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Quantifying capital goods for waste incineration

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ABSTRACT

Materials and energy used for the construction of modern waste incineration plants were quantified. The data was collected from five incineration plants (72,000–240,000 tonnes per year) built in Scandinavia (Norway, Finland and Denmark) between 2006 and 2012. Concrete for the buildings was the main material used amounting to 19,000–26,000 tonnes per plant. The quantification further included six main materials, electronic systems, cables and all transportation. The energy used for the actual on-site construction of the incinerators was in the range 4000–5000 MW h. In terms of the environmental burden of producing the materials used in the construction, steel for the building and the machinery contributed the most. The material and energy used for the construction corresponded to the emission of 7–14 kg CO_2 per tonne of waste combusted throughout the lifetime of the incineration plant. The assessment showed that, compared to data reported in the literature on direct emissions from the operation of incinerators, the environmental impacts caused by the construction of buildings and machinery (capital goods) could amount to 2–3% with respect to kg CO_2 per tonne of waste combusted.

1. Introduction

Incineration is a well-developed technology for energy recovery from municipal waste. The technology has been assessed over the last two decades using the environmental impact assessment tool life cycle assessment (LCA). These assessments have evaluated the environmental performance and assisted in the optimisation of waste management systems. The environmental assessments of waste incineration focus on operation and emissions, while capital goods (such as buildings, machinery and infrastructure at the facility) are rarely considered in the assessment. This could be due to lack of time or lack of sufficient data to include the capital goods in a LCA study. A review was made by Cleary (2009) of 20 peer-reviewed papers about LCA of waste management systems. Out of the 20 papers, only two (Buttol et al., 2007; Consonni et al., 2005) included capital goods, seven excluded the emissions from the production of capital goods and infrastructure and the rest (11) did not mention whether or not capital goods were included within the system boundaries.

The importance of including capital goods in the assessment of waste management systems has been previously assessed only by Frischknecht et al. (2007) using data from the Ecoinvent database (Ecoinvent, 2012). They found that the use of mineral resources was of major importance. They also found that the impact on global warming from capital goods in relation to the impact from the operation of a waste incinerator depended strongly on the composition of the waste treated. The reason was the importance of energy recovery, as more energy was recovered when the incinerated waste contained fractions with a high heating value (e.g. plastic).

Basic data on capital goods for waste incineration are few. The Ecoinvent database (Ecoinvent, 2012) includes data, obtained from Zimmermann et al. (1996), about the capital goods used for incineration. Ecoinvent (2012) address a plant estimated to have a capacity of 100,000 tonnes of waste per year and a lifetime of 40 years. The data in Ecoinvent includes steel, concrete (cement and gravel for concrete), bitumen and sand. Materials and transportation were considered but no consumption of energy during construction was included. From the background report, it was not possible to see which parts of the incinerator were included in the data. The total mass of the materials used was 55,000 tonnes corresponding to approximately 14 kg per tonne of waste combusted. Consonni et al. (2005) presented the use of materials for incinerators to be 20 kg of concrete and 15 kg of steel per tonne of waste combusted.

The goal of this study is to quantify the materials and energy consumption used for the construction of modern incinerators. The quantification covers five incineration plants, representative (in terms of scale and technology) of incineration plants built in Scandinavia.

2. Approach and method

To quantify the materials and energy consumption used for the construction of modern incinerators, data for five Scandinavian

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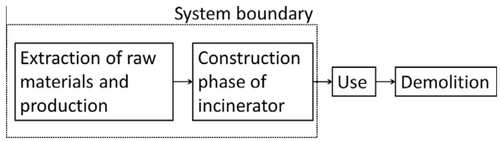

Fig. 1. Flow chart of the assessed part of the life cycle of an incinerator. Dotted line includes the system boundary for the environmental impact assessment. All inputs of transport and energy are included within the system boundary.

incineration plants were collected. Extraction and production of materials and the construction of the incinerator were assessed in this paper, see Fig. 1. Maintenance and substitution of parts and equipment during the operational lifetime of the incinerator were included. Disposal of the worn out parts should be considered in the disposal phase of the whole plant, but this phase was not included here. Furthermore, the inventory data was used to model the potential environmental impacts of the capital goods in order to assess their significance compared to the environmental impacts of the operation.

