Incineration residues in the EU: Quantities and fates

Report

September 2022 – Equanimator Ltd for Zero Waste Europe

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Executive Summary

E.1.1. Background

When Member States report figures regarding how they manage their municipal waste to DG Eurostat, the figures include quantities of municipal waste landfilled. Landfilled waste 'goes no further' (unless it is mined at some future date). In other words, there is no 'waste management destination' for the waste which is sent to landfills.

The same is not true of most other approaches to managing waste. For example, if waste is sent to a sorting facility, it is expected that there may be some 'residues', and that some of these may be landfilled. The same is true of mechanical biological treatment facilities, where some of the outputs may be recycled, some may be used for the generation of energy (at various types of facility) and others may be landfilled, hopefully, following stabilisation of the fraction destined for landfill.

Article 5(5) of Directive 1999/31/EC on the landfill of waste states:

Member States shall take the necessary measures to ensure that by 2035 the amount of municipal waste landfilled is reduced to 10 % or less of the total amount of municipal waste generated (by weight).

Eurostat Guidance on reporting clarifies how this should be done. It clarifies that the amount of waste landfilled should include:

the weight of waste resulting from treatment operations prior to recycling or other recovery of municipal waste, such as sorting or mechanical biological treatment, which is subsequently landfilled.'

This is as one might expect, recognising that such activities may give rise to residues which are landfilled. The same logic, though, is not extended to incineration. Incineration of waste clearly results in the generation of solid residues, and some of these may be landfilled. The way this is to be accounted for as regards the landfill target under Article 5(5), however, is completely different depending on whether the facility is classified as an R1 or a D10 facility. Hence:

In addition, the total amount of landfilling shall include the amount of waste entering incineration disposal operations, less the amount of material recovered from such operations.

If the intention is to report on waste which is landfilled, then whether or not the energy generation of an incinerator is such that it meets the R1 criterion would appear to be besides the point. It also seems very strange that the mass loss occurring in respect of the solid waste outputs (relative to the input) is not to be considered where D10 facilities are concerned.

More generally, because the majority of municipal waste incinerated in the EU-27 was classified as (R1) recovery, and not (D10) disposal (60.4 million tonnes of a total of 61.4 million tonnes, or 98%), so there is no clear reporting of how much waste derived from incineration of municipal waste was actually landfilled. Whereas it is accepted that other forms of waste management – including D10 incineration – can lead to landfilling of waste, the assumption regarding R1 incineration is effectively that nothing further happens. It could be argued that the waste from incinerators is 'no longer municipal' and falls into a different classification of waste. Since the landfill limit applies to 'municipal waste', so the change in the nature of the waste renders any landfilling 'uninteresting'.

There are, though, good reasons to be concerned as to how much residue, and of what type, is generated as a result of incineration, and how this is being managed. Some, after all, notably the residues associated with air pollution control, are likely to be hazardous.

This study has been desk-based, and sought to understand the quantity of residues generated by incineration of waste in the EU, and what happens to those residues. In particular, there was interest in how much residue may be being landfilled. Because the study has been desk-based, it has relied upon data in various published reports and available in public sources. Although the report is focused mainly on incineration, the report has sought to understand the quantity of residues from both incineration and co-incineration when considering 'all wastes'. The Industrial Emissions Directive distinguishes these according to whether the facility is 'dedicated to the thermal treatment of waste' (incineration) or a facility whose main purpose is the generation of energy or production of material products (co-incineration).[1]

E.2.0 Estimated Quantity of Residues Generated

The study first of all reviewed high level EU data – as reported to DG Eurostat – to understand how much waste – municipal only, and then all wastes – were sent for either R1 or D10 incineration. Immediately, one of the issues which presents itself is how the differences between the reporting on municipal waste and the reporting on 'all wastes' are to be accounted for. The use of the R1 classification for wastes can include a range of different types of installation, including cement kilns and power plants. The quantity, nature and fate of residues is likely to be quite different across these installations. Interpreting high level data of this nature requires some care to be taken.

High level data are available regarding residues from incineration, though the classifications of waste under which these are likely to fall in high level reporting mean that the data might not be especially accurate.
We sought to gain more detailed information from Member State level data sources as a means to derive a bottom-up estimate of the residues generated. We focused on the 11 Member States which, when combined, account for 92% of all municipal waste sent for R1 and D10 incineration, and 93% of all wastes sent to R1 and D10 facilities.

Based on the countries from which reliable estimates were obtained, and grossing up based on quantities of waste sent to R1 and D10 facilities, we made a first estimate of the quantity of residues. We called this the bottom-up approach. The figures are presented in Table E - 1, and they indicate a total residue quantity of 28.7 million tonnes based on data pertaining to the end of the last decade (2018-2020). Of this, almost a quarter was estimated to be hazardous in nature, the majority of this being air pollution control residues (of which, more than 90% were hazardous in nature).

[1] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32010L0075

Table E - 1: Estimated Quantities of Bottom Ash and Air-pollution Control Residues, by Bottom-up Method ('000 tonnes)

	Total generated	Non-hazardous	Hazardous
Bottom ash, excl. extracted metals	23,671	21,758	1,913
Air pollution control residues	5,090	462	4,628

Source: Equanimator estimate

In alternative top-down approaches, we estimated quantities of residues (excluding the quantity of metals likely to be extracted for recycling) for both 'municipal solid waste' (as reported to DG Eurostat) and for 'all wastes' sent for D10 and R1 incineration / combustion. We have estimated average quantities per tonne of input at the low and high level. There is at least some indication that bottom ash residues, expressed per tonne of waste input, may be lower (or at least, they are reported as lower) when one considers 'all wastes' as opposed to 'municipal waste' only. There may be all sorts of reasons for this (the wastes themselves are lower in ash content, or the R1 facilities dealing with waste through co-incineration are such that the reported ash quantities are lower than would be expected if the same wastes were incinerated (for example, if wastes sent to cement kilns that might – if incinerated – be a source of bottom ash are largely reporting to clinker, and not to ash residues). In our judgement, this justified lower unit figures when considering 'all wastes' than when considering only MSW.

The figures so derived are shown in Table E - 2. These are shown alongside some other estimates, including figures for bottom ash from Blasenbauer et al, discussed in Section 4.2 of the Main Report, figures quoted directly by CEWEP in a briefing note, and figures derived from the amount of waste reported by CEWEP as being sent to waste-to-energy facilities in 2019, combined with unit generation estimates.

For comparison, Eurostat reports data for 'mineral wastes from waste treatment', which cover 'wastes from waste incineration (bottom ash, slag, fly ash, etc.), mineral fractions from mechanical treatment, and solidified, stabilised or vitrified wastes'. Wastes from co-incineration are included in the category 'combustion waste'. If one restricts the source activity for these wastes to 'Waste collection, treatment and disposal activities; materials recovery', then the total quantity reported to Eurostat is 38.6 million tonnes, of which 5.2 million tonnes were reported as hazardous. These figures are shown in the rightmost column of Table E - 2.

E.3.0 Treatment of Residues

Because the treatment of residues is affected by policy and law, and because this varies by Member State, a grossing up based on a subsample of the total was deemed unwise. The only reliable way to understand the data regarding how residues from incineration are managed is to understand the flows at Member State level, sometimes implying a need to trace cross-border movements of such residues.

We assumed that (see Main Report for rationale):

- 40-50% (low / high) of bottom ashes (pre- or post-treatment) are landfilled; and
- 35-55% (low / high) of APCr are landfilled,

Then the total quantity of residues being landfilled can be estimated based on mid-point estimates from the bottom-up and the top-down estimates derived above. These figures are shown in Table E - 3.

To summarise, it would appear that:

- Regarding municipal waste:
  - Around 12.5 million tonnes of bottom ash and around 2 million tonnes of air pollution control residues are generated (this excludes metals captured for recycling) as a result of the incineration of municipal waste;
  - Together, this amounts to 14.5 million tonnes, or just over 6.4%, of MSW generated;
  - Of this, just under half – or around 6.5 million tonnes – is estimated to be landfilled;
  - The fate of much of the remainder seems likely to be oriented, in the case of bottom ash, towards either road building or other construction related activities, and in the case of air pollution control residues, to filling of salt mines. Although the latter (or the process preceding it) is frequently defined as a recovery activity, it might be reasonable to question whether it should be classified as such;
  - The air pollution control residues are mostly hazardous in nature in their raw form. Most bottom ash is reported as non-hazardous, though it would be helpful to understand the accuracy of this reporting (of the hazardousness, or otherwise, of bottom ash).

Table E - 2: Estimated Generation of Residues from R1 and D10 Facilities, Top-Down Estimates, '000 tonnes

	Based on unit estimates				CEWEP (2019)	CEWEP (2022) (mid-point unit estimates, low)	CEWEP (2022) (mid-point unit estimates, high)	Blasenbauer et al (2020) (excl. UK)	Eurostat reporting for all wastes
	MSW, low	**MSW, high**	**All wastes, low**	**All wastes, high**	**W-t-E, excl haz wastes**	**W-t-E, excl haz wastes**	**W-t-E, excl haz wastes**	**Municipal waste incinerators**	**All wastes**
R1 incineration	57,919	57,919	129,720	129,720					129,720
D10 Incineration	1,116	1,116	14,360	14,360					14,360
Basis Waste Quantity	59,035	59,035	144,080	144,080	96,000	99,000	99,000	78,000	144,090
Unit quantity bottom ash, excl metals (kg/tonne input)	0.185	0.240	0.160	0.230		0.173	0.235		
Unit quantity APC residues (kg/tonne input)	0.027	0.040	0.027	0.040		0.027	0.040		
Bottom ash, excl metals	**10,921**	**14,168**	**23,053**	**33,138**	**19,000**	**17,078**	**23,265**	**16,100**	**33,340[a]**

	Based on unit estimates				CEWEP (2019)	CEWEP (2022) (mid-point unit estimates, low)	CEWEP (2022) (mid-point unit estimates, high)	Blasenbauer et al (2020) (excl. UK)	Eurostat reporting for all wastes
	MSW, low	**MSW, high**	**All wastes, low**	**All wastes, high**	**W-t-E, excl haz wastes**	**W-t-E, excl haz wastes**	**W-t-E, excl haz wastes**	**Municipal waste incinerators**	**All wastes**
APC residues	**1,594**	**2,361**	**3,890**	**5,763**		**2,673**	**3,960**		**5,240[b]**
Total IBA + APCr, MSW only	12,515	16,530							
Total IBA + APCr, All wastes			26,943	38,902		19,751	27,225		38,580
Quantity of all residues (kg/tonne input)	*0.212*	*0.280*	*0.187*	*0.270*		*0.200*	*0.275*		*0.268*

[a] this is the Eurostat figure reported as the non-hazardous component of the relevant mineral and combustion residues
[b] this is the Eurostat figure reported as the hazardous component of the relevant mineral and combustion residues
Sources: Equanimator estimates; CEWEP (u.d.) Bottom Ash Factsheet; CEWEP (u.d.) Waste to Energy Plants in 2019, www.cewep.eu/waste-to-energy-plants-in-europe-in-2019; Dominik Blasenbauer et al (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, Waste Management, 102 pp.863-883; DG Eurostat waste Data Database.

Table E - 3: Quantity of Incineration and Combustion (of waste) Residues Generated and Quantity Landfilled

Generation based on...	Bottom-up, all wastes		Top-down, all wastes		Top-down, MSW, central	
Waste Generated and Quantity Landfilled	**Low**	**High**	**Low**	**High**	**Low**	**High**
Bottom Ash	23,671		28,096		12,545	
APC Residues	5,090		4,827		1,978	
Landfilled Bottom Ash	9,468	11,836	11,238	14,048	5,018	6,272
Landfilled APC Res	1,782	2,800	1,689	2,655	692	1,088
Total Landfilled	11,250	14,635	12,928	16,702	5,710	7,360

- Regarding all wastes:
  - Between 23.7 and 28.1 million tonnes of bottom ash (this excludes metals captured for recycling) and between 4.8 and 5.1 million tonnes of air pollution control residues are generated as a result of the incineration and combustion of all wastes;
  - Together, this amounts to 28.7-32.9 million tonnes, equivalent to between 12.7% and 14.6% of the quantity of MSW generated;
  - Of this, between 11.3 and 16.7 million tonnes – is estimated to be landfilled;
  - As with municipal waste, the fate of much of the remainder seems likely to be oriented, in the case of bottom ash, towards either road building or other construction related activities, and in the case of air pollution control residues, to filling of salt mines;
  - Again, as with municipal wastes, the air pollution control residues are mostly hazardous in nature in their raw form. Most bottom ash is reported as non-hazardous, though as noted above, it might be helpful to understand the accuracy of this reporting (of the hazardous nature, or otherwise, of bottom ash).

E.4.0 Concluding Observations

E.4.1 Equal Treatment?

There are good reasons to question why residues from incineration should be excluded from calculations regarding the quantity of municipal waste landfilled. When waste is incinerated, the residues are no longer classified as municipal waste. Whilst Eurostat Guidance notes the same may be true of residues from mechanical biological treatment (MBT), the Landfill Directive requires residues from MBT which are landfilled to be included in the scope of the target.[2]

Equality of treatment (of different treatments) would reflect on the following options:

- that the target is amended to exclude the residues from MBT also; or
- that the target is amended to include all residues from incineration – both R1 and D10 - which are landfilled); or
- that the landfill target is re-specified so as to ensure (in conjunction with other changes) that management of residual wastes delivers the most beneficial outcome.[3]

What ought to matter is what is being landfilled as a result of the management of municipal waste, and what are the implications of managing these wastes. There are relevant questions to be asked as to whether landfilling 10% of waste as a biostabilised residue from mechanical biological treatment is more or less harmful than handling 12 million tonnes of bottom ash, and 2 million tonnes of mainly hazardous air pollution control residues resulting from incinerating municipal waste.

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[2] Eurostat (2021) *Guidance for the compilation and reporting of data on municipal waste according to Commission Implementing Decisions 2019/1004/EC and 2019/1885/EC, and the Joint Questionnaire of Eurostat and OECD*, Version of 12/08/2021, ec.europa.eu/eurostat/documents/342366/351811/Guidance+on+municipal+waste+data+collection

[3] See proposals for change set out in Equanimator (2021) *Rethinking the EU Landfill Target*, Report for Zero Waste Europe, October 2021, zerowasteeurope.eu/library/rethinking-the-eu-landfill-target

E.4.2 Lack of Harmonisation

Where the treatment of residues is concerned, the framing laws and policies, as well as the available treatments, are not homogeneous across Member States. Because of differences in regulation, processes which are permissible in one Member State might not be considered permissible in another. This may lead to movements of waste that are either unnecessary (if the exporting Member State is 'over-regulating'), or unhelpful (if the receiving Member State is 'under-regulating').

Similarly, because of differences in interpretation of law, it may be that processes which are classified as 'recovery' in one Member State might not be classified as 'recovery' in another. This could have the effect of allowing waste to cross boundaries for the purposes of being recovered in a receiving Member State even though the process would not be classified as recovery in the Member State from which the waste originated;

Particular issues in this regard may be the categorisation of some treatments for APC residues as 'recovery' operations when they might be more properly classified as D9 disposal operations, and the extent to which activities classed as 'backfilling' should be classed as such.

Regarding APC residues, issues associated with classifying disposal and recovery processes were examined by a recent ruling in the UK. The Court upheld the decision of the Environment Agency of England and Wales to refuse a license to export air pollution control residues to a Norwegian facility on grounds that the waste would be undergoing a disposal operation, and not a recovery operation.[4] As reported in the Court Ruling, whilst the Swedish Environmental Protection Agency had a similar view to the Environment Agency of England and Wales, the Norwegian Environment Agency had consented to the export on the basis that the waste would be subject to a recovery operation.

E.5.0 Recommendations regarding reporting

It is recognised that our desk-based study will not have uncovered all sources and figures, but it seems clear that gaining information on the residues associated with incineration (including co-incineration) and of their fates is not entirely straightforward. The quality of data made available by different Member States appears rather variable.

The Main Report includes a small number of recommendations regarding reporting of data. Perhaps the most important of these in the context of this study's objectives relate to the way in which residues from incineration which are sent for treatment may then lead to residues further along the chain which may themselves need landfilling. In some respects, this highlights exactly the issue that this study seeks to address – the fact that the incineration of waste gives rise to residues which need further management, with some being landfilled. Exactly the same applies to some of the incineration residues which are not being reported as landfilled directly, but which may be reported as being treated, or recovered.

[4] Royal Courts of Justice (2022) The Queen (on the Application of New Earth Solutions (West) Limited) – Claimant - and Environment Agency – Defendant - and (1) Noah Solutions AS and (2) Norwegian Environment Agency, Case No: CO/4172/2021, 19/07/2022, www.bailii.org/ew/cases/EWHC/Admin/2022/1883.pdf

We sought to understand the extent to which this was the case in Germany. Where bottom ash was concerned, as far as we could discern, if one accounted for quantities of waste through the chain, then the quantity of (treated) wastes landfilled seemed to increase from 27% of the weight of residues initially generated (when reported at the point of generation) to 40% of the weight of residues initially generated (when taking into account residues generated by treatment processes). Evidently, the landfilled component of a treated waste of type A may not be 'waste of Type A' (indeed, for some hazardous wastes, it might be argued that such a treatment would be of limited value). However, tracing residues through the various treatment pathways to their end-points is important if one is to understand the amount of waste actually disposed of as a result of incinerating waste.

Hopefully, this study might encourage others to improve our understanding of the flows of different incinerator residues through various treatment steps.

1.0 Background

As a result of EU policies on recycling, the proportion of waste that is leftover to be dealt with as 'residual waste' has diminished and is set to continue to do so. At the same time, as we have highlighted in previous work, restrictions on landfilling have tightened, and the quantity of waste incinerated as a share of the overall quantity of residual waste has increased.[5]

There is a perception that incineration with energy recovery can avoid landfilling. This is the common view insofar as it is expressed in much of the discussion about waste management. Yet what is occasionally overlooked is that incineration itself implies the generation of waste. Whilst there are – for example, under Article 5(5) of Directive 1999/31/EC on the landfill of waste – targets for the reduction of the landfilling of municipal wastes, the reporting of 'landfilled municipal waste' excludes wastes which are generated by incinerators, and which are subsequently sent to landfills. More generally, the quantity of residues generated from incineration of waste, and the fate of the residues so generated, are not widely reported on.

This report aims to shed some light on that topic. It aims to understand the quantity of residues generated by incineration, by 'class of residue', and also, the fate of the residues generated.

Although the report is focused mainly on incineration, for reasons that will become clear, the report has sought to understand the quantity of residues from both incineration and co-incineration when considering 'all wastes'. The Industrial Emissions Directive distinguishes these according to whether the facility is 'dedicated to the thermal treatment of waste' (incineration) or a facility whose main purpose is the generation of energy or production of material products (co-incineration).[6]

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[5] See Equanimator (2021) *Rethinking the EU Landfill Target*, Report for Zero Waste Europe, October 2021, zerowasteeurope.eu/library/rethinking-the-eu-landfill-target

[6] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control), eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32010L0075

2.0 Quantities of Waste Incinerated

There are two main sets of data covering the quantities of waste being incinerated in the EU, one related specifically to municipal waste, and the other covering all wastes. These data are part of the DG Eurostat Waste Database. It is worth considering these sources separately in the first instance since they present relevant data for the different waste streams.

2.1 Municipal Waste

The reporting of data on municipal waste follows guidance developed by Eurostat.[7] Consistent with the Waste Framework Directive, this states that, as regards incineration, there are effectively two classifications for incineration. Incineration which, by virtue of the efficiency of energy recovery, qualifies for the classification as 'R1 – energy recovery' – and incineration which fails to qualify as recovery and is regarded as a disposal operation, D10. In respect of the former, the Eurostat Guidance notes:[8]

Regarding energy recovery, please fill in the table with the total weight of waste of each material that type has actually been subject to energy recovery.

The reported quantity of waste incinerated at R1 facilities should be reported under this category. There is an exception presented elsewhere in the Guidance where it appears that the quantity of metals extracted from incinerated waste for material recovery can be reported as such, and hence, deducted from the quantity reported as sent for R1 energy recovery.

The same effectively applies at D10 facilities. However, the quantity of waste sent for D10 incineration is included within reporting on performance in respect of reducing landfilling. In respect of the landfill reduction target, Eurostat Guidance notes:[9]

The following target under Article 5(5) of Directive 1999/31/EC on the landfill of waste must be reported on: Member States shall take the necessary measures to ensure that by 2035 the amount of municipal waste landfilled is reduced to 10 % or less of the total amount of municipal waste generated (by weight).

This target should be reported according to the format set out in Decision 2019/1885.

It also elaborates on how this should be done:[10]

It is important to note that for the purposes of monitoring compliance with the above target, landfilling includes: 'the weight of waste resulting from treatment operations prior to recycling or other recovery of municipal waste, such as sorting or mechanical biological treatment, which is subsequently landfilled.'

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[7] Eurostat (2021) *Guidance for the compilation and reporting of data on municipal waste according to Commission Implementing Decisions 2019/1004/EC and 2019/1885/EC, and the Joint Questionnaire of Eurostat and OECD*, Version of 12/08/2021, ec.europa.eu/eurostat/documents/342366/351811/Guidance+on+municipal+waste+data+collection

[8] Ibid.

[9] Ibid.

[10] Ibid.

