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DETERMINING NATIONAL GREENHOUSE GAS EMISSIONS FROM WASTE TO ENERGY USING THE BALANCE METHOD

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SUMMARY: Different directives of the European Union require operators of waste-to-energy (WTE) plants to report the amount of electricity that is produced from biomass in the waste feed, as well as the amount of fossil CO_2 emissions generated by the combustion of plastics. This paper describes the application of the Balance Method for determining the overall amount of fossil and thus climate relevant CO_2 emissions from waste incineration in Austria. Results of 10 Austrian WTE plants (annual waste throughput of around 2 million tons) demonstrate large seasonal variations in the specific fossil CO_2 emissions of the plants as well as large differences between the facilities (annual means from 34 ± 2 to 51 ± 3 kg fossil CO_2/GJ heating value). A total annual amount of around 850,000 tons of fossil CO_2 for all 10 WTE plants has been determined. In comparison biogenic (climate neutral) CO_2 emissions amount to 1,000,000 tons/a, which corresponds to 53 % of the total CO_2 emissions. The overall amount of energy input to the 10 facilities was about 18,000 TJ/a, from which 46.8 % stems from biogenic material.

1. INTRODUCTION

Different directives of the European Union (e.g. EU directive 2003/87/EC, EU directive 2001/77/EC) require operators of waste-to-energy (WTE) plants to report the amount of electricity that is produced from biomass in the waste feed, as well as the amount of fossil CO_2 emissions generated by the combustion of plastics. The latter is of importance with respect to the European Emissions Trading System, as some European countries such as Denmark or Sweden have already included waste incineration plants into the Emission Trading scheme. In most other countries these facilities are excluded from emission trading. Nevertheless for national greenhouse gas inventories fossil CO_2 emissions from WTE plants are to be considered in any case.

Up to recently the standard method for determining fossil CO_2 emissions from waste incineration was sorting of wastes into defined fractions of fossil and biogenic components and determining the carbon content of these fractions (details of the sorting analysis are found in EN 15440:2011). From this the share of the fossil CO_2 emissions can be calculated. This practice however is labor and cost-intensive and of limited reliability. The major reasons behind the limited significance of sorting analysis are:

- difficulties with respect to visual differentiation between biogenic and fossil organic matter (e.g. textiles),

- large share of composites, which can hardly be separated (e.g. hygienic articles, packaging materials), and
- the large waste quantities (serval tons) to be sorted several times per year in order to obtain representative results and to account for seasonal changes in waste composition.

In the recent years an alternative method for determining the biomass content in the feed of WTE plants has been developed. The approach, called Balance Method, is based on standard operating data derived routinely from incinerators (e.g. volume of flue gas, O_2 and CO_2 concentration in the flue gas, steam production, amount of solid residues). These data are combined with information about the chemical composition of (moisture and ash-free) biogenic and fossil matter, which subsequently allows determining the amount of biogenic and fossil organic matter in the waste feed. Based on this information the amount of fossil CO_2 emissions can easily be calculated. The advantages of the Balance Method are: known uncertainty range of the results, temporal resolution of the results down to hourly mean values, low implementation and virtually no permanent costs.

In the present study the Balance Method has been applied to operating data of all Austrian WTE plants in order to determine the total fossil and thus climate relevant CO_2 emissions from waste incineration in Austria. The results are required for the national greenhouse gas inventory.

2. MATERIALS AND METHODS

2.1 Balance Method

The Balance Method combines data on the chemical composition of biogenic and fossil organic matter with routinely measured operating data of the incineration plant. The method is based on five mass balances and one energy balance, whereby each balance describes a certain waste characteristic (e.g. content of organic carbon, heating value, ash content) (Figure 1 - right side). For setting up the theoretical balances, the waste is virtually divided into four “material groups”: inert (m_I), biogenic and fossil organic materials (m_B, m_F) and water (m_W). Inert materials include all incombustible solid residues like glass, stones, ashes or other inorganic matter from biowaste and plastics (e.g. kaolin in paper). Biogenic and fossil organic material groups refer only to the moisture- and ash-free organic matter (see Figure 1 - left side). As the qualitative composition of organic materials in the waste is usually well known (e.g. biogenic matter encompasses paper, wood, kitchen waste, etc. and fossil organic matter includes PP, PE, PET, PVC, etc.) the content of C, H, O, N, S and Cl of the biogenic and fossil organic materials (m_B and m_F) is easily derivable.

