LCA Case Studies

Geographical and Technological Differences in Life Cycle Inventories

Shown by the Use of Process Models for Waste Incinerators

Part I. Technological and Geographical Differences

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Preamble. This paper outlines in two parts to be published in the September and November edition of Int J LCA 2002.

Part I [Int J LCA 7 (5) 295–300 (2002)] prepares the field by defining technological and geographical differences, and by exploring the differences for a case study of four municipal solid waste incinerators.

Part II [Int J LCA 7 (6) 2002] will show the impacts of technological and geographical differences which are intentionally caused for the incinerator plants. The results allow clear recommendations on how to handle technological and geographical differences in future case studies.

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Abstract

Goal and Background. Geographical and technological differences in Life Cycle Inventory data are an important source for uncertainty in the result of Life Cycle Assessments. Knowledge on their impact on the result of an LCA is scarce, and also knowledge on how to manage them in an LCA case study.

Objective. Goal of this paper is to explore these differences for municipal solid waste incinerator plants, and to develop recommendations for managing technological and geographical differences.

Methodology. The paper provides a definition of technological and geographical differences, and analyses their possible impacts. In a case study, the differences are caused intentionally in 'games', by virtually transplanting incineration plants to a different location and by changing parameters such as the composition of the waste input incinerated. The games are performed by using a modular model for municipal solid waste incinerator plants. In each case, an LCA including an Impact Assessment is calculated to trace the impact of these changes, and the results are compared.

Conclusions. The conclusions of the paper are two-fold: (1) reduce the differences in inventory data where their impact on the result is high; where it is possible reducing them to a great extent, and the effort for performing the change acceptable; in the case of incineration plants: Adapt the flue gas treatment, especially a possible DeNOx step, to the real conditions; (2) make use of modular process models that allow adapting plant parameters to better meet real conditions, but be aware of possible modelling errors. The paper invites the scientific community to validate the model used for a waste incinerator plant, and suggest putting up similar models for other processes, preferably those of similar relevance for Life Cycle Inventories.

Keywords: Geographical differences; LCA; LCI; life cycle assessment (LCA); life cycle inventory (LCI); modular model; MSWI; municipal solid waste incinerator (MSWI); technological differences; uncertainty assessment

Introduction

Differences in input data are an important source for uncertainty in the result of Life Cycle Assessment (LCA) studies (ISO 14040). This holds both for whether the differences are caused by inaccurate or for non-representative data. For Life Cycle Inventories, (Huijbregts et al. 2001) propose to subsume the 'lack of representative data' (among others) under the point data uncertainty.

In the LCA context, the differences due to non-representative data are commonly distinguished in geographical, temporal and technological differences (Weidema 1998, Huijbregts et al. 2001).

Potting (2000) established a particular framework for addressing 'spatial differentiation' in Life Cycle Impact Assessment, thus addressing geographical differences. Site and temporal dependence of LCA for Thermal Waste Treatment Processes were considered by Hellweg (2000).

In general, these differences may exist in every input data of the LCA. This text explores possible impacts of geographical and technological differences in processes in LCA, especially in data for municipal solid waste incinerators (MSWIs). The municipal solid waste incinerator plants are modelled with modular process models, thus enabling one to change different aspects of the plants and of the plants' surroundings, and to calculate the impact of these changes for the Life Cycle Inventory. Changing aspects in input data means creating differences in input data. In order to get a picture of the overall impact of these changes on the result of a Life Cycle Assessment, scores according to Eco-indicator 95 (Goedkoop 1995) are calculated from each inventory. The discussion of the results leads up to recommendations for managing geographical and technological differences in data for complex processes in Life Cycle Assessments.

1 Geographical and Technological Differences in Life Cycle Inventories

"The indicator 'geographical correlation' expresses the degree of accordance between the production conditions in the area relevant for the study and in the geographical area covered by the data obtained. The indicator 'further technological correlation' concerns all other aspects of correlation than the temporal and geographical considerations." (Weidema 1998).

Extending a definition given by Weidema et al. (1998), the term 'geographical differences' may be defined as differences between the conditions in the area relevant for the study and in the geographical area covered by the data obtained (**Fig. 1**). Within this definition, conditions may be climate, areas of protection, technological and natural infrastructure like the electric grid power mix, rivers and waterfalls, and so on. Weidema (1998) restricts the definition to production conditions; the extension given here means that not only life cycle inventory, but also impact assessment is directly influenced by geographical differences.

