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PERFORMANCE IMPAIRMENT OF WASTE TO ENERGY PLANTS DUE TO INSUFFICIENT MIXING OF THE WASTE FEED

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ABSTRACT: Waste to Energy WtE plants allow the recovery of energy from mixed wastes whose recycling is not feasible from an economic or ecological point of view. The operation of WtE plants is challenged by the heterogeneous nature of waste. In particular, short-term variations in the waste feed composition may lead to reduced energy (steam) production, increased gaseous emissions, higher auxiliary fuel demand and lower energy efficiency. At present, operators of WtE are trying to compensate temporal variations in the waste feed composition by randomly mixing the received waste in the storage bunker prior combustion. Recent analysis of the authors indicate however, that this random mixing might in many cases not be sufficient to supply the plants with a sufficiently homogenous feed composition. Hence, a tool (software) was developed which allows the operator of WtE plants to instantly analyse the composition (incl. its variation) of the combusted waste. The tool uses different operating data (mainly data about the flue gas composition) to calculate the waste composition and its temporal variation. The latter can subsequently be utilized by the crane operator to control the mixing of the waste in the bunker prior combustion. For the present paper, real data of two WtE plants in Austria are analysed to determine the hourly variation of the biogenic carbon content and estimate its effect on selected operating parameters. Based on the analyses conducted, it is demonstrated that for an average sized WtE plant (annual waste throughput of 250,000 tonnes), additional revenues (incl. reduced costs for auxiliary fuels) of more than 400,000 € per year might be generated by controlled mixing of the waste feed.

Keywords: Waste to Energy, heterogeneity, mixing, steam production, waste feed, auxiliary fuel

1. INTRODUCTION

In many affluent countries, thermal recovery of waste has become an important part of their waste management, resource recovery and energy supply strategies. It is regarded as a viable treatment option to save land for waste management facilities, to significantly reduce waste volumes, and to completely disinfect waste. While these aspects have been the main arguments in the past, developments in recent years depict that thermal waste recovery (Waste to Energy) is also becoming an important tool for material recycling and resource conservation (Brunner and Rechberger, 2015; Li et al., 2015; Zhang et al., 2015).

Within the European Union, it is estimated that currently almost 100 Million tonnes of municipal solid waste are thermally utilized in Waste to Energy plants (WtE) every year, thereby generating more than 120,000 TJ of electricity and 300,000 TJ of heat (CEWEP, 2018). This corresponds to the demand of electricity and heat for around 17 Mio. European citizens. Due to different legislative framework conditions (e.g. landfill directive, waste framework directive), a further increase in thermal waste recovery capacities is expected (around 3 to 6 Mio. tonnes in the coming years), particularly in new member states. At global scale, it is estimated that at present more than 350 Mio tons of waste are thermally utilized.

In direct comparison to conventional power plants (using coal, gas, or oil), it can be seen that the energy efficiency of WtE plants is significantly lower (Brunner & Rechberger, 2015, Di Maria et al., 2016, Strobel et al., 2018). This is based primarily on three factors:

a) the steam parameters of the waste heat boiler, which are significantly lower than those of calorific power plants due to the highly corrosive properties of the flue gas (mostly due to high Cl content),
b) the higher air surplus, which is required as a buffer due to so far "unavoidable" fluctuations (also heterogeneity) of the fuel waste, and
c) the fluctuating heat input, which is also based on the fact that the energy content (calorific value) of the waste is not constant as for conventional fossil fuels, but subject to considerable temporal fluctuations.

Point a) is partially compensated by extracting heat only, or by reheating the steam between high pressure and low pressure parts of the turbine. In addition, individual WtE plants attempt to achieve higher steam parameters through increased corrosion protection (cladding of the boiler flues), which lead to a higher total electrical efficiency.