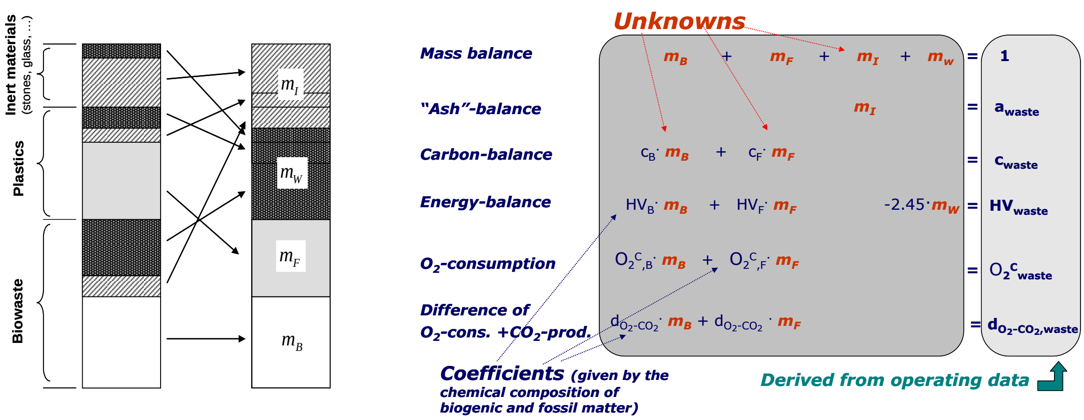

Figure 1. Left side: Split-up of waste fractions into the four “material groups” (m_B, m_F, m_W, and m_I); right side: simplified set of equations of the Balance Method (Staber et al., 2008).

Each balance equation encompasses a theoretically derived term (left side of equations) that has to be attuned to measured data of the plant (right side of equations). A simplified structure of the set of equations is illustrated in Figure 1 (right side). A detailed mathematical description of each equation is given in (Fellner et al., 2007). The input data required for the Balance Method are summarized in Figure 2. Besides information about the chemical composition of moisture and ash-free biogenic and fossil organic matter, information about the quantity of fuels incinerated (waste mass and auxiliary fuels), the amount of solid residues and steam produced, as well as data about the volume and composition of the flue gas are required.

Because the system of equations (set of constraints) used within the Balance Method is over-determined (6 equations for 4 unknowns), data reconciliation is performed to improve the accuracy of the results. The improved values are used to calculate the unknown quantities (m_B, m_F, m_W, and m_I) including their uncertainties. Inserting these results into the carbon balance, allows determining the amount of fossil CO_2 emissions.

Prior to solving the set of equations for calculating the single mass fractions, the input data (operating data of the plant) are checked regarding their plausibility. Thereto, existing correlations between the flue gas and the steam production are used (e.g. during the combustion of organic matter the consumption of 1 mole O_2 corresponds to an energy generation of 360 to 400 kJ; and the combustion of 1 g organic carbon produces a heat amount of 34 up to a maximum of 44 kJ). The calculations according to the Balance Method are only performed with plausible data, whereby the temporal resolution of the data used is preferably in the range of hourly averages for most input data.

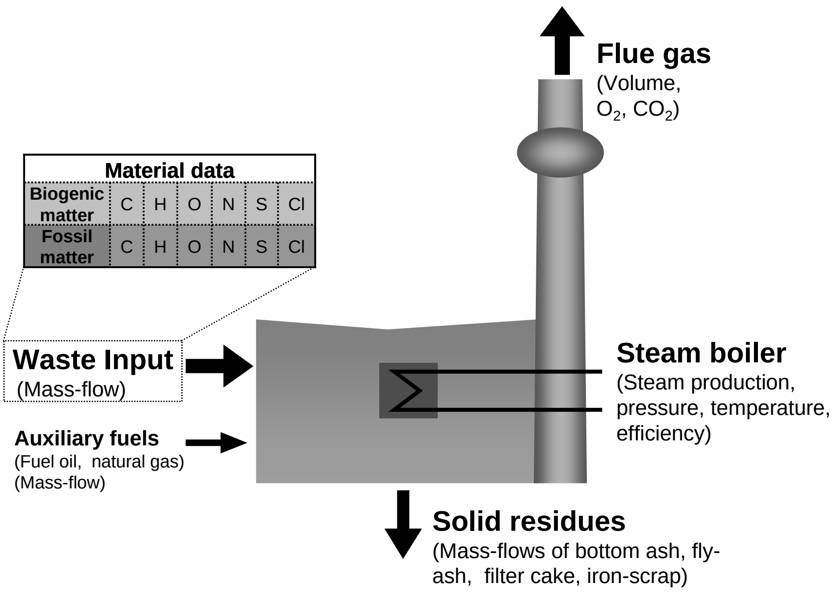

Figure 1. Required input data for the Balance Method.