'Technological differences' are defined following Weidema (1998) as all other aspects of differences in data than covered by temporal and geographical considerations (**Fig. 2**). The change in terminology (from correlation to differences) facilitates the task: To state a difference, two data points are sufficient; to state a correlation, several data points are required.

Temporal aspects will not be dealt with in this text, we limit our analysis to non-dynamic, traditional LCAs, and, both geographical and technological differences are restricted to the Life cycle inventory phase. That means, differences in impact assessment data are out of scope for this text[1]. By doing so, we assume that the influences in LCI and Life Cycle Impact Assessment (LCIA) are rather independent from each other. If they are independent indeed, there is not a direct compensation in impact assessment for high (or low) differences in inventory. From that follows, that having fewer differences after performing the inventory means having fewer differences after performing the impact assessment, and benefits by reducing differences are therefore already visible if looking at the inventory alone.

Technological and geographical differences are not independent. A change in the geographical setting may implicitly include a change in technology used for example in an MSWI plant, and, may be less common, a change in the technology may implicitly result in a different geographical setting. An example for the latter is an incineration plant that has a dry gas cleaning in a region with water shortages, and a wet gas cleaning elsewhere. Because a dry gas cleaning in general works less efficiently than a wet gas cleaning, the change in geography may imply a change in the emission data of the plant. Of course, it is not possible to foresee which technological changes exactly occur when changing geography.

[1] An example for geographical differences in impact assessment data would be to use a detailed impact assessment model for an impact of local scale (e.g. a model to assess the human health impacts of airborne pollutants (Nigge 2000, Nigge 2001a, Nigge 2001b), and the local setting used in the model does not fit to the location of the process.

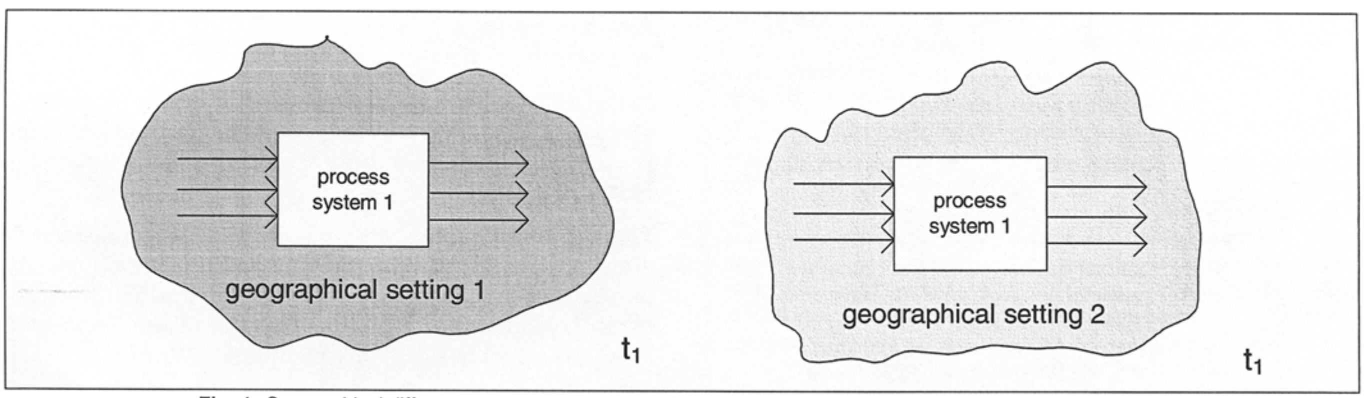

Fig. 1: Geographical differences – a process system in two different geographical settings at a certain time t_1

