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2013 survey of waste production and management at European refineries

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2013 survey of waste production and management at European refineries

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ABSTRACT

This report provides a statistical analysis of waste production by Concawe member company refineries in 2013, based on survey data returned from 74 member company refineries (71% response rate) situated in the EU-28 countries + Norway and Switzerland. It includes a breakdown of waste tonnage according to the origin of the waste, how it was managed and how it was classified under the 2008 Waste Framework Directive (2008/98/EC). This findings from the survey, together with those of previous Concawe waste surveys for 1993 (Concawe; 1-95) and 1986 (Concawe; 5-89), show how the sector has responded to developments in EU waste legislation over the past 30 years. In addition, the data constitute a modern baseline for the future assessment of performance.

Total waste production reported by the refining sector in 2013 was 1.2 million tonnes, of which 43% was classified as hazardous. The top 3 reported hazardous wastes types by tonnage are sludges (comprising tank bottoms, physical/chemical treatment, biological treatment and other), followed by spent chemicals/acids/bases and then contaminated soil/stones/aggregate/concrete (with approximately one third of these arising from remediation activities). The top 3 non-hazardous wastes comprise soils/stones/aggregate/concrete, followed by metal and biological wastewater treatment sludges. Soils/stones/aggregate/concrete constitute 65% of the total non-hazardous waste reported, while metal and biological wastewater treatment sludges constitute 9% and 4%, respectively.

The vast majority (94%) of refinery wastes were disposed within the country of origin, with only spent catalyst exported outside the EU (to specialist recovery facilities). Recycling accounted for the largest waste tonnage (34%), followed by waste going to landfill (20%). This is in contrast to the 1993 survey, which found that landfill accounted for 40% and recycling 21%. In parallel, the percentage of waste used for energy recovery reduced from 15% in 1993 to 7% in 2013, while the percentage of waste disposed of by incineration reduced slightly from 8% to 6%. These findings demonstrate that the sector has been successful in moving waste streams up the EU waste hierarchy, with an increasing proportion of waste going to recovery, recycling and re-use.

Legislative changes and associated changes in waste reporting practices mean that the 1993 and 2013 data on refinery waste tonnage and handling costs are not directly comparable. For example, the apparent increase in total waste tonnage from 1993 to 2013 may well reflect more systematic waste classification and reporting under the 2008 Waste Framework Directive. The total cost of refinery waste management appears to have significantly increased, from an inflation-adjusted figure of approximately 80 M$ in 1986 (for 89 refineries), to 137.2 M$ in 2013 (for 74 refineries).

KEYWORDS

Waste, European refinery waste, waste survey, inventory, waste framework directive, waste production, waste handling costs, waste management options, waste classification codes, waste hazard codes

INTERNET

This report is available as an Adobe pdf file on the Concawe website (www.concawe.eu).

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SUMMARY

This report presents the findings from a survey undertaken by the Concawe special taskforce on refining waste (WQ/STF-36) to determine the quantity of waste managed by Concawe member company refineries in 2013. The report includes a statistical analysis of waste production, handling costs, management options and the tonnages reported under different primary European Waste Catalogue codes (Annex of Commission Decision 2000/532/EC, as amended by Decisions 2001/118/EC; 2001/119/EC and 2001/573/EC) and Waste Hazard codes (Annex III of Directive 2008/98/EC).

The 2013 survey questionnaire was distributed to all 104 refineries operated by Concawe member companies. 74 refineries responded to the questionnaire which gave a response rate of 71%. Total waste production reported by the refining sector in 2013 was 1.2 million tonnes, of which 43% was classified as hazardous. The vast majority (94%) of refinery wastes were disposed within the country of origin. The only waste exported outside the EU was catalyst for recovery.

The top 3 reported hazardous wastes types by tonnage are sludges (comprising tank bottoms, physical/chemical treatment, biological treatment and other), followed by spent chemicals/acids/bases and then contaminated soil/stones/aggregate/concrete (with approximately one third of these arising from remediation activities). Sludges constitute 45% of the total hazardous waste reported, while spent chemicals/acids/bases and contaminated soil/stones/aggregate/concrete constitute 14% and 12%, respectively. The top 3 non-hazardous wastes comprise soils/stones/aggregate/concrete, followed by metal and biological wastewater treatment sludges. Soils/stones/aggregate/concrete constitute 65% of the total non-hazardous waste reported, while metal and biological wastewater treatment sludges constitute 9% and 4%, respectively. The focus on control of emissions to land and water, and soil remediation is evident in the fact that sludges from wastewater treatment and oil-impacted soil/stone/aggregate/concrete wastes together account for 53% of total reported hazardous waste.