The analysis algorithm of the Balance Method, including the plausibility check of the input data, has in the meantime been implemented into the software BIOMA (http://iwr.tuwien.ac.at/ressourcen/downloads/bioma.html), which allows determining the biomass content of the waste feed and thus also the amount of fossil CO_2 emissions for any time period required. A print screen of the user interface of BIOMA is given in Figure 3.

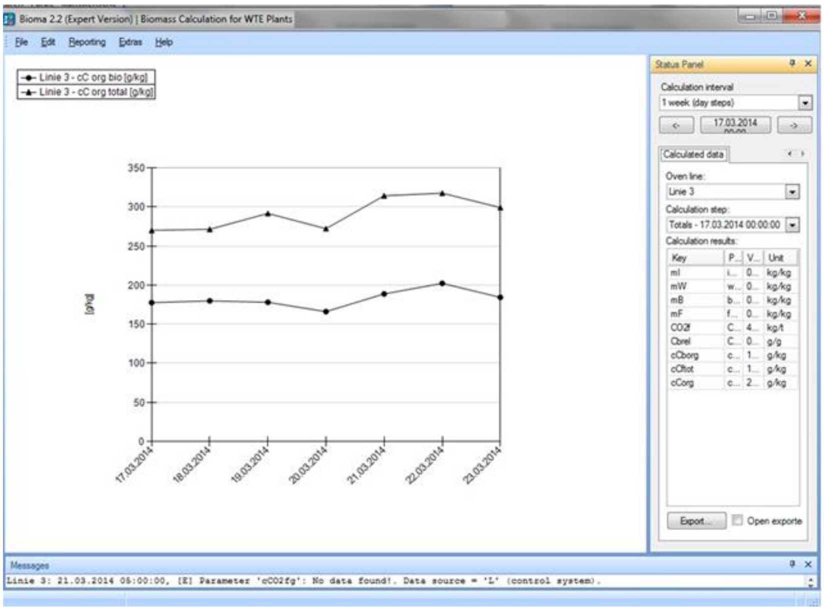

Figure 3. User interface of the software BIOMA (showing daily averages for the total and the biogenic carbon content of the waste feed for a period of one week).

2.2 Application of Balance Method to waste-to-energy plants in Austria

The Balance Method has been applied to all Austrian WTE plants with the exception of three facilities; two are combusting only hazardous waste and one was under reconstruction during the respective year. Thus altogether the waste feed from 10 waste incineration plants has been characterized with respect to its biogenic and fossil carbon content. Based on the information on the waste composition and the annual waste throughput of the plants the total fossil CO_2 emissions from WTE in Austria have been determined.

Table 1 gives an overview of the 10 Austrian WTE plants that have been investigated. The overall capacity of these facilities amounts to about 2 million tons of waste per year (Böhmer et al., 2007 and BMLFUW, 2011). The WTE plants operate with different types of combustion technologies (grate incineration or fluidized bed combustion) and incinerate municipal solid waste, commercial waste, sewage sludge and refuse derived fuels (see Table 1).

Table 1. Overview of waste-to-energy plants in Austria.

WTE plant	*Combustion technology*	*Waste incinerated (qualitative information)*
A	Grate incinerator (GI)	MSW
B	Grate incinerator (GI)	MSW and CW
C	Stationary fluidized bed combustion (FBC)	RDF and SS
D	Stationary fluidized bed combustion (FBC)	RDF and SS
E	Circulating fluidized bed combustion (FBC)	RDF and SS
F	Grate incinerator (GI)	MSW and CW
G	Stationary fluidized bed combustion (FBC)	RDF
I	Grate incinerator (GI)	MSW and CW
J	Grate incinerator (GI)	MSW
K	Grate incinerator (GI)	MSW and CW

MSW… Municipal solid waste, CW… commercial waste, SS… sewage sludge, RDF… refuse derived fuels

The procedure for the application of the Balance Method, and in particular the application of the software BIOMA to the operating data of the 10 plants is schematically illustrated in Figure 4. Detailed information about the proceeding is given in Schwarzböck et al. (2015).