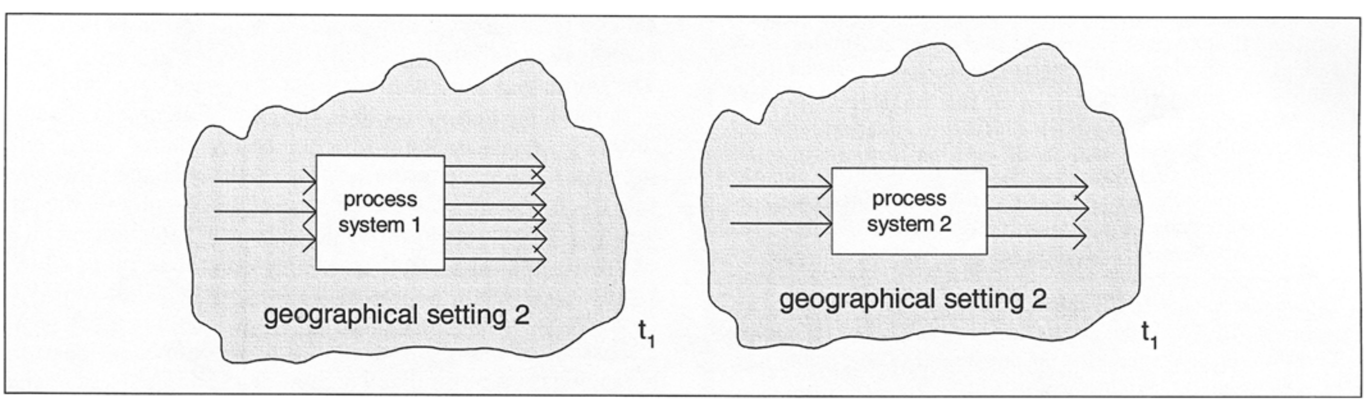

Fig. 2: Technological differences – two different process systems in an identical geographical setting at a certain time t_1

2 Example: Municipal Solid Waste Incineration Plants in LCAs

To explore and assess possible impacts of geographical and technological differences on the result of an LCA, four different types of MSWI plants will be looked at in more detail within this text:

- The MSWI data from the ETH database, representing a technology mix of Swiss and German plants dating from 1987–1995 (Frischknecht et al. 1996, Zimmermann et al. 1996).
- The MSWI plant in Tarragona, Spain (Pänkäläinen 2000, Sonnemann et al. 1998, STQ 1998).
- The MSWI plant in Würzburg, Germany, (Ciroth 1998, Heyde and Kremer 1999, ZVAWS 2000).
- A modular spreadsheet model of a 'state-of-the-art plant' (Hagelüken 2001, Kremer et al. 1998).

Evidently, data for these plants have underlying technological and geographical differences, which will be described in the following after a short description of the principles of MSWIs and their process chain.

2.1 MSWIs: Principles

A municipal solid waste incineration plant (MSWI plant) is a highly complex industrial system, and the number of different technical solutions for MSWIs are countless, e.g. (Thomé-Kozmiensky 1994, GEC 2000). Generally speaking, an MSWI incinerates a common sort of waste, generally household waste from public collection, with the purpose of destroying or separating its dangerous substances, to use its energy and to reduce the volume of wastes to landfills (Thomé-Kozmiensky 1994). The waste may undergo a pre-treatment before it is input in the plant; it may also be mixed and homogenised in the plant prior to passing it to the incineration unit. The municipal waste has to be collected and transported to the plant. Besides the waste, common incineration process inputs are (**Fig. 3**):

- water (for cooling, gas scrubbing),
- air (also for cooling and to provide oxygen for the incineration process),
- electricity (although the MSWI generates electricity itself and, in general, has a net output of electricity),
- auxiliaries (e.g. hydrated lime for flue gas treatment, filtration agency, gas for auxiliary burner, ...).

In the plant, there is usually a waste bunker used to store and homogenise the waste, an incineration unit, an electricity generating unit, and a flue gas treatment unit (cooling, cleaning which may be wet, dry or semi-dry). Units to collect and treat the residues from the incineration and flue gas cleaning processes are also necessary. The treatment may comprise a separation of iron scrap from the ashes, and cleaning/separation processes for the water used in gas cleaning and residue treatment.

Common outputs of the MSWI are:

- flue gas, cleaned,
- waste water (wet flue gas cleaning),
- ashes and slags,
- electricity and district (or process) heat.

