Closing the household metal packaging cycle through recovery of scrap from waste-to-energy bottom ash: the case study of Flanders

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Abstract

In Flanders, 45 279 t of household metal packaging was brought on the market, of which 25 639 t was separately collected via the dedicated waste bags after consumption. Literature data showed that indeed 16 880 t of the household metal packaging was present in residual waste that is incinerated in waste-to-energy (WtE) plants; together with the separately collected waste corresponding to 93.9% of the household metal packaging brought on the market. Metals that are present in the incinerated waste largely remain in the bottom ash. A representative sorting experiment showed that the different metal scrap fractions recovered from WtE bottom ash consisted for 2.2 to 11.3% of packaging. Combining these percentages with waste and bottom ash mass flows pointed out that only 2 577 t of metal packaging was present in WtE bottom ash, together with the metal packaging separately collected corresponding to an overall recycling rate of 62.3%. The difference between the household metal packaging mass flows obtained from literature data and from the sorting experiment is remarkable, even taking into account the uncertainty on the results of the sorting experiment and those due to assumptions made in the material flow analysis and the possible material losses to other ash fractions in the WtE process. It shows the need to gather more accurate information on the composition of the different household waste streams and of all WtE ash fractions to establish realistic recycling rates.

1. Introduction

Belgium and more specifically the Flanders region has a long tradition of separate collection and recycling of household waste. Data provided by Eurostat show that, along with Germany and Austria, Belgium's waste recycling rates are of the highest of all EU member states (European Environment Agency, 2018). In Flanders, separate collection systems exist for paper & cardboard, glass, PMD (a mix of Plastic bottles and flasks, household Metal packaging such as tins and cans, and Drink cartons) and kitchen and garden waste. Furthermore, in the municipal recycling centres many other waste types such as wood waste, waste mattresses, waste of electrical and electronic equipment and metal waste are collected in view of recycling. The PMD waste, collected in dedicated blue plastic bags, is separated into four recyclable fractions in highly automated sorting centres: a plastic fraction, a metal fraction, drink cartons and a sorting residue, corresponding to 44, 28, 11 and 17% of the total mass collected, respectively (OVAM, 2016). The PMD metal packaging fraction is further separated into a steel fraction (e.g. tins, cans, cookie jars, crown caps etc.) and an aluminium fraction (e.g. spray cans, cans, trays, bottle caps etc.) which are both delivered to the metal industry for recycling.

In Flanders, residual household waste (i.e. household waste that is not separately collected), is, together with municipal waste (i.e. waste collected by the municipalities in public places) and similar non-hazardous residual industrial waste incinerated in a waste-to-energy (WtE) plant. In such a plant, the waste is first collected and mixed by a crane in a bunker, after which it is dropped in a chute from where it is pushed on a moving combustion grate. The energy released in the combustion process is recovered from the hot combustion gas in a steam boiler after which the gas is purified and emitted at the stack. The produced steam can be send to a turbine for electricity production or can be used directly as a heat source in industry or residences. For each metric ton (t) of residual household or comparable waste, 200 to 250 kg of bottom ash remains at the end of the combustion grate (ISWA, 2012). From this ash, ferrous and non-ferrous metals are recovered by means of magnets and eddy-current separators, respectively. The amount of metals originating from the input waste and present in the bottom ash mainly depends on the separate collection systems in place. In Flanders, about 15% of the bottom ash mass or about 2.5% of the input waste mass consist of recoverable ferrous and non-ferrous metals (IMOG 2016; Indaver, 2016; IVAGO, 2016; IVOO, 2016).

In Belgium, the non-profit organisation FostPlus manages the collection and recycling of household packaging waste as part of the producer responsibility of its members (i.e. the producers of packed household consumables) as laid down in European Directive 2004/12/EC (European parliament and council, 2004). In 2015, 78 790 t of household metal packaging was brought on the Belgian market, of which 97.8% or 77 057 t was recycled, so the material cycle is almost fully closed (FostPlus, 2016). Of these 77 057 t, only 44 125 t were effectively collected via the PMD bags, whereas the remaining 32 932 t consisted of "metal packaging of WtE plants and their ash treatment centres". Indeed, FostPlus' legal recognition allows to also take into account "metal packaging waste collected at the entrance or exit of WtE plants or other treatment installations" for the calculation of the selectively collected household metal packaging waste and consequently the recycling rates (Interregional packaging commission, 2013). The only limitation is that the amount of household metal packaging supposed to be collected in WtE plants cannot be higher than the difference of the total amount of household metal packaging brought on the market and the amount collected via the PMD bags, multiplied by 0.95. In fact, this allowance explains the reported household metal packaging recycling rate of 97.8% (FostPlus, 2016):

$$\frac{((78\,790 - 44\,125) \times 0.95 + 44\,125)t}{78\,790\,t} = \frac{(32\,932 + 44\,125)t}{78\,790\,t} = \frac{77\,057\,t}{78\,790\,t} = 97.8\% \quad (1)$$