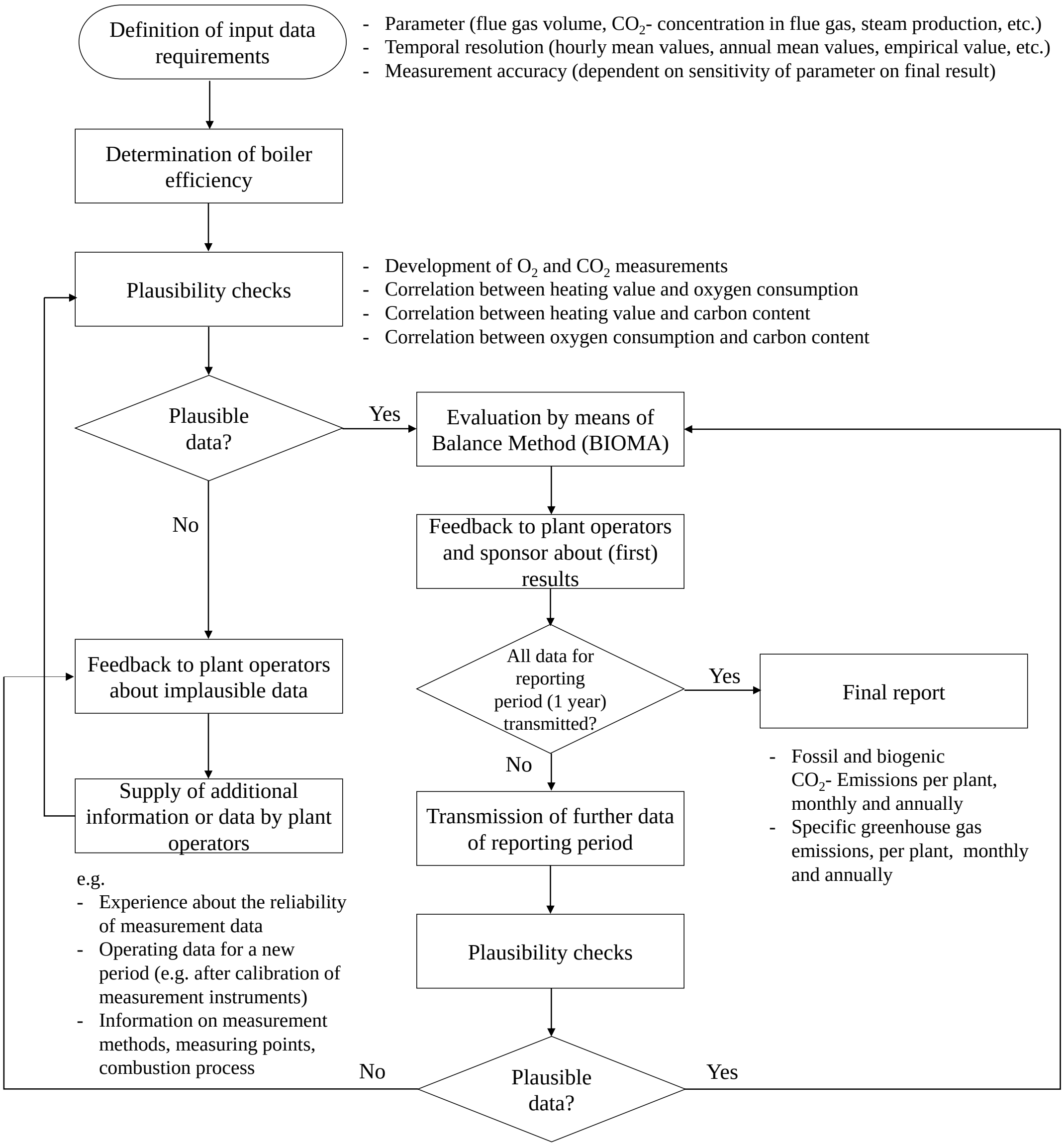

Figure 4. Procedure for the analysis of the operating data of the WTE plants using the Balance Method (software BIOMA) - based on Schwarzböck et al. (2015).

3. RESULTS AND DISCUSSION

As mentioned above the Balance Method has been applied to 10 WTE plants for a period of 1 year (2014). As for one facility (plant D) operating data required were incomplete or obviously measured wrong, the analysis period had to be reduced to 3 months for this particular plant. For this period reasonable measurement data were available.

An important step prior to determining the waste composition with regards to biomass and fossil organic matter is the plausibility test of the operating data (as indicated in Figure 4). Results of these plausibility checks (which utilize existing correlations between volume and composition of flue gas on the one hand and the steam production on the other hand) are summarized in the following section.

3.1 Plausibility checks on operating data

Prior the plausibility tests, operating data (hourly values) have been summed up to 6-hours averages, which have subsequently been tested for their correlation between O_2 consumption, C-content and lower calorific value of the waste. In Figure 5 and Figure 6 results of the plausibility tests for plant G are summarized. It becomes obvious that the vast majority (more than 90%) of the 6-hours averages is within the defined upper and lower limits for plausible data pairs and can thus be used for the analysis according to the Balance Method.