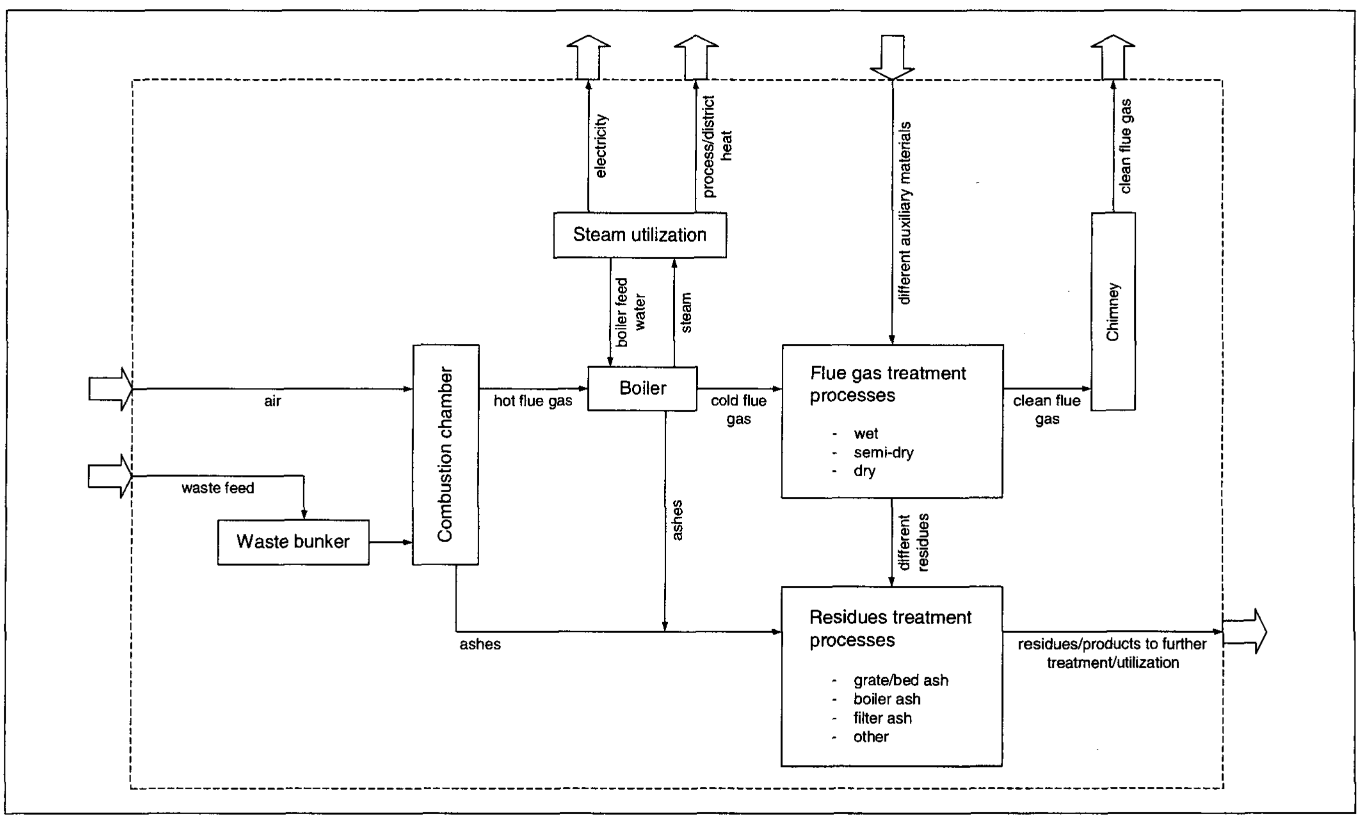

Fig. 3: Main in and output flows, and unit processes of a waste incineration plant

Real plants may deviate from the general characterisations given above, e.g. MSWI plants with dry flue gas cleaning do not cause any waste water and, therefore, have a different composition of inputs and outputs. For different countries, the regulations for waste treatment and incineration may be quite different (ESRS 1999).

2.2 The process chain of MSWIs in LCAs

Municipal Solid Waste Incineration plants commonly appear in product systems of Life Cycle Assessments, due to the fact that MSWIs play an important role in waste management in many countries. However, the relevance within the product system may be very different. MSWIs may be one among several 'end-of-life' processes used for treatment of a certain fraction of wastes in the product system (UBA 2000). Or, they may be the central process in the product system, e.g. if the product under study is the service of treating/incinerating a certain amount of wastes (Ecobilan 1999, VKE et al. 1995). In both cases, upstream and downstream processes for the MSWI should be included in the product system, as done by Sonnemann et al. (1998). Thus, having the MSWI plant as a central process in the product system yields a system that is included like a sub-system also in other life cycles that take the waste incineration process into account. In general, results for the incineration process will have a higher impact on the overall system in the case of the MSWI as a central process, and this text concentrates on this option mainly for this reason.

