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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 2006-2012. 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 4 000–5 000 MWh. 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.

Keywords: Capital goods, waste, incineration plant, environmental impact assessment.

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.

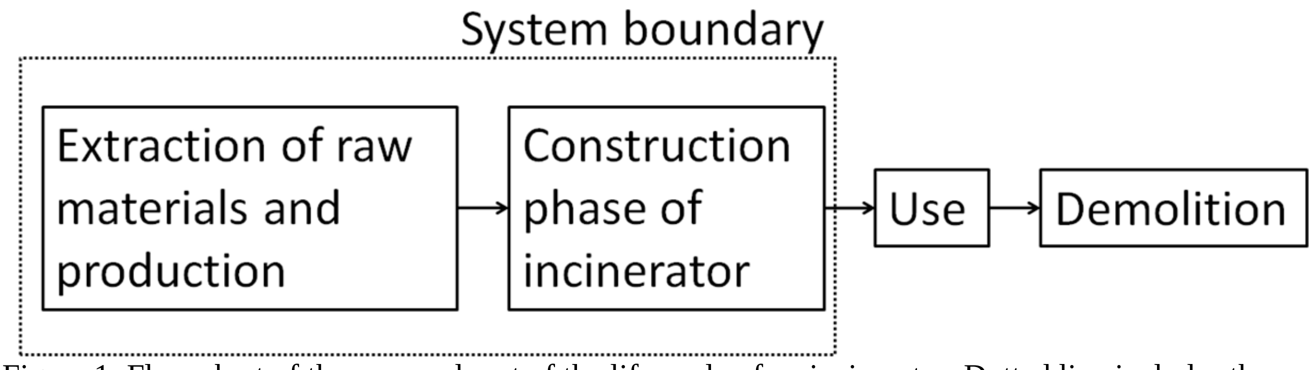

Figure 1: Flow chart of the assessed part of the life cycle of an incinerator. Dotted line includes the system boundary for the environmental impact assessment. All inputs of transport and energy are included within the system boundary.

2. Approach and method

To quantify the materials and energy consumption used for the construction of modern incinerators, data for five Scandinavian incineration plants were collected. Extraction and production of materials and the construction of the incinerator were assessed in this paper, see Figure 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 (six 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 (EDIP) 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 (PE). 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.

Table 1: Environmental impact categories and the normalisation references used for the assessment (Stranddorf *et al.*, 2005; 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	[m² 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	59700	[m².ppm.hr/person/year]
Photochemical ozone formation – impacts on human health	Europe	2.84	[m².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]

Table 2: Details of the five incinerators.

	Waste capacity	**Flue gas cleaning system**	**Electricity prod. capacity**	**Heat prod. capacity**	**Annual electricity production**	**Annual heat production**	**Annual steam production**
	[t/year]	[type]	[MW]	[MW]	[GWh]	[GWh]	[GWh]
Incinerator A	72000	Semi-dry	-	-	50	100	50
Incinerator B	120000	Wet	12	33	95	100	-
Incinerator C	160000	Semi-dry	15	45	80	180	-
Incinerator D	180000	Semi-dry	18	43	135	320	-
Incinerator E	240000	Semi-dry	20	57	160	490	-

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 GWh electricity per year and 100–490 GWh heat per year. Incinerator A, producing only 50 GWh of electricity per year, also produces 50 GWh steam per year for an adjacent industry.

The machinery (furnace, boiler, energy systems, flue gas cleaning system and auxiliary systems) for the different plants was assumed to be similar, though the suppliers of the machinery parts were different. Semi-dry flue gas cleaning systems are found at all plants except Incinerator B, where a wet flue gas cleaning system is employed. Semi-dry and wet flue gas cleaning systems are similar in terms of material use, except for the use of fibreglass reinforced plastic in a wet system.

4. Results

The results are divided into two parts; quantification of the materials and energy consumption for the construction, and an environmental impact assessment of the material production and the construction phase.

4.1 Capital goods (materials and energy use) for construction of incineration plants

The construction of the incineration plants was divided into four parts in order to ease the understanding of the data collected and organise the inventory data. The data for the four parts are presented in Tables 3 and 4.

It was not possible to obtain all data for all parts at all plants due to confidentiality. The data presented represents five plants with different capacities. Three datasets for the machinery and four datasets for the buildings were quantified.