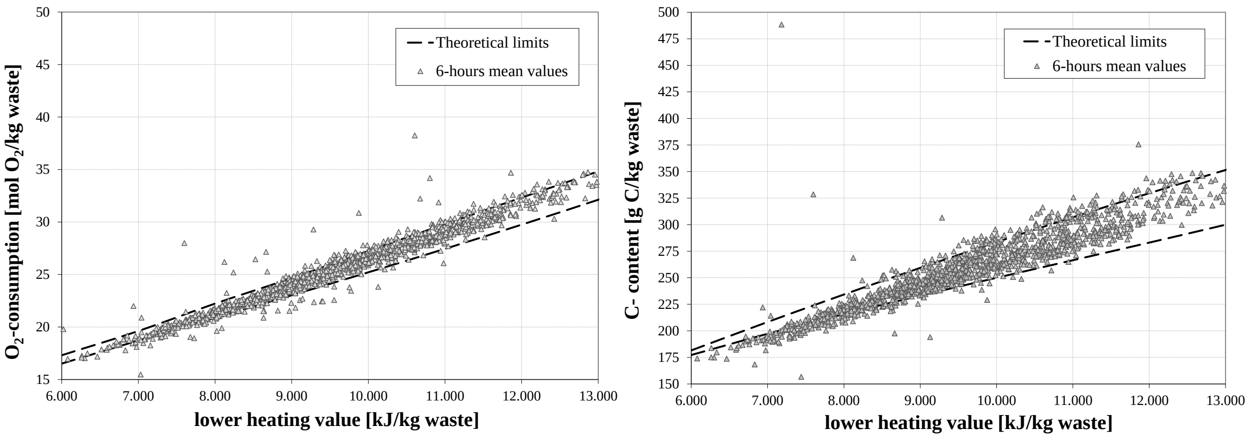

Figure 5. Results of plausibility checks (correlation between lower calorific value and O_2 consumption and C content, respectively) of the operating data of WTE plant G on a 6-hourly basis.

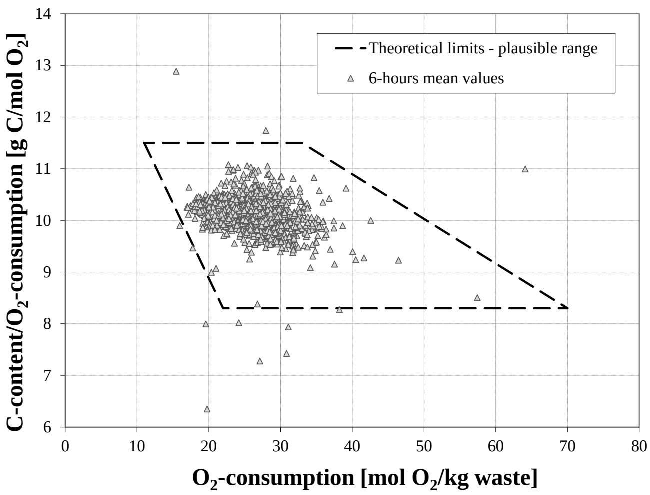

Figure 6. Results of plausibility checks (correlation between O_2 consumption and C content) of the operating data of WTE plant G on a 6-hourly basis.

Table 2 summarizes the share of plausible operating data for all 10 WTE plants analyzed. With the exception of plant D and J, all facilities are characterized by a high ratio (well above 95%) of plausible operating data. In other words over 90% of the waste has been analyzed in the study, a sample that can hardly be achieved by any other determination method.

Table 2. Share of plausible operating data (given in % of total waste mass combusted).

WTE plant	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*I*	*J*	*K*
Share of plausible data (referred to waste mass)	99.2	99.4	95.5	79.7[1)]	99.2	99.8	98.0	98.8	82.8	99.7

[1)] only a period of 3 months has been evaluated

3.2 Fossil CO_2 emissions from different Austrian WTE plants

The plausible operating data have finally been used to analyze the waste composition and to determine the amount of fossil CO_2 emissions using the Balance Method. In the subsequent figures results for the different plants are summarized and compared. Besides monthly results also annual averages are given.

Figure 7 shows the specific fossil CO_2-emissions per ton of waste on a monthly basis for five plants in which predominantly municipal solid waste and commercial waste are combusted. The results range from 213 ± 26 to 619 ± 40 kg fossil CO_2 emitted per ton of waste. This wide range of emission factors for different plants indicates a regional dependence of the waste feed composition, as the five presented plants in Figure 7 are situated in different federal states of Austria, which are characterized by different collection schemes. In addition diverse ratios of commercial and municipal solid waste may cause significantly different CO_2 emission factors. Furthermore, temporal variations of specific CO_2 emissions are obvious from Figure 7. For instance the monthly emission factors for WTE plant A range from 252 ± 23 to 405 ± 26 kg CO_2 per ton of waste input, thereby highlighting that a reliable analysis of the waste composition requires methods that characterize the waste feed over longer time periods. Monthly averages of an emission factor related to the energy content of the waste feed (lower heating value) are given in Figure 8. This specific emission factor is almost independent from the ash and water content of the waste. Hence, variations in the specific fossil CO_2-emissions are less pronounced in comparison to specific CO_2 emissions that are related to the waste mass. The monthly values range from 27 ± 2 to 65 ± 4 kg fossil CO_2 per GJ of heating value.