These data and calculations however raise two important questions: 1) If only 44 125 of the 78 790 t or 56.0% of household metal packaging brought on the Belgian market is separately collected via the dedicated PMD bags, where are the remaining 44.0% and 2) Do the 32 932 t of household metal packaging supposedly collected at WtE plants effectively consist of packaging and does thus the recycling rate of 97,8% correspond to the real recycling rate? Data provided in activity or environmental reports of Belgian WtE operators give a good indication of the mass flows of ferrous and non-ferrous metals that are recovered from WtE bottom ash (IMOG, 2016; Indaver, 2016; IVAGO, 2016; IVOO, 2016). However, up to our knowledge, there exist no data on the share of household packaging waste in these recovered metals.

Therefore, the first aim of this study was to establish, by means of sorting experiments, the share of steel and aluminium household metal packaging waste in the ferrous and non-ferrous metal fractions recovered from WtE bottom ash. Although material flow analysis of steel and aluminium, both metals that are used for household packaging, exist (e.g. Passarini et al., 2018; Warrings and Fellner, 2018), they consider the whole metal flow and do not focus specifically on household packaging. Therefore, the second aim of this study was to map the household metal packaging material flows in Flanders, as a part of Belgium, and to calculate a realistic recycling rate as an indication of the circularity of these materials.

2. Materials and methods

2.1 Sorting experiments

2.1.1 The WtE plant and bottom ash treatment installation

The sorting experiments were carried out at the Indaver grate furnace WtE plant located in Doel, Flanders, in January 2018. This installation was already described in detail in a previous publication (Vandecasteele et al., 2007) so here only a brief description is given. The plant consists of three incineration lines with a total capacity of about 400 000 t per year. The lines are fed from the same waste bunker, containing a mix of residual household, municipal and residual industrial waste. Yearly a total of around 85 000 t of bottom ash is produced over the three incineration lines. The Indaver grate furnaces are considered representative for Flanders, since they incinerate about one fourth of the residual household waste produced in this region. Furthermore, a comparison of operational data found on operators' websites shows that the "bottom ash" to "waste input" ratio is quite comparable to that of other Flemish WtE plants (IMOG 2016; Indaver, 2016; IVAGO, 2016; IVOO, 2016). In addition, the composition of the waste input mix is comparable in these plants i.e. consisting of the same types of residual wastes in about the same ratio's. Finally, these plants use the same combustion technology (grate furnace), operated at about the same temperature because they all have to comply with the 2s - 850 °C rule laid down in the Industrial Emission Directive 2010/75/EU.

The bottom ash is first collected in a water lock at the end of the grates, after which it is transported to a dedicated bottom ash treatment installation. Figure 1 gives a schematic representation of the material flows in this installation. The bottom ash is first fed in a rod sieve that removes items larger than 350 mm, including metal objects such as small barrels, pots, pans and bars. After a thorough visual inspection, it was clear that this > 350 mm fraction did not contain any household metal packaging and was therefore not further considered in the sorting experiment.

Figure 1

1 The bottom ash that passes the rod sieve is subsequently fed to a rotating screening and washing
2 drum in which water is continuously sprayed over the ash. Objects larger than 50 mm remain on the
3 rotating screen and fall on a conveyor belt at the end of the barrel. An overhead belt magnet attracts
4 the ferrous metal objects from this fraction, the resulting material stream is further referred to as
5 the > 50 mm ferrous fraction. From the > 50 mm material that remains after the removal of ferrous
6 metals, other non-ferrous metal objects such as stainless steel pots, copper water pipes, zinc gutters
7 are manually removed. Again, after a thorough visual inspection, it was clear that this > 50 mm non-
8 ferrous metal fraction did not contain any household metal packaging and was therefore not further
9 considered in the sorting experiment. The remaining > 50 mm non-metallic fraction is sent back to
10 the furnace.

