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Economic and environmental review of Waste-to-Energy systems for municipal solid waste management in medium and small municipalities

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ABSTRACT

The application of Directive 2008/98/CE on Municipal Solid Waste (MSW) implies the need to introduce technologies to generate energy from waste. Incineration, the most widely used method, is difficult to implement in low populated areas because it requires a large amount of waste to be viable (100,000 tons per year). This paper analyses the economic and environmental costs of different MSW-to-Energy technologies (WtE) in an area comprising of 13 municipalities in southern Spain. We analyse anaerobic digestion (Biomethanization), the production of solid recovered fuel (SRF) and gasification, and compare these approaches to the present Biological Mechanical Treatment (BMT) with elimination of the reject in landfill, and incineration with energy recovery. From an economic standpoint the implementation of WtE systems reduces the cost of running present BMT systems and incineration; gasification presents the lowest value. From the environmental standpoint, Life Cycle Assessment shows that any WtE alternatives, including incineration, present important advantages for the environment when compared to BMT. Finally, in order to select the best alternative, a multi-criteria method is applied, showing that anaerobic digestion is the optimal solution for the area studied.

1. Introduction

In recent decades, the disposal of municipal solid waste (MSW) in landfills is attracting much attention due to the clearly negative impact on the environment that derives from its inadequate management. Impacts include the deterioration of the landscape, the production of dust and leachate, and emissions of contaminating gases (Palmiotto et al., 2014). Since 1975 the European Union has been developing a common framework of standards to reduce this environmental hazard. The Directive 1999/31/CE, regarding the disposal of waste, demands the Member States to reduce the amount of biodegradable residue deposited in landfills by 50% in 2013 and 35% in 2016, compared to the levels of 1995. Meanwhile, the Directive 2008/98/CE calls for the implementation of changes to MSW management towards sustainable development.

These changes should contribute to the improvement of a number of issues such as the prevention of greenhouse gas emissions, the reduction of contaminants, energy savings, the conservation of resources, the generation of new jobs, and the development of clean technologies and economic opportunities (Ionescu et al., 2011a; Gutierrez et al., 2016). Furthermore, this Directive establishes a hierarchy of actions to be applied when setting up policies for waste management, based on prevention and societal changes (Cole et al., 2014) to encourage a better energetic exploitation of waste. In this sense, waste should be selected, in its origin or in a treatment plant, to be subjected to processes of material and energetic exploitation before landfill disposal.

MSW could be seen as a widely available source of domestic energy, due to its important energetic contents and its continuous production (Lombardi et al., 2015). Its calorific power ranges between 8 and 12 GJ/t, approximately 42% of the value of bituminous coal for combustion (24 GJ/t). Its availability has grown, with MSW generation reaching over 245 million tons in 2012 in UE-27, breaking down to 492 kg of waste per person and year. Therefore, whenever material recovery and re-use cannot be carried out, different treatment technologies open the possibility to efficiently generate energy from waste, leading to economic and environmental advantages (Baggio et al., 2009; Poulsen and Hansen, 2009; Ionescu et al., 2011b).

Biological and thermochemical treatments are among the most used technologies (Renkow and Rubin, 1998; Nelles et al., 2010).

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Anaerobic digestion or biomethanization takes advantage of more than 90% of the energy available from biowaste through the production of methane (Elango et al., 2007). Thermochemical treatment entailing some form of incineration (in situ or in an external facility), or through the production of solid recovered fuel (SRF) is most often used to date, as it reduces the volume and weight of waste, it allows energy retrieval in the form of electricity and heat, and it helps reducing emissions (Lee et al., 2007; Finney et al., 2012; Rada and Andreottola, 2012). Nonetheless, recent technologies such as pyrolysis and gasification use small amounts of oxygen, which improves Waste-to-Energy (WtE) efficiency and the reduction of greenhouse gas emissions (Scott et al., 1988; Huang and Tang, 2007; Arena, 2012). The growth of the population and the acknowledgement that landfills are the worst environmental alternative will make thermal treatment become the predominant option in the future (Paleologos et al., 2016).

Directive 2008/98 establishes for the year 2020 a minimum of 50% for the reutilization and recycling of materials such as paper/cardboard, metal, plastic and glass originated from domestic use or similar waste sources. In 2015, the European Commission adopted an ambitious package of measures to promote the transition to a circular economy. These measures include clear objectives for the reduction and recycling of waste, which open the way for the appearance of new approaches to waste management. Key elements of the revised waste proposal include (CES, 2015):

- A common EU target for recycling 65% of municipal waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;
- Concrete measures to promote re-use and stimulate industrial symbiosis turning one industry's by-product into another industry's raw material.