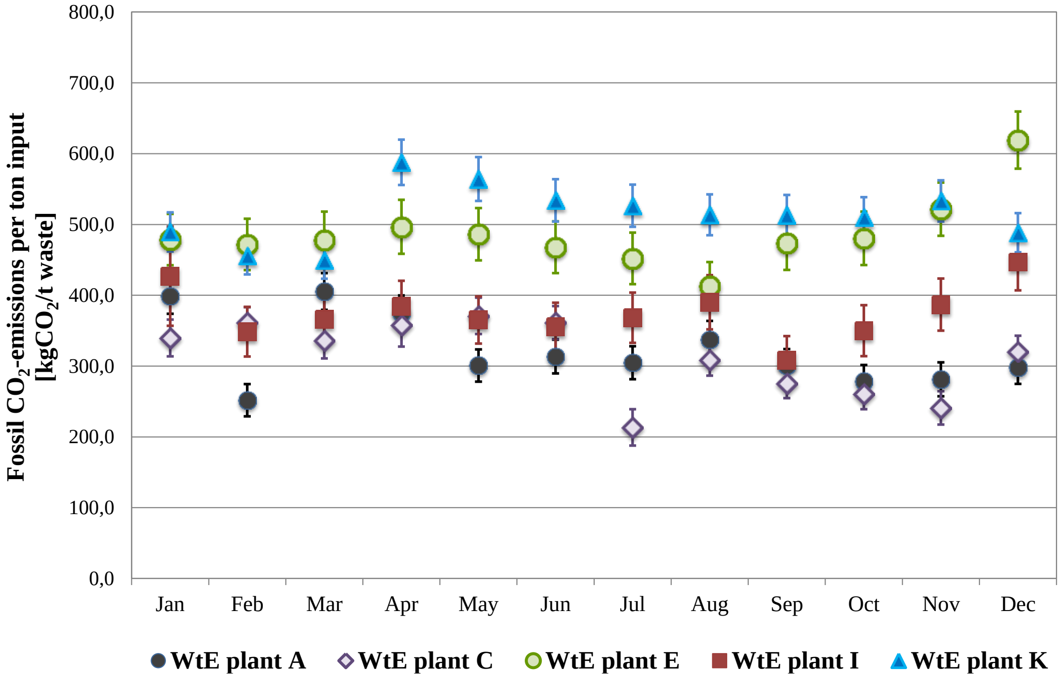

Figure 7. Monthly averages (with standard deviation) of fossil CO_2 emissions (given in kg CO_2 per ton of waste incl. sewage sludge) of selected WTE plants - preliminary results, as some of the operating data still need to be crosschecked.