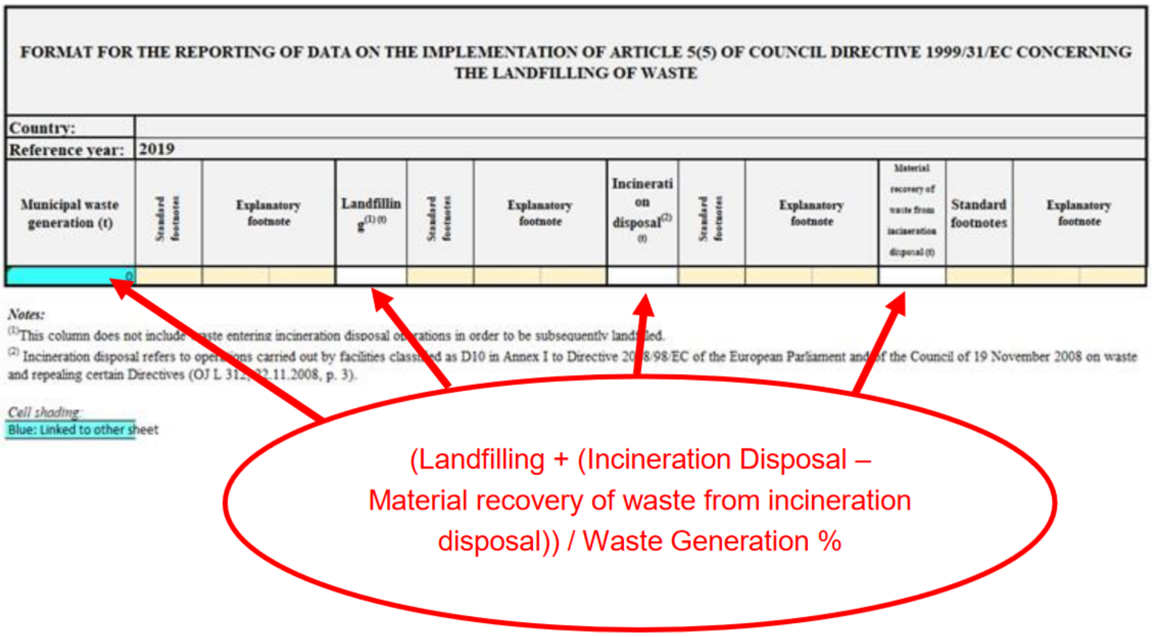
The landfilled output from such processes may be categorised under LoW chapter 19 (wastes from waste management facilities) not chapter 20 (municipal waste), so it is important to ensure the total municipal waste landfilled includes all relevant landfilled wastes from municipal sources (as per the previous Eurostat Guidance on municipal waste)

In addition, t<u>he total amount of landfilling shall include the amount of waste entering incineration disposal operations, less the amount of material recovered from such operations (i.e. column 'Incineration Disposal' minus column 'Material recovery of waste from incineration disposal')</u>. In this case, material recovery is any material recovery, not just metals extracted from IBA, and material recovery of the recovered IBA would also be deducted here (i.e. where recovered material is not finally landfilled).

We have, therefore, something of an oddity: a target for landfilling includes all waste entering D10 incineration facilities other than the materials which are removed for recovery. This calculation – of the quantity of municipal waste landfilled – is shown in Figure 1 below.

Figure 1: Calculation of Municipal Waste Landfilled

Figure A-14: Example of calculation of municipal waste landfilling target calculation

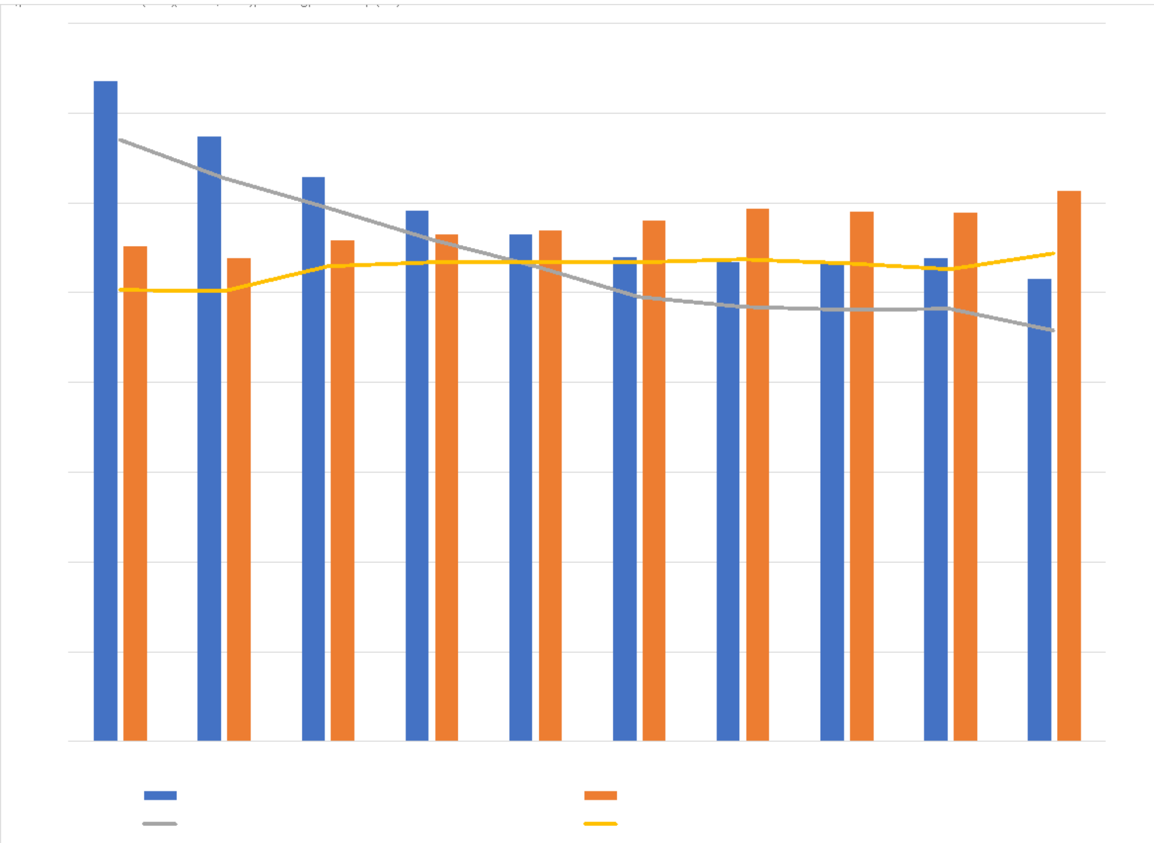


The treatment of R1 facilities is very different, though: there is no consideration of the amount of waste which is incinerated that ultimately leads to the landfilling of residues. Indeed, from municipal waste data, it is not possible – other than through estimation – to quantify the amount of residues generated by incineration, let alone how much of that waste is landfilled.

Indeed, this applies equally to D10 facilities as to R1 incineration since the calculation of the landfill target is likely to overstate the quantity of wastes generated from D10 incineration which are landfilled, whilst as far as R1 facilities are concerned, there is no reporting of what subsequently happens to any residues from the process unless they are recovered.

The broad evolution in the quantities of municipal waste sent for each of R1 and D10 incineration is illustrated in Figure 2 below, which also plots the quantity of each as a proportion of MSW generated on the right-hand axis.

Figure 2: Evolution in Incineration (D10, R1) and Other Disposal (D1-D7, D12) of Municipal Waste, EU-27 ('000 tonnes (l-h axis) and % of all municipal waste generated (r-h axis))



Within the EU, the breakdown of MSW incinerated by country is shown in Figure 3. Germany and France alone account for around half of all UK MSW incinerated. 11 Member States account for more than 90% (92%) of all MSW incinerated. These are shown in Table 1.

Figure 3: Shares of Municipal Waste Incinerated (R1 and D10) by Member State

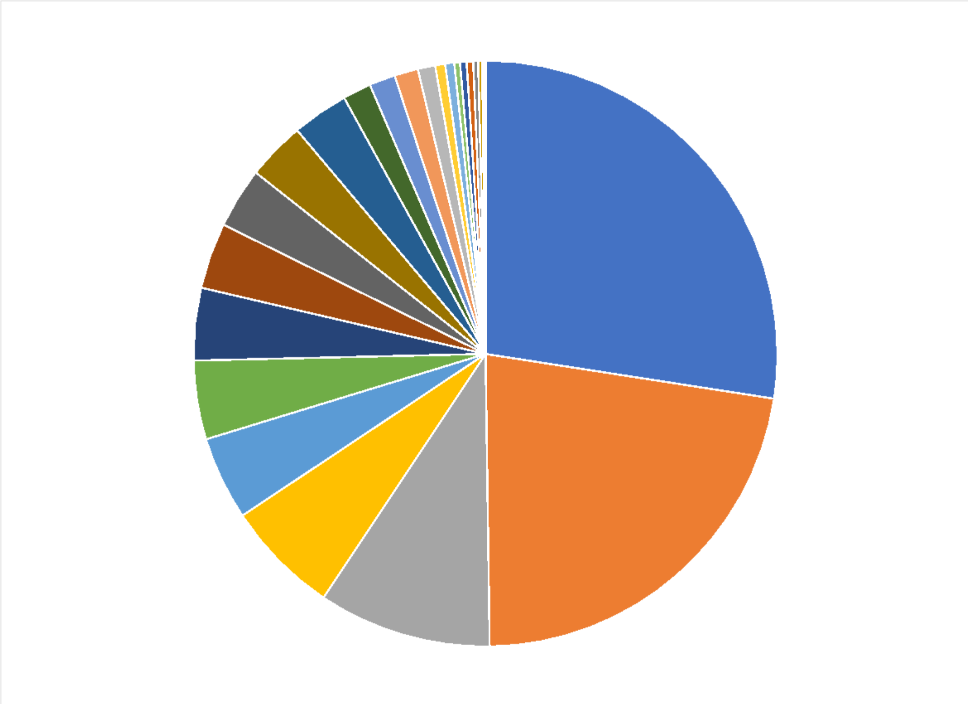


Table 1: Quantity of Municipal Waste Incinerated (R1 and D10) and Shares of EU-27 Totals (2020) by Member State

Country	Quantity ('000 tonnes)	Share of EU total incinerated
Germany	16,935	27%
France	13,758	22%
Italy	5,889	10%
Netherlands	3,894	6%
Poland	2,823	5%
Sweden	2,680	4%
Spain	2,487	4%
Denmark	2,226	4%
Belgium	2,061	3%
Austria	2,004	3%
Finland	1,908	3%

Source: Eurostat
Note: these data and calculations based on EU totals using a figure for Bulgaria from 2018, and figures for Greece, Italy and Austria from 2019.

2.2 All Wastes

The way in which the Manual on Waste Statistics (relevant for all wastes) treats 'incineration' is somewhat different to the way in which it is treated under the municipal waste statistics. Regarding 'Energy Recovery' the Manual reads as follows:[11]

Item 1: Energy recovery (R1)

The treatment operation R1 Use principally as a fuel or other means to generate energy covers the incineration and co-incineration of waste in power stations and industrial facilities such as cement kilns so that the resultant energy can be used to generate heat or electricity. Common examples of energy recovery are:

- *The use of tyres, waste oils, or spent solvents in cement kilns;*
- *The co-incineration of sewage sludge or refuse-derived fuel (RDF) from municipal waste in power stations.*

To be classified as an energy recovery operation, the incineration of waste must meet the following criteria [there is a link to a footnote which reads: 'established by the EJC's rulings in the cases C-228/00 and C-458/00']:

- *The main purpose of the operation must be to use the waste as a means of generating energy, replacing the use of a source of primary energy.*
- *The energy generated by, and recovered from, the combustion of the waste must be greater than the amount of energy consumed during the combustion process (net energy production).*
- *The surplus energy must effectively be used, either immediately in the form of the heat produced by incineration or, after processing, in the form of electricity.*
- *The greater part of the waste must be consumed during the operation and the greater part of the energy generated must be recovered and used.*

R1 also includes incineration facilities dedicated to the processing of municipal solid waste under the condition that their energy efficiency is equal to or above the level set in Annex II of the Waste Framework Directive (footnote to recovery operation R1) and referred to as R1 energy efficiency formula. The application of the efficiency formula is specified and explained in the document 'European Guidance for the use of the R1 energy efficiency formula for incineration facilities dedicated to the processing of Municipal Solid Waste according to Waste Framework Directive 2000/98/EC, Annex II, R1 formula'.

Item 1 does not cover:

- *The combustion of municipal solid waste in incineration facilities that do not fulfill the energy efficiency standards set in Annex II of the Waste Framework Directive (Item 2).*
- *The combustion of non-municipal waste in dedicated waste incineration plants where the main purpose of the operation is the thermal treatment of the waste and not the production of energy (Item 2).*

Item 2: Waste incineration (D10)

Disposal operation D10 Incineration on land covers the incineration of waste where the main purpose of the incineration is the thermal treatment of waste in order to reduce the volume and the hazardousness of the waste, and to obtain an inert product that can be disposed of. This primarily includes incineration plants dedicated to the thermal treatment of wastes by oxidation or other thermal treatment processes (e.g. pyrolysis,

[11] Eurostat (2013) *Manual on Waste Statistics - A Handbook for Data Collection on Waste Generation and Treatment - 2013 edition*, ec.europa.eu/eurostat/documents/3859598/5926045/KS-RA-13-015-EN.PDF.pdf/055ad62c-347b-4315-9faa-0a1ebcb1313e?t=1414782620000

gasification or plasma processes), with or without recovery of the combustion heat generated. The most common examples are:

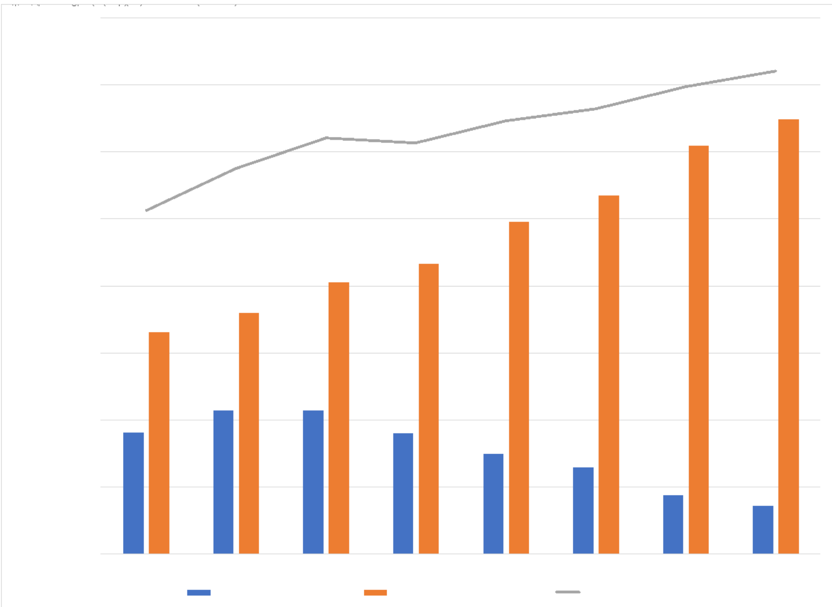
- *municipal solid waste incineration plants (unless they fulfill the energy efficiency standards set in Annex II of the Waste Framework Directive);*
- *hazardous waste incineration plants;*
- *sewage sludge incineration plants;*
- *incineration plants for clinical waste;*
- *incineration plants for animal carcasses.*

D10 also covers the incineration of waste in co-incineration plants where the waste undergoes thermal treatment rather than being used as a fuel.

Item 2 does not cover:
• the use of waste as fuel for energy production (Æ Item 1);

According to data reported to DG Eurostat, there were 144 million tonnes of waste incinerated (either D10 or R1) in 2018, most of this reported as R1 (see Figure 4).[12]

Figure 4: Total Incinerated Waste (R1 + D10) in the EU-27, 2004-2018 (tonnes)

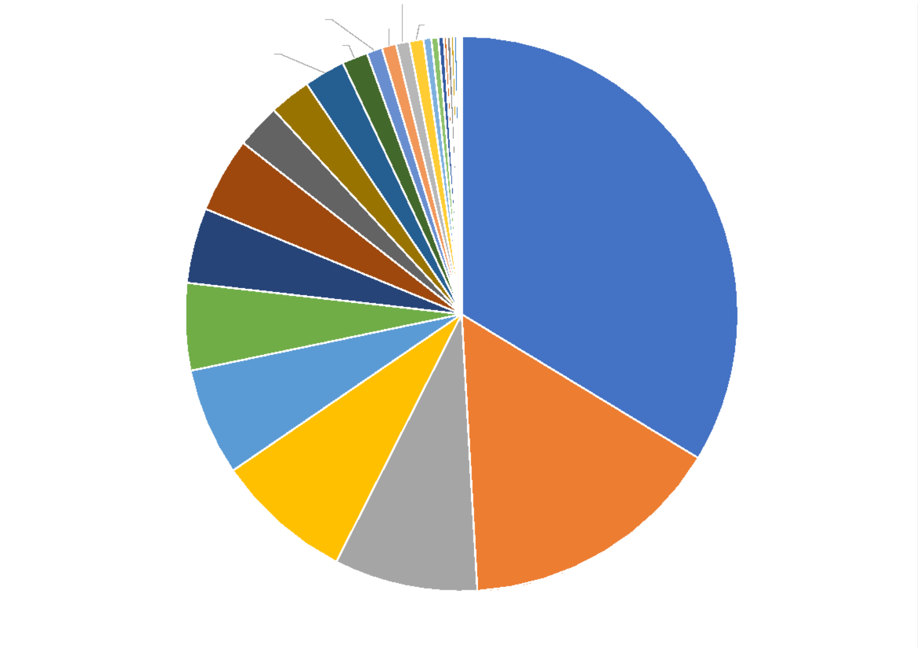


Source: data taken from DG Eurostat Waste Data Database

As with municipal waste, there is a significant concentration of incinerated waste within the EU 27, with Germany and France again together responsible for around half the EU-27 total (see Figure 5). The top 11 countries are responsible for 93% of the waste managed through R1 and D10 facilities. These are the same 11 that account for the vast majority of MSW incinerated, though the rank order is somewhat different for 'all wastes' (see Table 2).

[12] There was no figure for Austria – we estimated this, based on past years, to be of the order 3.5 million tonnes.

Figure 5: Shares of Municipal Waste Incinerated (R1 and D10) by Member State



Note: The Austrian figure was estimated at 3.5 million tonnes for the purpose of this analysis

Table 2: Quantity of Waste of All Types Incinerated (R1 and D10) and Shares of EU-27 Totals (2018) by Member State

Country	Tonnes incinerated, R1 and D10	Proportion of total in EU 27	Cumulative Proportion
Germany	48,468,971	34%	34%
France	22,155,785	15%	49%
Italy	12,099,189	8%	57%
Netherlands	11,462,144	8%	65%
Sweden	9,066,586	6%	72%
Belgium	7,248,008	5%	77%
Finland	6,348,886	4%	81%
Poland	6,273,797	4%	86%
Spain	3,720,677	3%	88%
Austria	3,500,000	2%	91%
Denmark	3,457,930	2%	93%

Note: The Austrian figure was estimated at 3.5 million tonnes for the purpose of this analysis

There is an interesting observation to be made regarding the amount of waste reportedly sent for 'R1 incineration'. The R1 criterion in the Waste Framework Directive applies to 'incineration facilities dedicated to the processing of municipal solid waste'. The Manual on Waste Statistics is clear that regarding non-municipal waste, if the main purpose of the operation is the thermal treatment of the waste and not the production of energy, then this would be a D10 operation.

Given this, what is of some interest is the difference in the quantities reported as R1 and D10 under the two sets of statistics in 2018. These data are shown in Table 3. This shows the difference in the quantities sent to R1 and D10 facilities in moving from consideration of 'municipal waste only' to consideration of 'all wastes'. These highlight considerable differences in the extent to which what are effectively non-municipal wastes are classified as R1 or D10 installations. For Germany, for example, the figures indicate that very little of the non-municipal waste being thermally treated was sent to facilities classed as D10 disposal. A similar observation can be made for Denmark, Finland and Sweden (where most incinerators are typically linked to district heating schemes), as well as for the Netherlands. On the other hand, the additional waste incinerated is more evenly spread across R1 and D10 facilities in the cases of France and Italy, whilst in Austria, more of the additional waste is reported as being disposed of (D10) than is reported as recovered (R1).

The reasons for this are not entirely clear, but could, for example, reflect different propensities to make use of co-incineration options in the different countries, as well as different attitudes of Member States to classifying approaches as R1 or D10.
This is of more than purely academic interest for this discussion: in respect of residues from waste that is not MSW, the nature and quantity of residues generated by the process will be affected both by the process itself, and the nature of the waste. So, for example, some of the material that might become waste if treated at incineration facilities may be used in clinker in the case of co-incineration of waste at a cement kiln. Also, combusting some liquid wastes from industry (solvents for example) would not necessarily generate much residue.

Table 3: Identification of Incinerated Wastes which are not Reported as Municipal Waste (2018, '000 tonnes)

	Non-municipal wastes sent to D10 facilities	Non-municipal wastes sent to R10 facilities
Belgium	1,715	3,511
Bulgaria	6	426
Czechia	89	326
Denmark	5	1,151
Germany	1,464	30,879
Estonia	0	177
Ireland	9	-36
Greece	7	216
Spain	156	985
France	4,252	5,524
Croatia	0	73

	Non-municipal wastes sent to D10 facilities	Non-municipal wastes sent to R10 facilities
Italy	3,554	2,789
Cyprus	0	128
Latvia	0	157
Lithuania	2	130
Luxembourg	0	41
Hungary	82	587
Malta	5	0
Netherlands	994	6,709
Austria	0	1,523
Poland	437	2,824
Portugal	30	201
Romania	80	1,814
Slovenia	32	109
Slovakia	11	412
Finland	97	4,519
Sweden	134	6,570

Source: based on Eurostat data; note, for the purposes of this analysis, we assume quantities of non-municipal wastes incinerated in 2019 are equal to the quantity incinerated in 2018 (the most recent years for which data were available at the time of writing were 2018 for all wastes and 2019 for municipal wastes).

In terms of types of waste incinerated, Table 4 shows that the majority of the waste incinerated in 2018 – 120 million tonnes of the 144 million tonnes total (or 84% of the total) – comes from 4 categories, these being household and similar wastes, mixed and undifferentiated materials (these are both classifications of 'mixed waste'), along with wood wastes and sorting residues. Of these, only the sorting residues and wood wastes contain wastes defined as 'hazardous', and for these categories, the proportion classified as hazardous is small (4% and 8%, respectively). An additional 5% of the total quantity incinerated comes from categories which are predominantly hazardous, including spent sludges, chemical wastes, healthcare and biological wastes, soils, dredging spoils, used oils and sludges and liquid wastes from waste treatment. The remainder is made up of other wastes, and the non-hazardous part of those hazardous wastes just mentioned.