The total reported waste tonnage in 2013 is split across seven different waste management option groups, with recycling accounting for the largest proportion (34%) followed by waste going to landfill (20%). This is in contrast to the 1993 survey, which found that landfill accounted for 40% and recycling 21%. In parallel, the percentage of waste used for energy recovery has reduced from 15% in 1993 to 7% in 2013, while the percentage of waste disposed of by incineration has reduced slightly from 8% to 6%. The main waste management option in 2013 for hazardous waste was treatment (24%), with the remaining tonnage split fairly evenly across the other management options. For non-hazardous waste, recycling was the dominant management option (49%), followed by landfill (29%).

Approximately 75% of the total hazardous or non-hazardous waste, and therefore, the majority of the waste classifications used in the industry are accounted for by the top 10 waste classification codes reported. Of the waste classified under these top 10 codes, the vast majority was disposed of in their country of origin and none was exported outside of the European community. With the exception of asbestos (hazardous waste landfill), there were no instances of codes for special types of waste being restricted to a single waste management option.

The median cost of all hazardous waste management (316 $/tonne) is similar to the median country group cost for Baltic, Benelux and France. In Central Europe and

Iberia the median cost is lower, at 63 $/tonne and 85 $/tonne, respectively, whereas in Germany, Mediterranean and UK & Ireland the median cost is closer to 500 $/tonne. The median cost of all non-hazardous waste management (83 $/tonne) is similar to the median country group cost for Baltic, Central Europe and Iberia. In Benelux and Germany the median cost is lower at 20 $/tonne, whereas in France, Mediterranean and UK & Ireland the median cost is closer to 200 $/tonne.

There is regional variation in waste management options for major waste types. This is observed, for example, when it comes to waste management of sludges. Landfill is an important management option for hazardous sludges in the Mediterranean, and for non-hazardous sludges in the Mediterranean and Iberia. Incineration and energy recovery are widely used for both hazardous and non-hazardous sludges. An important waste management option for non-hazardous sludges in Germany and UK & Ireland is use for land improvement. A significant fraction of hazardous sludges in the Baltic, Benelux and Germany areas are disposed of by recycling (possibly used as feedstock for coking units). While the data gathered in this study does not provide insight into the reasons behind such differences, possible explanations for the variation include differences in the interpretation of waste legislation across the EU Member States, and that more than one waste classification code can be used for a certain types of waste.

Legislative changes and associated changes in waste reporting practices mean that the 1993 and 2013 data on refinery waste tonnage and handling costs are not directly comparable. For example, the apparent increase in total waste tonnage from 1993 to 2013 may well reflect more systematic waste classification and reporting under the 2008 Waste Framework Directive. The total cost of refinery waste management appears to have significantly increased, from an inflation-adjusted figure of approximately 80 M$ in 1986 (for 89 refineries), to 137.2 M$ in 2013 (for 74 refineries).

1. INTRODUCTION

Ongoing developments in European waste management policy (e.g. 2016 revision of Waste Framework Directive (WsFD, 2008/98/EC)[1] and the circular economy initiative), have the potential to significantly impact refinery waste management practices and costs. In order to better understand the possible consequences of policy change, Concawe has compiled an inventory of waste production and management at member company refineries.

Concawe has carried out surveys of waste production at member company refineries in 1986, 1993, and most recently in 2013. The number of respondents has fluctuated over the years, but has generally exceeded 70%. The 2013 survey questionnaire was distributed to all 104 refineries operated by Concawe member companies, with the response rate being 71%.

The objectives of the latest Concawe waste survey, which was completed in 2015 for refinery operations in 2013, were as follows:

i. To provide initial baseline data on European refinery waste classification and management under the WsFD (2008/98/EC), the previous Concawe waste survey having been completed prior to the implementation of this directive (in 1993).

ii. To develop an improved understanding of regional differences in waste classification and management, and also exemptions for ‘by-products’.

iii. To demonstrate changes over time in refinery waste production and management practices

iv. To provide information that could be relevant concerning adoption of the Classification, Labelling and Packaging (CLP) criteria to waste classification

v. To examine the consistency of application of the List of Waste classification (often referred to as the European Waste Catalogue or EWC) codes assigned to refinery wastes

vi. To understand whether waste classification varies between National Regulatory Authorities, potentially leading to a non-'level playing field' for resource management

While objectives iv, v and vi were addressed by the data collection exercise, the associated data analysis and reporting requires additional time and resources, and so is not included in this report.

