Waste Management 80 (2018) 144–153

Contents lists available at ScienceDirect

Waste Management

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

# Life cycle assessment of the French municipal solid waste incineration sector

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ARTICLE INFO

*Article history:*
Received 15 November 2017
Revised 12 June 2018
Accepted 16 August 2018

*Keywords:*
LCA
Incineration
MSW
WILCI tool
Environmental impacts
Uncertainty

ABSTRACT

This study aims at assessing the environmental performances of the French MSW incineration sector in a life cycle perspective, considering nine midpoint impact categories. It is the first application of the WILCI tool, dedicated to the LCA of MSW incineration in the French situation (Beylot et al., 2017). The model is primarily based on operational data relative to 90 plants, representing 73% of the total mass of MSW annually incinerated in France. Regarding seven impact categories out of the nine under study, incineration of MSW in France provides a benefit (that is, a "negative" impact). The uncertainty analysis confirms the relatively large degree of confidence of this conclusion regarding acidification and particulate matter, but in the meantime highlights the remaining uncertainty regarding most other impact categories. Energy recovery is responsible for the main share of the total environmental impacts and benefits of MSW incineration in France. Moreover, this study confirms the importance of technology differentiation in the LCA of MSW incineration. The predominance, in the French incineration sector, of energy recovery as CHP, and of SCR for NOx abatement, results in the global environmental benefits calculated per tonne of average MSW incinerated. Finally, this study addresses the contribution of each waste fraction to the total impacts and benefits of MSW incineration. It identifies several fractions whose contributions to impacts and benefits are not in line with their share in the composition of MSW incinerated.


## 1. Introduction

In France, as in many countries equipped with modern waste management systems, incineration has become an essential treatment route for Municipal Solid Waste (MSW). In 2014, 14.7 million tonnes of MSW (28% of total French MSW) were incinerated in 126 MSW incineration plants (ADEME, 2017). While more and more waste has been incinerated in France in the last decades (+17% from 2000 to 2012), the number of plants has dramatically decreased in the meantime (from approximately 300 in 1990 down to 130 in 2005; ADEME, 2016a) due to an important increase in plant capacities. In 2012, 28 incineration plants (out of the 126 French ones), of capacity superior to 150,000 tonnes per year, have treated more than half of the total amount of French MSW annually incinerated (ADEME, 2017).

In Europe, the Waste Framework Directive (WFD; 2008/98/EC) requests that waste legislation and policy of the EU Member States shall apply as a priority order the following waste management hierarchy: prevention, preparation for re-use, recycling, recovery (including Waste-to-Energy) and finally, disposal. Moreover, the European Commission encourages the use of life cycle thinking to complement this waste hierarchy (Manfredi et al., 2011). In this respect, the environmental performances of waste management techniques, and in particular of waste incineration, have been intensively studied by use of Life Cycle Assessment (LCA) in recent decades. LCA studies especially aimed at comparing, on an environmental perspective, waste incineration with other waste management techniques: landfilling, anaerobic digestion, composting or recycling (Nabavi-Pelesaraei et al., 2017; Assamoi and Lawryshyn, 2012; Cherubini et al., 2009; Liu et al., 2017; Mendes et al., 2004; Arafat et al., 2015; Andersen et al., 2012; Thyberg and Tonjes, 2017; Boldrin et al., 2011; Jensen et al., 2016; Bueno et al., 2015).

LCA of waste incineration has been performed with respect to many distinct geographical contexts: Denmark (Turconi et al., 2011; Riber et al., 2008), Italy (Scipioni et al., 2009; Turconi et al., 2011), Switzerland (Boesch et al., 2014), France (Beylot and Villeneuve, 2013; Déchaux et al., 2017), the USA (Thyberg and Tonjes, 2017), China (Havukainen et al., 2017; Liu et al., 2017; Chen and Christensen, 2010), Iran (Nabavi-Pelesaraei et al., 2017), etc. Yet, these LCA studies are based on a mix of data relative

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https://doi.org/10.1016/j.wasman.2018.08.037
0956-053X/© 2018 Published by Elsevier Ltd.

to one or some specific incineration plants (e.g. regarding air emissions), often complemented by use of data at the scale of a larger set of plants - not corresponding to the country under study, but rather to some sort of "average performances" in a distinct geographical context (e.g. using BREF; European Commission, 2006). Accordingly, so far, no LCA study has been performed considering a comprehensive set of data at the scale of the whole incineration sector of a country. Furthermore, in their extensive literature review of LCA of thermal Waste-to-Energy technologies, Astrup et al. (2015) highlight that many studies omit to detail the technologies (in particular Air-Pollution-Control – APC - technologies) actually studied, whereas these may significantly affect the overall LCA results. They additionally report that when specific technology elements (e.g. air-pollution-control systems) were included, then "the underlying data were often very poorly described" (Astrup et al., 2015).

In this context, this study aims at assessing the environmental performances of the French MSW incineration sector in a life cycle perspective. It is based on a comprehensive data set, so that results are representative for the operation of the 126 MSW incinerators currently in function in France. Moreover, this study aims at quantifying how far the techniques (APC, energy recovery) implemented in the whole sector, and how far the MSW composition, both affect the environmental performances of MSW incineration in France.