The points b) and c) both arise from “unavoidable” and irregular variations of the fuel waste composition. The mixing of the waste in the bunker of the plant is an attempt to homogenize the waste in terms of calorific value and other combustion-relevant waste properties (for example water content, ash content). This "homogenization of the waste" is not only advantageous from an energetic point of view, but also leads to lower production of air pollutants (e.g., CO, NOx, dioxins). In particular, emission peaks, which are primarily due to unstable operation of the plant (fluctuating firing capacity) and insufficient burnout, are thereby avoided (Astrup et al.. 2011; Di Maria et al., 2016; Murer et al., 2011; Seifert & Merz, 2003; Strobel et al., 2018; Zhang et al., 2015). For the mixing of the waste in the waste bunker, the waste crane is used. So far, it is state of the art that the homogenization of the waste takes place based on the visual assessment and expertise of the operating personnel (crane operators). Alternatively, automated mixing routines (programs) are used. They provide that the crane automatically approaches random points in the bunker, the waste at these points is picked up by the crane and then the collected waste is scattered over another area in the bunker and thus mixed up. Both methods, "manual" or "automated" homogenization of bunker waste have their advantages and disadvantages. Automated mixing by "calculated" randomness is expected to achieve good homogenization of total bunker waste over longer periods of time. Whereas, the advantage of manual mixing is that significant differences in waste batches can be mixed in a short time if they are detected visually.

In the present paper a new method is presented which allows detecting short time variations in the waste feed composition and thereon based allows determining operational impairments due to these variations, such as reduced steam production, higher air surplus, higher auxiliary fuel consumption, and reduced waste throughput (as indicated by Fellner & Schwarzböck, 2021). Furthermore, this method might in future be used to control the mixing/homogenization of the bunker waste and thereby reduce impairments of the plant operation.

2. MATERIAL AND METHODS

2.1 Determining the variability of the waste feed composition of WtE plants

The analyses conducted are based on the evaluation of real operating data from two different WtE plants over a period of one year. Both WtE plants are located in Austria and are equipped with a grate firing system and have a capacity between 200,000 and 300,000 tonnes of waste per year. Hourly values during regular operation of the plant are used for the analyses. Shut-down and start-up periods are disregarded because they are considered as unavoidable due to annually required plant revisions. The analyses are conducted using operating data, which are routinely recorded at the plants. In particular, these data are used to assess the waste composition by the means of a simplified version of the Balance Method (original Balance Method in Fellner et al., 2007).

The Balance Method is used to generate data about the waste feed characteristics of the WtE plants. The method is based on different material and energy balances (mass balance, ash balance, carbon balance, energy balance and O_2 balance), which use plant operating data and information upon the elemental composition of biogenic and fossil materials. This allows the content of biogenic (biomass) and of fossil organic materials (plastics) to be determined.

If some equations of the original Balance Method (after Fellner et al., 2007) are disregarded, the five balance equations can be reduced to two equations to calculate the share of biogenic and fossil organic carbon with high temporal resolution (simplified Balance Method). The so obtained hourly data about the waste feed composition (e.g. share of biogenic carbon C_{bio}) are subsequently used to evaluate the temporal variability of the feed composition. Thereto the relative standard deviation of the share of biogenic carbon C_{bio} is calculated over a period of four consecutive hours. Hence, for every hour information about the temporal variability of the waste feed composition in terms of the share of biogenic carbon is assessed.