Data was also collected on the production of non-waste by-products, however the quantity of data returned was not sufficient to perform a sector-relevant analysis.

This report shows the findings from the 2013 waste inventory, which includes a statistical analysis of waste production, handling costs, management options and the tonnages reported under different List of Waste (EWC) codes (Annex of Commission

[1] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

Decision 2000/532/EC[2], as amended by Decisions 2001/118/EC[3]; 2001/119/EC[4] and 2001/573/EC[5]) and Waste Hazard codes (Annex III of Directive 2008/98/EC).

The findings from the 2013 survey, together with those of previous Concawe waste surveys for 1993 (Concawe; 1-95) and 1986 (Concawe; 5-89) provide insight into how waste generation and management has changed in Europe over the past 30 years.

Note: The data presented in this report has been compiled through the best endeavours of Concawe member companies, and has been checked for consistency and outliers. Notwithstanding the above, complete checking of the data returns is not possible and so for this reason, the data presented should be considered indicative rather than absolute.

1.1. WASTE HAZARD PROPERTIES AND CODES.

Properties of waste which render it hazardous are listed in Annex III to the Waste Framework Directive (2008/98/EC). Each hazardous property (e.g. "flammable", "toxic", etc.) is assigned a unique individual code.

This report references the Waste Hazard codes (H1 to H15) assigned according to the legislation in place at the time that the data collected for this report was generated (2013). Since then, Commission Regulation (EU) 1357/2014[6] replaced Annex III to the WsFD with an updated list of waste hazardous properties and a new coding structure (HP1 to HP15). The replacement of Annex III to Directive 2008/98/EC changed the basis for waste hazard classification from the use of risk phrases and associated substance threshold concentrations specified in the EU Dangerous Substances Directive (67/548/EEC)[7] and Dangerous Preparations Directive (1999/45/EC)[8] to the use of hazard statements and associated substance concentrations specified in the EU CLP Regulation (EC 1272/2008)[9]. This has resulted in changes to definitions and to substance concentration thresholds for some waste hazardous properties and as such it is important to note that direct translation

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[2] 2000/532/EC: Commission Decision of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste

[3] 2001/118/EC: Commission Decision of 16 January 2001 amending Decision 2000/532/EC as regards the list of wastes

[4] 2001/119/EC: Commission Decision of 22 January 2001 amending Decision 2000/532/EC replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste

[5] 2001/573/EC: Council Decision of 23 July 2001 amending Commission Decision 2000/532/EC as regards the list of wastes

[6] COMMISSION REGULATION (EU) No 1357/2014 of 18 December 2014 replacing Annex III to Directive 2008/98/EC of the European Parliament and of the Council on waste and repealing certain Directives

[7] Council Directive 67/548/EEC of 27 June 1967 on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances

[8] Directive 1999/45/EC of the European Parliament and of the Council of 31 May 1999 concerning the approximation of the laws, regulations and administrative provisions of the Member States relating to the classification, packaging and labelling of dangerous preparations

[9] REGULATION (EC) No 1272/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006

between the old and new waste hazard coding is not possible for a number of waste hazard properties.

2. DESIGN OF 2013 SURVEY QUESTIONNAIRE

The 2013 survey, which was issued in June 2014 in MS Excel spreadsheet format, comprised three data input worksheets, as follows:

- Identification and contact
- Information on Wastes
- Information on Non-wastes

The blank 2013 survey questionnaire template is provided in **Appendix 1**.

2.1. IDENTIFICATION AND CONTACT

Under "Information and contact" the following site details were collected: Company name, Refinery name and location, Ownership, Contact name, Contact details, JV-partners, and Type of site.

The type of site was entered by selection from a dropdown box, with the options being as follows:

- Refinery, Refinery and crude oil terminal, Bitumen plant, Lubricant plant, Combined refinery and chemical plant, and Other (as specified)

Data on refinery capacity and feedstock throughput was collected via a parallel 2013 Concawe survey questionnaire on refinery effluent quality and water consumption, which was also issued in June 2014. When no data on capacity and throughput was provided, the nameplate capacity of the installation and/or a statistical evaluation based upon the sector's 2013 performance and earlier data submission for the installation were used to estimate a throughput.