4.1.1 Buildings

The total size of the facades of the buildings was equal, despite the different architecture. The amount of glass depends on the different designs of the facades. Data about the building was not available for Incinerator A. Incinerator B was built on steel foundation piles on rocks and the consumption of steel (372 tonnes) was therefore higher for this plant than for the others. The concrete consumption was higher for Incinerator B due to the large foundations, a large bunker and staircases in concrete. Incinerator C was built directly onto the rock and had thereby no piles in the ground. Incinerator C includes a very large bunker and more concrete was used than normally needed. Incinerator D is an addition to an existing plant, which explains why the total amount of concrete was lower than for the other plants, even though the foundations were concrete piles in the ground.

4.1.2 Machinery

In this context, machinery is defined as furnace, boiler, energy systems, flue gas cleaning system and auxiliary systems, all primarily of steel (when weight is considered). The parts of the machinery were specified in the load plans, see Table 5. Boiler tubing and supporting steel structures for the boiler are the heaviest parts of the boiler system. The turbine generator set and turbine foundation spring element (concrete) are the heaviest parts in the turbine system. For the flue gas cleaning, stack, fabric filter system, induced draft fans and silos for lime, activated carbon and ash are the heaviest equipment. The total weight of all machinery varies from 1968 to 2672 tonnes. The weights of the turbine and boiler for Incinerator A were lighter than the other plants due to the lower capacity of this plant. The weights of the flue gas cleaning systems vary from 75 to 275 tonnes depending mainly on the plant size and cleaning technology. The turbines were in the range of 119–261 tonnes also mainly depending on size. Data about machinery weight was not available for Incinerators D and E.

4.1.3 Energy

The energy consumption at the construction site depends on the climate of the country where the incinerator is built. In a cold region, heating is needed for the building during the winter period. The energy consumption at the construction site includes: diesel for machinery, heating for buildings and site accommodation, and electricity for cranes. Consumption is measured by different partners at the construction sites and data are therefore not easy to collect.

Records for electricity consumption during construction were provided for this study by the plant management of a new plant being built in Sweden. Construction work was planned to last 30 months and the capacity of the plant is 160 000 tonnes of waste per year with a thermal capacity of 78 MW CHP. The total electricity consumption during the 30 months of construction was estimated to be approximately 4700 MWh electricity (Filborna, 2012). As the construction was scheduled to end after the end of the data collection, the consumption of electricity was estimated for the remaining part of the construction period based on observations from the first period of two years.

Table 3: Materials used for the building and machinery at five incinerators with an operational time of 30 years.

		Incinerator						
		A	**B**	**C**	**D**	**E**	**Other parts**	**Lifetime per unit**
Capacity at 12 GJ/tonne	[t/year]	72000	120000	160000	180000	240000		[years]
Building								
Facade elements	[m^2]	-	7500	10300	10930	17700		30
Facade glass	[m^2]	-	3000	1000	370	1300		30
Glass facade	[t]	-	30	10	3.7	13		
Facade total	**[m^2]**	**-**	**10500**	**11300**	**11300**	**19000**		
Concrete facade	[t]	-	-	-	374	-		30
Concrete	[t]	-	45600	45600	17300	26400		30
Piles (Concrete)	[t]	-	-	-	5011	-		30
Concrete total	**[t]**	**-**	**45600**	**45600**	**22685**	**26400**		
Steel (pile)	[t]	-	372	-	-	-		30
Steel (structural)	[t]	-	1000	1150	900	1300		30
Steel (reinforcement)	[t]	-	2150	2150	1100	1400		30
Steel total building	**[t]**	**-**	**3522**	**3300**	**2000**	**2700**		
Machinery fibreglass								
Fibreglass for a wet flue gas cleaning system	[t]	-	105	-	-	-		10
Machinery steel								
Flue gas cleaning	[t]	275	199	78	-	-		30
Turbine	[t]	119	256	261	-	-		30
Boiler	[t]	2135	2837	3272	-	-		20
Grate/furnace	[t]	906	906	906	-	-		5
Steel total machinery	**[t]**	**3436**	**4199**	**4518**	**-**	**-**		
Other components (Steel)								
District heating system	[t]						21	30
Pipes	[t]						73	30
Emergency water tank	[t]						25	30
Shredder	[t]						27	30
Shredder hydraulic system	[t]						5	30
Shredder control cabinet	[t]						0	30
Summer cooler	[t]						102	30
Summer heat exchanger	[t]						10	30
Steel total "other"	**[t]**						**263**	
Other components (concrete)								
Turbine foundation spring element	[t]						421	30