11 The bottom ash fraction smaller than 50 mm is fed to a second rotating drum in which the light
12 organic fraction floats to the surface and is skimmed off. This fraction consists mainly of
13 incompletely combusted plastics or other organic materials and is fed back to the grate furnaces. By
14 means of vibrating screens, the heavy fraction smaller than 50 mm is separated into a 6-50 mm and
15 a 2-6 mm granulate fraction and into a < 2 mm sand and sludge fraction. From the 6-50 mm
16 fraction, first ferrous metals are removed by an overhead belt magnet, resulting in a 6-50 mm strong
17 ferrous fraction. Next, a 6-50 mm weak ferrous fraction is removed in a drum magnet and finally an
18 eddy current separator removes the 6-50 mm non-ferrous fraction. Also from the 2-6 mm fraction
19 ferrous and non-ferrous metals are separated, but a visual inspection of these fractions showed that
20 they do not contain recognizable objects. Therefore the 2-6 mm ferrous and non-ferrous fractions
21 were not further considered in the sorting experiment. The remaining 6-50 mm and 2-6 mm
22 granulates are recycled as building material. A visual inspection of these granulates showed that
23 they did not contain recognizable metal objects, so they were also not considered in the sorting
24 experiment. The < 2 mm sand and sludge fraction was also not considered in the sorting experiment
25 for obvious reasons.

26 2.2.2 Sampling and sorting

27 The household metal packaging considered in the sorting experiment corresponds to the packaging
28 types that are also collected via the dedicated PMD bags. An overview is given in Table 1.

29 **Table 1**

30 As indicated in Figure 1, the > 50 mm ferrous, the 6-50 mm strong and weak ferrous and the 6-50
31 mm non-ferrous fraction were sampled and sorted into a household packaging and non-household
32 packaging fraction. Their sampling was performed according to the Flemish standards for sampling
33 CMA/1/A.14 (Sampling of wastes/raw materials – General guidelines for sampling) and CMA/1/A.15
34 (Sampling of wastes/raw materials – Sampling techniques solid materials). The aim was to obtain an
35 easy to handle quantity of material with an average composition that matched the composition of
36 the different sampled metal fractions as good as possible.

37 At the bottom ash treatment installation, the different metal fractions are stored on large heaps
38 with a volume < 500 m³ that are regularly collected by a truck and transported to secondary metal
39 recyclers. From these heaps, firstly four sub-lots were taken by means of a shovel with a scoop of
40 3m³. The grabs of the shovel were equally distributed over the surface and bulk and over the height
41 of the heaps. Each sub-lot was emptied over a clean concrete floor and shovelled up again several
42 times to homogenize the material as good as possible. Next, the sub-lot material was spread in a
43 layer with a height of less than 0.40 m. Then, from each sub-lot, manually a number of smaller grabs
44 was taken equally distributed over the layer of material. The grabs from the different sub-lots were

pooled to form the field sample. This field sample was then sorted into a packaging and a non-packaging fraction. The packaging fraction consisted of the metal objects that are listed in Table 1. The obtained fractions were weighted on site: masses higher than 20 kg were weighted by means of certified forklift scales to the nearest kg and masses lower than 20 kg were weighted on calibrated industrial scales to the nearest 100 g. Table 2 specifies the number of grabs, their volume and the volume of the obtained field sample for the > 50 mm and the 6-50 mm metal fractions.

Table 2

The visual, manual sorting of the field samples in a packaging and non-packaging fraction was in general rather straightforward for the ferrous fractions. Metal packaging, as defined in Table 1, was quite recognizable by shape and could be easily distinguished from other metal objects in the field samples. To illustrate this, Figure 2 (a) shows the sub-lots of the > 50 mm ferrous fraction and (b) the metal packaging fraction visually sorted from the > 50 mm ferrous fraction field sample. For the non-ferrous fractions, it was more difficult to clearly distinguish between packaging and other objects, since some of the metals were present as what seemed half molten lumps. The limitations of the visual sorting introduce uncertainty on the sorted masses and consequently on the calculated share of packaging material in the considered metal fractions. This uncertainty is taken into account in the calculations of the mass flows in the MFA as described in detail in Section 2.2.