Table 4: Wastes Treated Through D10 Incineration and R1 Incineration Facilities, EU-27, 2018 (tonnes)

	R1	D10	R1+10
Total waste	129,720,000	14,360,000	144,080,000
Waste excluding major mineral wastes	128,020,000	14,010,000	142,030,000
Household and similar wastes	49,210,000	2,670,000	51,880,000
Sorting residues	31,630,000	4,700,000	36,330,000
Wood wastes	23,360,000	170,000	23,530,000
Mixed and undifferentiated materials	8,550,000	450,000	9,000,000
Chemical wastes	1,590,000	1,900,000	3,490,000
Common sludges	1,830,000	1,180,000	3,010,000
Industrial effluent sludges	1,820,000	520,000	2,340,000
Plastic wastes	2,290,000	50,000	2,340,000
Vegetal wastes	1,950,000	40,000	1,990,000
Animal and mixed food waste	1,250,000	230,000	1,480,000
Mineral waste from construction and demolition	1,380,000	50,000	1,430,000
Health care and biological wastes	570,000	720,000	1,290,000
Spent solvents	510,000	540,000	1,050,000
Rubber wastes	930,000	0	930,000
Animal faeces, urine and manure	550,000	360,000	910,000
Combustion wastes	490,000	40,000	530,000
Sludges and liquid wastes from waste treatment	270,000	150,000	420,000
Paper and cardboard wastes	410,000	0	410,000
Used oils	290,000	80,000	370,000
Other mineral wastes (W122+W123+W125)	250,000	40,000	290,000
Textile wastes	210,000	10,000	220,000

	R1	D10	R1+10
Soils	70,000	120,000	190,000
Mineral wastes from waste treatment and stabilised wastes	90,000	60,000	150,000
Dredging spoils	0	140,000	140,000
Acid, alkaline or saline wastes	40,000	90,000	130,000
Metal wastes, ferrous	90,000	10,000	100,000
Discarded equipment (except discarded vehicles and batteries and accumulators waste) (W08 except W081, W0841)	80,000	10,000	90,000
Metal wastes, mixed ferrous and non-ferrous	10,000	0	10,000
Glass wastes	0	10,000	10,000
Waste containing PCB	0	10,000	10,000
Discarded vehicles	10,000	0	10,000

Source: DG Eurostat Waste Data Database

A number of the categories of incinerated wastes falling outside the top 4 categories are likely to be liquids, or may have a high liquid / moisture content. Wood – one of the top 4 categories - may have a relatively low ash content (depending on the forms being combusted).[13] It seems likely, therefore, that whilst 97 million tonnes of the waste being incinerated might be considered potentially 'similar' to municipal waste (household and similar wastes, mixed and undifferentiated materials and sorting residues), a further 47 million tonnes of waste being sent to either R1 or D10 facilities may, when treated, generate quite different quantities (and forms) of residues to that which can be expected from the incineration of municipal wastes. Indeed, many such wastes (wood waste, for example) may have a greater likelihood (than waste 'on average') of being utilised for energy generation at co-incineration facilities.

3.0 Residues Generated by (municipal waste) Incineration Facilities

The incineration process can lead to a number of different waste streams being generated. Some of these are dependent on the nature of the processes used for flue gas cleaning, and might vary depending on the reagents used to scrub emissions from the exhaust flue gas.

[13] See, for example, D. Smołka-Danielowska and M. Jabłońska (2022) Chemical and mineral composition of ashes from wood biomass combustion in domestic wood-fired furnaces. Int. J. Environ. Sci. Technol. 19, 5359–5372 (2022).

The best known of the incinerator residue streams, and the largest of them, is so-called incinerator bottom ash, or IBA. Probably the majority – not all – of incineration facilities in the EU are what are known as 'grate' incinerators, in which waste is moved into the combustion chamber on a grate, so that the IBA is essentially what falls through the grate as the waste is combusted. The quantity of ash generated on combustion of waste is – assuming that the combustion is more or less complete - dependent upon the composition of waste. Different materials leave differing quantities of ash behind when they are burned, especially when expressed in terms of the weight of waste 'as received' (i.e., as it is weighed as it comes in, as opposed to when it is free of moisture).

The Waste Incineration BREF note refers to 'fluidised bed ash' as the solid residue which is removed from the fluidised bed after the waste has been incinerated.[14] Some wastes do not so much burn as melt (good examples are some metals). Sometimes, the melted material is considered to be 'the slag' separately from the IBA, but in practice, this re-solidified melted residue is often removed from the combustion chamber after the waste has been incinerated as part of, or along with, the IBA.

Other residue streams are largely related to flue-gas cleaning. These are sometimes referred to collectively as 'fly ash', though equally, distinct fractions of the fly-ash stream are often referred to, not least since they may have different chemical properties that might offer prospects for different recovery routes. Some distinction could be drawn, for example, between:

- The particles from the combustion chamber or formed within the flue-gas stream that are transported in the flue-gas, but removed before the flue-gas exits the stack. The term 'fly ash' is sometimes used to refer explicitly to this stream. Sometimes, the term boiler ash is used to refer to the particulates that are removed from the boiler;
- The mixture of the pollutants originally present in the flue-gas and the substances / reagents that are used to react with and / or remove those pollutants. As such, they may include either:
    - Filter dusts from dry, or quasi-dry, flue gas cleaning processes,
    - Filter salts and sludges, from wet flue gas cleaning processes,
- Adsorbents which may be used to clean flue gas, such as activated carbon.

To simplify matters, in this report, we mainly refer simply to two residue streams: bottom ash, and air pollution control residues, other than where a more detailed breakdown is given.

3.1 Quantity of Residues Generated per tonne of Waste

There are plenty of 'ball-park estimates' (as noted above, figures will vary with composition and process configuration) as to the quantity of residue produced per tonne of waste. This Section provides a brief review of some figures that have been produced in various studies. The intention is not to be comprehensive, but to provide an indication of the likely magnitude of the residue streams. This is helpful given the figures indicated in Section 2.0: the per tonne figures provide a form of sense check on the macro-level data regarding residue quantities (for example, in Section 6.0 below).

The BREF note for Waste Incineration gives some typical figures for residues from the incineration process.[15] These are shown in Table 5.

[14] Frederik Neuwahl, Gianluca Cusano, Jorge Gómez Benavides, Simon Holbrook, Serge Roudier (2019) *Best Available Techniques (BAT) Reference Document for Waste Incineration*, JRC Science for Policy Report, 2019.

[15] Frederik Neuwahl, Gianluca Cusano, Jorge Gómez Benavides, Simon Holbrook, Serge Roudier (2019) Best Available Techniques (BAT) Reference Document for Waste Incineration, JRC Science for Policy Report, 2019.

Table 5: Typical data on the quantities of residues arising from waste incineration plants

Types of waste	Specific amount (dry) (kg/t of waste)
Bottom ash/slag	150-350
Boiler ash	620-40[(1)]
Fly ash from:	
Wet FGC	15-40
Semi-wet FGC	20-50
Dry FGC	15-60
Sludge from wastewater treatment	1-15

[(1)] Fluidised bed furnaces produce a higher amount of boiler ash.
Source: Frederik Neuwahl, Gianluca Cusano, Jorge Gómez Benavides, Simon Holbrook, Serge Roudier (2019) Best Available Techniques (BAT) Reference Document for Waste Incineration, JRC Science for Policy Report, 2019 (citing the TWG, Data collection 2016).

These are broad ranges. In explaining these, the BREF note states:[16]

MSWI [MSW incineration] plants generate between 150 kg and 350 kg bottom ashes per tonne of waste treated. This figure includes the grate siftings. The mass flow of siftings depends on the type of grate and its time of operation. The siftings increase the amount of unburned matter in the bottom ashes and can contribute to leaching of copper. Concerning the recovery of materials from the bottom ashes, ferrous and non-ferrous materials (e.g. aluminium) are commonly separated. [74, TWG 2004]

The generation of boiler ash depends on the type of boiler and on the amount of dust originally released from the furnace. Limited data are available on boiler ash production in fluidised bed furnaces, but they show a clear tendency for this type of furnace to produce a higher level of boiler ash.

Elsewhere, the same BREF note states:

Bottom ash is typically 20–30 % by dry mass of the waste input and FGC residues are approximately 2–3 %.

The figures are somewhat ambiguous as expressed: these seem to be stating figures as a proportion of the dry matter being incinerated. However, given the figures cited elsewhere in the same report, either these figures are rather low (20% of dry matter would imply something of the order 125-150kg for MSW, a figure well below what is routinely observed), or the intention was to state figures as a proportion of the weight of the waste 'as received'.

Regarding German incineration facilities, ITAD gives a figure for bottom ash as follows:[17]

Between 200 and 300 kg of slag are produced per tonne of waste.

[16] Ibid.

[17] ITAD (u.d.) *Reststoffe (allgemeine Informationen)* www.itad.de/wissen/reststoffe (accessed 06/07/22).

Regarding other residues, ITAD notes:[18]

Heat recovery produces between 5 and 15 kg of boiler ash per tonne of waste. In a subsequent dust separation before wet washing, another 10 to 30 kg of filter ash accumulate. Boiler and filter ash is nowadays mainly used in underground backfilling in salt mines that are subject to backfilling. The thermal treatment of fly ash or the solidification with water or in cement with subsequent disposal is rarely used for cost reasons.

Between 5 and 20 kg of solid residues per tonne of waste accumulate in the wet flue gas scrubber. These are mostly solid salts from the evaporation of the waste water. Here, too, recovery usually takes place underground.

Loaded adsorbents, such as activated carbon from the flue gas after-cleaning (approx. 2 to 5 kg per tonne of waste by weight) can either be returned to the furnace, regenerated in special systems or disposed of in special incinerators.

In developing its documentation regarding the impact of end-of-life treatment, Ademe reported:[19]

The bottom ash is approximately 220kg/t of MSW (approximately 200 kg/t of MSW without ferrous metal scrap).

And

According to the current situation in Europe, APC residues (40kg/t of MSW) including boiler ash, filter cake and slurries are disposed in salt mines or landfills.

In Italy, the facility in Turin suggests incinerator bottom ash is around 21% of the input waste quantity.[20] The ash from cleaning particulate / dust amounts to the order of 2% of input weight, whilst further flue gas scrubbing adds a further 1.5% to the residue stream, giving a total of 3.5% of input waste, or 35kg per tonne of waste incinerated.

In the UK, Tolvik reviewed data reported for around 50 incinerators in the UK. Regarding incinerator bottom ash (IBA), it noted:[21]

In 2021 IBA accounted on average for 19.8% (2020: 19.8%) of all waste inputs. In total, the tonnage of IBA generated in 2020 was just over 2.9Mt.

Except three ACT [Advanced Conversion Technology] facilities at the lower end of the range, IBA outputs expressed as a percentage of waste inputs fell within the 11% - 27% range.

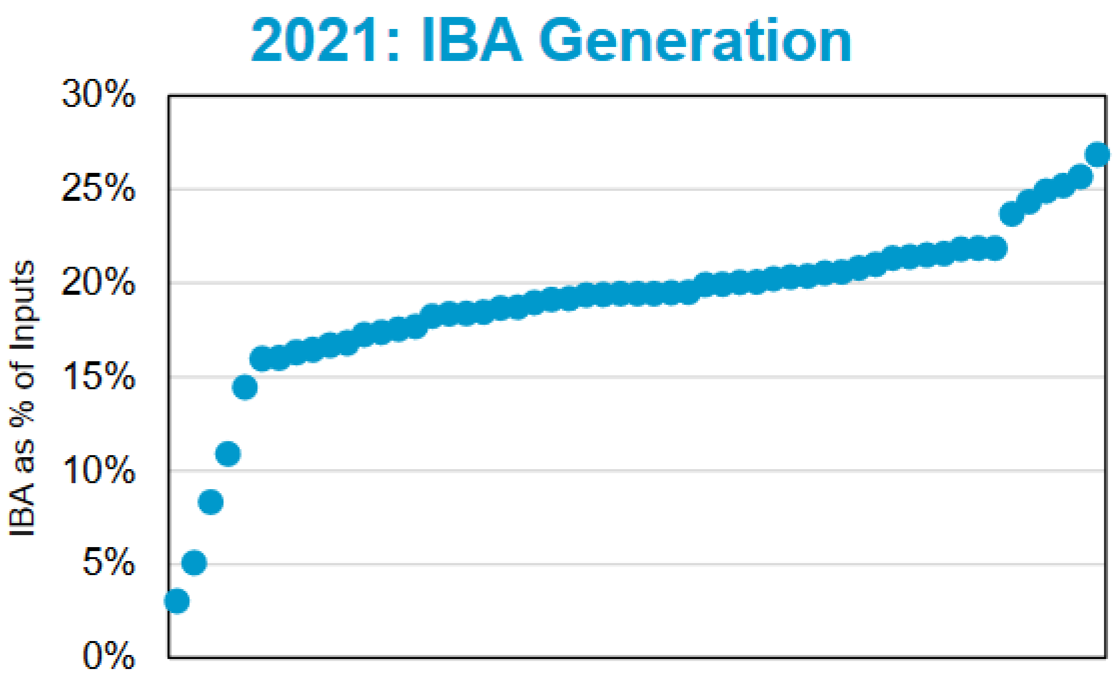
The distribution of the amounts reported is shown in Figure 6. This shows that the vast majority of facilities report IBA quantities in a range between 16-22% of input waste tonnage. Note that this excludes metals recycling, where the facilities report this separately, the figure being of the order 1.7% of waste input across the reporting facilities. It is not clear from the report whether the metals are 'additional to' the reported IBA figures, or whether

[18] Ibid.
[19] ADEME (2018) Base Impacts® Data Documentation - Sector: End of Life Treatment, Angers, 1.09.2018.
[20] TRM (2022) *How does it work?* trm.to.it/en/how-does-it-work

[21] Tolvik Consulting (2022) *UK Energy from Waste Statistics – 2021*, May 2022, www.tolvik.com/wp-content/uploads/2022/05/Tolvik-UK-EfW-Statistics-2021_Published-May-2022.pdf

the IBA figures are reported inclusive of the metals that are subsequently recovered. If the metals are 'additional', then this would imply a figure of 21.5% of input for IBA, of which around 8% is recovered as metals.

Figure 6: 2021 Distribution of IBA Generation (as % of inputs



Note: Tolvik analysis, based on 51 records
Source: Tolvik Consulting (2022) UK Energy from Waste Statistics – 2021, May 2022, www.tolvik.com/wp-content/uploads/2022/05/Tolvik-UK-EfW-Statistics-2021_Published-May-2022.pdf

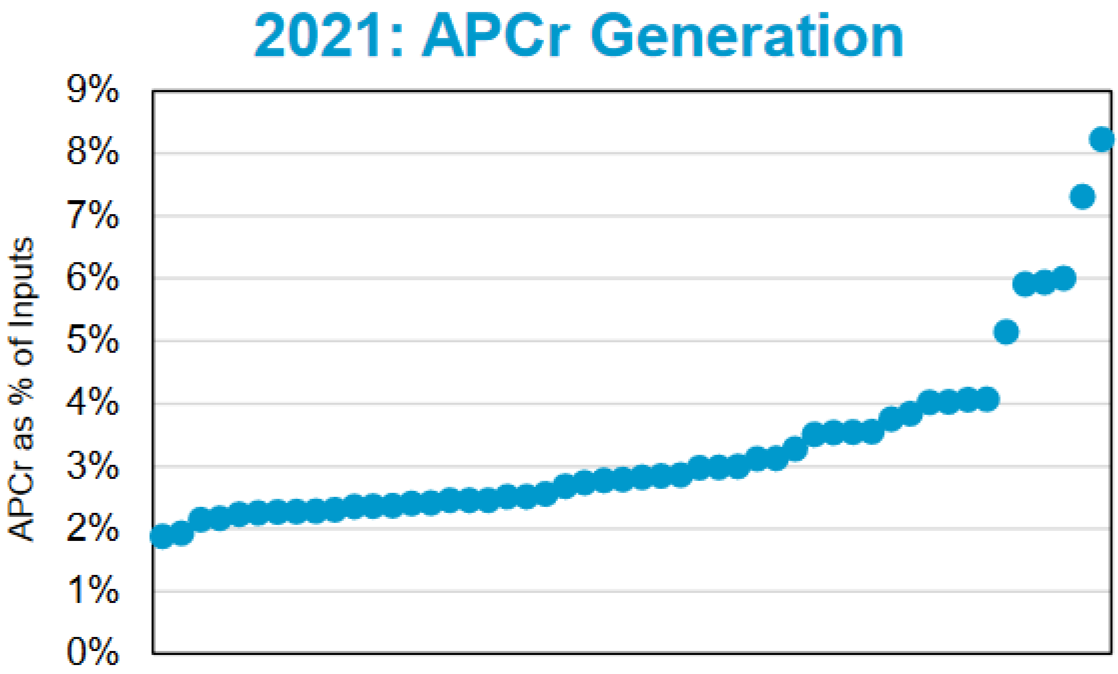
Regarding air pollution control residues (APCr), the same report states:[22]

In 2021 APCr generation was 3.2% of waste inputs (2020: 3.1%). Total generation of APCr in 2021 is estimated to have been 470kt with 35.6% recycled.

Six facilities generated more than 5% of APCr as a percentage of inputs – being those EfWs using fluidised bed technology, ACTs [advanced conversion technologies, such as gasification or pyrolysis] and one small EfW. Two EfWs generated less than 2% of APCr.

[22] Ibid.

Figure 8: 2021 Distribution of APCr Generation (as % of inputs



Note: Tolvik analysis, based on 51 records
Source: Tolvik Consulting (2022) UK Energy from Waste Statistics – 2021, May 2022,
www.tolvik.com/wp-content/uploads/2022/05/Tolvik-UK-EfW-Statistics-2021_Published-May-2022.pdf

The CEWEP 'Bottom Ash Factsheet' states that, in 2018:[23]

96 million tonnes of waste (municipal, commercial and industrial) were treated in Waste-to-Energy plants in Europe. The combustion process produced approximately 19 million tonnes of bottom ash, which is the incombustible residual part of the incinerated waste

The figure of 19 million tonnes, based on 96 million tonnes incinerated, suggests a figure of somewhat less than 200kg per tonne of waste incinerated.[24] The CEWEP study appears to be giving a figure including metals, which it suggests may be of the order 10-12% of the bottom ash composition.

Based on the above, it would seem that reasonable figures are as follows:

- for IBA, circa 200-250kg in total, of which around 7-10% may be extracted as metals for recovery;
- for combined FGC / APC residues, a figure which tends to be no lower than 30kg (3% of input), and may, depending on the nature of the FGC/ APC approach, rise above 40kg (4% of input).

[23] CEWEP (u.d.) *Bottom Ash Factsheet.*

[24] The figure of 96 million tonnes is not necessarily inconsistent with the figures in Section 2.0 in that the figures there include all R1 'incineration', including co-incineration. The CEWEP figures are likely to exclude co-incineration, given the interests of the organization, and focus on 'waste-to-energy' facilities.

4.0 Data on Incinerator Residues

Having considered the tonnages input to incineration facilities, it is worth examining what insight can be gained from data reported to Eurostat and included in the Waste Data Database.

4.1 Insights from Eurostat Data

4.1.1 Quantity of Resides Generated

At the high level of aggregation at which data are reported by Eurostat, the quantity of residues generated as a result of the incineration process cannot be directly accessed. The category reported which includes these residues is 'Mineral wastes from waste treatment and stabilised wastes'. This is described as follows:[25]

Mineral wastes from waste treatment and stabilised wastes

Code	Description	Definition	Includes	Source branches (nomenclature of LoW is **bold**, NACE is non-bold)	Excludes
12.8 13	Mineral wastes from waste treatment Solidified, stabilised and vitrified wastes	**Kind of waste:** Bottom ash and slag from waste incineration and pyrolysis Fly ashes and other wastes from flue gas treatment in waste incineration plants Solidified, stabilised and vitrified wastes from waste treatment **Origin:** Incineration or pyrolysis of waste Waste treatment **Hazardous:** When containing organic pollutants, heavy metals	Wastes from flue-gas cleaning in oil regeneration plants	In general incineration and pyrolysis of waste. In detail: • **Incineration or pyrolysis of waste** (38.2 Waste treatment and disposal) • **Stabilisation, solidification and vitrification of waste** (38.3 Materials recovery) • **Mechanical treatment of waste (for example sorting, crushing, compacting, pelletising)** (38.3 Materials recovery) • **Oil regeneration** (19.20 Manufacture of refined petroleum products)	Slag and ashes from co-incineration of waste in power stations and other combustion plants -> see cat. 12.4 Spent activated carbon -> see cat. 3.1 Non-vitrified solid phase -> see cat. 10.3 Aqueous liquid wastes from vitrified waste tempering -> see cat. 03.3

It includes the following wastes:

Mineral wastes from waste treatment and stabilised wastes
12.8 Waste from waste treatment
12.81 Waste from waste treatment
0 Non-hazardous
19 01 12 bottom ash and slag other than those mentioned in 19 01 11
19 01 14 fly ash other than those mentioned in 19 01 13
19 01 16 boiler dust other than those mentioned in 19 01 15
19 01 18 pyrolysis wastes other than those mentioned in 19 01 17
19 01 19 sands from fluidised beds
19 12 09 minerals (for example sand, stones)
1 Hazardous
19 01 05 filter cake from gas treatment*

[25] Eurostat (2010) *Guidance on classification of waste according to EWC-Stat categories: Supplement to the Manual for the Implementation of the Regulation (EC No 2150/2002 on Waste Statistics*, Version 2, December 2010.