Assessment of the impact of major environmental factors in urban solid waste have highlighted a range of environmental benefits to be gained through energy generation from municipal solid waste (MSW), including reduced greenhouse gas emissions, acid gas emissions, depletion of natural resources (fossil fuels and materials), impact on water (leaching), and land contamination (Sonesson et al., 2000; Khraisheh and Li, 2010).

Several studies have tried to clarify which WtE system is best suited for a given land or area, evaluating economical and environmental impact. From the economic standpoint, most models focus on strictly operational aspects (Plata-Díaz et al., 2014). Panepinto et al. (2015) analyse waste gas emissions, energy recovery and feasibility of both combustion and pyrolysis/gasification, concluding that gasification is more competitive, while the direct combustion of MSW allows for higher power production. Arafat et al. (2015) evaluate the environmental impacts for five MSW treatment processes with energy recovery potential (incineration, gasification, anaerobic digestion, bio-landfills, and composting). In their study, individual non-mixed waste streams were considered. Anaerobic digestion and gasification were found to perform better environmentally than incineration and bio-landfills, while composting had the least environmental benefit.

Evangelisti et al. (2015) compare the environmental impacts of three dual-stage advanced WtE technologies, i.e. gasification and plasma gas cleaning, fast pyrolysis and combustion and gasification with syngas combustion, with electricity production and incineration. Tan et al. (2015) evaluate the energy, economic and environmental (3E) impact of WtE for municipal solid waste management at an existing landfill site in Malaysia.

In this paper, we present a novel approach that takes into account not only economic and environmental aspects but also territorial factors (geographical/spacial and social) In Spain, where an average of 463 kg of MSW is generated per person every year, over 60% is eliminated in landfills, and 10% is energetically exploited, as compared to the overall 31% and 26% in Europe (Bueno et al., 2015; Eurostat, 2015). Clearly, the policy for waste management can be improved to better fulfil the objectives established.

Spain has a particularly high number of scarcely populated municipalities: there are 8092 municipalities, 86% of them with fewer than 5000 inhabitants, and 32% with just between 250 and 1000 inhabitants. This situation complicates waste management by the municipalities, for different environmental and economic reasons, affecting the quality of the service offered (Zamorano et al., 2015). The difficulties are even greater when trying to implement technologies destined to recover energy, due to the greater cost of installations and exploitation (Lauret, 2010; Cappello et al., 2013). The high investment required for ovens, systems for gas cleaning and pollution control implies there is a loss of net electric efficiency in small plants (Lombardi et al., 2015).

This study looks into the application of different WtE technologies for a broad area in the province of Granada (southern Spain), characterized by villages with populations ranging from 300 to 21,500 inhabitants. Their application is analysed from the point of view of economic, environmental and territorial viability, applying a cost analysis, a life cycle assessment, and a multi-criteria method, in view of the technologies currently available and the possibility to implement them in the territory. Different alternatives for the treatment and assessment of MSW were compared with the present mechanical-biological treatment (MBT). More specifically, anaerobic digestion (Biomethanization), production of solid recovered fuel (SRF), gasification, incineration and the recovery of biogas generated in landfill were comparatively evaluated.

2. Materials and methods

2.1. Alternatives studied

The solutions studied were grouped into five alternatives designated as A, B, C, D and E, representing presently available technologies and based on the combination of unitary processes (Table 2). Also included in this study is Alternative 0, which is the current situation of waste management in the area of study. The selection of the different alternatives was made taking into account the comparative economic, environmental and technical aspects of the WtE processes reported by previous authors (Bayard et al., 2009; Tan et al., 2014; Panepinto et al., 2015; Server et al., 2016).

Table 3 offers the characteristics of each alternative studied. Alternatives 0, A, B and C include a mechanical-biological treatment plant for municipal solid waste (MSW), including the

Table 1
Urban Waste breakdown in the study area. *Source:* FCC Operating plant.

Components		Percentage (%)
Organic matter		49.1
Paper/cardboard		9.1
Glass		5
Bricks		2.3
Light packaging	PET	7
	HDPE	1.5
	Film	9.1
	Plastic mix	3
Metal	Ferric	3.5
	Non-ferric	0.4
Others		10
Total		100