Figure 2

2.2 Material Flow analysis

The household metal packaging flows in Flanders were mapped by means of the material flow analysis (MFA) methodology using the STAN software (version 2.6.801). 2015 was chosen as reference year since it was the most recent year for which all the data were available. It was assumed that the total household metal packaging waste generation equals the mass of household metal packaging brought on the market the same year as it is used for packing fast moving consumer goods of which the packaging is generally disposed of directly after use, so stocks can be neglected. The same approach was used by Warrings and Fellner (2018). The Belgian import of water and soft drinks plastic packaging was estimated by FEVIA (Belgian federation of food industry) at 5 to 7% in 2005 (OVAM, 2015b). However, no specific data on the import of household metal packaging are available in the literature. Furthermore, the import of packaging on the Belgian of Flemish market is probably (partly) balanced by their export, but no export data were found in the literature to sustain this. The uncertainty due to possible net import or export was taken into account by applying an uncertainty interval of $\pm 10\%$ to the metal packaging mass flows in the MFA as explained below.

By means of information found in official publications and reports by e.g. the Flemish Waste Agency (OVAM) and FostPlus, the different flows of waste household metal packaging from the consumer to the recycling industry were estimated. The report of FostPlus on the PMD waste provides only data on the national Belgian level. To obtain specific data for metal packaging brought on the market for Flanders, these national data were multiplied by 0.575, which is the ratio of the number of inhabitants in Flanders (6 444 127) and the total number of inhabitants in Belgium (11 209 044) in 2015 (Statbel, 2017). By doing so it is assumed that the consumption patterns are evenly distributed over the different regions in Belgium.

The literature sources consulted for the MFA do not give any indication of the uncertainty on the reported data. Therefore, the uncertainty on the mass flows was estimated based on the method applied by Cooper and Carliell-Marquet (2013) and Coppens et al (2016). The applied levels of uncertainty depend on the source of information and are given in Table 3. Because of the limitations

of the visual sorting, an uncertainty interval of $\pm 30\%$ was applied to the metal packaging flows in the bottom ash. The collected in- and output mass flows with their uncertainty intervals were statistically processed by the STAN software using error propagation and data reconciliation to detect errors in the data set and close the mass balances (Coppens et al, 2016).

Table 3

3. Results and discussion

3.1 Sorting experiments

Table 4 gives the results of the bottom ash metal fractions sorting experiments.

Table 4.

The > 50 mm fraction contained the highest percentage of household metal packaging of all sorted metal fractions, i.e. 11.3%, and it was easy to distinguish between packaging and non-packaging objects. Packaging consisted mainly of entire drink cans, tins and spray cans. In the 6-50 mm strong ferrous fraction, the household metal packaging consisted mainly of recognizable parts of drink cans and tins, crown caps and stay tabs. The share of packaging was the lowest in the 6-50 mm weak ferrous fraction (2.2%); the packaging consisted mainly of crown caps. In the 6-50 mm non-ferrous fraction, it was more difficult to make a clear distinction between packaging and non-packaging materials, since some of the metals were present as what seemed half molten lumps. The recognizable metal packaging consisted mainly of parts of drink cans and of stay tabs. The non-packaging ferrous and non-ferrous metal objects were very diverse in shape and nature and consisted e.g. of bars, profiles, cutlery, pots and pans, wires, mechanical parts such as gears and bearings and even a horseshoe.

3.2 Material flow analysis

Table 5 gives the mass flows (for the year 2015) of the different waste types that were incinerated in WtE plants in Flanders and that contain metal packaging. Table 5 also indicates that the household metal packaging separately collected as PMD waste corresponds to 56.6% (25 639 t/45 297 t) of the household metal packaging brought on the market. This indicates that 43.4% of the household metal packaging brought on the market is present in the other waste streams or is littered.

Table 5

The *residual household waste* indeed likely contains metal packaging that was disposed in the residual waste bag instead of in the dedicated PMD waste bag. The fractions in the *municipal waste* that are likely to contain household metal packaging are litter that is collected by dedicated clean-up actions and waste from public waste bins. The remainder of the municipal waste consist of 18 881 t (43 621 t – 17739 t– 7001 t, Table 5) of sweepings and non-recyclable waste illegally dumped in public places. Because of lack of data on the composition of the latter two waste streams, it is reasonably assumed that they do not contain household metal packaging. Besides the litter collected by the municipalities, in 2015, also 2 687 t of litter was collected by agencies and waterway managers.