(concrete)								
Concrete total "other"	**[t]**						**421**	
Transport	[km]	300	300	300	300	300	300	-
of materials for machinery and buildings	[1000 tkm]	1031	16037	16028	7407	8734	205	-

Table 4: Materials used for control and monitoring system (CMS), high voltage components (HVCs) and other parts at the incinerator site. Amounts given for an operational time of 30 years of the plant.

Parts	**Unit**	**Amount per lifetime**	**Total weight**	**Lifetime per unit**
Control and monitoring system (CMS)			[tonnes]	[years]
Screens 24"	[pcs]	60	0.24	10
Computers/PCs	[pcs]	24	0.26	10
Server	[pcs]	39	0.43	10
Switch	[pcs]	72	0.79	10
CMS electronic cards	[pcs]	3600	11.74	10
CMS instruments	[pcs]	1050	3.42	10
Optical fibre cable	[m]	6000	4.80	10
High voltage components (HVCs)				
Transformer	[pcs]	6	6.00	20
Motor	[t]	135	135.00	20
Cables	[m]	240000	9.65	20
Cable ladder	[m]	1000	2.50	30
Breaker panel	[m]	68	0.003	20
Panel instruments/electronics	[pcs]	300	0.98	20
Frequency converter 100 kW	[pcs]	113	0.37	20
Generator 15 MW	[pcs]	1	207.00	30
Diesel generator 1.5 MW	[pcs]	1	0.60	30
Other parts				
Weighbridge	[pcs]	6	295.24	10
Diesel consumption for clearing the site	[l]	4000	3.33	-
Asphalt	[m^2]	6000	403.20	30
Fences	[m]	2880	26.13	10
Gates	[pcs]	12	3.42	10
Transport				
Distance "CMS/HVC"	[km]	300		
of CMS/HVC	[1000 tkm]	115		
Distance "Other parts"	[km]	100		
of "Other parts"	[1000 tkm]	73		

4.1.4 Control and Monitoring System (CMS)

Besides control and monitoring equipment, the CMS also covers, in this context, the high voltage components (HVCs). The CMS includes computers, screens, servers, switches and data cables. The lighting and cables used in offices were not quantified due to the lack of available data. The HVCs include transformers, motors, cables and cable ladders, breaker panels and generators. All components are presented in Table 4 and represent the need of CMS and HVC systems in an average plant with a capacity of 72 000–240 000 tonnes of waste per year.

4.1.5 Materials per tonne of waste combusted

Table 6 presents the use of materials per tonne of waste combusted. Incinerators A, B, C, D and E are all assumed to have a lifetime of 30 years. The data for the incinerator from Ecoinvent are included for comparison. The lifetime of this incinerator is 40 years. Concrete was found to be the material used in the largest amount (4–13 kg/tonne of waste) both in this study and in the dataset found in the Ecoinvent database (12.5 kg/tonne of waste combusted). The total amount of materials used is equal for Incinerator B (15 kg/tonne of waste combusted), Incinerator C (12 kg/tonne of waste combusted) and the Ecoinvent incinerator (14 kg/tonne of waste combusted). Only concrete and steel is covered by Ecoinvent and the similarity in totals could be due to the low weight of the additional parts in the present study (e.g. the CMS). The amounts of materials used for the bunker and the foundations do not differ significantly among the assessed plants and thus, the use of materials per tonne of waste combusted is lower for the larger plants.

Table 5: Main parts included in the boiler system, turbine system and flue gas cleaning system.

