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Environmental impact of rejected materials generated in organic fraction of municipal solid waste anaerobic digestion plants: Comparison of wet and dry process layout

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ABSTRACT

Anaerobic digestion of source separated organic fraction of municipal solid waste is an increasing waste valorization alternative instead of incineration or landfilling of untreated biodegradable wastes. Nevertheless, a significant portion of biodegradable wastes entering the plant is lost in pre-treatments and post-treatments of anaerobic digestion facilities together with other improper materials such as plastics, paper, textile materials and metals. The rejected materials lost in these stages have two main implications: (i) less organic material enters to digesters and, as a consequence, there is a loss of biogas production and (ii) the rejected materials end up in landfills or incinerators contributing to environmental impacts such as global warming or eutrophication.

The main goals of this study are (i) to estimate potential losses of biogas in the rejected solid materials generated during the pre- and post-treatments of two full-scale anaerobic digestion facilities and (ii) to evaluate the environmental burdens associated to the final disposal (landfill or incineration) of these rejected materials by means of Life Cycle Assessment.

This study shows that there is a lost of potential biogas production, ranging from 8% to 15%, due to the loss of organic matter during pre-treatment stages in anaerobic digestion facilities. From an environmental point of view, the Life Cycle Assessment shows that the incineration scenario is the most favorable alternative for eight out of nine impact categories compared with the landfill scenario. The studied impact categories are Climate Change, Fossil depletion, Freshwater eutrophication, Marine eutrophication, Ozone depletion, Particulate matter formation, Photochemical oxidant formation, Terrestrial acidification and Water depletion.

1. Introduction

During the last several years European Union (EU) has promoted some directives to reduce MSW generation, increase recycling, promote source selection and reduce biodegradable wastes to landfilling. For example, EU published the Landfill Directive (European Commission, 1999) in 1999 through which all of its member states are required to minimize landfill disposal and are encouraged to adopt more sustainable measures, with the objective to reduce the environmental impact of landfills. Later, the EU waste policy, Framework Directive (2008/98/CE) (European Commission, 2008), required all of its member states to apply the waste hierarchy concept. Waste management options are classified into five categories according to their environmental impact (most favoured options first): prevention, reuse, recycling, recovery and disposal. As a consequence, currently, EU municipal solid waste is disposed through landfills (33.6%), incineration (24.2%), recycling (27.4%) and composting and anaerobic digestion (14.8%) (Eurostat, 2012).

The Landfill Directive is mainly responsible for increasing the number of waste treatment facilities in Europe. Among them, anaerobic digestion facilities play an important role in the waste management systems in Europe. Indeed, while in 1990 the annual treatment capacity of anaerobic digestion facilities was approximately 0.1 million $t\,y^{-1}$, by 2010, in Europe, there were approximately 200 plants with a total treatment capacity of 6 million $t\,y^{-1}$ spread in 17 EU countries (De Baere and Mattheeuws, 2010). However, there is growing interest in the diversion of food waste from landfills in other countries, such as the United States or Canada (Levis et al., 2010).

These plants are based on three main stages. The first mechanical stage deals with, on the one hand, recyclables (ferrous and

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Abbreviations

BMP_{100}	Biogas Production at 100 days
BMP_{21}	Biogas Production at 21 days
DM	Dry Matter
Dp	Particle diameter
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LFG	Landfill gas
MC	Moisture content
MSW	Municipal Solid Wastes
NL	Normal litres
OFMSW	Organic Fraction of Municipal Solid Wastes
TOC	Total organic carbon
VS	Volatile Solids

Waste treatments

DAD	Dry Anaerobic Digestion
WAD	Wet Anaerobic Digestion
WWTP	Wastewater Treatment Plant

Rejected solid materials

HFC	Heavy Fraction from Hydrocyclone
HFP	Heavy Fraction from Pulpers
LFP	Light Fraction from Pulpers

Impact categories

FEP	Freshwater eutrophication
FDP	Fossil Depletion
GWP100	Climate Change (Global Warming)
MEP	Marine eutrophication
ODP	Ozone Depletion
PMFP	Particulate Matter Formation
POFP	Photochemical Oxidant Formation
TAP100	Terrestrial Acidification
WDP	Water Depletion

non-ferrous metals, plastics...) and, on the other hand, the organic (biodegradable) fraction. Recyclable material is sold and recycled as raw materials. The organic fraction undergoes a second stage based on a biological degradation process. Anaerobic digestion followed by a composting process of this fraction is the most commonly used option for organic waste valorization and energy recovery. Finally, the raw compost is refined through mechanical processes. Biogas, compost and recyclables are thus obtained as final products.