19 01 06 aqueous liquid wastes from gas treatment and other aqueous liquid wastes*
19 01 07 solid wastes from gas treatment*
19 01 11 bottom ash and slag containing dangerous substances*
19 01 13 fly ash containing dangerous substances*
19 01 15 boiler dust containing dangerous substances*
19 01 17 pyrolysis wastes containing dangerous substances*
19 04 02 fly ash and other flue-gas treatment wastes*
19 11 07 wastes from flue-gas cleaning*
13 Solidified, stabilised or vitrified waste
13.1 Solidified or stabilised waste
13.11 Solidified or stabilised waste
0 Non-hazardous
19 03 05 stabilised wastes other than those mentioned in 19 03 04
19 03 07 solidified wastes other than those mentioned in 19 03 06
1 Hazardous
19 03 04 wastes marked as hazardous, partly stabilised*
19 03 06 wastes marked as hazardous, solidified*
13.2 Vitrified wastes
13.21 Vitrified wastes
0 Non-hazardous
19 04 01 vitrified waste"

This clearly includes residues from incineration, but it potentially also includes some other waste streams. The non-hazardous / hazardous split would indicate a rough split between the bottom ash and air pollution control residues, though there are several so-called mirror entries in this group of wastes, i.e., cases where there is both a non-hazardous and hazardous entry, with the hazardousness being determined (at least in theory) on the basis of testing of waste generated. Mirror entries exist for bottom ash (usually reported as non-hazardous, but which can be hazardous), fly ash (usually reported as hazardous, but can be non-hazardous), boiler dust and pyrolysis wastes.

There are a number of categories which are also reported under the classification, 'Combustion Wastes'. It is clear that the majority of these wastes come from power stations and industrial facilities, including (R1) co-incineration installations. Within this class of waste are '12.42 Slags and ashes from thermal treatment and combustion', and included within this are bottom ash and fly ash, both non-hazardous and hazardous, from co-incineration.

Given these data reported under the Waste Statistics Regulation, we have reported both the 'Mineral wastes from waste treatment and stabilised wastes' and 'Combustion Wastes', extracting the data only for those generated by the sector 'Waste collection, treatment and disposal activities; materials recovery'. This gives the figures shown in Table 6. Note that these data do not include some residues, such as spent catalysts / spent activated carbon.

Table 6: Mineral Wastes from Waste Treatment and Stabilised Wastes and Combustion wastes from the Sector 'Waste collection, treatment and disposal activities; materials recovery', tonnes, 2018

	Mineral wastes from waste treatment and stabilised wastes			Combustion wastes		
	Non-haz	Haz	Total	Non-haz	Haz	Total
EU 27	28,670,000	5,000,000	33,670,000	4,670,000	240,000	4,910,000
Belgium	624,646	205,973	830,619	747,263	35,920	783,183
Bulgaria	35,968	500	36,468	1,764,667	0	1,764,667
Czechia	298,835	144,505	443,340	2374	nd	2,374
Denmark	301,091	29,585	330,676	3,677	238	3,915
Germany	15,533,346	1,416,591	16,949,937	403,106	110,178	513,284
Estonia	55,937	5	55,942	4	0	4
Ireland	45,205	104,061	149,266	0	0	0
Greece	143,382	49,708	193,090	243	1,499	1,742
Spain	664,182	111,287	775,469	114,652	27,475	142,127
France	3,159,683	767,999	3,927,682	683,206	10,597	693,803
Croatia	9,191	0	9,191	5,596	0	5,596
Italy	2,252,941	1,256,858	3,509,799	11,015	7,718	18,733
Cyprus	0	2,535	2,535	0	0	0
Latvia	1	0	1	980	0	980
Lithuania	15,271	2,255	17,526	911	104	1,015

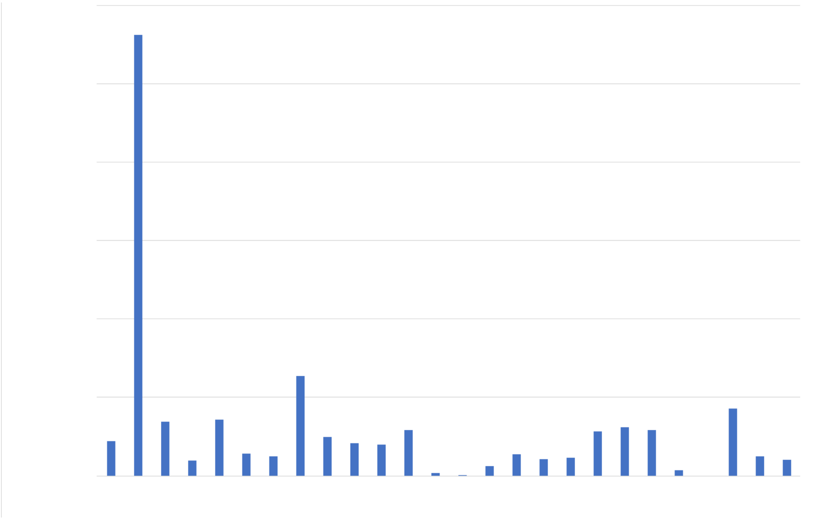
	Mineral wastes from waste treatment and stabilised wastes			Combustion wastes		
Luxembourg	32,370	4,952	37,322	0	0	0
Hungary	21,592	43,496	65,088	26,663	34,117	60,780
Malta	310	274	584	0	0	0
Netherlands	3,019,092	199,034	3,218,126	13,577	11	13,588
Austria	272,458	108,237	380,695	nd	nd	nd
Poland	1,156,717	66,491	1,223,208	698,878	14,252	713,130
Portugal	12,045	309,683	321,728	21,811	164	21,975
Romania	73,965	204	74,169	3,399	44	3,443
Slovenia			0	234	0	234
Slovakia	177,571	15,015	192,586	68,503	727	69,230
Finland	773	0	773	0	14	14
Sweden	28,670,000	157,406	924,849	12,883	74	12,957

Source: Eurostat

Based on the total quantity reportedly sent for treatment through R1 and D10 facilities, the total quantity of residues generated at the EU-27 level seems reasonable. The sum of the non-hazardous fractions gives a specific figure of 231kg per tonne of waste, with the sum of the hazardous fractions giving a specific figure of 36kg per tonne of waste.

Closer inspection of the Member State-level data suggests some problems with this dataset, indicating that the apparent plausibility of the data at the EU level may be reflective more of a coincidence than of the quality of the underlying dataset. For example, if one considers the quantity of these residues per unit of waste treated through R1 and D10 incineration, there are clearly some problems with the data. We show this for all Member States in Figure 9 and for all Member States except Bulgaria (a clear outlier in Figure 9) in Figure 10. In Figure 10, we have indicated a band where we would expect most data points to fall.

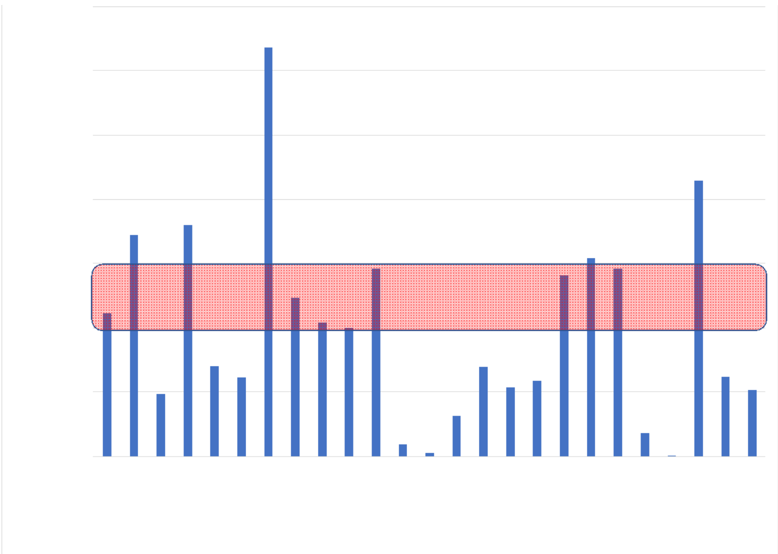
Figure 9: Mineral Wastes and Combustion Wastes Resulting from Waste Sector Activity, tonnes generated per tonne treated via R1+D10 (2018 data)



Source: Equanimator analysis based on data in Eurostat waste data database

Only 7 Member States' data points lie within this range, though 3 others have data points reasonably close, but for many Member States, reported figures seem to be unreasonably low. The reasons for this are unclear and deserve to be explored further by the relevant authorities. Note also that Austria has not reported data, and the figures for Slovenia appeared to be a factor of 1000 too low (even accounting for the poor quality of the data). Portuguese data may also have reported hazardous and non-hazardous figures the wrong way round.

Figure 10: Mineral Wastes and Combustion Wastes Resulting from Waste Sector Activity, tonnes generated per tonne treated via R1+D10 (excluding Bulgaria) (2018 data)



Source: Equanimator analysis based on data in Eurostat waste data database

4.1.2 Management of Residues

The treatment shares are not available for the specific waste streams by sector of origin. Hence, data on the way in which the category 'Mineral wastes from waste treatment and stabilised wastes' is managed is not available for a specific sector. Nonetheless, we note the figures provided for treatment of all such wastes in Table 7. Even if the quantities are much higher than those presented in Table 6 (they are 61% higher), the treatment shares may still be of interest as a means to sense-check what happens to incinerator ash residues. It would clearly be desirable to have a further breakdown of the nature of the 'recovery' activity.

Table 7: Treatments Used for Management of 'Mineral wastes from waste treatment and stabilised wastes' (2018 data)

Treatment	Tonnes (2018)	As % o the total
Waste Treatment	62,920,000	
Disposal – landfill and other (D1-D7, D12)	9,970,000	15.8%
Disposal – landfill (D1, D5, D12)	9,970,000	15.8%
Disposal – incineration (D10)	60,000	0.1%
Disposal – other (D2-D4, D6, D-7)	0	0.0%
Recovery – energy recovery (R1	90,000	0.1%
Recovery – recycling and backfilling (R2-R11)	52,800,000	83.9%
Recovery – recycling	50,480,000	80.2%
Recovery – backfilling	2,320,000	3.7%

Source: Eurostat Waste Data Database

4.2 Bottom Ash from Municipal Waste Incineration

One paper, resulting from the EU's COST action Mining the European Anthroposphere (MINEA), has sought to estimate the quantity of bottom ash generated by municipal waste incinerators in the EU. On the basis of an estimated capacity of 90 million tonnes, it was estimated that 17.64 million tonnes of incinerator bottom ash were generated (195kg per tonne input). Of this, 54% was estimated to be utilised outside landfills, leaving the remaining 8 million or so tonnes to be landfilled (see Table 8). These estimates provide a cross-check on figures obtained in country-specific analysis, or may be used to fill gaps regarding treatment routes for bottom ash.

Note that the above figures refer only to municipal waste. The specific (per tonne) figures are also lower than would appear to be indicated by Table 6.

Table 8: Overview on number and incineration capacity of MSWI plants, annually generated amount of IBA in the observed countries, information if utilisation is permitted and practiced, how much MIBA is utilised

Country	MSWI plants		IBA mass	MIBA Utilisation		MIBA utilisation rate outside landfills
	No.	Capacity [Mt/a]	[Mt/a]	Permitted	Practised	[wt.%]
Austria	11	2.6	0.53	yes	no	0
Belgium	15	3.3	0.47	Flanders: yes Wallonia: yes (mandatory) Brussels capital region: not regulated	yes	69
Czechia	4	0.65	0.2	yes	no	0
Denmark	24	3.7	0.6	yes	yes	99
Estonia	1	0.25	0.058	Not regulated	No data-	0
Finland	9	1.6	0.3	yes	yes	20
France	126	14.7	2.9	yes	yes	80
Germany	68	19.8	4.8	yes	yes	30
Hungary	1	0.42	0.12	not regulated	no	0
Ireland	2	0.8	0.14	not regulated	no	0 (partial export)

Country	MSWI plants		IBA mass	MIBA Utilisation		MIBA utilisation rate outside landfills
	No.	**Capacity [Mt/a]**	**[Mt/a]**	**Permitted**	**Practised**	**[wt.%]**
Italy	39	6.1	1.03	yes	yes	85
Lithuania	1	0.28	0.075	yes	no	0
Luxembourg	1	0.17	0.028	not regulated	no	0 (full export)
Netherlands	12	7.6	1.9	yes (mandatory)	yes	100
Norway	18	1.8	0.25	not permitted	no	0
Poland	6	0.97	0.21	yes	yes	60
Portugal	4	1.3	0.22	yes	yes	56
Slovakia	2	0.29	0.062	not regulated	no	0
Spain	10	2.4	0.44	Catalonia: yes Rest of Spain: not regulated	yes	58
Sweden	34	5.4	0.99	yes	no	0
Switzerland	30	3.7	0.82	yes	no	0
United Kingdom	45	12	1.5	yes	yes	99
Total	463	90	17.64	16	11	54 (or 9.6 Mt/a)

Source: adapted from Dominik Blasenbauer, Florian Huber, Jakob Lederer, Margarida J. Quina, Denise Blanc-Biscarat, Anna Bogush, Elza Bontempi, Julien Blondeau, Josep Maria Chimenos, Helena Dahlbo, Johan Fagerqvist, Jessica Giro-Paloma, Ole Hjelmar, Jiri Hyks, Jackie Keaney, Maria Lupsea-Toader, Catherine Joyce O'Caollai, Kaja Orupõld, Tadeusz Paja, Franz-Georg Simon, Lenka Svecova, Michal Šyc, Roy Ulvang, Kati Vaajasaari, Jo Van Caneghem, Andre van Zomeren, Saulius Vasarevic˘ius, Krisztina Wégner and Johann Fellner (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, Waste Management, 102 pp.863-883.

5.0 Country-specific data

In Section 2.0, we highlighted the fact that, whether looking at municipal waste alone, or at 'waste' more broadly, 11 countries account for more than 90% of R1+D10 incineration (and co-incineration) in the EU. Recognising that this is the case, we have conducted a non-exhaustive desk review regarding the quantities of the different residues generated in each of these key Member States, and their fate where we found that this was reported.

5.1 Germany

At the beginning of 2019, the federal associations IGAM (the trade body for the processors for waste incineration slag) and ITAD (the trade body for thermal waste treatment plants in Germany) published current figures, data and facts about the processing and recycling of residues from the thermal treatment of municipal and commercial waste (MVA and RDF power plants with grate firing) from members and non-members.[26]

The data was collected by industry-specific questionnaire, and although data for one of the facilities had to be estimated, the data covers all 40 known plants processing incinerator bottom ash residues in Germany. The exercise appears to have been repeated for the year 2020.[27]

The results for the years 2017 and 2020 are shown in Table 9. The total quantities of waste incinerated have been taken from the ITAD yearbook 2021 to be 23,584,000 tonnes and 24,982,000 tonnes in 2017 and 2020, respectively. This indicates a total quantity of bottom ash of the order 22.6% of input waste by weight, or 18.8% after processing and metals extraction.

Table 9: Quantities of Bottom Ash Treated, and Quantity / Proportion Extracted as Metals

Fraction	Weight (2017) (tonnes per annum)	Weight (2017) (tonnes per annum)
Bottom ash from incineration	5,670,727	6,050,905
Unburned fraction (coarse)	15,687	
Metals separated before processing (approx.)	33,686	25,062
Of which, pure metals	32,002	
Treated raw bottom ash**	5,607,737	5,822,539
Unburned fraction	76,832	
Ferrous metals from processing	380,561	425,002

[26] IGAM and ITAD (2019) Umfrage zur Aufbereitung von HMV-Schlacken (Rostfeuerungsanlagen MVA und EBS-Kraftwerke).

[27] ITAD (2022) *ITAD Jahresbericht 2021*, www.itad.de/ueber-uns/mehr/jahresbericht/itad-jahresbericht-2021

Fraction	Weight (2017) (tonnes per annum)	Weight (2017) (tonnes per annum)
Of which, pure metals	350,116	
Non-ferrous metals from processing	145,724	169,560
Of which, pure metals	95,553	
Sum of all separated metals	559,971	
Of which, pure metals	477,671	496,535
Changes in inventory, unburned materials, water, losses		203,304
Finished slag**	4,730,915	4,688,034

Notes: *) based on fresh slag; **) includes water losses and stock inventory differences
Source: IGAM and ITAD (2019) Umfrage zur Aufbereitung von HMV-Schlacken (Rostfeuerungsanlagen MVA und EBS-Kraftwerke); ITAD (2022) ITAD Jahresbericht 2021, www.itad.de/ueber-uns/mehr/jahresbericht/itad-jahresbericht-2021.

The 2017 work also gave a breakdown of how the resulting finished ash was managed. The results are shown in Table 10.

Table 10: Fates of Treated Bottom Ash, 2017

Fate of ash	Quantity (tonnes per annum)	Proportion
Recycling techn. buildings	856,707	18.11%
Utilisation underground	260,090	5.50%
Other exploitation	226,177	4.78%
Use at landfills	2,412,947	51.00%
Landfill disposal	974,004	20.61%

Source: IGAM and ITAD (2019) Umfrage zur Aufbereitung von HMV-Schlacken (Rostfeuerungsanlagen MVA und EBS-Kraftwerke).

The 2021 Yearbook for ITAD gives the breakdown for 2020, though the categories do not quite correspond to those data gathered for 2017.[28] Nonetheless, they indicate the shares shown in Table 11 for the year 2020. These suggest that some 19-20% of all bottom ash after metals extraction is landfilled, but that also, the recovery categories include classes of utilisation which may represent something similar to landfilling. The technical recycling, which seems to represent use of ash in construction applications, accounts for 17-18% of the bottom ash after metals extraction.

Table 11: Fates of Treated Bottom Ash, 2020

Fate of ash	Tonnes	Proportion
Utilisation 2 - landfilling / backfilling	3,012,823	64.27%
Utilisation 1 - technical buildings, other	792,729	16.91%
Landfill disposal	882,482	18.82%

Source: ITAD (2022) ITAD Jahresbericht 2021, www.itad.de/ueber-uns/mehr/jahresbericht/itad-jahresbericht-2021

Statistics from DeStatis (Statistisches Bundesamt) give figures for waste treated at Thermal waste treatment plants and at combustion plants with energy recovery. The quantities in 2020 were 25.23 million tonnes and 21.85 million tonnes, respectively. It also provides data for quantities of waste generated by Thermal Waste Treatment plants under the 19 01 codes and indicates a total generated from incineration / pyrolysis of waste, and originating from thermal waste treatment plants, of the order 6.9 million tonnes (see Table 12). Given the figure for the quantity of waste treated at these facilities, the bottom ash generation amounts to 226kg per tonne of input, including the metals. The remaining wastes amount to 48kg per tonne of input.

Table 12: Wastes from Incineration or Pyrolysis of Waste Originating from Thermal Waste Treatment Plants ('000 tonnes)

Fate of ash	Output of waste treatment plants	Wastes to be disposed of	Wastes to be recovered	Waste to preparatory processes	Distribution to other plants, users or traders
Ferrous mat. fr.bottom ash	87.6	-	79.9	7.7	-
Filter cake fr. gas treat.	39.9	37.2	2.7	-	-
Aqueous liquid wastes	107.6	50.6	52.8	3.7	0.5
Solid wastes fr.gas treat.	600.8	28.2	520	52.3	0.3
Spent activated carbon	10.9	2	9	-	-

[28] ITAD (2022) *ITAD Jahresbericht 2021*, www.itad.de/ueber-uns/mehr/jahresbericht/itad-jahresbericht-2021

Fate of ash	Output of waste treatment plants	Wastes to be disposed of	Wastes to be recovered	Waste to preparatory processes	Distribution to other plants, users or traders
Bottom ash and slag	309.8	174.7	109.9	25.2	-
Bottom ash and slag (except 190111)	5,325.2	60.2	4421	835	9
Fly ash cont. haza. subst.	386.1	89	264.9	32.2	-
Fly ash (except 190113)	10.6	2.1	8.5	-	-
Boiler dust cont.haza.sub.	45.8	10.7	34.9	0.1	-
Boiler dust (except 190115)	-	-	-	-	-
Pyrolysis wastes containing hazardous substances	-	-	-	-	-
Pyrolysis wastes (except 190117)	7.2	7.2	-	-	-
Sands from fluidised beds	-	-	-	-	-
Wastes n.o.s.	10.2	0.5	8.7	0.7	0.3
Total	6,941.7	462.4	5,512.3	956.9	10.1
Of which, hazardous	1,500.9	392.4	994.2	113.5	0.8
Of which, non-hazardous	5,440.8	70	4,518.1	843.4	9.3

Source: DeStatis (Statistisches Bundesamt)

In addition, however, similar residues are generated by the treatment of waste at combustion plants (i.e., co-incineration) (see Table 13). The quantities of waste reported as treated at these facilities is similar to the quantity treated at the Thermal Waste Treatment plants, but the reported quantities of residues are far lower, in both absolute terms and when expressed per tonne of waste input (the bottom ash figure is of the order 65kg per tonne of input, for example, with the other residues contributing an additional 18kg per tonne). This might be expected if, for example, ash is used in clinker in cement kilns. On the other hand, the picture is a little more complicated when one notes that there are separately reported residues under Category 10 (wastes from thermal processes). This includes wastes reported as coming from co-incineration (which one might have expected to include cement kilns). These are the source of an additional 275kt of bottom ash, slag and boiler dust, of which 52.4 kt were deemed hazardous, and 367kt of fly ash, of which 346.5 kt were deemed hazardous. Somewhat confusingly, the quantities landfilled of each of these are reported as far in excess of the quantities generated by the combustion facilities at 503kt and 1,614 kt respectively. It is entirely possible that the quantity managed can exceed the quantity generated in a given year if, for example, stored materials become available for treatment. The differences are, however, very large.