Boiler system	Turbine system	Flue gas cleaning system
Boiler	Baseplate oil reservoir	Ash silo
Primary air pre-heater	Condensor	Carbon silo
Slag conveying system, Ram type slag extractor	Gear	Channels
Steel structure for boiler	Glycole heat exchangers	Cooling tower
Waste cranes	Turbine	Fabric bag filter
	Turbine foundation spring element	Induced draft fan
		Lime reactor
		Lime silo
		Platforms
		Selective catalytic reduction (SCR) system
		Silencer support
		Stack
		Staircases
		Walkways

4.2 Environmental impact assessment of capital goods related to incineration

Impacts related to the capital goods used in the construction of five incinerators (Incinerators A–E) are presented in Figure 2. The potential impacts are given in milli person equivalents (mPE) per tonne of waste combusted as “normalised impact potentials”. The impact on Ozone Depletion was not significant and is not shown. The “Building” presented in Figure 2 includes all materials for the buildings, roads around the plant, fences and gates, weighbridge, diesel for clearing the site, transportation of materials and the energy used during construction. The “Machinery” includes the turbine, the boiler including the grate, flue gas cleaning system, CMS, HVCs and the transportation of all machinery. For Incinerator B the machinery also includes fibreglass reinforced plastic for the wet flue gas cleaning system.

Steel used for machinery causes the largest potential impact (31–87%) on all impact categories (Figure 2). This is due to the high energy consumption during production of the steel. The use of structural steel also makes a significant contribution (8–25%) to all impact categories. The contribution from electricity consumption during construction was minor (0.04–8%) for all potential impact categories. The CMS contributed in the range of 5–45% to the total impact in all categories. Transportation of materials for machinery and building contributed less than 8% to all the impact categories.

Incinerator B has larger impacts for all impact categories than the other plants (Figure 2). This was caused by a smaller capacity and thereby higher impact per tonne of waste combusted than the other plants. Another factor determining the larger impacts for Incinerator B is the fibreglass reinforced plastic used for the wet flue gas cleaning system. Despite having the smallest boiler, Incinerator A has the largest impacts per tonne of waste from the machinery compared to Incinerators B and C; this is due to the lower capacity of Incinerator A.

Table 6: Use of materials presented as kg per tonne of waste incinerated for the individual incineration plants over 30 years. * Ecoinvent dataset for "Municipal waste incineration plant" with an operational time of 40 years (Ecoinvent, 2012). CMS: Control and monitoring system. HVCs: High voltage components.

	Incinerator					
	A	**B**	**C**	**D**	**E**	**Ecoinvent**
	[kg/tonne of waste]	[kg/tonne of waste]	[kg/tonne of waste]	[kg/tonne of waste]	[kg/tonne of waste]	[kg/tonne of waste]
Building						
Concrete total		12.67	9.50	4.20	3.67	
Steel total building		0.98	0.69	0.37	0.38	0.98
Total glass		0.008	0.002	0.001	0.002	
Machinery						
Fibreglass		0.03				
Machinery steel	1.59	1.17	0.94			0.02
CMS and HVCs	0.18	0.11	0.08			
Others						
Other steel		0.08	0.06	0.05	0.04	
Other concrete		0.20	0.15	0.13	0.10	
Asphalt		0.11	0.08	0.07	0.06	
Concrete cement						1.25
Concrete gravel						8.75
Bitumen						0.20
Sand						2.50
Total	**2**	**15**	**12**	**5**	**4**	**14**

Large potential impacts were found for Human Toxicity related to cancer and Resource Depletion (Figure 2). The large impacts were a consequence of the use of metals for the CMS and the use of steel for machinery. The potential impact on GW was 0.9–1.8 mPE per tonne of waste combusted. Larsen and Astrup (2011) reported 27–40 kg CO_2 per GJ energy content of the residual household waste incinerated. With energy content of 12 GJ per tonne the direct emission would be 324–480 kg CO_2 per tonne of waste combusted. Emissions related to the capital goods of 7–14 kg CO_2 per tonne of waste combusted was thereby 2–3% of the total emissions from the operation and capital goods.