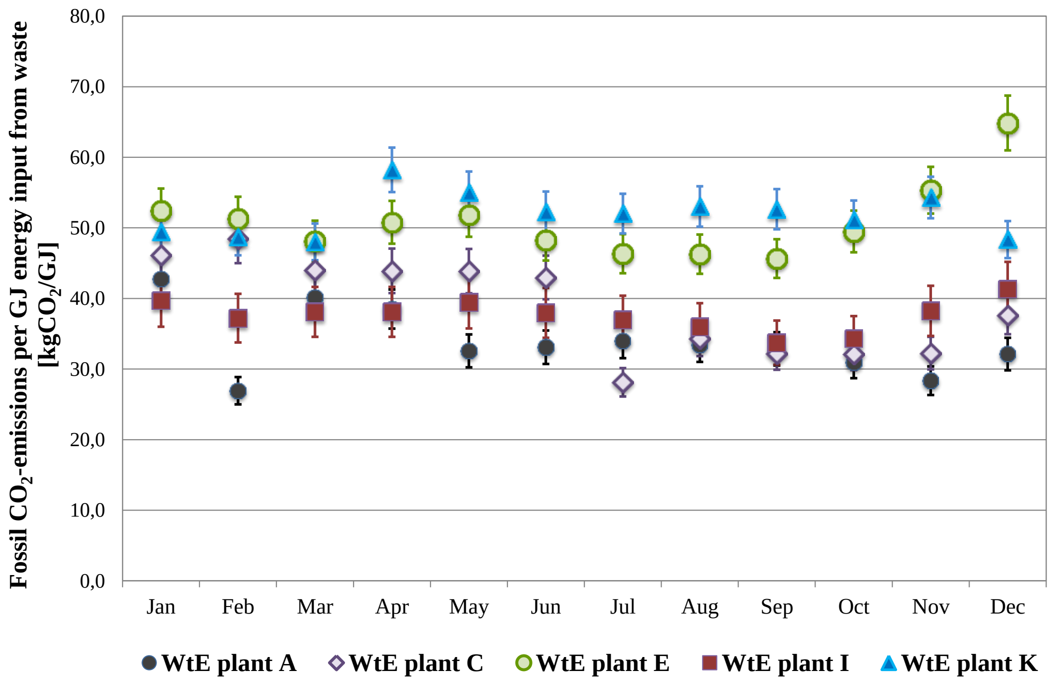

Figure 8. Monthly averages (with standard deviation) of fossil CO_2 emissions (given in kg CO_2 per GJ heating value of the waste incl. sewage sludge) of selected WTE plants - preliminary results, as some of the operating data still need to be crosschecked.

Annual averages for the specific CO_2-emissions per ton of waste and per GJ energy content are presented in Figure 9 a) and b) for all 10 plants analyzed. Again a high variation of the results for the plants can be identified, ranging from 314 ± 23 (WTE plant C) to 535 ± 30 (WTE plant F) kg CO_2 per ton of waste. The annual waste throughput amounts to around 2 million tons. The overall amount of energy input to the 10 facilities was about 18,000 TJ per year, resulting in energy specific greenhouse gas emissions between 34 ± 2 (WTE plant A) and 51 ± 3 (WTE plant E) kg CO_2 per GJ of energy input from waste. Thus, in average the energy specific greenhouse gas emissions of Austrians WTE plants amount to 45 ± 2 kg CO_2/GJ. From the overall amount of energy input to the 10 facilities 46.8 % stems from biogenic material.

Comparing results in Figure 9 a) and b) it is noticeable that variations in energy related emissions factors are smaller in comparison to waste mass related CO_2 emission factors. This can be explained by the fact that not only the ratio between biogenic and fossil organic matter determines the quantity of fossil CO_2 emissions, but also the total content of carbon which is strongly related to the energy content.

When considering a recommended standard emission factor provided by the Intergovernmental Panel on Climate Change (IPCC) of 557 kg fossil CO_2 per ton of waste (IPCC in Pacher et al., 2007), the fossil CO_2 emissions would be significantly overestimated for almost all WTE plants (up to 80 %).

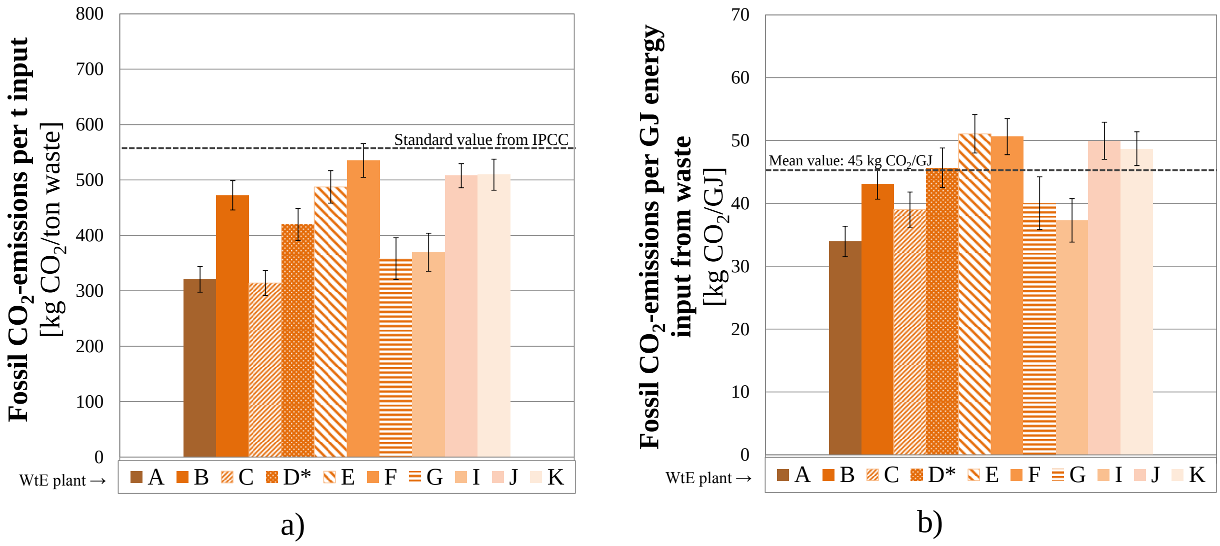

Figure 9. Annual averages (with standard deviation) of fossil CO_2 emission from WTE plants in Austria; a) related to total waste input; b) related to energy input from waste (preliminary results) & standard value for fossil CO_2 emissions from waste incineration according to IPCC, reported in Pacher et al. (2007).