Table 13: Wastes from Incineration or Pyrolysis of Waste Originating from Combustion Plants ('000 tonnes)

Fate of ash	Output of waste treatment plants	Wastes to be disposed of	Wastes to be recovered	Waste to preparatory processes	Distribution to other plants, users or traders
Ferrous mat. fr.bottom ash	6.5		6.5		
Filter cake fr. gas treat.					
Aqueous liquid wastes					
Solid wastes fr.gas treat.	102.3	31.7	70.7		
Spent activated carbon					
Bottom ash and slag	259.9	133.9	117.8	8.2	-
Bottom ash and slag (except 190111)	1,153.9	153.1	954.7	46	0.1
Fly ash cont. haza. subst.	238.8	43.6	191	4.1	
Fly ash (except 190113)					
Boiler dust cont.haza.sub.	22	8.8	11.2	2.1	
Boiler dust (except 190115)	33.1	3.5	29.6		
Pyrolysis wastes containing hazardous substances					
Pyrolysis wastes (except 190117)					
Sands from fluidised beds					
Wastes n.o.s.					
Total	1,816.5	374.6	1,381.5	60.4	0.1
Of which, hazardous	623	218	390.7	14.4	0
Of which, non-hazardous	1,193.5	156.6	990.8	46	0.1

Source: DeStatis (Statistisches Bundesamt)

We have summed the contributions from Thermal Waste Treatment Plants and Combustion Plants in Table 14.

Table 14: Wastes from Incineration or Pyrolysis of Waste Originating from Thermal Waste Treatment Plants and Combustion Plan

Fate of ash	Output of waste treatment plants	Wastes to be disposed of	Wastes to be recovered	Waste to preparatory processes	Distribution to other plants, users or traders
Ferrous mat. fr.bottom ash	94.1	0	86.4	7.7	0
Filter cake fr. gas treat.	39.9	37.2	2.7	0	0
Aqueous liquid wastes	107.6	50.6	52.8	3.7	0.5
Solid wastes fr.gas treat.	703.1	59.9	590.7	52.3	0.3
Spent activated carbon	10.9	2	9	0	0
Bottom ash and slag	569.7	308.6	227.7	33.4	0
Bottom ash and slag (except 190111)	6,479.1	213.3	5,375.7	881	9.1
Fly ash cont. haza. subst.	624.9	132.6	455.9	36.3	0
Fly ash (except 190113)	10.6	2.1	8.5	0	0
Boiler dust cont.haza.sub.	67.8	19.5	46.1	2.2	0
Boiler dust (except 190115)	33.1	3.5	29.6	0	0
Pyrolysis wastes containing hazardous substances	0	0	0	0	0
Pyrolysis wastes (except 190117)	7.2	7.2	0	0	0
Sands from fluidised beds	0	0	0	0	0
Wastes n.o.s.	10.2	0.5	8.7	0.7	0.3

Fate of ash	Output of waste treatment plants	Wastes to be disposed of	Wastes to be recovered	Waste to preparatory processes	Distribution to other plants, users or traders
Total	8,758.2	837	6,893.8	1,017.3	10.2
Of which, hazardous	2,123.9	610.4	1,384.9	127.9	0.8
Of which, non-hazardous	6,634.3	226.6	5,508.9	889.4	9.4

Source: DeStatis (Statistisches Bundesamt)

The total residues generated are reported as 8.76 million tonnes. Of this, 6.63 million tonnes were non-hazardous, of which the majority (6.48 million tonnes) were bottom ash and slag. Marginally less than 10% of the total was reported to be disposed of. The majority – 6.89 million tonnes – was to be recovered, including 1.38 million tonnes of the 2.12 million tonnes of hazardous residues (or around two thirds of the total generated).

One can seek to render these statistics internally consistent with the reported treatment of these wastes. In Table 15 through to Table 18, we highlight the fates of the waste generated, insofar as we can discern from the statistics.

Table 15: Wastes from Incineration or Pyrolysis of Waste Managed by 'Other Treatment Plants'

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad	Output of waste treatment plants	Wastes to be disposed of	Wastes to be recovered	Waste to preparatory processes	Distribution to other plants, users or traders
Ferrous mat. fr.bottom ash	5.5		5.5	0.1	223.9	-	198.6	-	25.2
Filter cake fr. gas treat.	26.6		12.5	14.1				-	-
Aqueous liquid wastes									
Solid wastes fr.gas treat.	117		90.7	26.3	26	4.1	21.3	0.6	
Spent activated carbon									
Bottom ash and slag	195.2	24.1	169.6	1.5	23	0.5	22.6	-	
Bottom ash and slag (except 190111)	5,104.10	183	4,818.30	102.8	3476.2	1006.6	2363.6	35.4	70.5
Fly ash cont. haza. subst.	139.6		116.5	23.1	32.1	11.7	20.4	0	
Fly ash (except 190113)	13.2		1.5	11.8	2.1	1.8	0.4	-	

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad	Output of waste treatment plants	Wastes to be disposed of	Wastes to be recovered	Waste to preparatory processes	Distribution to other plants, users or traders
Boiler dust cont.haza.sub.	16.4		12.2	4.1					
Boiler dust (except 190115)	4.9		4.9	-					
Pyrolysis wastes containing hazardous substances	-		-	-					
Pyrolysis wastes (except 190117)	-		-	-					
Sands from fluidised beds	8.8		8.8	-					
Wastes n.o.s.	5.4		3.9	1.6					
Total	5636.7	207.1	5244.4	185.4	3783.3	1024.7	2626.9	36	95.7
Of which, hazardous	494.8	24.1	389	26.3	81.1	16.3	64.3	0.6	0
Of which, non-hazardous	5141.9	183	4855.4	159.1	3702.2	1008.4	2562.6	35.4	95.7

Source: DeStatis (Statistisches Bundesamt)

Table 16: Wastes from Incineration or Pyrolysis of Waste Managed by 'Chemical Physical Treatment Plants'

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad
Ferrous mat. fr.bottom ash				
Filter cake fr. gas treat.	2.1		0.1	2
Aqueous liquid wastes	35	13.5	21.5	
Solid wastes fr.gas treat.	84.2		73.7	10.5
Spent activated carbon				
Bottom ash and slag	16	2.1	14	
Bottom ash and slag (except 190111)	37.7	23	14.7	
Fly ash cont. haza. subst.	82.4		51.4	31.1
Fly ash (except 190113)				
Boiler dust cont.haza.sub.				

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad
Boiler dust (except 190115)				
Pyrolysis wastes containing hazardous substances				
Pyrolysis wastes (except 190117)				
Sands from fluidised beds				
Wastes n.o.s.				
Total	257.4	38.6	175.4	43.6
Of which, hazardous	219.7	15.6	160.7	43.6
Of which, non-hazardous	37.7	23	14.7	0

Source: DeStatis (Statistisches Bundesamt)

Table 17: Wastes from Incineration or Pyrolysis of Waste Managed at Landfills

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad
Ferrous mat. fr.bottom ash				
Filter cake fr. gas treat.	35.8	5.9	29.8	0.2
Aqueous liquid wastes				
Solid wastes fr.gas treat.	34.6	2.2	30.8	1.6
Spent activated carbon				
Bottom ash and slag	266.4	6.6	259.8	
Bottom ash and slag (except 190111)	1458.2		1448.2	10
Fly ash cont. haza. subst.	111.7	10.9	87.1	13.7
Fly ash (except 190113)				
Boiler dust cont.haza.sub.	23.1		20.5	2.6

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad
Boiler dust (except 190115)				
Pyrolysis wastes containing hazardous substances				
Pyrolysis wastes (except 190117)	0.3		0.3	
Sands from fluidised beds	25.2	0.3	24.9	
Wastes n.o.s.				
Total	1955.3	25.9	1901.4	28.1
Of which, hazardous	471.6	25.6	428	17.9
Of which, non-hazardous	1483.7	0.3	1473.4	10.2

Source: DeStatis (Statistisches Bundesamt)

Table 18: Wastes from Incineration or Pyrolysis of Waste Managed at Underground Extraction / Mining Sites

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad
Ferrous mat. fr.bottom ash				
Filter cake fr. gas treat.	39.7	9.9	5.6	24.2
Aqueous liquid wastes				
Solid wastes fr.gas treat.	493.1	20.4	415	57.7
Spent activated carbon				
Bottom ash and slag	22.6	0	22.6	
Bottom ash and slag (except 190111)	43.2		43.2	
Fly ash cont. haza. subst.	408.8	19.2	302.3	87.3
Fly ash (except 190113)				
Boiler dust cont.haza.sub.	40.9	2.3	33.5	5.1

	Input to waste treatment plants	Wastes generated in the own local unit	Waste delivered from the domestic territory	Waste delivered from abroad
Boiler dust (except 190115)				
Pyrolysis wastes containing hazardous substances				
Pyrolysis wastes (except 190117)				
Sands from fluidised beds				
Wastes n.o.s.				
Total	1048.3	51.8	822.2	174.3
Of which, hazardous	1005.1	51.8	779	174.3
Of which, non-hazardous	43.2	0	43.2	0

Source: DeStatis (Statistisches Bundesamt)

Based on these, we have sought to generate Tables for bottom ash and for other residues that reflect something approximating to a mass balance. This is unlikely to be entirely accurate since the data for treatment plants report inputs and outputs from treatment facilities, for example, and from the statistical Tables, tracking the outputs back to the inputs is not always straightforward (for example, a facility may have bottom ash as input, but part of the output will be ferrous metals, as well as non-ferrous metals).

Table 19 shows the estimates for bottom ash and slag. In the middle of the Table, we record in italicised rows, the reported fate – disposal, recovery, or further preparation – of each waste as per the foundational Tables for how much is generated from the different treatment facilities. In the rest of the Tables, we have tried to track the waste through their respective treatments to gain further insight as to where they are sent.

Table 19: Generation / Treatment of Bottom Ash and Slag from Thermal Waste Treatment Plants and Combustion Plants, 2020 ('000 tonnes)

	Non-hazardous	Hazardous	Total
Fe-metals extracted pre next treatment	87.6	0.0	87.6
Non-haz (excl metals extracted pre next treatment)	6,479.1	569.7	7,048.8
Landfill (incl long term storage) direct	1,458.2	266.4	1,724.6
Underground extraction	43.2	22.6	65.8
Surface extraction sites	267.3	0.0	267.3
Disposal	213.3	308.6	521.9
Recovery	5,375.7	227.7	5,603.4
Prep	881.0	33.4	914.4
Other treatment	5,104.1	195.2	5,299.3
Chem/phys treatment	37.7	16.0	53.7
For disposal (post-treatment)	1,006.6	0.5	1,007.1
Recovery (post-treatment)	2,363.6	22.6	2,386.2
Fe-metals (post treatment)	205.7	18.1	223.8
Total landfilled (incl long term storage) + disposal	2,464.8	266.9	2,731.7

	Non-hazardous	Hazardous	Total
Total landfilled (incl long term storage) + disposal + underground extraction + surface extraction	2,775.3	289.5	3,064.8
Total landfilled (incl long term storage) + disposal (%)	38%	47%	38%
Total landfilled (incl long term storage) + disposal + underground extraction + surface extraction (%)	42%	51%	43%

Source: Equanimator estimates based on data tables from DeStatis (Statistisches Bundesamt)

We assume that where landfills (including long-term storage sites) report receiving the specific waste stream, they receive it in untreated form. We assume the same for deposits to underground extraction sites (we assume these are mines). There are also some wastes sent to surface extraction sites (we assume this is a form of backfilling), and we assume these are sent directly. Where the respective wastes are sent for 'Other treatment', we regard this as intermediate – the treatment produces (some) wastes which undergo further treatment, and we have therefore recorded output quantities which are to be sent for disposal, or recovery. We have assumed that the 'disposal' route is a landfill.

The final rows indicate, under these assumptions, how much waste is sent for landfill or long-term storage under these assumptions. It also indicates the quantity of waste sent to these routes as well as underground and surface extraction sites. For non-hazardous materials, landfill and long-term storage accounts for 38% of the total, and if underground and surface extraction sites are included, the figure rises to 42%. For hazardous materials, the respective figures are 47% and 51%, giving a picture for the total residue stream of 38% and 43%, respectively.

Using similar assumptions, we have also derived a Table for other wastes from Thermal Waste Treatment plants and Combustion facilities. This is given in Table 20. This is shown first for hazardous wastes, then for non-hazardous wastes, and then for the total.

Table 20: Generation / Treatment of Other Residues from Thermal Waste Treatment Plants and Combustion Plants, 2020 ('000 tonnes)

	Filter cake fr. gas treat.	Aqueous liquid wastes	Solid wastes fr. gas treat.	Spent activated carbon	Fly ash	Pyrolysis wastes	Wastes not otherwise specified
Quantity generated, hazardous	39.9	107.6	703.1	10.9	624.9	67.8	
Landfill direct	35.8	0.0	34.6	0.0	111.7	23.1	
Underground extract	15.5	0.0	435.4	0.0	321.5	35.8	
Disposal	37.2	50.6	59.9	2.0	132.6	19.5	
Recovery direct	2.7	52.8	590.7	9.0	455.9	46.1	
Prep	0.0	3.7	52.3	0.0	33.4	2.2	
Other treatment	26.6	0.0	117.0	0.0	139.6	16.4	
Chem/phys treatment	2.1	35.0	84.2	0.0	82.4	0.0	
Disposal (post-treatment)	0.0	0.0	4.1	0.0	11.7	0.0	
Recovery (post-treatment)	0.0	0.0	21.3	0.0	20.4	0.0	

	Filter cake fr. gas treat.	Aqueous liquid wastes	Solid wastes fr. gas treat.	Spent activated carbon	Fly ash	Pyrolysis wastes	Wastes not otherwise specified
Total landfilled (incl. long-term storage) + disposal	35.8	0.0	38.7	0.0	123.4	23.1	
Total landfilled (incl. long-term storage) + disposal + underground extraction + surface extraction	51.3	0.0	474.1	0.0	444.9	58.9	
Total landfilled (incl. long-term storage) + disposal (%)	90%	0%	6%	0%	20%	34%	
Total landfilled (incl. long-term storage) + disposal + underground extraction + surface extraction (%)	129%	0%	67%	0%	71%	87%	
Quantity generated, non-hazardous					10.6	40.3	10.2
Landfill (incl. long-term storage) direct					0.0	0.0	0.0
Underground extraction					0.0	0.0	0.0
Disposal					2.1	3.5	0.5
Recovery direct					8.5	29.6	8.7

	Filter cake fr. gas treat.	Aqueous liquid wastes	Solid wastes fr. gas treat.	Spent activated carbon	Fly ash	Pyrolysis wastes	Wastes not otherwise specified
Prep					0.0	0.0	0.7
Other treatment					13.2	4.9	
Chem/phys treatment					0.0	0.0	0.0
Disposal (post-treatment)					1.8	0.0	0.0
Recovery (post-treatment)					0.4	0.0	0.0
Total landfilled (incl. long-term storage) + disposal	0.0				1.8	0.0	0.0
Total landfilled (incl. long-term storage) + disposal + underground extraction + surface extraction	0.0				1.8	0.0	0.0
Total landfilled (incl. long-term storage) + disposal (%)	0%				17%	0%	0%
Total landfilled (incl. long-term storage) + disposal + underground extraction + surface extraction (%)	0%				17%	0%	0%
Total generated	39.9	107.6	703.1	10.9	635.5	108.1	10.2

	Filter cake fr. gas treat.	Aqueous liquid wastes	Solid wastes fr. gas treat.	Spent activated carbon	Fly ash	Pyrolysis wastes	Wastes not otherwise specified
Landfill (incl. long-term storage) direct	35.8	0.0	34.6	0.0	111.7	23.1	0.0
Underground extraction	15.5	0.0	435.4	0.0	321.5	35.8	0.0

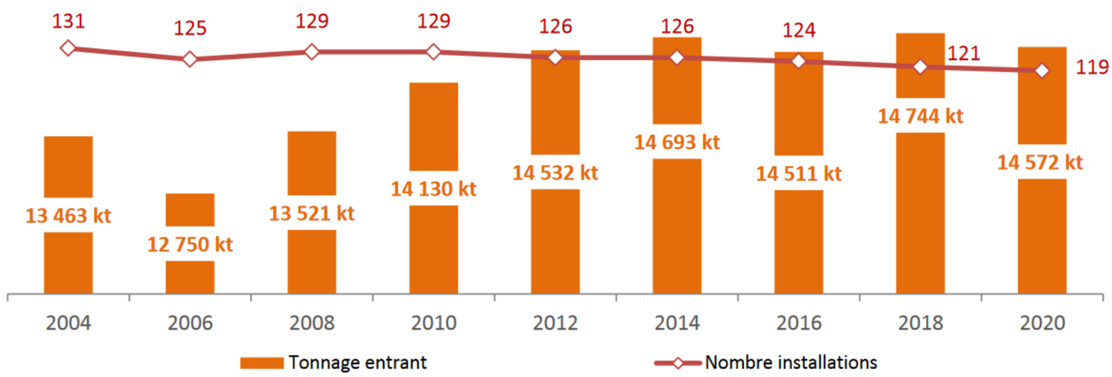
5.2 France

In France, a paper from 2017 indicated the following:[29]

French MSW incineration plants generate in average 209 kilograms (kg) of bottom ashes and 29 kg of APC residues per tonne of MSW (ADEME 2015), that both require further downstream treatment. French bottom ashes are currently mainly routed to treatment and maturation bottom ash platforms (86%; CEREMA [2014]). All these platforms include a first step of iron scrap removal and, in most cases (88%), additionally complete nonferrous metals sorting. Overall, 81% of French bottom ashes are valorized (mostly in the road construction sector) while the rest is disposed of in MSW landfills. Moreover, around 70% of French APC residues are disposed of in hazardous waste landfills (AMORCE 2012), in most cases with the prior implementation of stabilization. At the same time, around 22% of French APC residues are disposed of as a backfill for old German salt mines, while the remaining part (8%) is processed in other ways (e.g., disposed of in MSW landfills)

The French Agency, ADEME, conducts a study on management of waste periodically, and the 2022 version of that indicates that in 2020, French incineration facilities treated 14.57 million tonnes of waste (see Figure 10). It also shows the number of installations treating bottom ash, and the amount they handled (see Figure 11).

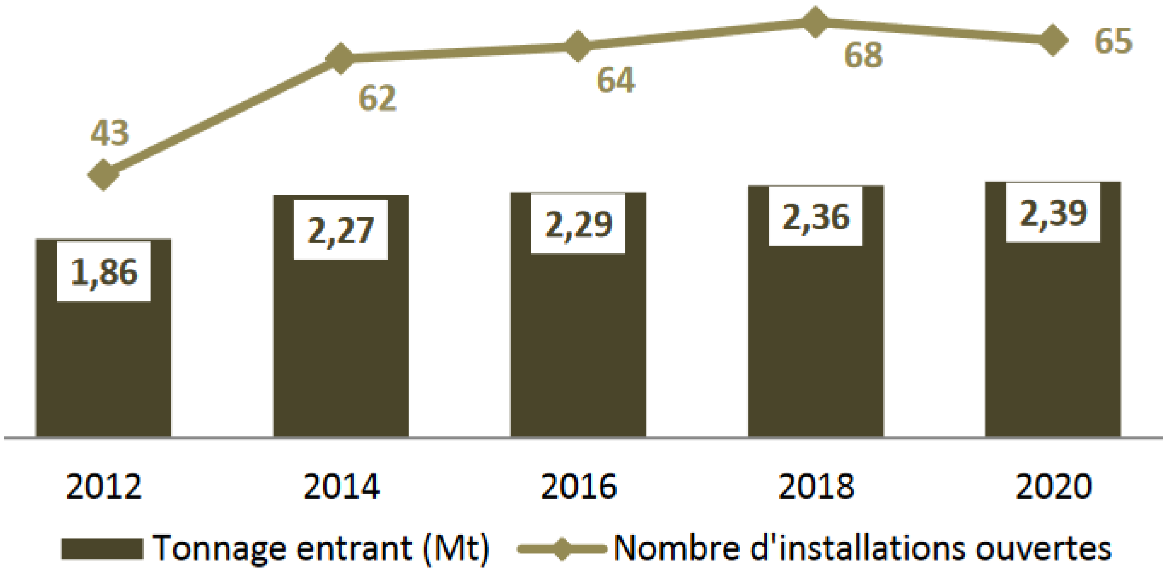
Figure 10: Number of Incineration Plants and Quantity of Waste Incinerated in France



Source: ADEME (2022) Le traitement des Déchets Ménagers et Assimilés en 2020: Exploitation des données de l'enquête sur les installations de traitement des déchets ménagers et assimilés en France en 2020. Mai 2022, librairie.ademe.fr/cadic/7176/resultats_enquete_itom_2020-v2.pdf

[29] Antoine Beylot, Antoine Hochar, Pascale Michel, Marie Descat, Yannick Ménard, and Jacques Villeneuve (2017) Municipal Solid Waste Incineration in France: An Overview of Air Pollution Control Techniques, Emissions, and Energy Efficiency, *Journal of Industrial Ecology*, Volume 22, No.5.