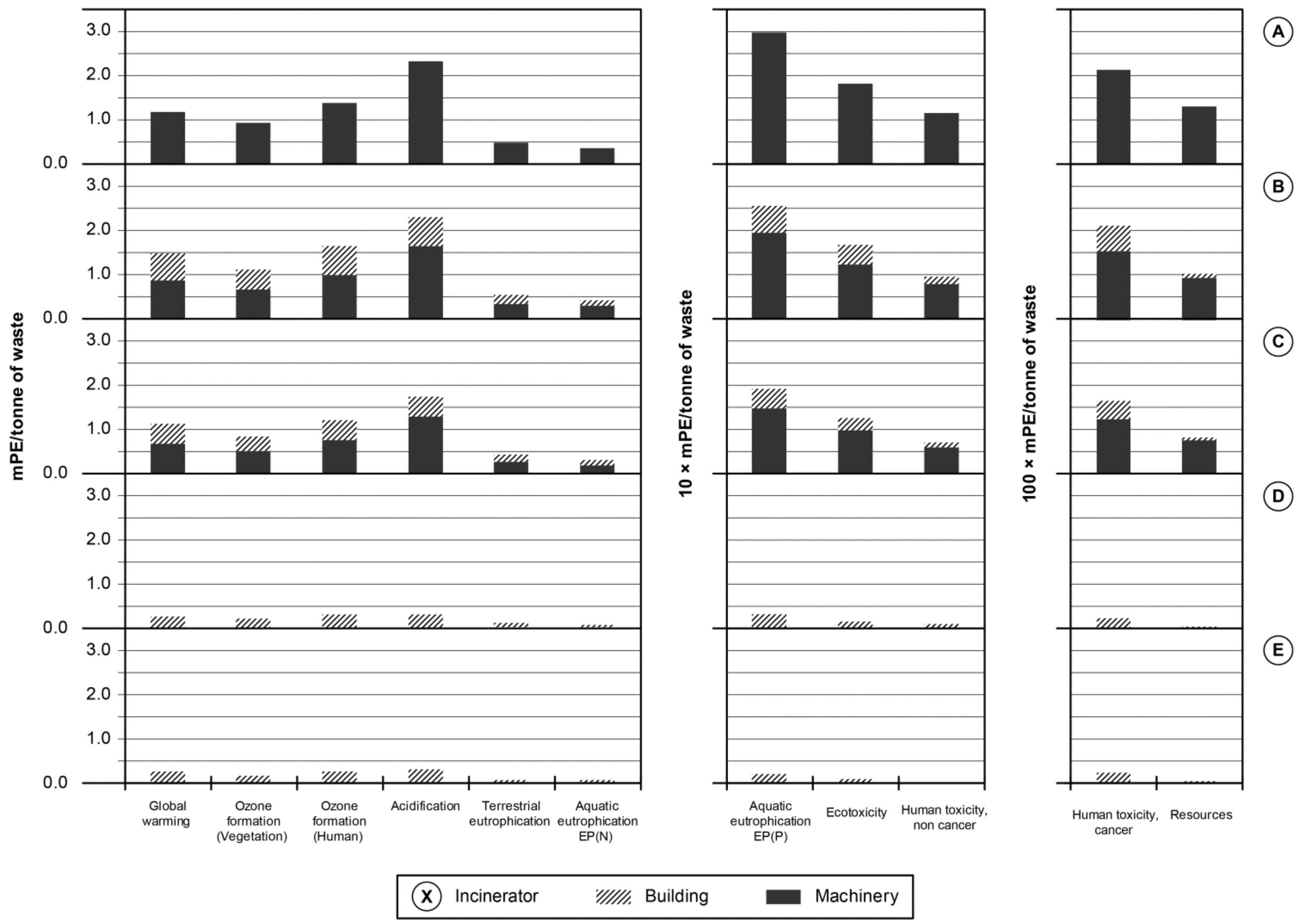

Figure 2: Contribution of Incinerators A–E to EDIP impact categories (non-toxicity impact categories), USEtox impact categories on Human Toxicity related to cancer and non-cancer and Ecotoxicity from the construction of the assessed incinerators.

5. Discussion and uncertainty assessment

Thorough data collection was carried out to give the best possible picture of materials and energy needed for construction of incineration plants. These data are more detailed and better described than any other data published before. Earlier studies have either given guestimates or are aggregated data and not well documented. The data given in this paper shows that resources used should be included in future life cycle assessments of incineration plants. Especially the use of metals and steel for machinery were important to consider. Impacts caused by the full life cycle of capital goods will depend on the choices made in the disposal phase. Depending on the disposal processes chosen impacts will be less, if all materials are recycled.

Not all parts of the five plants are included in this study but the data presented provide a fair estimate of the amounts of materials needed for the different components of an incinerator. From these data it is possible for the reader to estimate the use of materials needed for other incineration plants with different capacities.