Since 2013, In Flanders, *residual industrial waste* comparable to residual household waste such as the waste collected in the company waste bins, has to be collected and treated separately from the other industrial waste. Given that the source of this waste is partly comparable to that of the residual household waste, it will also contain household metal packaging.

Besides residual household waste, municipal waste and residual industrial waste, also *bulky waste* is combusted in WtE plants. A thorough visual inspection of the bulky waste in the central collection and treatment centre of IMOG (Harelbeke, Flanders) pointed out that it does not contain household metal packaging. Therefore, this waste was not further considered in this study.

In 2015, 397 325 t of mixed residual household waste, municipal waste and residual industrial waste was incinerated in the Indaver grate furnaces, resulting in 85 508 t of bottom ash, corresponding to 21,5% in the input waste mass (Indaver, 2016). As already explained in section 2.2, the Indaver installation is representative for all the WtE plants in Flanders treating residual MSW and comparable industrial waste. Applying the percentage of 21,5% to the total amount of waste containing household metal packaging incinerated in Flanders i.e. 1 550 347 t (Table 5) results in 333 649 t of bottom ash that was generated in Flanders in 2015.

3.2.1 Material flows based on data reported in literature

Figure 3 gives a schematic overview of the household metal packaging flows in the different waste streams based on literature data. For this overview, it is assumed that all the metal packaging present in the waste flows that enter the incinerator are recovered from the bottom ash.

Figure 3

According to a sorting analysis performed by OVAM, residual household waste consists of 0.95% of metal packaging (OVAM, 2015a). Applying this percentage to the amount of residual household waste collected in 2015, results in 6 764 t of metal packaging that is estimated to be present in this waste stream.

No data were found on the composition of residual industrial waste that is incinerated in WtE plants. Since the sources of this waste i.e. mainly residual waste bins and company kitchens is comparable to the sources of residual household waste, it can be assumed that also its composition is comparable to the composition of residual household waste. On the other hand, it might be argued that the activities in companies are partly of a different nature than in households and that this might reflect in the waste composition. Residual industrial waste might e.g. contain a higher amount of office paper than residual household waste. In addition, in many companies there is still no consistent separate collection of e.g. PMD waste, although there has been a catching-up over the last years. By lack of composition data, in this study it is assumed that the composition of residual industrial waste is comparable to that of the residual household waste and also consists of 0.95% of metal packaging. Applying this percentage to the total mass flow of 775 736 t of residual industrial waste yields 7 369 t of metal packaging that would be present in this waste flow (Figure 3).

A sorting experiment conducted by the intermunicipal utility company Limburg.net pointed out that litter collected e.g. on road shoulders, on public footpaths, in recreational areas etc. consisted of 11.19% of household metal packaging (Limburg.net, personal communication). Based on this percentage, the amount of household metal packaging in the 17 739 t of litter collected by the communities can be estimated at 1 985 t. According to a study commissioned by OVAM, waste in public waste bins consist for 55% of litter and 45% of residual household waste (KPlusV, 2015). Assuming that the litter fraction in the public waste bins contains 11.19% of metal packaging and the residual household waste fraction 0.95%, the waste collected in public waste bins accounts for another 461 t of household metal packaging. This result in an overall estimated amount of 2 446 t of household metal packaging present in the municipal waste. Finally, the litter collected by agencies and waterway managers would contain 301 t of household metal packaging (11.19% of 2 687 t).

Based on composition data found in the literature and on the assumptions made in the previous paragraph, the total amount of household metal packaging in the non- PMD waste streams adds up to 16 880 t. Together with the metal packaging collected via the dedicated PMD bags, a total of 42 519 t of household metal packaging can be accounted for, corresponding to 93.9% of the amount brought on the market. This implies that 6.1% of the metal packaging brought on the market remains unaccounted for. Figure 3 shows that the household metal packaging flows in the different waste streams that are incinerated have the highest uncertainties, ranging from about 18 to 30%.

3.2.2 Material flows based on results of sorting experiments

Table 6 shows the mass flow of each ferrous and non-ferrous fraction considered in the sorting experiments in the Indaver bottom ash treatment plant for the year 2015 (Indaver, 2018). These mass flows were extrapolated from the plant level to the Flemish level and the amounts of metal packaging were estimated based on the percentages of metal packaging given in table 4.