Anaerobic digestion processes can be defined as wet or dry processes. Wet anaerobic digestion (WAD) is defined as when the waste to treat is digested at less than 20% dry solids. However, dry anaerobic digestion (DAD) processes are when wastes with a higher dry solids content are digested, and when working at the boundary, the process is called semi-dry (Hartmann and Ahring, 2006). Depending on the type, wet or dry, the initial mechanical stage will be different. Both cases comprise a dry mechanical treatment (trommel, ballistic separation, magnetic separation...), but wet anaerobic processes also require a previous wet treatment. The objective of this wet treatment is to increase the water content, to remove the light fraction (low-density material such plastics or fibers) and to remove high-density materials (such as sands).

During these stages, mainly the first mechanical stage, some reject materials are generated. The rejected material is composed of materials that cannot be clearly separated as recyclables or as a biodegradable fraction and are normally landfilled or incinerated. In an OFMSW treatment plant, rejected material is related to the non-biodegradable materials present in the waste (plastics, metals, sand, etc.). A quantity of the undesirable wastes in the OFMSW is related with some socio-economic factors: population density, gross disposable household income, educational level or the collection system (street bins or door to door) (Alvarez et al., 2008).

Because mechanical selection (dry and wet) is not 100% efficient, the rejected material fraction will contain organic biodegradable matter among other recyclables. Thus, some of the biodegradable matter that should be valorized through the biological stage is sent to the landfill, with consequent economic and environmental impacts: less biogas and compost are produced and there will be an increase in landfill emissions.

Landfills are responsible for a considerable contribution to several environmental burdens, one of which is being global warming, which is caused by increasing amounts of greenhouse gases (CO_2, CH_4, N_2O...) being emitted to the atmosphere. Among these, methane emissions represent a major contribution because they are 25 times more harmful than the same volume of carbon dioxide (IPCC, 2013). Landfills remain one of the main sources of methane emissions because most of the methane gas produced leaks into the atmosphere. In Europe, it is estimated that approximately 60% of landfill biogas (LFG) is lost to the environment (Cherubini et al., 2009; Buttol et al., 2007; Monni, 2012).

In this context, it is essential to evaluate the environmental impact associated with OFMSW treatment facilities. Some studies have assessed the sustainability of the process itself (Colón et al., 2012; Cadena et al., 2009; Montejo et al., 2013). Other works have studied the input and output flows of these plants and the mass balance (Pognani et al., 2012a), including the rejected material produced. However, no data have been found in the literature about the environmental impact of these rejected materials generated by full-scale OFMSW treatment plants that have landfill or incineration as destination. The environmental impact of complex systems can be addressed by means of life cycle assessment (LCA). LCA is a methodological tool for studying the environmental aspects and potential impacts of a product or service throughout its lifecycle, from the extraction of raw materials to its production, use and, finally, disposal. LCA involves the development of relevant information on the inputs and outputs of the system (inventory analysis), the assessment of their potential impact (impact assessment) and the interpretation of the results within the context of the proposed targets (interpretation) (ISO 14040, 2006). Simply stated, LCA performs mass and energy balances of a product system and makes an assessment of the environmental impacts associated with them.

The main goals of this study are: (i) to estimate potential loses of biogas in the rejected solid materials generated during the pre- and post-treatments of OFMSW in wet and dry anaerobic digestion full-scale facilities and (ii) to evaluate the environmental burdens associated to the final disposal (landfill or incineration) of these solid rejected materials by means of LCA.

2. Materials and methods

2.1. Plant description

Two different anaerobic digestion facilities were studied, the first one relying on a wet anaerobic process and the second one relying on a dry anaerobic process.