Hence, within this text, the system to analyse and the boundaries comprise all the processes from the waste disposal in containers via waste incineration to the landfill of the final waste. This system includes the up-stream processes for the main raw materials and all the transport activities as well as the relevant treatments of the residues from the incineration process. It excludes the stop and go of the trucks during the collection of the waste. Due to lack of data, emissions associated to the landfill and infrastructure are not taken into account.

Fig. 4 gives an overview of the processes and the transport distances included in the comparison. As a base scenario for the comparison, the Spanish case (Sonnemann et al. 1998, STQ 1998) is taken. Most transport distances correspond to that situation; estimations were only made for ammonia and activated coke. In Spain the ashes are treated with cement.

In the same way as for the incineration, the situation of the other processes in this industrial chain is also site-dependent, i.e. processes at different locations may have underlying technological and geographical differences. For example, not in all countries the ashes are treated with cement and especially the transportation distances differ from one region to another. However, as this work only investigates the influence of the incinerator models, these processes are not varied in the calculation of the inventories.

The inventories of all upstream and downstream processes are based on the data from Frischknecht et al. (1996) used in the spreadsheet model developed by (Castells et al. 1995) and applied for a waste incinerator process chain by Sonnemann et al. (1998). The added natural gas and ammonia process inventories are also taken from Frischknecht et al. (1996) and the inventory for activated coke (assumed as coke) originates from the BUWAL250 database as presented by the SimaPro 4.0 software (Pré Consultants 2001).

