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Life Cycle Assessment of mechanical biological pre-treatment of Municipal Solid Waste: A case study

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ABSTRACT

The environmental performance of mechanical biological pre-treatment (MBT) of Municipal Solid Waste is quantified using Life Cycle Assessment (LCA), considering one of the 57 French plants currently in operation as a case study. The inventory is mostly based on plant-specific data, extrapolated from on-site measurements regarding mechanical and biological operations (including anaerobic digestion and composting of digestate). The combined treatment of 46,929 tonnes of residual Municipal Solid Waste and 12,158 tonnes of source-sorted biowaste (as treated in 2010 at the plant) generates 24,550 tonnes CO_2-eq as an impact on climate change, 69,943 kg SO_2-eq on terrestrial acidification and 19,929 kg NMVOC-eq on photochemical oxidant formation, in a life-cycle perspective. On the contrary MBT induces environmental benefits in terms of fossil resource depletion, human toxicity (carcinogenic) and eco-toxicity. The results firstly highlight the relatively large contribution of some pollutants, such as CH_4, emitted at the plant and yet sometimes neglected in the LCA of waste MBT. Moreover this study identifies 4 plant-specific operation conditions which drive the environmental impact potentials induced by MBT: the conditions of degradation of the fermentable fraction, the collection of gaseous flows emitted from biological operations, the abatement of collected pollutants and NOx emissions from biogas combustion. Finally the results underline the relatively large influence of the operations downstream the plant (in particular residuals incineration) on the environmental performance of waste MBT.

1. Introduction

Mechanical biological pre-treatment (MBT) of residual Municipal Solid Waste (MSW), i.e. of the share of MSW collected after source segregation and collection, has been increasingly implemented in France in the last decade. 57 MBT plants are currently operating as opposed to just a single plant in the year 2000, and 21 additional installations are planned to be installed in the near future (Gautier et al., 2013; BIPE, 2009). Mechanical biological operations result in the transformation and separation of residual MSW into recyclables, combustibles, compost and biogas. Most of the existing and planned French MBT plants primarily aim at producing compost (50%), e.g. for agricultural applications, while the remaining plants either mainly generate biogas (37%) or are devoted to waste stabilization prior to landfilling (13%). MBT implementation within existing municipal waste management systems therefore enables to divert waste in the sense of the waste hierarchy as defined in the EU Waste Framework Directive (WFD) (2008/98/EC).

In the past years numerous Life Cycle Assessment (LCA) studies have been performed with respect to waste management. These LCA studies aimed on the one hand at the comparison between waste management options (e.g. Cherubini et al., 2009) and on the other hand at the optimization and help in decision-making regarding different waste management technologies (e.g. with respect to incineration, Scipioni et al., 2009). Specifically considering MBT, several LCA studies, such as Abeliotis et al. (2012), Hong et al. (2006), Valerio (2010) and Pires et al. (2011), have emphasized that their environmental performance is globally better than the performance of other waste management options.

Life Cycle Assessment studies of waste MBT however raise several methodological issues, in particular as to the steps of system definition and inventory. Firstly, the environmental performance of waste MBT is significantly influenced by the downstream systems in charge of treating the sorted products (Pires et al., 2011). Secondly, only a restricted number of diffuse air pollutants are sometimes accounted for in the LCA of MBT (e.g. CO_2, H_2S and

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NH_3 regarding the composting phase in Hong et al., 2006), excluding potentially significant contributors to the environmental impacts such as CH_4. Finally, the plant specific operation conditions (such as pollutant abatement) are usually not addressed, whereas such specificities appear significant regarding the environmental performance of other waste treatment techniques such as landfilling or incineration (Beylot et al., 2013; Beylot and Villeneuve, 2013).

In this context this study aims at evaluating the environmental performance of Municipal Solid Waste mechanical biological pre-treatment, in a life-cycle perspective and in the case of a specific French plant (so-called "plant A" in the following). The latter is representative of the share of current French MBT plants which combine anaerobic digestion, composting and compost use on land. The environmental assessment is mostly based on a specific data inventory extrapolated from on-site specific measurements. Moreover, this study investigates the plant-specific operation conditions which drive the MBT plant environmental performance. Finally the MBT plant environmental impact potentials' sensitivity to hypotheses on the data inventory and to the background system (upstream and downstream the plant) is discussed.