Table 6

Figure 4 gives a schematic overview of the household metal packaging flows that can be expected to be present in the different waste streams based on the results of the sorting experiments and resulting from the calculation by the STAN software taking into account the uncertainty intervals. It shows that in Flanders, a total of 28 216 t household metal packaging was collected in 2015, i.e. 25 639 t via the dedicated PMD collection scheme and 2 577 t from bottom ash, corresponding to an overall household metal packaging recycling rate of 62.3%. The metal packaging in WtE bottom ash only accounted for 5.7% of the packaging mass brought on the market. As was the case for the MFA based on literature data, the household metal packaging flows in the different waste streams that are incinerated show the highest uncertainties, ranging from about 19 to 30%.

Figure 4

The 2 577 t of household packaging recovered from bottom ash in Flanders correspond to 4 483 t on the Belgian level. This is only 13.6% of the 32 932 t of “metal packaging of MSW incinerators and their ash treatment centers” (equation 1) that is taken into account to obtain the officially reported metal packaging recycling rate of 97.8%. Hence, based on the results of the sorting experiment, the way the metal packaging recycling rate is calculated does not correspond to the real situation because 86.4% of the “metals of MSW incinerators” taken into account for the calculation of the recycling rate of 97.8% does not consist of packaging.

There is a significant difference between the mass of household metal packaging in the waste streams based on composition data found in literature and based on the sorting experiment of the metal fractions recovered from the WtE bottom ash. Indeed, the 2 577 t found in the sorting experiment (Figure 4) only correspond to 15.3% of the 16 880 t of metal packaging that is expected to be present in WtE bottom ash (based on waste flows and literature composition data, Figure 3). This is a remarkably low percentage, even taking into account the uncertainty on the literature and experimental data. A similar conclusion was drawn by Warrings and Fellner (2018), who conducted an MFA of aluminium from household waste in Austria. In their study, only about 7% of the aluminium beverage cans brought on the market were found in the separately and comingled collected household waste. The low share of packaging found in the bottom ash metal scrap in the sorting experiment also explains the high flow of household metal packaging that is unaccounted for in Figure 4 (i.e. 17 081 t or 37.7% of the packaging brought on the market).

3.3 Uncertainty assessment

The sometimes poor recognisability of packaging in the sorting experiment is a first source of uncertainty on the metal packaging mass flows in the bottom ash. Therefore, an uncertainty interval of $\pm 30\%$ was applied to this mass flows in the MFA as explained in Section 2.2, which resulted after calculation by the STAN software in the uncertainties on the mass flows as shown in Figure 4.

However, another source of uncertainty on the share of packaging metal in bottom ash is the possible breakdown of this metal packaging into smaller, non- recognizable pieces due to the mechanical action of the moving tiles in the grate furnace. In the bottom ash treatment process, these small metal pieces are sorted in the 2-6 mm ferrous and non-ferrous fractions or are not removed by the magnets and eddy-current separators and remain in the 2-6 mm granulate fraction. As indicated in Section 2.1, these small metal pieces are not recognizable as packaging material, so it was impossible to quantify their mass in the sorting experiments.

Furthermore, aluminium packaging can (partly) melt at the temperature prevailing in the furnace of about 700 °C, rendering the objects unrecognizable and also possibly shifting part of the aluminium to the gas phase. Biganzoli and Grosso (2013) estimated that overall 81% of aluminium cans and 51% of aluminium trays can be recovered from WtE bottom ash, whereas the rest of the input aluminium is lost in the fine (< 0.8 mm) bottom ash fraction or in the fly ash. Hu et al. (2011) estimated that 85% of aluminium cans can be recovered from WtE bottom ash. Allegrini et al. (2014) reported an overall recovery rate for aluminium from WtE bottom ash of 62 $\pm$ 2.4%. No data were found on the recovery rate of steel packaging from WtE bottom ash. However, Allegrini et al. (2014) reported an overall ferrous metal recovery rate from WtE bottom ash of 85 $\pm$ 28%.

Taking into account the lowest recovery rates of 51% for aluminium packaging, and 57% for steel packaging, the total household metal packaging flow in WtE bottom ash based on the sorting experiment (table 6) still only adds up to 4 589 t or 27.2% of the 16 880 t expected based on the literature data. Therefore it is unlikely that only mechanical degradation and thermal losses account for the big difference in the household metal packaging mass flows obtained from literature data and based on the sorting experiment. The question remains however where is the household metal packaging that was brought on the market but was not collected via the PMD bags nor recovered from the WtE bottom ash. It seems not realistic to assume that it was all littered (and not collected), so there are probably other disposal routes that were not considered in this study such as e.g. the separate collection of metals in the recycling centres that are in fact intended for large metal objects such as bicycle frames, corrugated iron sheets, fences etc.