Average capacities for the incinerators were used to present the data per tonne of waste combusted. The actual amount of waste incinerated per year may vary substantially for an incinerator. It is, however, believed that, during the lifetime of an incinerator, the average capacity is reached.

The electricity consumption contributed 6% to the total impact on GW for Incinerator B. Incinerator B was used because it represents a full dataset. Data for the electricity consumption during construction work were only reported from one construction site and other energy sources were not reported. This means that additional energy consumption would change the environmental impacts caused by the construction work for Incinerators B, C, D and E.

The available data represents the materials used in the greatest quantities. This means that minor, but important materials were not well represented. An example is the rare earth metals used for electronics. These were not covered due to the limited data on the specific electronic equipment.

Table 7 presents the data from Ecoinvent (Ecoinvent, 2012) used for the assessment in this paper. We believe these data are relevant for the study and that they are of good quality. The data quality was assessed by the pedigree matrix used by Weidema and Wesnæs (1996) and was found to be sufficient for the study. The processes are presented in Table 7 to allow the reader to use the same data or change it for another assessment.

The results were also largely influenced by the time frame. By extending the lifetime of Incinerator B (as an example) from 30 years to 40 years the impacts per tonne of waste combusted would decrease by 5–12%. The decrease is determined by the increased amount of waste being processed together with the longer lifetime of the main parts of the capital goods (concrete and structural steel).

Table 7: Material processes used in modelling the environmental profile of the capital goods. UCTE: Union for the Coordination of the Transmission of Electricity

Material name	Type	Stage	Geographical area	Reference
Building and machinery				
Concrete	Normal	At plant	Switzerland	Ecoinvent, 2012
Steel	Low alloyed	At plant	Europe	Ecoinvent, 2012
Flat glass	Coated	At plant	Europe	Ecoinvent, 2012
Electricity	High voltage, UCTE	At grid	Europe	Ecoinvent, 2012
Chromium steel	18/08	At plant	Europe	Ecoinvent, 2012
Fibreglass reinforced plastic	Polyamide, injection moulding	At plant	Europe	Ecoinvent, 2012
Roads	Company, internal		Switzerland	Ecoinvent, 2012
CMS				
LCD flat screen	17 inches	At plant	World	Ecoinvent, 2012
Desktop computer without		At plant	World	Ecoinvent, 2012
Printed wiring board	Mounted, desktop	At plant	World	Ecoinvent, 2012
Cable, data cable in		At plant	World	Ecoinvent, 2012
Copper	Primary	At refinery	World	Ecoinvent, 2012
Chromium steel	18/08	At plant	Europe	Ecoinvent, 2012
Diesel-electric generating set	10MW	-	Europe	Ecoinvent, 2012
Cables				
Copper	Primary	At refinery	World	Ecoinvent, 2012
Polyvinylchloride resin (B-PVC)	Bulk polymerisation	At plant	Europe	Ecoinvent, 2012
Limestone	Milled and packed	At plant	Switzerland	Ecoinvent, 2012
Dimethyl p-phthalate			Switzerland	ETH-ESU, 1996
Electricity	High voltage, UCTE	At grid	Europe	Ecoinvent, 2012
Transport				
Lorry	>32t, EURO5		Europe	Ecoinvent, 2012
Lorry (Operation)	16–32t, EURO3		Europe	Ecoinvent, 2012
Lorry	16–32t, EURO5		Europe	Ecoinvent, 2012

6. Conclusion

Capital goods in terms of buildings and machinery used for waste incineration were quantified and presented. Inventory data included the buildings of four incinerators and machinery for three incinerators. Very detailed data was provided in this study which allows the reader to produce inventories for other incineration plants. Concrete was the material used in the greatest quantities.

An environmental impact assessment showed that the steel used for the machinery and structural steel for the buildings were the materials contributing the most to all potential impact categories.

The buildings contributed 0.2–0.6 mPE per tonne of waste combusted to the impact on GW and the machinery contributed 0.7–1.2 mPE per tonne of waste combusted. Following Larsen and Astrup (2011), the potential impact on GW from the direct emissions was calculated to be 324–480 kg CO_2 per tonne of waste combusted. The emissions related to the capital goods of 7–14 kg CO_2 per tonne of waste combusted was thereby 2–3% of the total emissions from the operation and the capital goods. The impact on Resource Depletion is considered to be significant for the capital goods for waste incineration.

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