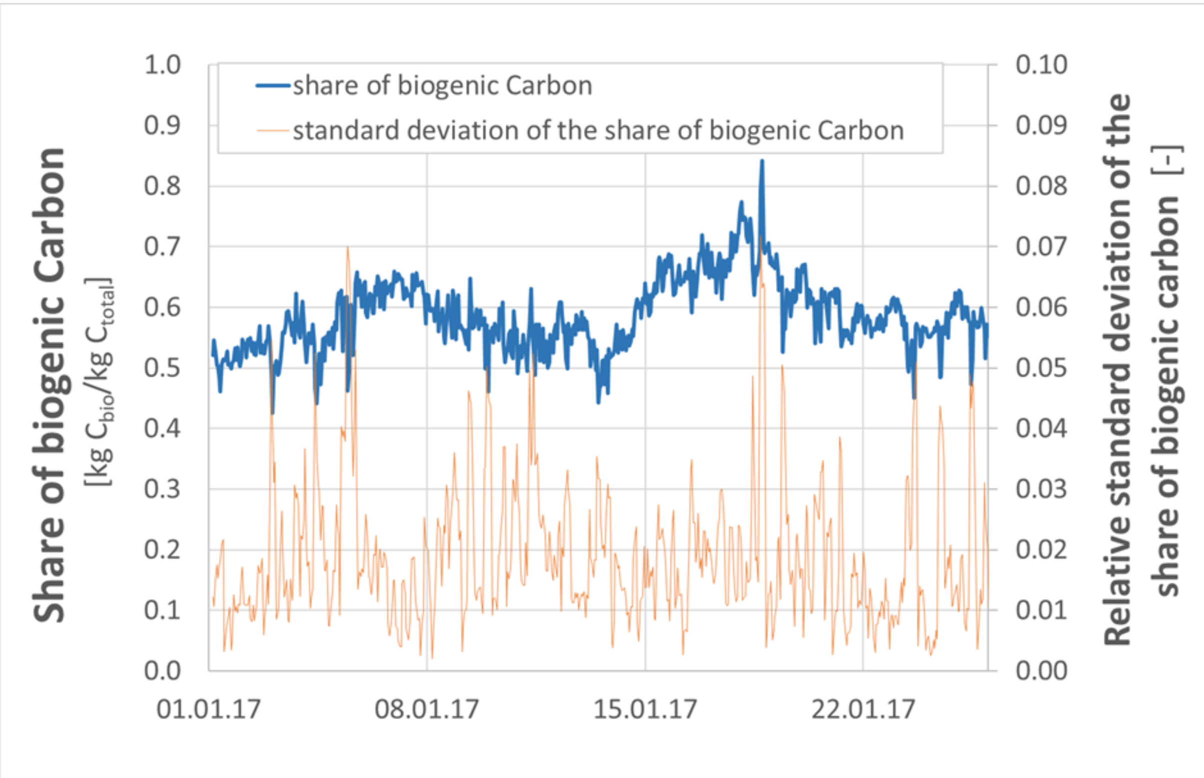

Figure 1. Share of biogenic carbon (blue line) and relative standard deviation of the share of biogenic carbon (orange line) – results of a simplified version of the Balance Method

2.2 Analyzing the impairment of the plant operation due to varying waste feed composition

The variability of the waste feed composition is subsequently compared to different operating data of the WtE plant (e.g., steam production, auxiliary fuel consumption, O_2 content in the flue gas, waste throughput, …). Thereto in a first step, the variability of the waste feed composition (with regard to share of biogenic carbon) is classified into different classes ranging from no variability to very high variability (see Table 1). In a subsequent step, all operating hours are assigned to the different classes according to the standard deviation of the share of biogenic carbon C_{bio} determined by the Balance Method. Finally, the mean values of selected operating data (e.g. steam production, auxiliary fuel consumption) for the different classes are determined in order to check the relation between variability of waste feed composition and operating parameter (see Figure 2 to Figure 5).

Table 1. Categories of variability for the relative standard deviation of the share of biogenic Carbon C_{bio}

Variability of the share of biogenic Carbon C_{bio} (relative standard deviation over 4 hours)	**Qualitative description of the variability**
<0.5%	*no variability*
0.5 – 1%	*very low variability*
1 – 2%	*low variability*
2 – 3%	*medium variability*
3 – 5%	*high variability*
>5%	*very high variability*

3. RESULTS

3.1 Impact of the variability of the waste feed composition on the plant operation

3.1.1 Steam production

In Figure 2 the mean steam production for the different classes of the variability of the waste feed composition is displayed for the two WtE plants analyzed. The results clearly indicate a reduced steam production for periods of higher variability in the waste feed composition (higher relative standard deviation of the share of biogenic carbon). For plant A for instance, steam production is reduced from 83 t/h to below 80 t/h. For plant B a significant drop (by almost 10%) in steam production for times of highest variability of the waste feed composition can be observed.