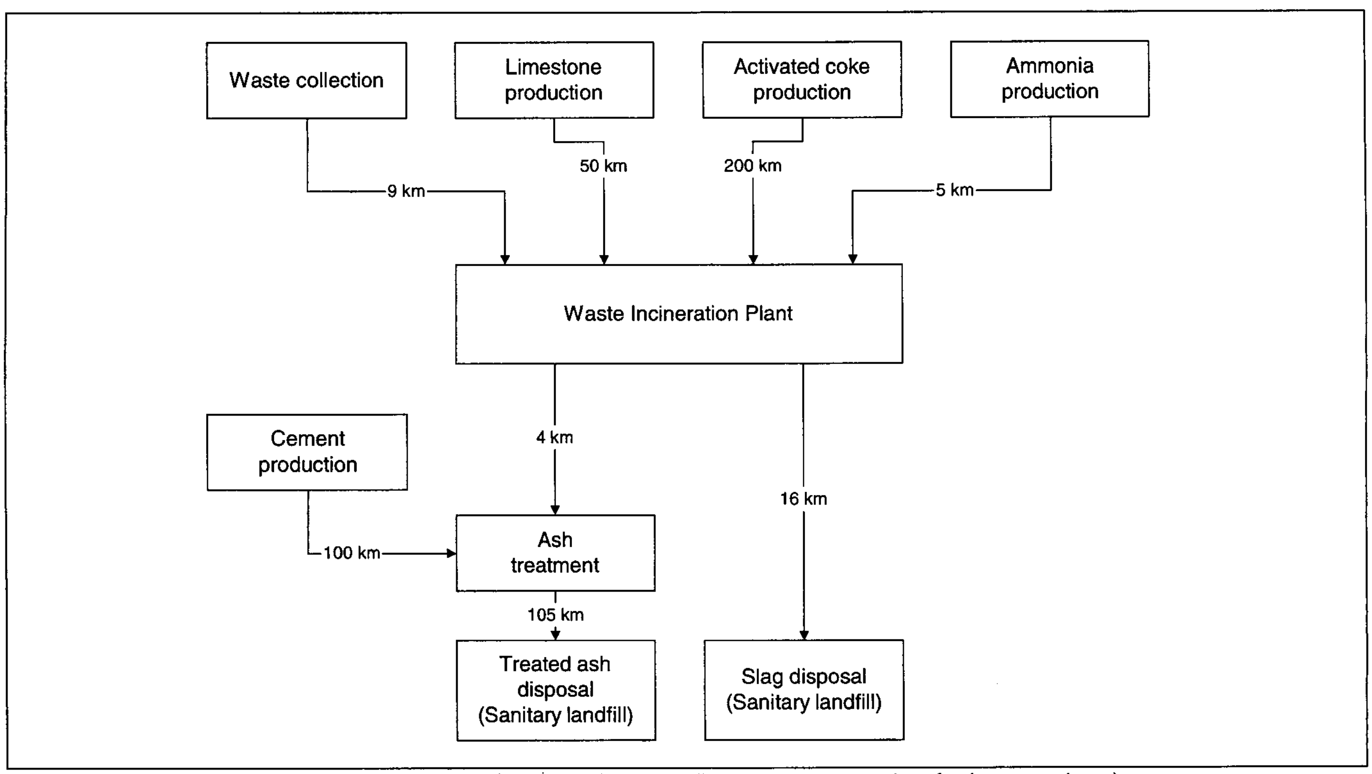

Fig. 4: Process chain of MSWI plants (transport distances are assumptions for the comparisons)

Table 1: Geographical differences of selected MSWI models

Geographical differences	ETH	Tarragona	Würzburg	Hypothetical model
Location	**Switzerland**	**Spain**	**Germany**	**Germany**
Original plant data	Switzerland: St. Gallen and unknown plant Germany: Essen-Karnap, Bamberg, Göppingen	SIRUSA	ZVAW	See (VKE et al.1995)
Inhabitants		113,000	120,000	
Climate		Mediterranean	Moderate	
Origin of waste composition	Elementary composition derived from French, German, Swiss data from 1987 till 1995	(STQ 1998), year 1998	(VKE et al. 1995), year 1992	

2.3 MSWIs – Geographical differences

ETH incinerator model. The ETH database for waste treatment processes (Zimmermann et al. 1996) provides a black box model for solid waste incinerators. For this model, data has been taken from plants of different sources and geographical origins (**Table 1**). The data has been used to calculate combined transfer coefficients which reflect the geographical setting of the examined plants, e.g. the composition of their waste input. The model therefore represents an average between German and Swiss plant data. The elementary waste composition used in the ETH study also has been derived from different sources.

SIRUSA waste incinerator, Tarragona, Spain. Tarragona is situated on the east coast of Spain, approximately 100 kilometres south-east of Barcelona. The average fractions of the remaining waste are shown in **Table 2**.

ZVAWS waste incinerator, Würzburg, Germany. Würzburg is in the northern part of the province of Bavaria in Germany. The average fractions of the waste are shown in Table 2.

Hypothetical state-of-the-art plant, Germany. The hypothetical state-of-the-art plant is based on a model described in 1998 by Kremer et al. (1998) assuming "the technical state of the art for modern municipal waste incineration plants in Germany". Kremer et al. (1998) derive the state of the art from legal requirements[2] that have to be fulfilled by incinerators as well as from the requirement to provide a technology ready for different waste compositions and prepared for future changes. Thus, the model has no specific geographical setting except legal conditions valid for Germany and empirical data from German plants.

Table 2: Waste compositions in (in weight-%) for Würzburg, Germany (year 1992, according to VKE 1995) and Catalonia, Spain (year 1998, according to STQ 1998)

Fraction	Würzburg	Tarragona
Organics	35%	46%
Paper and cardboard	9%	21%
Plastics	11%	13%
Glass	3%	9%
Metals	2%	3%
Textiles	3%	–
Fine	18%	–
Misc. combustibles	16%	–
Misc. non-combustibles	3%	–
Ceramics	–	2%
Soil	–	1%
Others	–	5%
	100%	100%
Humidity	28%	35%
Calorific value	11023 kJ/kg	8230 kJ/kg

2.4 MSWIs – Technological differences

Apart from the geographical differences, the MSWIs differ also in technical aspects.

ETH incinerator model. The ETH model given by Zimmermann et al. (1996) is derived from different plant data. For calculation, the process data are combined to a single set of coefficients according to the technology mixture of the Swiss incinerators. Hence, the black box model represents the spectrum of incinerators in use in Switzerland, but data from Germany also has been used for calculating transfer coefficients.

SIRUSA and ZVAWS waste incinerator. The data on the SIRUSA plant has been taken from STQ (1998) and Hagelüken (2001). Information on the ZVAWS plant was available from ZVAWS (2000). In contrast to the Würzburg plant, the plant in Tarragona has a semi-dry flue gas cleaning (Würzburg: wet flue gas cleaning), and it has no DeNOx-step in the flue gas cleaning process (Würzburg: Selective catalytic reduction module to reduce NO_x to N_2, H_2O and CO_2 with added ammonia).