2.1. Inventory data

Data concerning the incinerators were divided into four parts: building structures, machinery, energy, and control and monitoring system (CMS). All data was based on design data from the construction phase of the incineration plants obtained from Ramboll, a consulting engineering company which has designed many waste incineration plants around the world. Ramboll also designed the five plants in this study and provided the data presented in this paper. For some of the plants it was not possible to quantify both the machinery and buildings. In total four buildings and three machineries were quantified for the five plants.

The lifetime of the incineration plants was needed to estimate the need for maintenance and to calculate the amount of waste incinerated during the lifetime of the incinerators. Maintenance prolongs the lifetime of the incinerators. The operational lifetime varies from 20 to 40 years. For quantification, 30 years was used as an average operational time.

Materials used for civil engineering were estimated via the records of materials used for the foundations, walls, facades and windows. To estimate the weight of the machinery, load plans were used for each plant. Load plans show loads on the building structures at each level of the building and are used by the entrepreneurs to make sure that the buildings can support all loads from the weight of machinery, operation of the system and external loads, such as snow and wind. The dead loads from the machinery with an empty non-operating system were used to estimate the weight of the specific parts of the machinery.

Energy consumption during construction was obtained from a construction site in Sweden. The electricity consumption was measured from the first 1.5 years of the construction period and was forecasted for the remaining period (6 months) for the construction work. Data for the consumption of diesel and heat was not available. Due to lack of data, in the present study the consumption of electricity during construction was assumed to be the same for all incineration plants.

2.2. Environmental profile

Simapro 7.2 (PRé, 2011) is a LCA software containing extensive databases. Simapro 7.2 was used for the environmental impact assessment. For this project mainly data from Ecoinvent 2.2 (Ecoinvent, 2012) was used.

All emissions from the quantified system were characterised and normalised for the impact categories presented in Table 1. The environmental design of industrial products (EDIPs) methodology (Wenzel et al., 1997) was used with the non-toxic categories: Global warming (GW), Ozone Depletion, Acidification, Terrestrial eutrophication, Aquatic eutrophication (N- and P-equivalents), Photochemical ozone formation (impacts on vegetation and human health) and Resource Depletion. Normalisation references defined by Laurent et al. (2011a) were used to present the results in person equivalents (PEs). This unit presents impacts as an average value for the total impact of the activities from one person in a specific area in the reference year.

The USEtox methodology (USEtox, 2009) was used to evaluate the emissions in relation to toxicity. The methodology includes the impact categories Human toxicity (cancer and non-cancer related) and Ecotoxicity. The normalisation references used for this methodology are defined by Laurent et al. (2011b), see also Table 1.

3. Presentation of incinerators

The incinerators described in this paper were built in Norway, Finland and Denmark in the period 2006–2012, thus representative of new plants being built in northern Europe. The plants described are relatively small with a capacity of 72,000–240,000 tonnes of waste incinerated per year. All of the five plants have combined heat and power (CHP) production and a high energy efficiency of 86–97%. See Table 2 for details of the incinerators. The energy productions from the assessed plants were 50–160 GW h electricity per year and 100–490 GW h heat per year. Incinerator A, producing

Table 1
Environmental impact categories and the normalisation references used for the assessment (Laurent et al., 2011a) and USEtox (Laurent et al., 2011b). UES: Unprotected Eco-System. CTU: Comparative Toxic Unit, e: Ecotoxicity, h: human.

Impact categories	Geographical scope	Normalisation references	Unit
EDIP			
Global warming	World	7730	(kg CO_2-eq/person/year)
Ozone Depletion	World	0.0205	(kg CFC-11-eq/person/year)
Acidification	Europe	54.8	(kg SO_2-eq/person/year)
Terrestrial eutrophication	Europe	1370	(m^2 UES/person/year)
Aquatic eutrophication (N-equivalents)	Europe	8.32	(kg N eq/person/year)
Aquatic eutrophication (P-equivalents)	Europe	0.282	(kg P eq/person/year)
Photochemical ozone formation – impacts on vegetation	Europe	59,700	(m^2 ppm hr/person/year)
Photochemical ozone formation – impacts on human health	Europe	2.84	(m^2 ppm hr/person/year)
Resource Depletion	World	0.817	(person reserves/person/year)
USEtox			
Human toxicity, cancer	Europe	0.0000325	(CTUh/person/year)
Human toxicity, non-cancer	Europe	0.000814	(CTUh/person/year)
Ecotoxicity	Europe	5060	(CTUe/person/year)