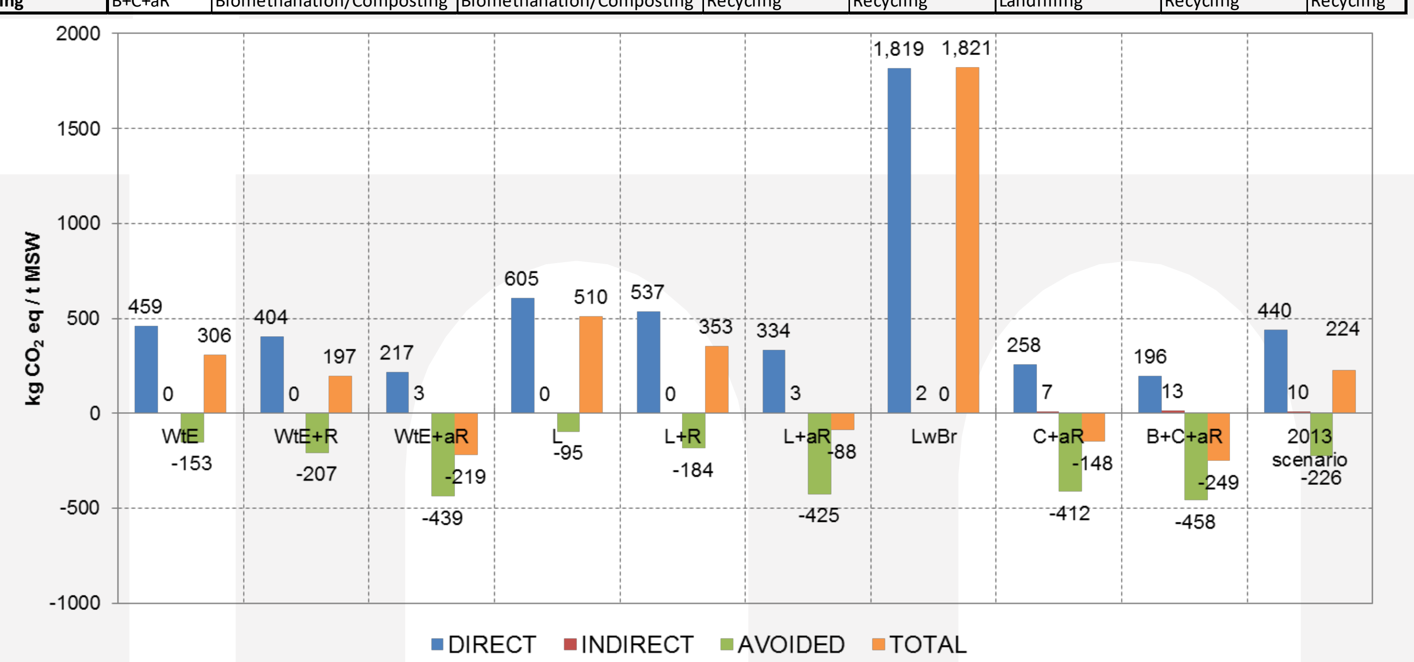

Fig. 6. Comparison between scenarios: CF disaggregation per type of GHG emission considered

The total CF of MSWM of Madrid City is 253 kg CO_2 eq/$t_{MSW\ collected}$, from which 1.4% corresponds to the collection stage, 9.9 % to transport and 88.7% to final treatments.

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