Hypothetical model. The basic version of this model represents a hypothetical state-of-the-art MSWI. The plant layout is similar to the Würzburg plant. However, the flue gas cleaning comprises a wet gas scrubbing in two stages, and the firing temperature is higher than in Würzburg. The model itself will be described in more detail in the next section.

2.5 A modular process model for MSWIs

On the basis of the model described by Kremer et al. (1998) and a spreadsheet version by Ciroth (1998), a modular steady-state process model with several enhancements has been created by Hagelüken (2001). The Microsoft-Excel based model considers the elementary waste input composition and important plant data, such as plant layout and process specific constants.

In the model, the steam generator consists of grate firing and heat recovery system, and a regenerative air pre-heater. Energy production is calculated using the heat value of the waste input and the state points of the steam utilisation process. For the macro elements (C, H, N, O, S and Cl, F), the flue gas composition is determined by simple thermodynamic

[2] Most of these defined in the German decree 'Verordnung über Verbrennungsanlagen für Abfälle und ähnliche brennbare Stoffe – 17. BImSchV', November 23rd, 1990. Storage of the waste, firing process, threshold values, disposal of residues, and usage of produced heat are regulated.

calculation of the combustion, taking excess air into account. The heavy metals, however, are calculated on the basis of transfer coefficients (Kremer et al. 1998). Emissions of CO and TOC depend on the amount of flue gas. For the emissions of NO_x and PCDD/F, empirical formulas are used. Due to the fact that acid forming substances like S, Cl, and F are partly absorbed by basic ash components, the total amount of SO_2, HCl, and HF in the flue gas is reduced respectively. The flue gas purification consists of an electrostatic precipitator, a two stage gas scrubber for the removal of acid gases (using NaOH and $CaCO_3$ for neutralization), a denitrogenation unit (selective catalytic reduction using NH_3) and an entrained flow absorber with active carbon injection for the removal of dioxins and heavy metals. The plant is of the semi-dry type, all waste water is evaporated in a spray dryer after the heat exchanger.

The processes and calculations are distributed to several MS-Excel workbooks. The processes represented by the workbook files are linked by their input/output sheets. The division into workbooks and their major dependencies are shown in **Fig. 5**.

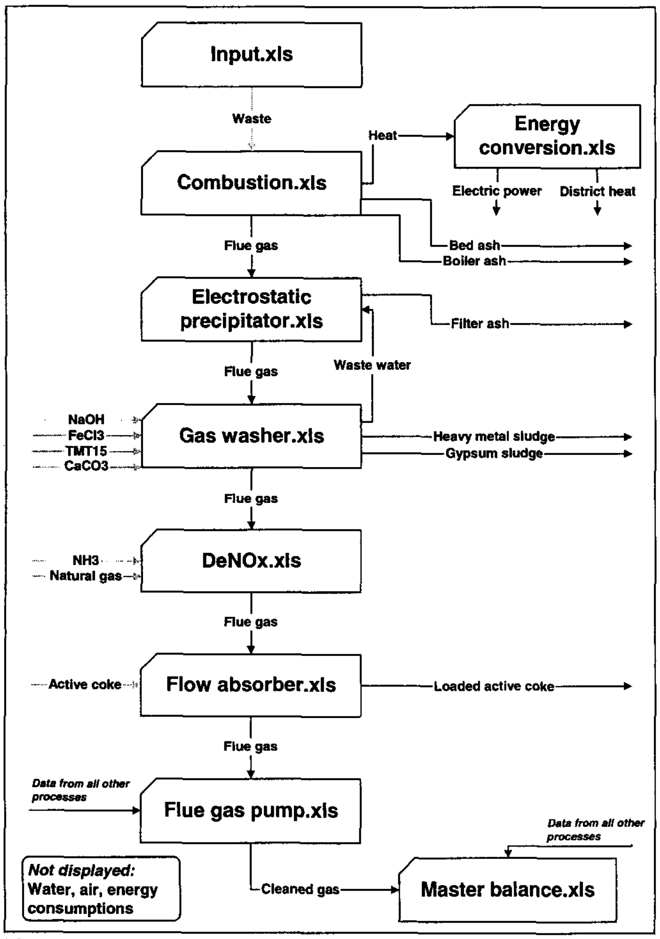

Fig. 5: Workbook structure of the modular spreadsheet model. Major dependencies, some energy and material flows are also shown

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