2.2. WASTES

Respondents were requested to provide data on all refinery wastes[10], whether produced directly by the reporting member company or by contractors undertaking work on their behalf. The "Waste" worksheet comprised a single table for the entry of data on refinery hazardous and non-hazardous waste production and management, with the following column headings:

- Waste Classification (EWC) Code (entered by user)
- Waste Type (selected from a dropdown list, as shown in **Table 1**)
- Waste Source (selected from dropdown list, as shown in **Table 2**)
- Waste Producer (to indicate if waste produced by refinery or a contractor)
- Total amount of waste produced (entered by user, units of tonnes)
- Final Recovery or Disposal route (selected from dropdown list, as shown in **Table 3**)

[10] Data was also collected on the production of non-waste by products, however the quantity of data returned was not sufficient to perform a sector-relevant analysis

- Location of Final Recovery or Disposal (two options: Exported within European Community (including NO & CH); Exported outside the European Community)
- Waste Hazard codes ("x" entered by user under applicable listed H codes H1 to H15)
- Additional Comments

It was requested that separate rows of data should be entered for each unique combination of waste classification (EWC) code / waste type / waste source / waste management option (final recovery or disposal route) and location (of final recovery or disposal). EWC codes reflecting hazardous waste types are indicated with an asterisk (*).

In addition to the waste-type specific information listed above, refineries were asked to provide the total cost (in M$) of hazardous and, separately, non-hazardous waste management in 2013[11].

Table 1: List of waste types included in survey template

Waste Type
Air Pollutant Control wastes (FGD, carbon filters etc)
Absorbents / Dessicants / Ion Exchange
Catalysts - FCC
Catalysts - Hydrotreating/hydrodesulphurisation
Catalysts - Other, please specify (e.g polymerisation, residue conversion etc)
Catalyst bed support
Domestic trash - mixed
General plant trash - mixed
Packaging (if collected separately from general trash)
Oily solids (e.g debris, rags)
Bituminous wastes
Tars
Metal
Insulation / refectory / asbestos
Acids / bases
Aqueous wastes
Organic solvents
Filter cakes
Waste Oils
Sludges - Alkylation
Sludges - Boiler feed water
Sludges - Desalter
Sludges - Tank bottom
Sludges - Interceptor (API type, CPI type, etc.)
Sludges - Wastewater Physical/Chemical Treatment (DAF, IAF, etc)

[11] Refineries were requested to list the activities included in the cost total (e.g. waste disposal, waste transport, waste related taxes, etc.). However only 32 % of sites returned this data and the categories reported were not consistent. It was therefore decided that the data did not merit statistical analysis.

Waste Type
Sludges - Wastewater Biological Treatment
Sludges - Domestic sewage treatment
Sludges - Other, please specify
Soil / stones / aggregate / concrete
Spent Chemicals
Vegetation
Waste Electrical & Electronic Equipment (WEEE)
Wastes from external cleaning of equipment (e.g shot blast)
Wastes from internal cleaning of equipment (e.g scale)
Other wastes not covered above - please specify

Table 2: List of waste sources included in survey template

Waste Source
Refinery operations
Major event (e.g Turnaround)
Remediation
Split by source not available
Other - please specify

Table 3: List of waste management options included in survey template

Generic Final Recovery or Disposal route
R1 - Energy recovery
R2/6 - Regeneration
R3/4/5 - Recycle / reclaim
R7/8 - Recovery of components
R9 - Reuse
R10 - Agriculture/ecological benefit
D1/5 - Landfill
D2 - Land Treatment
D3 - Deep injection
D8 - Biological Treatment
D9 - Physico-chemical treatment
D10 - Incineration on Land
D12 - Permanent storage
Multiple Recovery methods - please specify
Multiple Disposal routes - please specify
Mixture of any/all methods - please specify
Other - please specify

3. ANALYSIS OF SURVEY DATA

The statistical analysis of data captured by the 2013 refinery waste survey was performed by Newfields Consultants (US). Data provided in the survey questionnaires was first extracted into a MS Access database and then structured to facilitate quality assurance checks and data analysis. The data was analysed to provide insight into:

- Variation in production and management practices for hazardous and non-hazardous refinery wastes (as defined by EWC codes) across different European regions (as defined by country groups).
- Variation in total hazardous and non-hazardous waste management costs across different European regions.
- Any regional variation in the classification of refinery waste types and application of EWC codes and Waste Hazard codes.
- Whether waste/non-waste classification varies between National Regulatory Authorities, potentially leading to a non-'level playing field' for resource management.