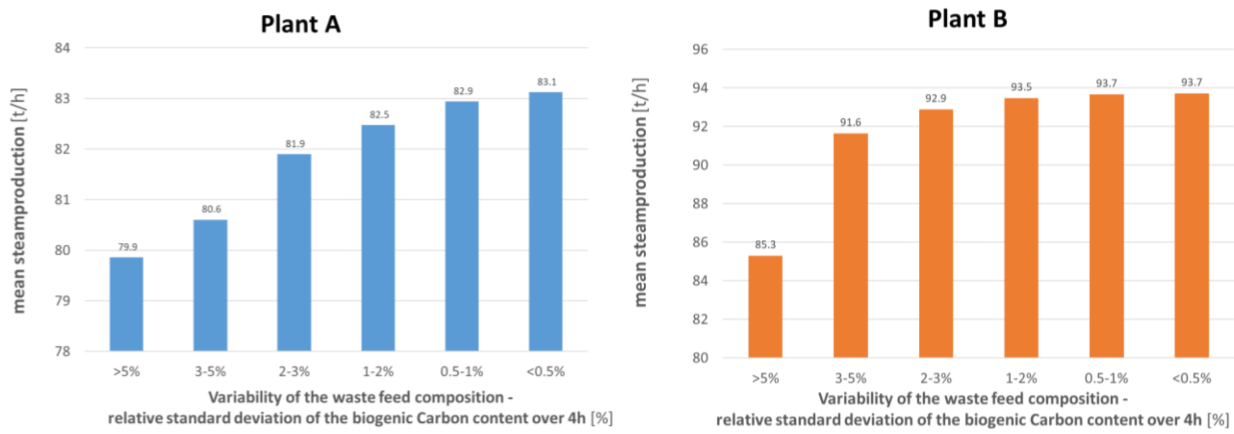

Figure 2. Mean steam production against the different classes of variability of the waste feed composition

3.1.2 Waste throughput

In Figure 3 the mean waste throughput for the different classes of the variability of the waste composition is displayed for the two WtE plants. Similar to the steam production, the mean waste throughput is smaller for periods of higher variability in the waste feed composition (relative standard deviation of the share of biogenic carbon). For plant A, for instance, the average waste throughput drops from 22.5 t/h to 21.4 t/h (reduction of 5%), whereas for plant B a reduction from 27.6 to 22.7 t/h is observed for the period with "*very high variability*" in the waste feed composition. For periods of "*high variability*", the reduction is significantly smaller (26.6 t/h in comparison to 27.6 t/h), but nonetheless amounts to almost 4%.