3.4 Material losses in sorting and recycling processes

For the calculation of the recycling rates in Sections 3.2 and 3.3, it was assumed that the mass of the recycled packaging equals the mass of the collected packaging. This way of calculation is sustained by Decision 2005/270/EC (European Commission, 2005). However, in practice, the metal packaging collected via the dedicated PMD bags contains some residues of its contents. In addition, the metals recovered in WtE plants are possibly soiled with fine ash particles, so their metal content is not 100%. Furthermore, in each sorting and recycling process, material losses occur e.g. because some types of packaging cannot be recognized by the sorting equipment. Last but not least, not 100% of the mass of the metal packaging delivered to the eventual recyclers is recycled into new products. Depending on the characteristics of the delivered waste metal packaging (e.g. degree of purity) and of the specification of the recycled product, recycling losses occur. Both sorting and recycling losses lower the effective recycling rate of metal packaging. A study by EXPRA, the extended producer responsibility alliance, conducted in eight European member states, showed that for household metal packaging the average sorting loss is 5%, and the average recycling loss is 14% (Christiaens,

2014). In accordance, Haupt et al. (2016) showed that for steel packaging (tinplate) and aluminium from household waste, the real recycling rates are about 13% and 5% lower than the collection rates, respectively. Therefore, although the way the recycling rates are calculated in this study agrees with the official recommendations of the European Commission, they are not fully representative for the recycling rates obtained in practice.

4. Conclusions and recommendations for future work

In Flanders, in 2015, 25 639 t of household metal packaging waste was collected via the dedicated PMD bags, which corresponds to 56.6% of the household metal packaging brought on the market. By means of literature data on waste flows and their composition it was estimated that another 16 880 t of the household metal packaging was present in residual household or industrial waste, waste from public waste bins or collected litter, corresponding to another 37.3% of the household metal packaging brought on the market.

In Flanders, residual household and industrial waste, waste collected from public bins and collected litter are incinerated in WtE plants and metals are recovered from the remaining bottom ash. However, a sorting experiment in a representative WtE plant in Flanders pointed out that only 2 577 t of household metal packaging were present in the metal scrap fractions recovered from the WtE bottom ash. This remarkably only corresponds to 15.3% of the 16 880 t of metal packaging that is expected to be present based on literature data on the composition of the input waste, and results in a recycling rate of 62.3%. To explain this large and unexpected discrepancy between literature and measured data and to correctly balance the household metal packaging mass flows, it is essential to gather more and accurate information on the composition of the different considered waste streams, more specifically on the composition of the collected litter, the waste collected in public waste bins and of the residual industrial waste. Furthermore, more elaborate WtE bottom ash sorting experiments including the granulate fractions and the fine (2-6 mm) ferrous and non-ferrous fraction need to be performed to determine the degree of steel and aluminium packaging that end up in these fractions. The results of the visual sorting experiments should be completed with chemical analyses to determine the iron and aluminium content of the sand and sludge (< 2 mm) fraction of the bottom ash and of the ash collected in the boiler and flue gas cleaning unit of WtE plants. Furthermore, other metal waste streams such as the metals collected in the municipal recycling centres have to be included in the scope. In this way a full mass balance over the WtE plants and a more comprehensive MFA can be performed. The results of this future research can then form the basis for a method to calculate a realistic household metal packaging recycling rate, which preferably also takes into account sorting and recycling losses.

Acknowledgements

The authors kindly thank Roel Van De Voorde for his assistance with the sorting experiments. Also Johan Bonnier is gratefully acknowledged for guiding during our visit to the IMOG sorting installations and WtE plant.

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Highlights

In Flanders, 56% of waste household metal packaging is separately collected

Another 37.3% or 16 880 t is present in waste that is incinerated

Only 2 577 t of household metal packaging was found in incinerator bottom ash

There is a gap between literature and experimental data

More research is needed to correctly determine metal packaging mass flows

Table captions

Table 1: Overview of the household metal packaging types considered in the sorting experiment.

Table 2: Sampling specifications for the “> 50 mm (< 350 mm)” and “6-50 mm” metal scrap fractions recovered from the bottom ash at the Indaver bottom ash treatment plant.