Figure 11: Number of Facilities Treating Bottom Ash, and Quantity treated, in France



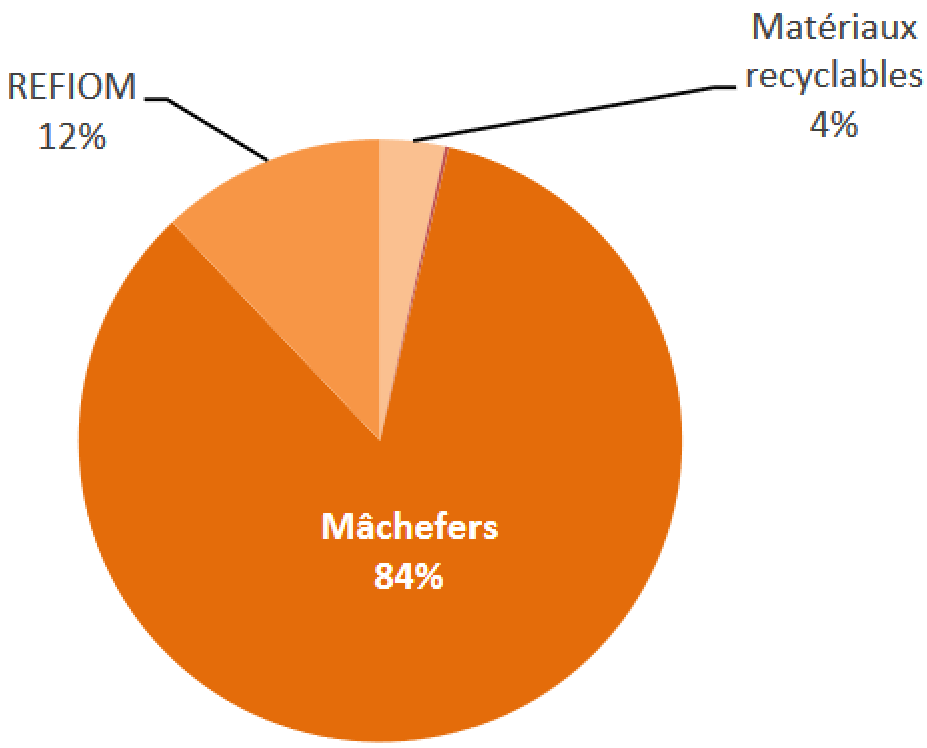
Source: ADEME (2022) Le traitement des Déchets Ménagers et Assimilés en 2020: Exploitation des données de l'enquête sur les installations de traitement des déchets ménagers et assimilés en France en 2020. Mai 2022, librairie.ademe.fr/cadic/7176/resultats_enquete_itom_2020-v2.pdf

Of the 2.39 million tonnes of bottom ash entering the facility for maturation in 2020, the quantity emerging was barely altered (2.31 million tonnes). As the bottom ash maturation period takes several months, there is little stock effect from one year to the next and it therefore makes sense to have relatively close input/output orders of magnitude. At the facilities, the bottom ash can be sorted to extract metals, these representing 7% of the quantities leaving the facilities (identical to 2016 and 2018). Rejected materials are of the order of one percent of outgoing flows.

89% of outgoing flows are reportedly recovered, mostly in alternative materials for road construction. The rest of the recoverable materials (mainly ferrous metals, and non-ferrous metals to a lesser extent) are recycled. Note that the report indicates that an additional 66kt are sent directly from incineration to non-hazardous landfill.

The document also shows the split of residues produced by incinerators in terms of their relative shares. Elsewhere (in showing a rough mass balance), it gives a figure for APC residues (REFIOM in Figure 13 below) as 391,000 tonnes. The document indicates that these materials are sent either to hazardous waste landfills or to salt mines. The document does not give a split between these two fates.

Figure 13: Share of residues from Incinerators in France, 2020



Note: REFIOM = Résidus d'Épuration des Fumées d'Incinération des Ordures Ménagères (i.e., air pollution control residues, including those from particulate removal).

Source: ADEME (2022) Le traitement des Déchets Ménagers et Assimilés en 2020: Exploitation des données de l'enquête sur les installations de traitement des déchets ménagers et assimilés en France en 2020. Mai 2022, librairie.ademe.fr/cadic/7176/resultats_enquete_itom_2020-v2.pdf

Generally, compared to the waste being incinerated, the figures appear quite low. This may be because the reporting is of the way bottom ash is treated in France. This assumes, therefore, that no bottom ash is exported from France to other countries.

5.3 Italy

The ISPRA study on municipal waste suggests that there were 37 facilities in Italy in 2020 dealing with municipal waste.[30] The total quantity incinerated at these facilities was 6.242 million tonnes, of which 5.325 million tonnes were 'urban' waste. The Urban waste was split roughly equally across untreated waste, and the dry, combustible and biostabilised fractions from MBT facilities (around 2.7 million tonnes of the output arising from the 9.5 million tonnes treated through MBT).

The study gives a breakdown by Region and Province of the quantity of residues generated by the incineration process. The summary figures for Italy are shown in Table 21. If one sums the hazardous and non-hazardous bottom ash and slags, the amount is of the order 19.2% of the total waste input, with the FGC residues (including fly ash) accounting for the balance of the total of 23.1% of the waste input. Of this balance, the bulk (3.2%) is hazardous waste resulting from flue gas cleaning.

[30] ISPRA (2021) *Rapporto Rifiuti Urbani, Edizione 2021*, Rapporti 355/2021, December 2021, www.isprambiente.gov.it/files2022/pubblicazioni/rapporti/rapportorifiutiurbani_ed-2021-n-355-conappendice_agg18_01_2022.pdf

Table 21: Residues from Incineration

Types of waste	Quantity
Bottom ash, fly ash and dangerous slag [190111*- 190113*- 190115*]	147,521
Waste from flue gas treatment processes [190105*- 190107*- 190110*- 190117*]	203,724
Liquid waste and hazardous sludge from flue gas treatment [190106*- 190205*] (t)	9,468
Bottom ash and non-hazardous slag [190112- 190114- 190116]	1,053,410
Sands from fluidized bed reactors [190119]	2,072
Non-hazardous chemical-physical sludges [190814- 190206] (t)	1,634
Ferrous materials extracted from ashes and incineration slags [190102]	25,049
Total	1,442,878
Total waste incinerated	6,242,511
Quantity in relation to the total incinerated	23.1%

Source: ISPRA (2021) Rapporto Rifiuti Urbani, Edizione 2021, Rapporti 355/2021, December 2021.

The same report identifies that an additional 289,488 tonnes were co-incinerated.[31] This waste mainly consisted of combustible waste, and the (bio-)dried fraction from MBT facilities.

Neither the aforementioned ISPRA report, nor a separate report on special wastes, contained information on the treatment of waste from incineration. A report from Utilitalia notes:[32]

[31] Ibid.

[32] Utilitalia (2020) *White Paper on Municipal Waste Incineration*, September 2020.

With particular reference to bottom ash, which represents the most significant residue in terms of mass, landfill disposal is now almost completely abandoned in favour of increasingly advanced recovery and re-use practices.

Bottom ash contains several recoverable components: first of all, ferrous and non-ferrous metals that, present in the initial waste, are then concentrated in the solid residue of combustion. The content of ferrous metals varies on average between 7 and 10% by weight of bottom ash, while the content of non-ferrous metals is between 1 and 2.5%, of which the predominant fraction (about two thirds) is represented by aluminium, followed by copper (Lamers, 2015a; Allegrini et al., 2014; Biganzoli et al., 2013). The mineral fraction, predominant component of the ashes (up to 90% in weight), can instead be used as an inert material mainly in the production of cements and concretes, or in civil engineering for the construction of road foundations or asphalt mixes.

[...] In Italy, bottom ash treatment takes place in medium-large size plants located mainly in Lombardy and Emilia-Romagna, where the main incinerators are concentrated. The main companies include RMB and Officina dell'Ambiente, which have been active in the sector for a long time, and are characterised by very advanced treatment, in the first case aimed at maximising metal recovery, and in the second case at enhancing the value of inert components.

Elsewhere, a pan-European survey indicated a proportion of bottom ash that was not going to landfill of 85%:[33] We have assumed the same figure here.

The Utilitalia report notes, regarding fly ash and (other) flue gas treatment residues, that fly as is:[34]

'normally disposed of in hazardous waste landfills.
Then there are the salts from flue gas treatments, the characteristics of which depend on the type of reagent used (e.g. RSP - Residual Sodium Products, in the case of using sodium bicarbonate). These are generally hazardous wastes that can be disposed of in special landfills or even sent to recovery processes. The possibility to re-use or recycle solid residues is basically determined by their characteristics in terms of organic matter content and leachability of metals and salts.'

As with France, therefore, there is no clear indication of how flue gas treatment residues are treated. We note that in Germany, the figures for this type of material lie between 12% (landfill, incl. long-term storage, and disposal) to 72% (landfill, incl. long-term storage, plus disposal plus treatment at (presumably salt) mines).

5.4 Netherlands

Table 22 shows the quantity of waste incinerated at Dutch installations between 2015 and 2019. These figures include waste which originates in the Netherlands, as well as imports (see Figure 14).

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[33] Dominik Blasenbauer, Florian Huber, Jakob Lederer, Margarida J. Quina, Denise Blanc-Biscarat, Anna Bogush, Elza Bontempi, Julien Blondeau, Josep Maria Chimenos, Helena Dahlbo, Johan Fagerqvist, Jessica Giro-Paloma, Ole Hjelmar, Jiri Hyks, Jackie Keaney, Maria Lupsea-Toader, Catherine Joyce O'Caollai, Kaja Orupõld, Tadeusz Paja, Franz-Georg Simon, Lenka Svecova, Michal Šyc, Roy Ulvang, Kati Vaajasaari, Jo Van Caneghem, Andre van Zomeren, Saulius Vasarevic˘ius, Krisztina Wégner and Johann Fellner (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883.

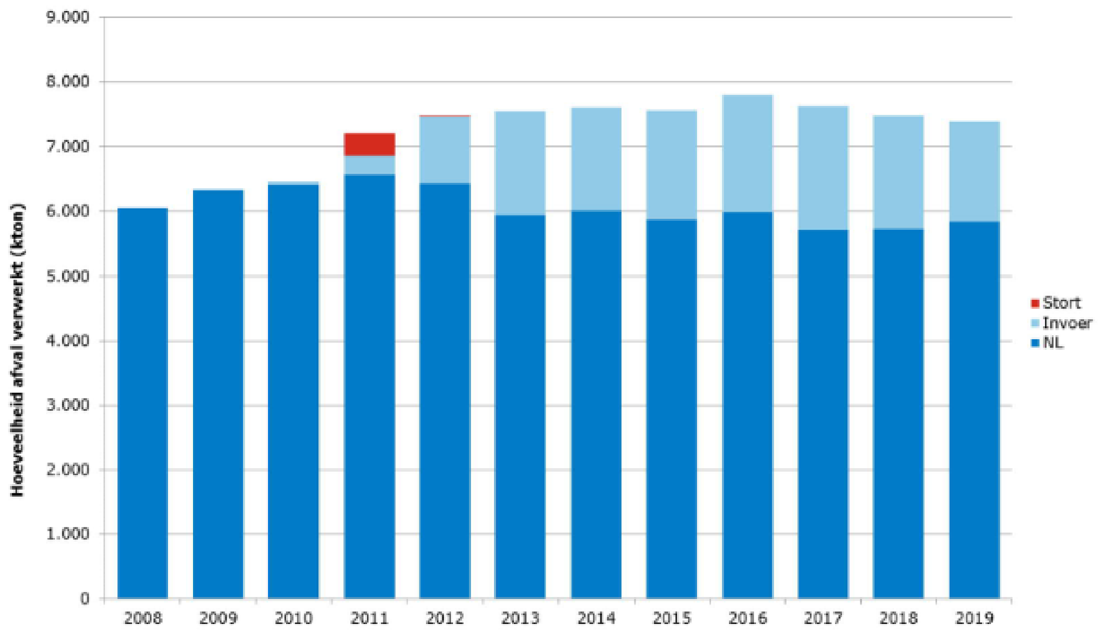
[34] Utilitalia (2020) *White Paper on Municipal Waste Incineration*, September 2020.

Table 22: Quantity of Waste Incinerated in Netherlands, 2015-2019

Types of waste	Installation	Amount of waste incinerated ('000 tonnes)				
		2015	*2016*	*2017*	*2018*	*2019*
Groningen	EEW Energy from Waste Delfzijl BV	373	377	344	382	516
Friesland	REC Harlingen	232	256	261	217	233
Drenthe	Attero Noord BV GAVI Wijster	702	712	658	649	653
Overijssel	Twence Afval en energie	644	637	622	608	606
Gelderland	ARN B.V.	304	276	272	233	271
	AVR Afvalverwerking BV	380	387	390	394	389
Noord-Holland	HVCafvalcentrale locatie Alkmaar	668	671	678	642	665
	AEB Amsterdam	1,352	1,483	1,477	1,487	1,105
Zuid-Holland	AVR Afvalverwerking Rijnmond	1,333	1,372	1,283	1,323	1,314
	HVCafvalcentrale locatie Dordrecht	307	311	291	280	268
	ZAVIN CV	10	11	12	11	10
Noord-Brabant	AEC Moerdijk	913	958	1,017	887	993
	SUEZ ReEnergy	347	345	321	366	363
Total		7,565	7,796	7,627	7,478	7,386

Source: Rijkswaterstaat (2021) Afvalverwerking in Nederland: gegevens 2019, report of the Werkgroep Afvalregistratie. – Utrecht: Rijkswaterstaat, August 2021

Figure 14: Incineration of Waste in the Netherlands (note *Invoer = imports*)



Source: Rijkswaterstaat (2021) Afvalverwerking in Nederland: gegevens 2019, report of the Werkgroep Afvalregistratie. – Utrecht: Rijkswaterstaat, August 2021

Table 23 shows the generation of bottom ash, the amount processed after the separation of ferrous and non-ferrous metals, the deposited bottom ash and the recovery of bottom ash for the past three years. Ferrous and non-ferrous metals are first separated from the raw bottom ashes, after which the ash is processed. The extent to which treated bottom ashes are able to be recovered depends to an extent on the number of (usually) large infrastructure projects which are ongoing, and where it can be used. As a result, the quantity held in storage may rise or fall in any given year depending on demand (the amount generated largely depends on the amount of waste incinerated, which has not changed significantly over recent years).

The quantity generated per tonne of waste incinerated varied between 248-255 kg per tonne incinerated over the last three years.

Table 23: Production, Processing and marketing of bottom ash

Types of waste	Amount of waste incinerated ('000 tonnes)		
	2017	*2018*	*2019*
Raw bottom ashes from incineration	1,907	1,855	1,880
Ferrous separation	103	126	132
Non-ferrous separation (incl. stainless steel)	29	34	32
Bottom ash production modified	1,350	1,758	1,517
Bottom ash landfilled (including support layer)*	2	42	40
Outlet as NT (including as backing layer)	1,383	1,969	1,517

* This can be bottom ash as well as residue from cleaning of bottom ash

Source: Rijkswaterstaat (2021) Afvalverwerking in Nederland: gegevens 2019, report of the Werkgroep Afvalregistratie. – Utrecht: Rijkswaterstaat, August 2021

Generation of other residues from incineration plants are listed in Table 24, which distinguishes between residues that are landfilled and residues that are recovered. The specific quantity per tonne of waste incinerated of all these residues varies between 22kg and 26kg per tonne of waste treated. Of the total, roughly half was landfilled: the nature of the 'recovery' referred to is unclear, but may include transfer to salt-mines, for example, as well as some treatments using residues as neutralising agent.

Table 24: Outputs of Waste Incineration Plants, Excluding Bottom Ash

Incinerator residues	Net landfilled ('000 tonnes)			Recovery ('000 tonnes)			Total ('000 tonnes)		
	2017	*2018*	*2019*	*2017*	*2018*	*2019*	*2017*	*2018*	*2019*
Salts form flue gas cleaning	6	23	20	35	36	31	41	59	51
Filter cake	6	10	10	-	-	-	6	10	10
Sludge	-	8	8	-	-	-	-	8	8
Gypsum	7	7	1	3	1	1	10	8	2
Fly ash (dry matter)	63	48	47	46	51	55	109	103	102

Incinerator residues	Net landfilled ('000 tonnes)			Recovery ('000 tonnes)			Total ('000 tonnes)		
Total	82	96	86	84	98	98	166	194	184
% Landfilled							49%	49%	47%

Source: Rijkswaterstaat (2021) Afvalverwerking in Nederland: gegevens 2019, report of the Werkgroep Afvalregistratie. – Utrecht: Rijkswaterstaat, August 2021

5.5 Sweden

The publication of Avfall Sverige regarding Swedish Waste Management in 2020 states that:[35]

In 2020, 2,240,990 tonnes of municipal waste went to energy recovery. [...]
In addition to municipal waste, 4.6 million tonnes of other waste, primarily industrial waste and sorting residue, was also treated by Swedish plants [...]

The capacity for energy recovery in Sweden is greater than the domestic availability of combustible waste. In 2020, Swedish energy recovery plants therefore also treated 1.9 million tonnes of waste from other European countries, 550,000 tonnes of which was municipal waste

As regards the residues generated, the 2020 study notes:

There is residue from combustion. Slag from the furnace makes up about 5 percent by weight of the amount of input waste, and flue gas treatment residues make up 4 percent by weight. Slag consists of materials that are not combustible or do not evaporate during combustion. Examples of such materials are glass, porcelain, iron scrap and gravel.

Once larger objects and metal residues have been sorted out for material recycling and the remaining material has been sifted and stabilised, what remains is granulated slag. This is mainly used as a construction material in landfill sites, but it would be beneficial to be able to use it instead of sand and gravel from natural deposits in road construction, for example. Sand and gravel from natural deposits are a finite resource that should be reserved for particularly pressing areas of application. [...]

Flue gas treatment residues is the collective term for a fine-grain fraction that is created during treatment of flue gas. The fraction consists of fly ash, filter cake from hose filters, and sludge from wet flue gas treatment. After they are stabilised, flue gas treatment residues are either transported to landfill or used as a neutralisation agent when refilling mines and pits.

The underlined figure in the above extract is presumably a typing error (figures are included in Table 25, and the slag makes up about 15 percent, not 5%, by weight of the amount of input waste).

[35] Avfall Sverige (2021) *Swedish Waste Management 2020*, www.avfallsverige.se/fileadmin/user_upload/Publikationer/Svensk_Avfallshantering_2020_EN_01.pdf

Table 25: Incineration Facilities 2016-2020

	2016	2017	2018	2019	2020
Incineration (tonnes)					
Municipal waste	2,262,610	2,400,440	2,362,160	2,426,610	2,240,990
Business waste	4,231,500	4,334,230	4,138,760	4,281,900	4,646,980
Total	6,494,110	6,734,670	6,500,920	6,708,510	6,887,970
Slag, bottom ash (tonnes)	1,000,780	1,012,730	974,100	1,192,270	1,024,510
Fly ash and gas cleaning residues (tonnes)	296,660	293,140	281,070	293,070	303,060
Slag, bottom ash (% input)	15.4%	15.0%	15.0%	17.8%	14.9%
Fly ash and gas cleaning residues (% input)	4.6%	4.4%	4.3%	4.4%	4.4%

Source: Avfall Sverige (2021) Swedish Waste Management 2020,
www.avfallsverige.se/fileadmin/user_upload/Publikationer/Svensk_Avfallshantering_2020_EN_01.pdf

Although the figure for bottom ash appears low (relative to quantity of waste treated), the relatively large share of 'business waste' may mean that the nature and form of waste incinerated is disproportionately influenced by the nature of this waste, which might have an inherently lower ash (or / and solids) content (see discussion in Section 4.1.1 above). Three of the 37 facilities, treating more than 10% of the total incinerated, treat no municipal waste at all. Note that the figures may also be reported following the extraction of metals. Equally, the fly ash and gas cleaning residues, as a proportion of input, are comparatively high.

The fates of the residues are not clearly apportioned in the report. Nonetheless, it appears to be the case that once metals are removed, bottom ash is destined for landfill. This is consistent with the pan-EU report referenced previously.[36] As regards fly ash and (other) air pollution control residues, there is no split given between the treatment routes.

5.6 Belgium

It has been difficult to obtain accurate data on incinerator residues for the Belgian case. Stabel gives figures for 'Mineral wastes from waste treatment and stabilised wastes', as per reporting under the Waste Statistics Regulation. Inspection of the sources of such waste suggests that the figures may be being reported under the 'Recycling' header. In 2018, these quantities were 205,973 in the hazardous category and 624,646 tonnes in the non-hazardous category. If one takes the CEWEP data for quantity incinerated in 2019 (3.36 million tonnes), then the total quantity is of the order 247kg per tonne of waste incinerated.

[36] Blasenbauer, D., et al. (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883.

This is split between 186kg non-hazardous, and 61 kg hazardous.[37] This ratio is not so dissimilar to that which is found in Germany for all residues, and could indicate (for example) a reasonable proportion of bottom ash being classified as hazardous in Belgium.

An earlier study sought to understand the fate of bottom ash in Belgium. It noted:

In Flanders, 401 kT (Figure 2b) bottom ash is generated. A part of it is utilized in Flanders, a part outside Flanders and the rest outside Belgium; 174 kT bottom ash are processed, 24 kT as an alternative for gravel in Flanders; 72 kT are processed in Flanders and utilized in The Netherlands; 47 kT processed (in two treatment installations, one wet and one dry) and utilized in Germany; and 164 kT are landfilled [17]. Out of the processed fraction, 39 kT are used as alternative building sand in Flanders; 16 kT utilized in The Netherlands; and 40 kT are landfilled. To sum up, a total of 63 kT (15%) is utilized in Flanders; 134 Kt (34%) are utilized outside Flanders; and about 204 Kt (51%) are landfilled [18]. Utilization in Flanders is done as a road subbase material, landfill finishing material and elevation material for dike cores [17]. Furthermore, 134 kT are transported to the Netherlands and Germany due to stricter environmental regulations in Belgium [...]
The bottom ash quantities described here are not only from municipal waste, but also from certain other non-hazardous waste streams.

In Flanders, 62 kT of fly ash are used as an alternative building material. In Wallonia, part of the bottom ash that conforms to environmental stipulations is used in road construction, and the rest (usually exceeding the limit molybdenum content) is used in the cement industry [17]

Blasenbauer et al estimate that around 69% of bottom ash is used in areas other than landfilling.[38] The source of this figure is given as a private communication, so might not be reliable. In particular, the above extract, although from a somewhat dated source, does highlight that bottom ash does travel, typically to countries where it may be considered to be recovered through specific forms of treatment at which it might be more difficult to achieve a recovery classification within the country where the waste originates.

5.7 Finland

In Finland, around 6.37 million tonnes of waste are either incinerated without energy recovery, or are treated at facilities where energy is recovered (see Table 26). Of this, around 1.63 million tonnes were of municipal origin (see Table 27).

[37] Note that Blasenbauer et al indicate a quantity of bottom ash of 470kt for Belgium (Blasenbauer, D., et al. (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883). This figure applies only to municipal wastes, although the 'capacity' of incineration is given in that report as 3.3 million tonnes (only around 2 million tonnes of municipal waste are reported as being incinerated elsewhere, whether directly by StaBel, or via reporting to Eurostat). The implication would be an even lower quantity of ash per tonne than seems likely (142kg per tonne treated, if one assumes the 3.3 million tonnes figure).