## 2. Method

### 2.1. Goal and scope definition

#### 2.1.1. Goal and functional unit

The goal of this LCA study is to assess the environmental performances of MSW incineration in France, considering the whole incineration sector currently in function. This study therefore belongs to the archetypal goal Situation C1 as defined by the International Reference Life Cycle Data System (ILCD: "purely descriptive documentation of the system under analysis" including "existing benefits outside the analyzed system"; JRC, 2010). The functional unit is set as the "thermal treatment of 1 tonne of Municipal Solid Waste in France". MSW derived to incineration in France are primarily made of residual MSW (i.e. the share of MSW collected after source segregation and collection) and mixed non-hazardous waste from economic activities, respectively representing 82% and 11% of the total amount of MSW incinerated (ADEME, 2015). In addition, French MSW incineration plants treat minor quantities of clinical waste (2%), discarded equipment (2%), residues from sorting and composting operations (2%) and sludge (1%).

Now considering waste categories, one may note that MSW incinerated in France are mainly made of organic waste (38.4% in total wet waste), paper and cardboard (15.7%), textiles and sanitary textiles (12.5%) and plastics (11.4%; Table 1). The average chemical composition of MSW routed to incineration in France is subsequently derived considering the composition of each waste category in chemical elements, that is primarily drawn from national series of sampling performed in 2007 (regarding 14 chemical elements; ADEME, 2010) and completed with additional data sources regarding 27 other chemical elements (Koehler et al., 2011; Doka, 2003; AWAST, 2002; Supporting Information document 1).

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.wasman.2018.08.037.

**Table 1**
Composition of MSW incinerated in France (derived from ADEME, 2010, 2015).

| Waste categories | Share, in % |
|---|---|
| Organic waste | 38.4 |
| Paper | 10.2 |
| Cardboard | 5.5 |
| Composite waste | 1.7 |
| Textiles | 2.2 |
| Sanitary textiles | 10.3 |
| Plastics | 11.4 |
| Combustibles nec. (e.g. wood pallets) | 2.5 |
| Glass | 6.1 |
| Metals | 2.9 |
| Non combustibles nec. (e.g. gravel, ceramics, etc.) | 5.1 |
| Hazardous waste | 2.7 |
| Sludge | 1.0 |

**Table 2**
Average heat and electricity consumption mixes, excluding heat from incineration, based on 57 French heating networks co-supplied by heat recovered from incineration (VIA SEVA, 2017) and ecoinvent v3.3 data relative to electricity markets (Weidema et al., 2013).

| | Proportion in the mix (in %) | |
|---|---|---|
| Production | Heat | Electricity |
| Hard coal | 27.4 | 4.2 |
| Fuel oil | 8.6 | 1.0 |
| Natural gas | 48.6 | 4.3 |
| Biomass | 15.4 | 0.4 |
| Nuclear | – | 75.9 |
| Hydropower | – | 11.0 |
| Wind | – | 1.1 |
| Imports | – | 2.1 |

#### 2.1.2. System boundaries and multi-functionality

System boundaries include incineration direct emissions to air and water; production of ancillary products and reagents; management of bottom ashes, including on the one hand ferrous and aluminium scraps recovery and recycling, and on the other hand descrapped bottom ashes use in road construction or landfilling; management of APC residues; energy recovery as heat and electricity; and capital goods. Incineration provides two functions in addition to the thermal treatment of waste (that is the function tackled by the functional unit): namely energy generation and material recovery. Considering ILCD Handbook guidelines on Life Cycle Inventory (LCI) modelling in case of goal Situation C1, this multi-functionality issue is solved by system expansion (JRC, 2010). The not required co-functions are substituted with the average market consumption mix of the processes or systems that they supersede. Electricity recovered from MSW incineration is considered to supersede the average French electricity consumption mix; heat recovered from MSW incineration is considered to supersede an average heat consumption mix derived from data on 57 French heating networks co-supplied by heat recovered from incineration (VIA SEVA, 2017; Table 2); steel and aluminium scraps recovered from bottom ashes and further recycled are considered to supersede the primary productions of respectively low-alloyed steel and aluminium; and finally, bottom ashes used in road construction are considered to supersede primary gravel production.

#### 2.1.3. Environmental impact categories and LCA software

Nine up-to-date midpoint impact categories, for most of them already implemented in LCA studies of waste management techniques in a French context (Beylot et al., 2013, 2015) are considered to quantify the environmental performances of the French MSW incineration sector: climate change; photochemical ozone formation; particulate matter; acidification; terrestrial eutrophication; marine eutrophication; human toxicity (distinguishing between cancer and non-cancer effects) and freshwater ecotoxicity. Characterization factors of the ILCD recommended Life Cycle Impact Assessment (LCIA) methods are used to perform the impact assessment (JRC, 2012).

Calculations, in particular those aimed at comparing the performances of APC-techniques and to assess the contribution of each