Table 3: Uncertainty intervals for the MFA data adapted from Cooper and Carliell-Marquet (2013) and Coppens et al (2016)

Table 4. Results of the bottom ash metal fractions sorting experiments. (F = Ferrous; N-F = Non-Ferrous)

Table 5: Mass flows of waste streams that contain metal packaging and of metal packaging brought on the market (Flanders, 2015)

Table 6: Mass flows (t) of the different metal fractions recovered from bottom ash and the share of household metal packaging in them based on the results of the sorting experiment (2015). (Indaver, personal communication)

Table 1

Ferrous metal packaging	Aluminium (non-ferrous) metal packaging
Spray cans of food and cosmetics Cans Tins Crown caps Cookie jars Bottles and flasks	Spray cans of cosmetics Cans Bottle caps Trays

Table 2

Material dimension	> 50 mm (< 350 mm)	6-50 mm
Number of 3m ³ sub-lots from lot (heap)	4	4
Number of grabs from each sub-lot	7	10
Grab volume (l)	20	2.5
Total volume of field sample (l)	560	100

Table 3

Uncertainty interval	Source of information	Example
±10%	Official national and regional statistics.	Mass of household waste collected in Flanders.
±20%	Official statistics with additional calculation of metal packaging content.	Mass of metal packaging in residual household waste.
±30%	Values from literature without reference or methodology. Own sorting experiments.	Mass of metal packaging in collected litter. Mass of metal packaging in scrap recovered from bottom ash

Table 4

	> 50 mm F	6-50 mm strong F	6-50 mm weak F	6-50 mm F Total	6-50 mm N-F
Packaging (kg)	29	4.9	2.2	7.1	16.3
Non- packaging (kg)	227	62	99	161	184
Total (kg)	256	70	101	168	200
% (m/m) of packaging	11.3	7.3	2.2	4.2	8.1

Table 5

	Mass flow t/year (2015)	Source
<u>Waste incinerated in WtE plants:</u>		
Residual household waste	728 303	OVAM (2016)
Municipal waste, of which	43 621	OVAM (2016)
Litter collected by dedicated clean-up actions	17 739	Bilsen and Núñez (2018)
Waste from public waste bins	7 001	Bilsen and Núñez (2018)
Litter collected by agencies and waterway managers	2 687	Bilsen and Núñez (2018)
Residual industrial waste	775 736	OVAM (2016)
Total	1 550 347	
<u>Metal packaging</u>		
Brought on the market	45 297	FostPlus (2016), Statbel (2017)
Separately collected (PMD bags)	25 639	OVAM (2017)

Table 6

	Indaver WtE plant	Flanders	Of which metal packaging (Flanders)
Bottom ash	85 508	333 649	
> 50 mm ferrous	2 921	11 398	1 290
6-50 mm strong ferrous	2 753	10 741	787
6-50 mm weak ferrous	2 022	7 890	171
<i>Total considered ferrous fractions</i>	<i>7 696</i>	<i>30 028</i>	<i>2248</i>
6-50 mm non ferrous	1 037	4 046	329
Total of metals recovered from bottom ash	8 733	34 074	2 577

Figure captions

Figure 1: Schematic representation of the dedicated bottom ash treatment installation where the sorting experiment took place. The material flows indicated in bold and underlined were sorted in a packaging and non-packaging fraction.

Figure 2: Illustration of (a) the sub lots of the > 50 mm ferrous fraction and (b) the packaging sorted from the field sample of this fraction.

Figure 3: Schematic representation of the household metal packaging mass flows (t/year) in the different waste streams in Flanders, 2015, based on literature data. If all the household metal packaging present in the waste that is incinerated is recovered from the bottom ash, the total recycling rate would be 93.9%. (MP = household metal packaging)

Figure 4: Schematic representation of the household metal packaging mass flows (t/year) in the different waste streams in Flanders (2015), based on the results of the bottom ash sorting experiment. The mass flows of the household metal packaging in the residual household and industrial waste, the municipal waste and the collected litter were obtained by multiplying the metal packaging mass flow in the bottom ash metal scrap by the share of the household metal packaging in each waste stream in the total amount of household metal packaging in all the waste streams that are treated in the WtE plant as given in Figure 4. For calculation details, see supplementary information. (MP = household metal packaging)

Figure 1

Figure 2

(a)

(b)

Figure 3

Figure 4