[38] Blasenbauer, D., et al. (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883.

Table 26: Waste Treated by Energy Recovery / Incineration without Energy recovery in Finland, 2020 ('000 tonnes)

2020	Energy recovery	Incineration without energy recovery
Total	6,231	138
Chemical waste	34	93
Metallic waste	0	0
Glass waste	0	0
Paper and cardboard waste	13	0
Plastic and rubber waste	77	0
Wood waste	2,319	3
Animal and vegetal waste	615	0
Household and mixed waste	2,114	6
Sludges	372	8
Mineral waste	407	2
Other waste	280	25
Of which hazardous waste	116	104

Source: Statistics Finland

Table 27: Treatment of Municipal Waste in Finland, 2020 (tonnes)

	Total waste treatment	Material recovery (excl. aerobic and anaerobic digestion)	Aerobic and anaerobic digestion	Energy recovery	Incineration without energy recovery	Landfilling
Mixed waste	1,658,712	1,010	16,365	1,628,358	111	12,868
Separately collected waste total, of which:	1,524,310	913,643	425,465	180,214	1,932	3,056
- Paper and cardboard waste	483,962	478,834	0	5,121	7	0
- Biodegradable waste	494,279	27,401	411,920	53,306	7	1,645
- Glass waste	80,860	80,138	0	22	20	680
- Metal waste	128,948	128,941	0	0	7	0
- Wood waste	102,384	77,790	150	24,285	2	157
- Plastic waste	92,662	56,802	0	35,305	21	534
- Electrical and electronic waste	61,778	61,757	0	0	21	0
- Other separately collected fractions	79,437	1,980	13,395	62,175	1,847	40
Other and unspecified waste	113,135	11,794	2,356	96,414	479	2,092
Total waste	**3,296,157**	**926,447**	**444,186**	**1,904,986**	**2,522**	**18,016**

Source: Statistics Finland

No data were obtained regarding quantities of residues generated by incinerators, or their fates. The work by Blasenbauer et al relies on personal communication to estimate a figure of 20% for the proportion of waste which is not sent to landfill.[39] They estimated a figure for bottom ash generation of 0.3 million tonnes from 1.6 million tonnes of municipal waste incinerated, a specific generation of 188kg per tonne of input.

WStatR data reported in Section 4.1 suggest that in 2018, 773 kt of non-hazardous waste and 14kt of hazardous wastes were generated. This gives a very low 124kg per tonne of waste input, with the non-hazardous quantity a very high proportion of the

[39] Blasenbauer, D., et al. (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883.

total (at 122 kg per tonne input) and the hazardous waste figure a correspondingly small share of the total (at 2 kg per tonne of input). Note that these calculations assume that the Finnish data reported to WStatR require correction (by a factor of 1,000).

5.8 Poland

In Poland, figures have been reported separately by Statistics Poland for industrial waste and municipal waste.[40] It was reported that in 2021, 107.7 million tonnes of industrial waste were generated and that the predominant ways of treating waste that was generated were recovery (47.5%) and landfilling (43.8%). However, a clear breakdown that enables a determination of how much industrial waste was incinerated was not provided.

For municipal waste, in the same year, 13.7 million tonnes were collected, and 2.702 million tonnes were sent for incineration with energy recovery and a further 170.8 thousand tonnes were treated by incineration without energy recovery.

No data were obtained regarding quantities of residues generated by incinerators, or their fates. The work by Blasenbauer et al relies on personal communication to estimate a figure of 60% for the proportion of waste which is not sent to landfill.[41] They estimated a figure for bottom ash generation of 0.21 million tonnes from 0.97 million tonnes incinerated, a specific generation of 216kg per tonne of input.

WStatR data reported in Section 4.1 suggest that in 2018, 1.856 million tonnes of non-hazardous waste and 80.7kt of hazardous wastes were generated. This gives around 308kg per tonne of waste input, with the non-hazardous quantity relatively high at 296kg per tonne input and the hazardous waste figure rather low at 13kg per tonne of input.

5.9 Spain

The National Statistical Institute indicates that in 2019, there was a total of 3.93 million tonnes of waste incinerated of which 3.77 million tonnes were non-hazardous in nature and 0.16 million tonnes were hazardous (see Table 28).

Table 28: Quantity of Waste Incinerated in Spain, 2019

	Non-hazardous	Hazardous	Total
Total	3,766,975	164,608	3,931,583

Source: Instituto Nacional de Estadistica www.ine.es/jaxi/Tabla.htm?tpx=33000&L=1

We interrogated the database of the National Statistical Institute to identify the amount of waste generated of the classification '12.8 and 13. Waste from the treatment of waste and Solidified, stabilised or vitrified waste'. These categories cover residues from incineration of waste and are described as follows:[42]

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[40] Statistics Poland (2022) *Environment in 2021*, 30 June 2022.

[41] Blasenbauer, D., et al. (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883.

[42] Eurostat (2010) Guidance on classification of waste according to EWC-Stat categories: Supplement to the Manual for the Implementation of the Regulation (EC No 2150/2002 on Waste Statistics, Version 2, December 2010.

Kind of waste: Bottom ash and slag from waste incineration and pyrolysis Fly ashes and other wastes from flue gas treatment in waste incineration plants Solidified, stabilised and vitrified wastes from waste treatment
Origin: Incineration or pyrolysis of waste; Waste treatment
Hazardous: When containing organic pollutants, heavy metals
The residues from these were reported as per Table 29. The overall quantity of residues – at 25.5% of all waste reported as being incinerated – is consistent with what one would expect. The split between hazardous and non-hazardous waste indicates a hazardous waste generation of 5.6% of the weight of waste incinerated, somewhat higher than one might expect to result from only air pollution control residues. Given, though, that bottom ash is 'a mirror entry' for the purposes of its classification as hazardousness or otherwise, it may be that some of the bottom ash is deemed to be hazardous (e.g., as a result of ecotoxicity classification).

Separate data are available for municipal waste from MITECO (Ministerio para la Transición Ecológica). Data are shown in Table 30. The data as reported by MITECO in documentation do not quite correspond to the aggregated data reported in the document summarising the data presented.[43] Closer inspection of the Table indicated that some anomalous figures – for the amount of ash and amount of power generated per tonne of waste – were implied for the SOGAMA facility. SOGAMA itself reports that some 525,160 tonnes of waste were sent for energy recovery in 2020.[44]

If one uses this figure for the total waste treated at SOGAMA, all figures seem to fall within reasonable boundaries, and the total incinerated – at 2.435 million tonnes - more closely corresponds to the aggregated total in the text version (reported as 2.416 million tonnes in 2019). Note that of the 2.4 million tonnes, a significant quantity originates from other installations, such as sorting plants / MBT facilities.

Table 29: Treatment of Waste in Categories 12.8 and 13, 2019

	Recovery			Filling operations			Dumping			Total		
	Non-haz	Haz	Total	Non-haz	Haz	Total	Non-haz	Haz	Total	NON-HAZ	HAZ	TOTAL
12.8 and 13. Waste from the treatment of waste and Solidified, stabilised or vitrified waste	232,954	10,832	243,786	21,381	0	21,381	528,840	208,628	737,468	783,175	219,460	1,002,635

[43] MITECO (2020) *Memoria Anual de Generación y Gestión de Residuos: Residuos de Competencia Municipal.* 2019, www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/memoriaanual2019generacionygestionresiduosrescompetenciamunicipal_tcm30-534462.pdf

[44] SOGAMA (2021) Modelo SOGAMA: Datos Gestión Residuos Urbanos 2020.

Table 30: Incineration of Waste Under the Competence of Municipalities, 2019

Autonomous Region, Province and Installation	Capacity		Total Received (t)		Salida total		
	Nº of Lines	Nominal Capacity (t/annum)	Mixed waste	Waste from other installations	Power generated (kwh/annum)	Residues generated (t)	Destination for Residues
C. A. Cantabria	1.00	120,507	-	119,696.00	87,245,220.00	19,366.04	
Cantabria	1.00	120,507	-	119,696.00	87,245,220.00	19,366.04	
PLANTA DE TRATAMIENTO INTEGRAL DE RSU DE CANTABRIA (MERUELO)	1.00	120,507	-	119,696.00	87,245,220.00	19,366.04	Non-haz landfill (MERUELO)
C. A. Cataluña	9.00	690,620	156,791.07	481,908.30	351,599.00	162,660.40	
Barcelona	5.00	490,250	26,655.54	481,908.30	301,951.00	131,241.18	
TERSA Incineradora de Sant Adrià del Besòs	3.00	326,250	14,472.52	336,818.81	216,515.00	81,494.22	Private contractors
TRM Incineradora de Mataró	2.00	164,000	12,183.02	145,089.49	85,436.00	49,746.96	Private contractors
Girona	2.00	35,250	-				
TRARGISA Incineradora de RSU de Gerona, Salt i Sarriá de Ter	2.00	35,250	-				
Tarragona	2.00	165,120	130,135.53	-	49,648.00	31,419.22	
SIRUSA Incineradora de Tarragona	2.00	165,120	130,135.53	-	49,648.00	31,419.22	Private contractors

Autonomous Region, Province and Installation	Capacity		Total Received (t)		Salida total		
	Nº of Lines	Nominal Capacity (t/annum)	Mixed waste	Waste from other installations	Power generated (kwh/annum)	Residues generated (t)	Destination for Residues
C. A. Galicia	2.00	360,000	516,115.24	9,044.76	334,461,290.00	97,947.79	
La Coruña	2.00	360,000	516,115.24	9,044.76	334,461,290.00	97,947.79	
Complejo ambiental de Cerceda (Sociedad Gallega del Medio Ambiente-SOGA MA)	2.00	360,000	516,115.24	9,044.76	334,461,290.00	97,947.79	Landfill for ash (RP) and slag of SOGAMA
C. A. Islas Baleares	4.00	732,000	459,327.27	108,152.74	347,126,000.00	172,666.51	
Baleares	4.00	732,000	459,327.27	108,152.74	347,126,000.00	172,666.51	
Parque Tecnologías Ambientales - TIRME, S.A.	4.00	732,000	459,327.27	108,152.74	347,126,000.00	172,666.51	Recycling of slag and secure deposit for ash
Comunidad de Madrid	3.00	300,000		332,980.00	228,262,800.00	39,984.82	
Madrid	3.00	300,000		332,980.00	228,262,800.00	39,984.82	
Centro de tratamiento integral de RSU Las Lomas	3.00	300,000		332,980.00	228,262,800.00	39,984.82	Slag – inert landfill Fly ash – secure landfill
C. A. Melilla	1.00	47,000	37,386.80	1,628.71		11,611.70	
Melilla	1.00	47,000	37,386.80	1,628.71		11,611.70	

Autonomous Region, Province and Installation	Capacity		Total Received (t)		Salida total		
	Nº of Lines	Nominal Capacity (t/annum)	Mixed waste	Waste from other installations	Power generated (kwh/annum)	Residues generated (t)	Destination for Residues
REMESA (RESIDUOS DE MELILLA, SA.)	1.00	47,000	37,386.80	1,628.71		11,611.70	GAMASUR (LOS BARRIOS) Y DITECSA (HUELVA) UTE RECICLADOS MELILLA (MELILLA) REMESA CATVFU'S-CT
C. A. País Vasco	1.00	245,910	144,727.00	67,950.00	630,525,111.00	45,308.02	
Vizcaya	1.00	245,910	144,727.00	67,950.00	630,525,111.00	45,308.02	
Zabalgarbi, S.A.	1.00	245,910	144,727.00	67,950.00	630,525,111.00	45,308.02	"COMPLEJO MEDIOAMBIENTAL DE GIPUZKOA_FASE II SADER - S.A. DE DESCONTAMINACION Y ELIMINACION DE RESIDUOS Vertedero de ZALLA Vertedero DEYDESA IGORRE"
Total general	**21.00**		**1,314,347**	**1,121,360.51**	**1,627,972,020.00**	**549,545.28**	

Source: MITECO, with adjusted data for SOGAMA (see main text)

The final column shows the quantity of residues derived from the incineration facilities. It is not clear whether this includes all residues, or all residues net of extracted metals, for example (which would appear to be the case for many of the facilities, given the suggested destination). The quantity of residue per tonne of input is 226kg. If it were the case that this excludes some / all metals recovered, then the figures per unit of waste treated might be aligned with the 255kg per tonne figure for 'all wastes' which we have estimated.

An earlier report for Greenpeace estimated that, based on ten facilities treating 1.9 million tonnes of municipal waste, and based on PRTR data, there were 548kt of non-hazardous residues generated by the ten facilities, as well as 69kt of hazardous residues. This is a higher figure than is implied by the MITECO figures above.[45]

[45] Greenpeace (2010) *La incineración de residuos en cifras: Análisis socio-económico de la incineración de residuos municipales en España*, July 2010, archivo-es.greenpeace.org/espana/Global/espana/report/contaminacion/100720.pdf

5.10 Austria

The Austrian Bundesministerium for Climate, Environment, Energy, Mobility, Innovation and Technology gives data on combustion residues from combustion plants and from thermal waste treatment (including installations dealing with a range of 'residues').[46] The number of plants for the thermal treatment of municipal waste remained constant from 2015 to 2019 at 11 plants with an annual capacity of 2.6 million tonnes. In the case of the thermal treatment plants (excluding treatment plants for municipal waste) (in the scope of the Waste Incineration Ordinance, Federal Law Gazette II No. 389/2002 as amended), the number fell from 54 to 47 between 2015 and 2019, and the quantity of waste dealt with by these plants fell from 2.4 million tonnes to 1.6 million tonnes over the same period.

Table 31 shows the development of the amount of incineration residues (reported amount of waste).[47]

This waste includes ash, slag, dust and other residues from:

- Plants for thermal treatment of waste,
- Combustion plants in which waste with a high calorific value is also incinerated, and
- Other combustion systems (such as thermal power plants)

The residues related to incineration of waste (in bold below), when summed, total 620,400 tonnes, of which 510,400 are bottom ash, and 110,000 tonnes relate to air pollution control.

Table 31: Combustion residues from combustion plants and from thermal waste treatment (tonnes, unless stated)

SN	Category of waste	2017	2018	2019
31301 **31301 77**	Fly ash and dust from other combustion plants	221,100	230,700	253,400
31305	Coal ash	7,700	21,500	13,300
31306 **31306 70** **31306 72** **31306 74** **31306 77** **31306 91** **92303**	Wood ash, straw ash, plant ash	133,600	134,800	137,000

[46] Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (2022) *Bundes-Abfallwirtschaftsplan 2022: Teil 1; Entwurfsfassung zur Konsultation*, www.bmk.gv.at/dam/jcr:3cf3a571-2f88-4a19-b955-8531a5725f86/BAWP_2022_Teil_1.pdf

[47] Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (2022) *Bundes-Abfallwirtschaftsplan 2022: Teil 1; Entwurfsfassung zur Konsultation*, www.bmk.gv.at/dam/jcr:3cf3a571-2f88-4a19-b955-8531a5725f86/BAWP_2022_Teil_1.pdf

SN	Category of waste	2017	2018	2019
92303 71 **92303 73**				
31307 **31307 77**	Boiler slag	300	5,100*	1,200
31308 **31308 88**	**Slag and ash from waste incineration plants**	**522,300**	**516,300**	**510,400**
31309 **31309 88**	**Fly ash and dust from waste incineration plants**	**108,200**	**122,000**	**98,400**
31312 **31312 88**	**Solid saline residues from flue gas cleaning of waste incineration plants and waste pyrolysis plants**	**8,500**	**9,500**	**11,600**
31314 **31314 88**	Solid saline residues from the flue gas cleaning of combustion plants for conventional fuels (without gypsum)	800	700	700
31315	Gypsum	11,100	4,800	3,300
31316 **31316 88**	Slag and ash from waste pyrolysis plants	55	18	19
31317	Fly ash and dust from oil firing systems	49	4	2
Total [Mio. t]		1.01	1.05	1.03

Source: Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (2022) Bundes-Abfallwirtschaftsplan 2022: Teil 1; Entwurfsfassung zur Konsultation, www.bmk.gv.at/dam/jcr:3cf3a571-2f88-4a19-b955-8531a5725f86/BAWP_2022_Teil_1.pdf

The same report notes that, regarding treatment:[48]

In 2019, most of the treated waste was landfilled domestically (863,000 t). Another 170,000 t were recycled, the majority of them in the cement industry, partly also in the building materials industry. The plant ashes [i.e. from the combustion of plant

[48] Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (2022) *Bundes-Abfallwirtschaftsplan 2022: Teil 1; Entwurfsfassung zur Konsultation*, www.bmk.gv.at/dam/jcr:3cf3a571-2f88-4a19-b955-8531a5725f86/BAWP_2022_Teil_1.pdf

material] were treated in composting plants [...]. In addition, around 45,000 t of incineration residues were imported in 2019 and around 12,000 t were exported for landfill or material recycling.

It also indicates that among the main types of waste landfilled, slag and ash from incineration (in particular, categories 31308 88 and 31308 91) accounts for 610,000 tonnes. It also indicates that facilities seeking to stabilise / solidify residues deal with incinerator residues, presumably, prior to landfilling. In total, 250,850 tonnes of residue appear to be treated in this way (see Table 32).

Table 32: Key Inputs for Solidification Facilities

Input (SN)	Category of waste	t
31308 88	Slag and ash from waste incineration plants	166.550
31309	Fly ash and dust from waste incineration plants	63.077
31309 88	Fly ash and dust from waste incineration plants	21.223
31301	Fly ash and dust from other combustion plants	19.280
31223	Dust, ash and dross from other melting processes	6.680
	Rest	71.619

A further Table in the same report indicates the quantity of hazardous waste generated in 2019. This quantity includes a reported 49,500 tonnes of slag and ash from waste incineration plants, and 71,800 tonnes of fly ash and dust from waste incineration plants. The latter quantity does not correspond to the total generated as reported in Table 31. The total quantity amounts to 121,300 tonnes.

5.1 Denmark

The Statistics Denmark Waste Accounts for 2019 indicate that 1,700,905 tonnes of household waste generated in Denmark were incinerated as well as 1,489,453 tonnes of waste from industry, a total of 3,190,358 tonnes.[49] In addition, there were imports of 638,360 tonnes, and exports of 64,414 tonnes for incineration. 3,764,304 tonnes.

The figures regarding 'Residuals from incineration' in the Waste Accounts indicates a figure of 535,587 tonnes. However, a review of the sources of the waste, by industry classification, suggests this might include a range of ashes from other combustion activities (this is not entirely clear). On the other hand, exports of Residuals from incineration are reported as 139,897 tonnes, with imports reported at 48,786 tonnes.

[49] Data extracted from *Statistics Denmark Tables* – see www.dst.dk/en/Statistik/dokumentation/documentationofstatistics/waste-accounts/statistical-presentation

Based on a quantity incinerated of 3.76 million tonnes, the ash residues might be expected to be in excess of 700,000 tonnes. We come close to this figure if we sum the total residues as well as the exports but since the generation figures refer to generation, it seems unclear that exports should be added to, rather than being considered part of, the total generation. Blasenbauer et al give a figure of 0.6 million tonnes of bottom ash, of which it is suggested that 99% is 'not landfilled'.[50]

WStatR data reported in Section 4.1 suggest that in 2018, 0.305 million tonnes of non-hazardous waste and 29.3 kt of hazardous wastes were generated. This gives a very low 97kg per tonne of waste input, with the non-hazardous quantity also low at 88kg per tonne input and the hazardous waste figure rather low at 9kg per tonne of input.

6.0 Towards an Estimate of Residues

We present below a range of estimates for the quantity of residues generated before moving on to estimate the fates of these residues, and in particular, the quantity landfilled.

6.1 Quantities Generated

6.1.1 Bottom-up Approach

In the bottom-up approach, we have used country-specific research to derive estimates for the quantities of residue generated. In doing so we have:

- Used only data from the 11 Member States considered above that we deem to be of acceptable quality and which can be related back to a specified input quantity of waste (Germany, France, Italy, Netherlands, Sweden, Spain and Austria);
- On the basis of an aggregated view from these countries, we have then grossed up to total figures based on the share of wastes treated accounted for by the countries for which data of quality have been obtained;
- A split between hazardous and non-hazardous outputs was not available for all Member States. In the data presented, we have based the split between the classes on the data reported by Germany, which accounts for around half of the quantity used as the basis for deriving the total figures.

This approach gives the figures presented in Table 33.

Table 33: Estimated Quantities of Bottom Ash and Air-pollution Control Residues, by Bottom-up Method ('000 tonnes)

	Total Generated	Non-hazardous	Hazardous
Bottom ash, excl. extracted metals	23,671	21,758	1,913
Air pollution control residues	5,090	462	4,628

Source: Equanimator estimate

[50] Blasenbauer, D., et al. (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883.

6.1.2 Top-Down Estimates

In the top-down approach, we have presented a range of approaches:

1. For both MSW and for all wastes sent for D10 and R1 incineration / combustion, we have estimated average quantities per tonne of input at the low and high level. The basis for the figures is shown in Table 34. There is at least some indication that bottom ash residues, expressed per tonne of waste input, are lower (or at least, they are reported as lower) when one considers 'all wastes' as opposed to municipal waste only. There may be all sorts of reasons for this (the wastes themselves are lower in ash content, or the R1 facilities dealing with waste through co-incineration are such that the reported ash quantities are lower than would be expected if the same wastes were incinerated (for example, if wastes sent to cement kilns that might – if incinerated – be a source of bottom ash are largely reporting to clinker, and not to ash residues). It was felt that this justified lower unit figures when considering 'all wastes' than when considering only MSW.
2. Based on the amount of waste being sent to waste-to-energy facilities in 2020 as reported by CEWEP, we first of all report the estimate of bottom ash generation from CEWEP. We then used mid-point estimates of the unit generation quantities used for MSW and for 'all wastes' to estimate a range based on the input figure from the same source.
3. For bottom ash, we also include the data from Blasenbauer et al already reported in Section 4.2;
4. Finally, we include the WStatR reporting already presented in 4.1.