Based on the evaluations, the total annual CO_2 emissions from WTE plants in Austria can be estimated to approximately 1.9 Mio tons. In Figure 10 these emissions are divided according to their climate relevance, with 45 % originating from the combustion of fossil matter (850,000 tons fossil CO_2), 53 % originating from the combustion of biomass (1,000,000 tons biogenic CO_2) and 2 % caused by the utilization of auxiliary fuels, such as oil and gas (36,000 tons CO_2).

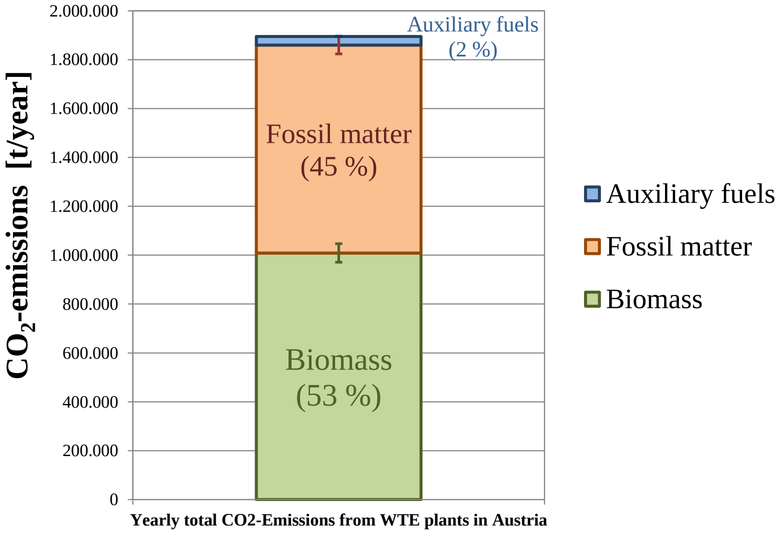

Figure 10: Annual CO_2 emissions from 10 WTE plants in Austria with an annual waste throughput of about 2 Mio. tons (preliminary results).

4. CONCLUSIONS

The evaluation of the waste composition of 10 WTE plants in Austria (with a total annual capacity of around 2 Mio. tons of waste) via the Balance Method revealed that there are significant differences regarding the specific fossil CO_2 emissions between the plants. Energy specific greenhouse gas emissions for Austria's WTE plants range from 34 ± 2 to 51 ± 3 kg CO_2 per GJ of energy input from waste. The average fossil CO_2 emission factor amounts to 45 ± 2 kg CO_2 per GJ.

In addition to regional differences large temporal variations regarding the composition of the waste (biogenic, fossil) can be observed for at least some of the plants analyzed. It is assumed that these variations are caused by a changing composition of the different wastes combusted, but also by changing shares of the different types of waste (municipal solid waste, commercial waste, refuse derived fuels, sewage sludge).

The results further indicate that the usage of generic emission factors (for example 557 kgCO_2/t waste recommended by IPCC - Pacher et al., 2007) probably result in considerable overestimations (or in some cases possibly underestimations) of fossil CO_2 emissions (as already demonstrated by Obermoser et al., 2009). Thus, a plant-specific and continuous evaluation of the waste composition is highly recommended, as it represents the only option for a secured quantification of fossil CO_2 emissions or green electricity production from WTE plants.

By means of the Balance Method the waste composition can be evaluated for any time period required. The method allows identifying trends, and also the variability in the composition of the waste feed. In addition the Balance Method delivers statistically valid results with specified uncertainties and requires no additional sampling or measurements (except in some cases the CO_2 measurements of the flue gas needs to be implemented).

However, fundamental for robust and reliable results of the Balance Method are valid operation data obtained from the measurement devices installed at the WTE plant. Thus, in most cases additional calibration efforts and control measurements are required, in particular for the O_2 and CO_2 content in the flue gas, which both represent parameters of high sensitivity for the final outcomes of the Balance Method. The plausibility checks done within the software BIOMA can help to discover systematic measurement errors or faulty data documentations, but do not replace regular calibration measurements.

ACKNOWLEDGEMENTS

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