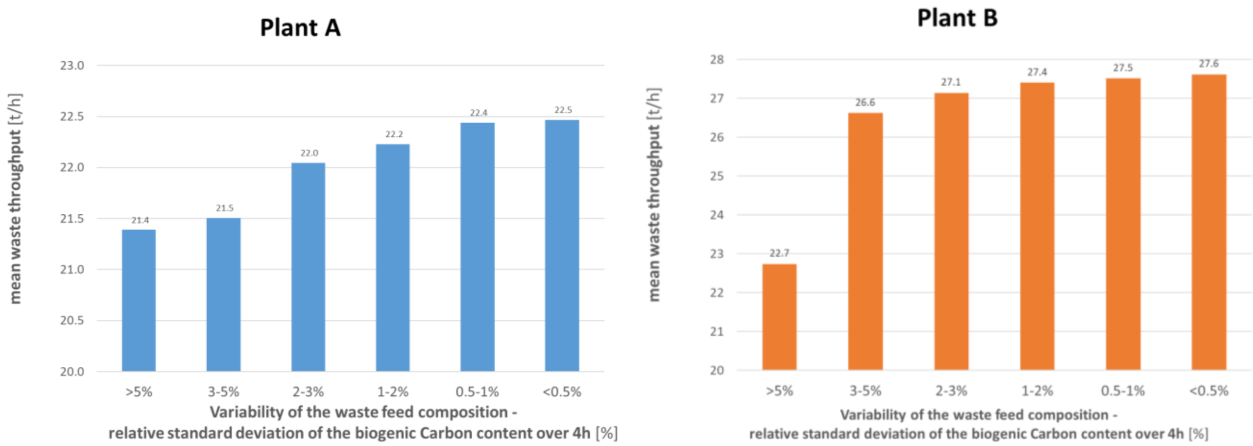

Figure 3. Mean steam production against the different classes of variability of the waste feed composition

3.1.3 Oxygen content in the flue gas

For the Oxygen content, a contra vise trend is observable. Higher variability in the waste feed composition results in higher oxygen content in the flue gas (8.1 Vol-% in comparison to 7.5 Vol-% at plant A, and 9.4 Vol-% in comparison to 8.4 Vol-% at plant B). This implies that more heterogeneous waste leads to a lower energy efficiency of the plants, since a higher oxygen content in the flue gas is associated with higher flue gas volumes and thus higher energy losses. For the plant A, the relative flue gas volume flow is increased by 4% when comparing periods of "*very high variability*" with periods of "*no variability*".

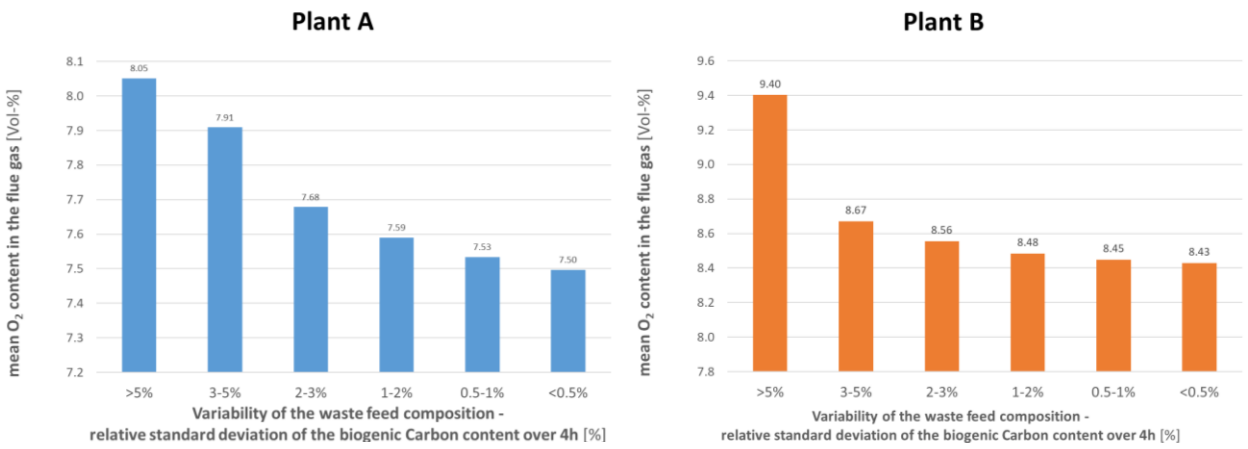

Figure 4. Mean O_2 content in the flue gas against the different classes of variability of the waste feed composition

3.1.4 Auxiliary fuel consumption

The auxiliary fuel consumption is significantly higher with increasing variability of the waste feed composition. For instance during periods of "*no variability*" the average fuel oil consumption of plant A amounts to 2 liter/h, whereas for the class with the highest variability, the consumption rates are factor 100 higher (200 liter/h). Also for plant B, the increase in natural gas is almost factor 100 higher for the class of "*very high variability*" of the waste feed composition.

