Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Municipal solid waste incineration plant: A multi-step approach to the evaluation of an energy-recovery configuration

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ARTICLE INFO

Article history:
Received 9 February 2017
Revised 18 July 2017
Accepted 21 July 2017
Available online xxxx

Keywords:
Waste management
Thermal treatment
Environmental compatibility
Economic analysis
Energetic configuration

ABSTRACT

This study proposes a multi-step approach to evaluating the environmental and economic aspects of a thermal treatment plant with an energy-recovery configuration. In order to validate the proposed approach, the Turin incineration plant was analyzed, and the potential of the incinerator and several different possible connections to the district heating network were then considered. Both local and global environmental balances were defined. The global-scale results provided information on carbon dioxide emissions, while the local-scale results were used as reference values for the implementation of a Gaussian model that could evaluate the actual concentrations of pollutants released into the atmosphere. The economic aspects were then analyzed, and a correspondence between the environmental and economic advantages defined.

The results showed a high energy efficiency for the combined production of heat and electricity, and the opportunity to minimize environmental impacts by including cogeneration in a district heating scheme. This scheme showed an environmental advantage, whereas the electricity-only configuration showed an economic advantage. A change in the thermal energy price (specifically, to 40 €/MWh), however, would make it possible to obtain both environmental and economic advantages.

1. Introduction

Both national and international trends for the treatment and final disposal of solid waste are toward systems that separate collected materials and provide for the reuse of secondary by-products, although with considerable differences in implementation between more and less advanced regions and territories. Downstream of the treatment process, the waste flow is composed not only of the materials discarded during the collection and differentiation screening processes, but also of those wastes collected without differentiation, which must be suitably disposed of. This constitutes a very large fraction of the gross produced waste, and may be further broken down into combustible, wet organic, and substantially inert/mineral constituents, along with a lesser quantity of the more easily exploitable materials (i.e. metal, glass, and compostable organics). Given the interest in the production of both thermal and thermo-electric energy from non-fossil fuel sources (Stehlik, 2009), the valorization of potential energy contained in the downstream wasteflow is an important consideration (Consonni et al., 2011; Rada, 2014).

The aim of this work was the creation of a tool (a multi-step approach) capable of analyzing both environmental and economic aspects, in order to determine which technologies would be most advantageous to implement. In particular, we wanted to find those environmental advantages that also presented economic advantages. After the individual evaluation components of the tool were combined to develop a unique analytical approach, the method was applied to the Turin incineration plant. Two different energy recovery configurations were analyzed: electricity only, and cogenerative. In addition to this specific application, the approach we developed can be applied to other industrial plants, making it a useful decision-making tool for policy-makers.

1.1. WtE: technological overview

In the literature there are a large number of studies about the technological and energetic aspects of waste incineration. Dvorak et al. (2009) evaluated off-gas cleaning systems, considering their costs and performances; Bébar et al. (2005) analyzed both waste

Abbreviations: WtE, Waste to Energy; MSW, Municipal Solid Waste; GHG, Greenhouse Gases; DH, District Heating; IPA, Impact Pathway Analysis; NPV, Net Present Value (of Economic Plan); TOE, Tonnes of Oil Equivalent; CHPC, Combined Heat, Power and Cooling; DHN, District Heating Network; CHP, Combined Heat and Power.

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http://dx.doi.org/10.1016/j.wasman.2017.07.036
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incineration and gasification technologies. Other authors analyzed each of these technologies in more detail. For example, both Arena (2012), and Morris and Waldheim (1998), analyzed waste gasification, while Münster and Lund (2010) and (Fruergaard et al. 2010) analyzed waste incineration.

Some researchers have analyzed thermal treatment processes: for example, Panepinto and Genon (2011) used a model to predict the yield of the processes and composition of syngas output from waste and biomass gasification. And Panepinto et al. (2014b) treated the critical aspects of environmental advantages and operating costs for off-gas treatment systems.

The thermal treatment of waste produces high-pressure steam, and this steam can be used to generate electrical energy, using a steam turbine, and can also directly produce thermal energy; this double usage is referred to as cogeneration. A cogeneration plant, in fact, has environmental advantages, as it can replace existing, more polluting plants, while at the same time providing the economic advantage of producing two types of energy in one plant.