The different figures arising from this approach are shown in Table 34. The 'bottom up' figures (see Table 33), which give a point estimate, lie within the range of the top-down estimates for all wastes (see columns labelled (C) and (D) in Table 34.

Table 34: Estimated Generation of Residues from R1 and D10 Facilities, Top-Down Estimates, '000 tonnes

	Based on unit estimates				CEWEP	CEWEP (2022) (mid-point unit estimates, low)	CEWEP (2022) (mid-point unit estimates, high)	Blasenbauer et al (2020) (excl. UK)	Eurostat reporting for all wastes
	(A) MSW, low	**(B) MSW, high**	**(C) All Wastes, low**	**(D) All Wastes, high**	**W-t-E, excl. haz wastes**	**W-t-E, excl. haz wastes**	**W-t-E, excl. haz wastes**	**Municipal waste incinerators**	**All wastes**
R1 Incineration	57,919	57,919	129,720	129,720					129,720
D10 Incineration	1,116	1,116	14,360	14,360					14,360
Basis Waste Quantity	59,035	59,035	144,080	144,080	96,000	99,000	99,000	78,000	144,080
Unit quantity bottom ash, excl metals (kg/tonne input)	0.185	0.230	0.160	0.210		0.173	0.220		
Unit quantity APC residues	0.027	0.040	0.027	0.040		0.027	0.040		

	Based on unit estimates				CEWEP	CEWEP (2022) (mid-point unit estimates, low)	CEWEP (2022) (mid-point unit estimates, high)	Blasenbauer et al (2020) (excl. UK)	Eurostat reporting for all wastes
	(A) MSW, low	(B) MSW, high	(C) All Wastes, low	(D) All Wastes, high	W-t-E, excl. haz wastes	W-t-E, excl. haz wastes	W-t-E, excl. haz wastes	Municipal waste incinerators	All wastes
(kg/tonne input)									
Bottom ash, excl metals	**10,921**	**13,578**	**23,053**	**30,257**	**19,000**	**17,078**	**21,780**	**16,100**	**33,340a**
APC residues	**1,594**	**2,361**	**3,890**	**5,763**		**2,673**	**3,960**		**5,240b**
Total IBA + APCr, MSW only	12,515	15,939							
Total IBA + APCr, All wastes			26,943	36,020		19,751	25,740		38,580
Quantity of all residues (kg/tonne input))	*0.212*	*0.270*	*0.187*	*0.250*		*0.200*	*0.260*		*0.268*

[a] this is the Eurostat figure reported as the non-hazardous component of the relevant mineral and combustion residues
[b] this is the Eurostat figure reported as the hazardous component of the relevant mineral and combustion residues
Sources: Equanimator estimates; CEWEP (u.d.) Bottom Ash Factsheet; CEWEP (u.d.) Waste to Energy Plants in 2019, www.cewep.eu/waste-to-energy-plants-in-europe-in-2019 ; Dominik Blasenbauer et al (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, Waste Management, 102 pp.863-883; DG Eurostat waste Data Database

6.2 Treatment of Residues

Because the treatment of residues is affected by policy and law, and because this varies by Member State, a grossing up based on a subsample of the total is probably unwise.

Instead, we note that:

- Regarding bottom ash:
    - In Germany, statistics suggests (if our interpretation is correct) that whilst 18.8% of bottom ash may be landfilled directly, when one accounts for the outputs of treatment, the total landfilled (incl long term storage) plus the

quantity sent for disposal (presumably, landfill) rises to 38%. If one includes materials sent to mines and backfilling, this rises to 43%;
    - The figures from Blasenbauer et al, when the data for the UK are excluded, indicate a figure of 49.8% of all bottom ash 'not being landfilled', indicating that the balance of 50% is still landfilled.
    - The Blasenbauer et al study assumed that 30% of the bottom ash generated by German incineration was used outside landfills. Our investigation suggests that this may be closer to 60%. If one revises the figures in Blasenbauer et al to account for this, the proportion of the EU27 total sent to landfill falls to 41%;
    - This figure is very similar to the figure assumed in an earlier study by ADEME (see Table 35);
- Regarding APC residues:
    - Data from Netherlands suggests that 50% or so of APC residues are landfilled;
    - Data from Germany indicate that the total landfilled (incl long term storage) plus disposal amounted to 14% of the total. This rose to 64% once deposits in mines were added. It is not clear whether these data fully take into account the effect of exports of such wastes (the imports to treatment facilities are clear);
    - ADEME has previously suggested a split for the EU as 43% to salt mines and 57% to (presumably hazardous waste) landfills.[51]

Table 35: Figures Proposed by ADEME

	Used of bottom ash after metal recovery	Disposal of APC residues
France	82,5% reuse as construction material 17,5% landfill	24% in salt mines 76% in landfills
Europe	60% reuse as construction material 40% landfill	43% in salt mines 57% in landfills

Source: ADEME (2018) Base Impacts® Data Documentation - Sector: End of Life Treatment, Angers, 1.09.2018.

If, based on the above figures, one assumes that:
- 40-50% (low / high) of bottom ashes (pre- or post-treatment) are landfilled; and
- 35-55% (low/high) of APC residues are also landfilled,

then the total quantity of residues being landfilled can be estimated based on mid-point estimates from the bottom-up and the top-down estimates derived above. We show both the mid-point estimates for bottom ash and APC residues, as well as the estimated quantities landfilled, in Table 36.

[51] ADEME (2018) *Base Impacts® Data Documentation - Sector: End of Life Treatment*, Angers, 1.09.2018.

Table 36: Quantity of Incineration and Combustion (of waste) Residues Generated and Quantity Landfilled

Generation based on...	Bottom-up, all wastes		Top-down, all wastes, central		Top-down, MSW, central	
Waste generated and quantity landfilled	Low	High	Low	High	Low	High
Bottom ash	23,671		26,555		12,250	
APC residues	5,090		4,827		1,978	
Landfilled bottom ash	9,468	11,836	10,662	13,327	4,900	6,125
Landfilled APC res	1,782	2,800	1,689	2,655	692	1,088
Total Landfilled	11,250	14,635	12,351.26	15,982	5,592	7,213

Source: Equanimator estimates

To summarise, it would appear that:

- Regarding municipal waste:
    - Just over 12 million tonnes of bottom ash and around 2 million tonnes of air pollution control residues are generated (this excludes metals captured for recycling) as a result of the incineration of municipal waste;
    - Together, this amounts to 14 million tonnes, or just over 6%, of MSW generated;
    - Of this, just under half – or around 6.4 million tonnes, taking the mid-point of the low and high estimates – is estimated to be landfilled;
    - The fate of much of the remainder seems likely to be oriented, in the case of bottom ash, towards either road building or other construction related activities, and in the case of air pollution control residues, to filling of salt mines.
    - Although the latter (or the process preceding it) is frequently defined as a recovery activity, there are reasonable questions as to whether it should be so classified (and indeed, Member States may have different interpretations);
    - The air pollution control residues are mostly hazardous in nature in their raw form. Most bottom ash is reported as non-hazardous, though the accuracy of this reporting may warrant closer scrutiny.
- Regarding all wastes:
    - Between 23.6 and 26.7 million tonnes of bottom ash and between 4.8 and 5.1 million tonnes of air pollution control residues are generated (this excludes metals captured for recycling) as a result of the incineration and combustion of all wastes treated in such a manner;
    - Together, this amounts to 28.4-31.8 million tonnes of residues. To contextualise this within the MSW landfill target, this is equivalent to between 12.6% and 14.1% of the quantity of MSW generated;
    - Of this, we estimate between 11.3 and 16.0 million tonnes to be landfilled;
    - As with municipal waste, the fate of much of the remainder seems likely to be oriented, in the case of bottom ash, towards either road building or other construction related activities, and in the case of air pollution control residues, to filling of salt mines.

- The latter (or the process preceding it) is frequently defined as a recovery activity, there are reasonable questions as to whether it should be so classified;
- Again, as with municipal wastes, the air pollution control residues are mostly hazardous in nature in their raw form. Most bottom ash is reported as non-hazardous, though the accuracy of this reporting may warrant closer scrutiny.

6.3 Concluding Remarks

The comparison with figures regarding municipal waste generation is obviously more relevant to the case where only municipal waste is being considered. If, in meeting a 65% recycling target, all wastes which were not recycled were being incinerated, then based on 2020 MSW generation figures, the quantity being incinerated would increase from 61.4 in 2020 to 79.0 million tonnes. The quantity of residues generated from incineration would then be of the order 8% of MSW generation. We estimate that the residues (or results from treating them) being landfilled would be of the order 4% of MSW generation.

6.3.1 Unequal Treatment

There are good reasons to question why residues from incineration should be excluded from calculations regarding the quantity of municipal waste landfilled. After all, this is landfilling that results from the management of municipal waste. The argument might run that once municipal waste has been incinerated, then the residues are no longer 'municipal waste'. Yet Eurostat Guidance notes:[52]

It is important to note that for the purposes of monitoring compliance with the above target, landfilling includes: 'the weight of waste resulting from treatment operations prior to recycling or other recovery of municipal waste, such as sorting or mechanical biological treatment, which is subsequently landfilled.'

The landfilled output from such processes may be categorised under LoW [List of Waste] chapter 19 (wastes from waste management facilities) not chapter 20 (municipal waste), so it is important to ensure the total municipal waste landfilled includes all relevant landfilled wastes from municipal sources (as per the previous Eurostat Guidance on municipal waste).

The last of these paragraphs highlights why excluding landfilled residues from incineration on the basis that they are no longer 'municipal waste' would be inconsistent. Outputs of MBT processes that are subsequently sent to landfill may be classified under LoW chapter 19, and no longer as 'municipal waste'. Chapter 19 also includes wastes from incineration or pyrolysis of waste. If the targets under Article 5(5) of Directive 1999/31/EC on the landfill of waste are indeed focussed on the reduction of 'municipal waste' landfilled, then it is inconsistent to treat the outputs of MBT facilities as though they are still municipal waste, and count towards this target, whereas the residues from incineration of MSW which are landfilled do not.

In terms of how similar the outputs may be to input municipal waste, residues from mechanical biological treatment plants that have been stabilised prior to landfilling are akin to a contaminated compost, and bear little or no resemblance to the input waste (no more so that compost resembles an apple), the more so, the more the waste treatment is oriented towards stabilisation, which necessitates the degradation of the biodegradable fractions).

Equality of treatment ought to require that all residues resulting from the treatment of municipal waste which are subsequently landfilled are treated on a fair basis as regards the Landfill Directive Article 5(5) target. Options are

[52] Eurostat (2021) *Guidance for the compilation and reporting of data on municipal waste according to Commission Implementing Decisions 2019/1004/EC and 2019/1885/EC, and the Joint Questionnaire of Eurostat and OECD*, Version of 12/08/2021, ec.europa.eu/eurostat/documents/342366/351811/Guidance+on+municipal+waste+data+collection

- that the target is amended to exclude the residues from MBT also; or
- that the target is amended to include all residues from incineration – both R1 and D10 - which are landfilled); or
- that the landfill target is re-specified so as to ensure (in conjunction with other changes) that management of residual wastes delivers the most beneficial outcome.[53]

Article 5a(1) of the Landfill Directive states:

1. For the purpose of calculating whether the targets laid down in Article 5(5) and (6) have been attained:
(a) the weight of the municipal waste generated and directed to landfilling shall be calculated in a given calendar year;

(b) the weight of waste resulting from treatment operations prior to recycling or other recovery of municipal waste, such as sorting or mechanical biological treatment, which is subsequently landfilled shall be included in the weight of municipal waste reported as landfilled;

(c) the weight of municipal waste that enters incineration disposal operations and the weight of waste produced in the stabilisation operations of the biodegradable fraction of municipal waste in order to be subsequently landfilled shall be reported as landfilled;

(d) the weight of waste produced during recycling or other recovery operations of municipal waste which is subsequently landfilled shall not be included in the weight of municipal waste reported as landfilled.

Note that 'mechanical biological treatment' is not defined. If facilities classified wholly or partly as an R3 or R4 operation sent waste to landfill, then according to sub-paragraph d) this might imply that the wastes produced in the process were not to be counted towards the targets.

Treatment processes relying on biological stabilisation have shown to be capable of ensuring a significant reduction of impacts associated with landfilling of waste, and may include biological stabilisation alone or in combination with recovery of metals and other recyclables still included in residual waste. Indeed, we have argued elsewhere that in respect of greenhouse gas emissions, an approach to waste management based around mechanical biological treatment that utilises high quality mixed waste sorting systems in conjunction with stabilisation of the remaining waste to be sent to landfill is on a par with mixed waste sorting coupled to an incinerator.[54]

Subparagraphs c) and d) have the effect of differentiating whether the landfilled waste from an incinerator should be included within the targets based on whether or not the facility is classified as D10 as opposed to R1. There can be expected to be limited, if any, effect on the quantity and nature of the residues resulting from how much energy the facility generates. As such, the rationale for this distinction seems at least questionable: why does the nature, quantity and form of the landfilled waste change as a result of its R1 or D10 status? Elsewhere, we have argued for a removal of the R1 criterion in Annex II of the WFD, and this would seem a further rationale for doing so.[55]

Surely, what ought to matter is what is being landfilled as a result of the management of municipal waste, and what are the implications of doing so. There are relevant questions to be asked as to whether landfilling 10% of waste as a biostabilised residue from mechanical biological treatment is more or less harmful than handling 12 million tonnes of bottom ash, and 2 million tonnes of mainly hazardous air pollution control residues. Indeed, the incineration of waste – because of the nature of APC residues – implies a need for managing hazardous waste which might not otherwise have been necessary.

[53] See proposals for change set out in Equanimator (2021) *Rethinking the EU Landfill Target*, Report for Zero Waste Europe, October 2021, zerowasteeurope.eu/library/rethinking-the-eu-landfill-target

[54] See Dominic Hogg (2022) *The Case for Sorting Recyclables Prior to Landfill and Incineration*, Special Report prepared for Reloop, June 2022.

[55] Equanimator (2021) *Rethinking the EU Landfill Target*, Report for Zero Waste Europe, October 2021, zerowasteeurope.eu/library/rethinking-the-eu-landfill-target

6.3.2 Lack of Harmonisation in what is Allowed

Where the treatment of residues is concerned, the framing laws and policies, as well as the available treatments, are not homogeneous across Member States. This was already highlighted by Blasenbauer et al for the case of bottom ash, and classification of both the residues themselves (at the detailed level) and of the ways in which they are treated is not always consistent.[56] Because of differences in regulation, processes which are permissible in one Member State might not be considered permissible in another. This may lead to movements of waste that are either unnecessary (if the exporting Member State is 'over-regulating'), or unhelpful (if the receiving Member State is 'under-regulating').

Similarly, because of differences in interpretation of law, it may be that processes which are classified as 'recovery' in one Member State might not be classified as 'recovery' in another. This could have the effect of allowing waste to cross boundaries for the purposes of being recovered in a receiving Member State even though the process would not be classified as recovery in the Member State from which the waste originated;

Furthermore, the categorisation of treatments of some residues as 'recovery' operations can mask the extent to which those recovery operations themselves may give rise to disposal of residues from the recovery process. The extent to which some recovery activities might be more properly classified as D9, and the extent to which activities classed as 'backfilling' should be classed as such is deserving of some closer inspection. The definition of backfilling is:

'backfilling' means any recovery operation where suitable non-hazardous waste is used for purposes of reclamation in excavated areas or for engineering purposes in landscaping. Waste used for backfilling must substitute non-waste materials, be suitable for the aforementioned purposes, and be limited to the amount strictly necessary to achieve those purposes

The definition of D9 is:

Physico-chemical treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D 1 to D 12 (e.g., evaporation, drying, calcination, etc.)

The issues associated with classifying disposal and recovery processes, especially in respect of air pollution control residues, were examined by a recent ruling in the UK, where the relevant authority in England and Wales – the Environment Agency – refused a license to export air pollution control residues to a Norwegian facility on grounds that the waste would be undergoing a disposal operation, and not a recovery operation.[57] As reported in the Court Ruling, the Norwegian Environment Agency and Swedish Environmental Protection Agency had different views:

'The Norwegian Environment Agency considers the waste operations to be a recovery operation. It has explained its decision on the basis that NOAH needs to use suitable materials to neutralise and stabilise the sulphuric acid before landfilling. Regardless of whether NOAH obtains access to APCr the acid must be landfilled, but the landfilling cannot take place until the acid is neutralised and stabilised. APCr is highly suitable for neutralising and stabilising the acid. NOAH can use limestone instead of APCr but it is less effective and large quantities of limestone must then be extracted. NOAH's use of APCr replaces the extraction and use of virgin materials (limestone) that would otherwise have been used. The principal result in this case is that the acid is neutralised and stabilised and this use of APCr is to be regarded as a recovery operation.

26. In contrast, the Swedish Environmental Protection Agency has expressed the view that APCr is used in a pre-treatment process (neutralizing and/or stabilizing other wastes) at NOAH's site. This process results in a new hazardous waste, which in

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[56] Blasenbauer, D., et al. (2020) Legal situation and current practice of waste incineration bottom ash utilisation in Europe, *Waste Management*, 102 pp.863-883.

[57] Royal Courts of Justice (2022) The Queen (on the Application of New Earth Solutions (West) Limited) – Claimant - and Environment Agency – Defendant - and (1) Noah Solutions AS and (2) Norwegian Environment Agency, Case No: CO/4172/2021, 19/07/2022, www.bailii.org/ew/cases/EWHC/Admin/2022/1883.pdf

turn is placed in a hazardous waste landfill. Although the APCr is useful in the pre-treatment, the treatment in its entirety is aimed for disposal of the waste (landfilling). The treatment should, therefore, be seen as disposal.

These decisions are important in that they shape how investment may or may not be made in waste management, and the extent of cross-border flows of what may be hazardous wastes.

6.4 Reporting Issues

On the basis of our literature review, and accepting that this has limitations in terms of its ability to identify and acquire all data which may be available, it is clear that gaining information on the residues associated with incineration (including co-incineration) and of their fates is not entirely straightforward. At least superficially, one could simply take data from Eurostat for the (most) relevant waste codes, but whilst these aggregate level data seem plausible enough, they are derived from Member State data that seem less reliable (given what we think we know regarding generation of residues per tonne of waste input) (see Section 4.1). Indeed, this raises some questions regarding why it is that these data appear to be unreliable.

Some countries are exceptions in seeking to understand these residues, both in terms of quantities or residues generated, and the fates of the residues (how they are managed). Germany, France, Italy, the Netherlands and Austria are all countries where we have found up-to-date data, and there may be others who provide quality data, including some countries whose figures we have not specifically sought to track down.

Relevant issues, though, are as follows:

1. First, when speaking about 'residues from incineration', there is some merit in being clear what one means by the term 'incineration'. The distinction between R1 and D10 does not help differentiate between different ways of managing waste: a (perhaps considerable) proportion of R1 treatment will represent waste being managed at co-incineration facilities. It also seems at least possible that some non-municipal wastes reportedly treated through R1 facilities might actually be managed at dedicated waste treatment facilities whose principal purpose is the thermal treatment of the waste and not the production of energy (so should, perhaps, be considered D10). The Industrial Emissions Directive does distinguish between incineration and co-incineration, but it is not always so easy to understand the amounts of waste sent to different facility types, and to link the residues directly back to those different receiving installations. These data should exist at Member State level, and it would be helpful to distinguish, for example, the quantities of Combustion Residues generated from different types of co-incineration facility. Currently, residues associated with the incineration of waste should be reported as 'Mineral wastes from waste treatment and stabilised wastes', whilst residues from co-incineration of waste are reported as 'Combustion wastes'. Given that, for example, bottom ash and fly ash being reported under "Combustion wastes" have to be (or should be) reported as a separate code within the category of "Combustion wastes", there might be some argument for assigning those waste streams to the "Mineral wastes from waste treatment and stabilised wastes", and for waste treatment statistics to distinguish between different types of R1 facility so that the residues from co-incineration can be linked back to the quantities being treated. Again, this data likely already exists, but if there is interest in improving understanding of residues generated from incineration / co-incineration of wastes, it might be useful to consider such changes to aid transparency in, and verification of, reporting;
2. The quantities of wastes being treated from which specific residues originate is not always made clear (i.e. the links are not always clear between a source term (waste treated) and an output term (residue generated). Helpfully, the German presentation includes a form of 'input / output' matrix for treatment facilities. For others, however, the fact that the distinction between R1 and D10 does not always clarify what is the source of combustion residues (co-incineration), and what is managed through incineration, is not helpful. Again, the basis for doing this ought to exist already if statistical reporting is on a sound basis;
3. In Member States where wastes generated by incineration facilities are destined (initially) for recovery, the recovery activity itself may subsequently give rise to residues which are destined for disposal. We sought to understand the extent to which this was the case in Germany. Where bottom ash was concerned, as far as we could discern, if one accounted for quantities of waste through the chain, then the quantity of (treated) wastes landfilled seemed to

increase from 27% of the weight of residues initially generated (when reported at the point of generation) to 40% of the weight of residues initially generated (when taking into account residues generated by treatment processes). Evidently, the landfilled component of a treated waste of type A may not be 'waste of Type A'. Tracing through the various treatment pathways to their end-points is important if one is to understand the amount of waste actually disposed of as a result of treating incinerator residues;

4. It would be helpful if statistics were always clear about the extent to which quantities of residues generated by activities within a Member State led to the export of such wastes. The German presentation is, once again, helpful in this regard in identifying where input to different treatment facilities is related to on-site waste generation, waste generated elsewhere in Germany, or waste that is imported.

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Zero Waste Europe, 2022

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Zero Waste Europe gratefully acknowledges financial assistance from the European Union. The sole responsibility for the content of this material lies with Zero Waste Europe. It does not necessarily reflect the opinion of the funder mentioned above. The funder cannot be held responsible for any use that may be made of the information contained therein.