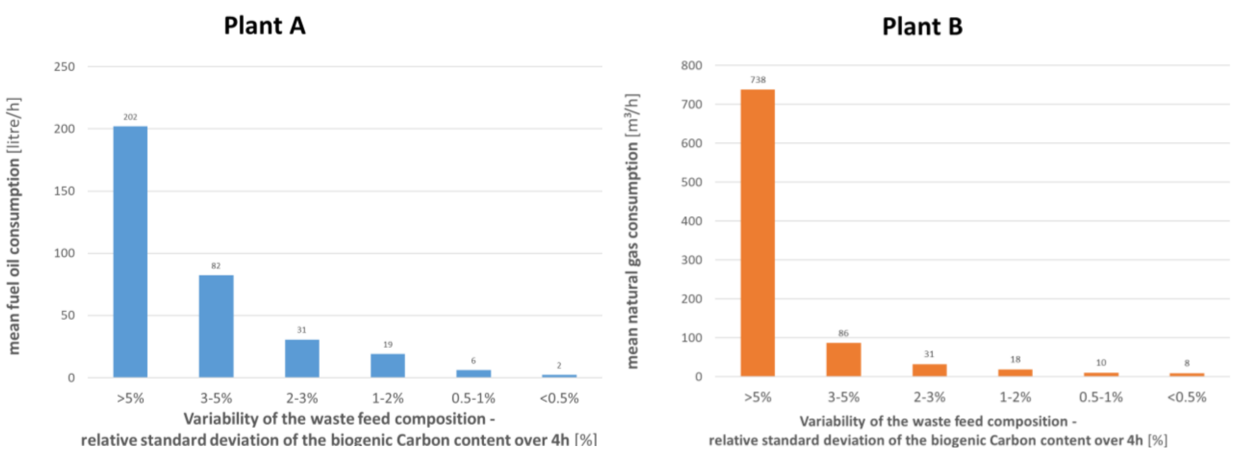

Figure 5. Auxiliary fuel consumption against the different classes of variability of the waste feed composition

3.1.5 Share of operating hours for the periods of the different variability classes

In Figure 6, the share of operating hours for the different classes of variability of the waste feed composition is summarized for both plants. The results clearly demonstrate that at plant B, either more homogeneous waste is delivered or the waste is better mixed in the bunker prior combustion. At plant B almost 50% of the time, the variability in the waste feed composition in terms of the standard deviation of the share of biogenic carbon is less than 1%. In comparison at plant A only 26% of the operating hours show a temporal variability of less than 1%.

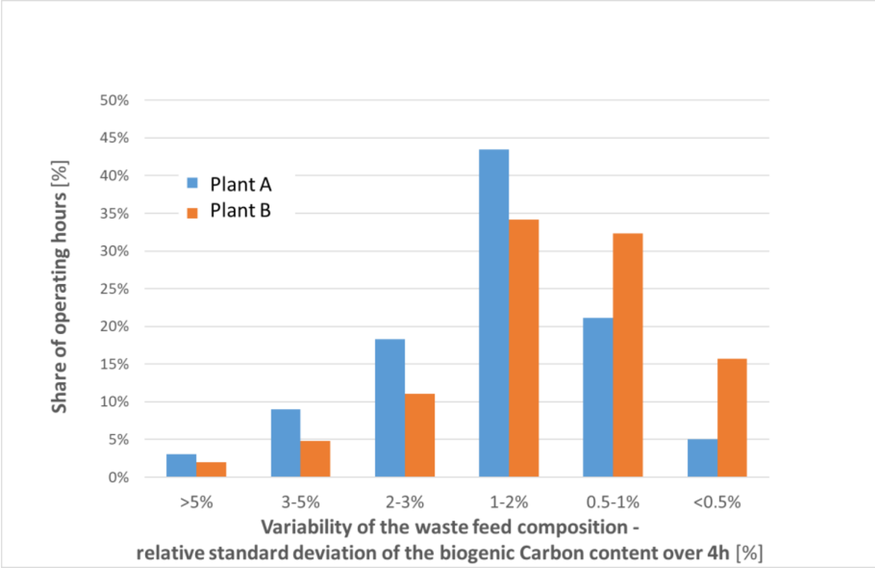

Figure 6. Share of operating hours for the different classes of variability of the waste feed composition