1.2. WtE: energy recovery overview

Cogeneration using WtE systems has been considered and described in several researches, analyzing the technological, economic and environmental aspects of WtE energy recovery. Economopoulos (2010) utilized literature data, examining the construction and operating costs of various technological operating schemes; Donovan and Collins (2011) evaluated thermal systems—in particular, cogenerative incineration—for meeting the waste-disposal requirements of Ireland, by individuating general cost estimations; and Murphy and McKeogh (2004) compared a cogeneration system for MSW incineration using gasification and other innovative technologies, examining the technical, economic and environmental aspects.

From the point of view of climate change, Astrup et al. (2009) examined waste incineration and co–combustion from the aspect of GHG (greenhouse gas) emissions, and Menikpura et al. (2013) examined in detail the climate benefits deriving from resource recovery. A hypothesis of cogenerative recovery from an MSW thermal treatment in an Italian town (Lo Mastro and Mistretta, 2004) demonstrated that the proposed technology represents a practical and sustainable strategy for waste valorization as an alternative to fossil fuels; and an energy analysis conducted by Lombardi et al. (2015) led to the conclusion that cogeneration systems are a tool for improving energy recovery, especially for small-scale plants. The information contained in the cited references represents an overview of the general situation—useful for understanding the main aspects that must be studied.

1.3. Italian waste thermal treatment legislation

In Italy the main rule concerning waste incineration is Legislative Decree n. 133 of 11 May 2005 "Implementation of Directive 2000/76/EC on waste incineration" (D. Lgs. 133/2005). This decree regulates in a single document all incineration and co-incineration operations, and provides criteria and technical standards regarding the architectural and functional characteristics, as well as the operating conditions, of the installations. Furthermore, the implementing decree of Italian Directive 2000/76/EC covers all waste incineration operations, from waste collection to the disposal of residual ashes.

In particular, the Decree covers the following aspects:

- emission limit values for pollutant concentrations in output from chimneys (the adoption of the treatment indicated in the Bref document of the European Commission (2006) is needed, to obtain these limit values);
- sampling, analysis and evaluation methods for waste incineration and co-incineration plants;
- criteria and technical standards regarding the architectural, functional and management aspects of waste incineration and co-incineration plants, with particular reference to ensuring integrated environmental protections.

2. Methodology

On the basis of the technological, environmental, energy and economic information obtained from the reported literature review, it is possible to conclude that the main aspects that must be taken into account are the environmental and economic ones. The tools needed to perform this evaluation include: a pollutant dispersion model (for analyzing the actual air-quality modifications resulting from the plant activation), an externalities tool (for analyzing the effects of the air-quality modification on population health), and finally, an economic evaluation tool, for analyzing the economic benefits. The proposed multi-step approach employs these tools in order to develop a useful decision tool for plant operators.

2.1. Multi-step approach

The research was performed using the following multi-step approach:

(1) Energy and environmental balances: in order to evaluate the introduced load and the local and global environmental benefits of substitution, it is necessary to compare the emissive fluxes before and after the startup of the plant. The environmental balance can then be computed according to the following formula (Panepinto et al., 2014a; Torretta et al., 2014):

$$\begin{aligned}&\text{Local/global emissions(added/eliminated)}\\&\quad = \text{emissions from incineration plant}\\&\qquad - \text{substituted emissions}\end{aligned} \tag{1}$$

It is important to emphasize that since the electricity that will be transferred to the network will substitute for a portion of the current centralized electricity production, the related environmental impacts of that current system, expressed in terms of primary energy consumption and atmospheric emissions, will be avoided. This same principle applies to the thermal energy supplied by the district heating (DH) system. The avoided impacts (heat and emissions) of the new plant constitute a compensation for the environmental load introduced by the plant; the aggregation of the avoided and introduced impacts represents the environmental balance. The balance was computed at both local and global scales. The local scale considered only the thermal energy (produced from the plant and transferred through a district heating network to the domestic boilers), while the global scale considered both the local thermal energy and the electrical energy (produced from the plant and sent out to the national grid).

The formulation of the environmental balance on the local scale is only preparatory to the implementation of the pollutant dispersion models:

(2) Implementation of pollutant dispersion models: in order to evaluate the severity of the environmental impacts produced by the plant, it is necessary to consider the results of the dispersion models. With this approach it is possible to calculate the real air–quality modifications: the concentrations (annual mean values and maximum hourly values)