2. Method

2.1. Scope definition

2.1.1. Functional Unit

Life Cycle Assessment is performed following the ISO standards 14040 and 14044 (International Standard Organization, 2006a and International Standard Organization, 2006b), and the provisions of the International Reference Life Cycle Data System (ILCD) Handbook (JRC, 2010). The Functional Unit is defined as the combined treatment of 46,929 tonnes of residual MSW (in wet mass), whose composition is described in Table 1, and 12,158 tonnes of source-sorted biowaste (including kitchen waste, garden waste, paper and cardboard). This corresponds to the waste treated at the plant A over the year 2010, as reported by the plant operator. Based on this Functional Unit, the environmental impact potentials induced by the plant are determined and the plant specific operation conditions driving its environmental performance are subsequently discussed. The goal of this LCA study therefore belongs to the "archetypal goal Situation C1" as defined by the ILCD Handbook (JRC, 2010), implying the attributional modeling of the Life Cycle Inventory.

2.1.2. Plant description and system boundaries

This study is performed in a life-cycle perspective, encompassing both the MBT process-chain operations and the upstream and downstream operations associated with the plant functioning. Plant A, of nominal capacity 100,000 tonnes of waste a year, is located in the North of France. Its related material flows are represented in Fig. 1. The process-chain includes:

- A first 3 day-retention-step in a Biologic Reactor Stabilizator (BRS®, also called rotary drum reactor), in order to pre-compost the input waste. Two BRS® function in parallel at the plant, respectively dedicated to residual MSW and to source-sorted biowaste. The permanent rotation of the tube homogenizes the matrix while knives dilacerate the waste (see e.g Morvan and Blanquart, 2009). The open inlet and outlet ensure aerobic conditions in the tube;
- A sequence of mechanical sorting operations, including: a drum (30 mm sieve), an overband magnetic separator, instep waves sieve Liwell (12 mm sieve) and ballistic separation. This step results in 3 types of material flows: the sorted fraction, which mainly contains organic matter; iron scraps, separated in order to be recycled downstream the MBT plant; and residuals (of composition described in Table 1), which also require an additional downstream treatment (incineration or landfilling);
- The anaerobic digestion of the sorted fraction, in 28 days. The produced biogas is used for electricity and heat generation;
- Finally, the agitated bay composting of the digestate during 2 weeks in a dedicated composting hall, with periodic turning and aeration of windrows. The resulting compost complies with the French standards regarding the use of compost in agriculture (NF U44-051, 2006, which sets thresholds in particular with respect to impurities and metallic trace elements). The compost is eventually stored in outdoor windrows before it is routed toward fields.

2.1.3. Environmental impact assessment methods

The environmental impact potentials are assessed by use of 9 up-to-date midpoint impact categories, including the majority of the impact categories most frequently used for the Life Cycle Impact Assessment of solid waste management systems (JRC, 2011; Laurent et al., 2014). Firstly, non-toxic impact categories encompass climate change (calculated with IPCC factors with a timeframe of 100 years, IPCC, 2007)), photochemical oxidant formation, particulate matter formation, terrestrial acidification and marine eutrophication (calculated by use of ReCiPe 2008; Goedkoop et al., 2008). Toxic impact categories include human toxicity (distinguishing between cancer and non-cancer effects) and ecotoxicity, and are calculated by means of the USEtox recommended characterization factors (Rosenbaum et al., 2008). Finally the assessment of resource consumption focuses on energetic resources only (ReCiPe 2008). Biogenic CO_2 emissions from the technosphere (in particular MBT diffuse emissions and emissions resulting from biogas combustion) are considered to have no effect on climate change, while biogenic carbon binding is ascribed a negative value. The influence of such a methodological choice in the LCA of waste management options is discussed by Christensen et al. (2009) and is therefore not addressed any further in the following.

2.2. Life Cycle Inventory

The data used for the compilation of the Life Cycle Inventory mainly originate from three sources. Firstly, the data on energy (in terms of consumption and recovery) and on total mass balances (in particular considering the input waste and the output residuals and compost) are based on continuous measurements performed by the plant-operator over the year 2010. These data on total mass flows are completed with specific data on the composition of the input waste and output residuals (in terms of waste fractions)

Table 1
Composition, in waste fractions and in % of total dry waste, of the input waste and output residuals at the plant A (ADEME, 2014).

Waste fractions	Input residual MSW	Output residuals to incineration
Organic waste	18.7	1.5
Paper	10.8	0.2
Cardboard	7.4	0.1
Composite waste	2.1	0.2
Textiles	4.8	13.5
Sanitary textiles	10.7	2.9
Plastics	17.9	40.9
Combustibles nec.[a] (e.g. wood pallets)	5.7	10.8
Glass	12.7	16.1
Metals	5.5	4.0
Non-combustibles nec.[a] (e.g. gravel, ceramics, etc.)	3.7	9.8

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