3.2 Impact of the variability of the waste feed composition on economics

The impairment of the operation can also be translated into economic losses. When doing so (see Figure 7), the results demonstrate that if all periods with "*very high variability", "high variability", "medium variability",* and *"low variability"* (relative standard deviation of C_{bio} > 1%) of the waste feed composition could (theoretically) be turned into "*no variability"* or "*very low variability"* (relative standard deviation of C_{bio} < 1%), the economic savings or additional income amounts to almost 500 000 € per year, which equals about 2 to 2.5 €/tonne of waste throughput. In case that only the period of "*very high variability*" can be prevented (turned into "*low variability"*), then annual savings are still in the range of 70 000 to 200 000 €/yr. The biggest contribution to these savings or additional income comes from a higher waste throughput, which accounts for two-thirds of all savings/additional income.

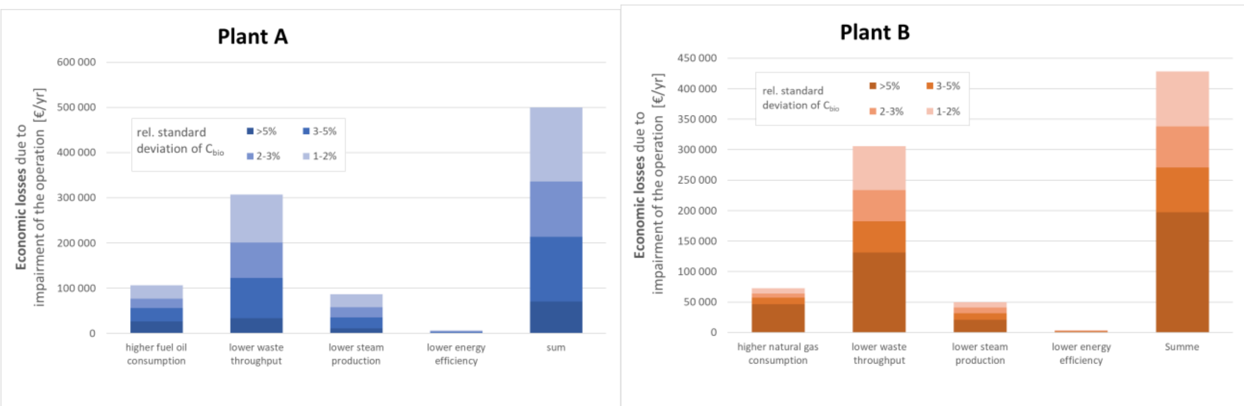

Figure 7. Economic losses of the impairment of plant operation due to insufficient mixing of the waste feed

4. RESULTS AND DISCUSSION

The results of the analysis presented in the paper clearly indicate that insufficient mixing of the waste and thus higher variability in the waste feed composition results in severe impairments of the plant operation. For both WtE plants analyzed a significant reduction in steam production and waste throughput was observed at higher variability of the waste feed composition. Furthermore, higher consumption of auxiliary fuels and higher air surplus occurred during times of higher variability in the feed composition.

A controlled mixing of the waste in the bunker might reduce these impairments and may results in additional income (or lower expenses) of about 2 to 2.5 €/tonnes waste incinerated. For such a controlled mixing, the installation of an adapted version of the Balance Method in the operating center of the plant is recommended, as it allows obtaining real time information about the feed composition. The later assists the crane operator to better mix and to control the mixing of the waste.

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