In this report hazardous waste is defined as waste reported with a waste classification code containing an "*", and/or waste reported with a hazard code (H1 to H15 at time of survey in 2013). Note that following data quality assurance checks, some wastes reported as non-hazardous were reclassified as hazardous, and vice versa (see Section 3.1 below).

For the purpose of analysing the survey data, waste management options were grouped as shown in **Table 4**. Groups were established to reflect, where possible, the waste hierarchy (c.f. **Figure 11**). Note that for two groups the final waste management option in the hierarchy is not clear, e.g. "Multiple Disposal/Recovery methods" and "Treatment". This is discussed further in the Opportunities for Improvement (Section 11).

Table 4: Waste management options grouping

Waste management options group	Waste management option(s) included in group
Incineration	D10 - Incineration on land
Landfill	D1/D5 - Landfill D4 - Surface impoundment D12 - Permanent storage D15* - Storage pending any further operations (numbered D1 to D14)
Multiple Disposal/Other	D14* - Repackaging prior to submission to any further operations (numbered D1 to D13) Other - please specify Multiple Disposal/Recovery methods - please specify
Recovery-Energy	R1 - Energy Recovery
Recovery-Other	R2/R6 - Regeneration R6 - Regeneration of acids or bases R7/R8 - Recovery of components R10 - Agriculture/ecological benefit R11 - Uses of waste obtained from any of the operations numbered R1 to R10 R12** - Exchange of waste for submission to any of the operations numbered R1 to R11 R13** - Storage prior to recovery
Recycling	R3/R4/R5 - Recycle/reclaim R9 - Reuse
Treatment	D2 - Land Treatment D8* - Biological Treatment D9* - Physico-chemical treatment D13* - Blending or mixing prior to submission to any of the operations numbered D1 to D12
Not Specified	Null Missing

*These codes (i.e. D8, D9, D13, D14, D15) refer to pre-treatment operations, which must be followed by one of the other disposal operations
** These codes (i.e. R12, R13) refer to pre-treatment operations, which must be followed by one of the other recovery operations

3.1. DATA QUALITY CHECKS

A total of 77 questionnaires were received as a result of refinery sites with multiple operational facilities. Refineries that returned more than one questionnaire (showing different parts of the facility operation) were aggregated into one site for analysis. Refineries provided data for the operation year 2013 except for one refinery, which provided data for 2012.

The following Quality Assurance and Quality Control (QA/QC) checks and corrections were performed:

- Cost data were requested in US dollars. In some instances, survey responders provided cost data in their local currency. In these cases, cost data were converted to consistent units of US dollars. When converting from a different currency, the average historical conversion rate in 2013 was utilized[12]. Specific conversion rates used include: 1 Euro = 1.33 US Dollar and 1 PLN = 0.282 US Dollars.

- Outlier testing was performed using cost per tonne as a normalizing basis. Follow-up requests were sent to refineries to confirm or clarify outlier costs and/or quantities. When applicable, values were changed in the database based on responses. All changes were documented along with valid reasoning for each change and preservation of the original respondents' input.
- Based on respondent notes, some waste types were converted from "Other" to more descriptive categories. For example, some refineries commented that waste classified as "Other" was spent batteries which was subsequently changed to "Waste Electrical & Electronic Equipment (WEEE)."
- Some waste totals were provided as volumetric measures. These were converted to a consistent tonnage basis by using specific gravity or density values cited from on-line sources. Specific conversions included:
  - Number of fluorescent tubes to tonnes assuming each fluorescent tube was 269 g.[13]
  - Cubic meters of waste oils to tonnes assuming a specific gravity of 0.88 g/cm^3.[14]
  - Cubic meters of polystyrene to tonnes assuming a density of 1.04 g/cm^3.[15]
  - Cubic meters of waste water to tonnes assuming a density of 1 g/cm^3.
- Concerning reported Waste Classification codes:
  - Consistent formatting was applied. Leading zeros were added to maintain the 6-digit format of the codes.
  - An asterisk "*" (indicating a hazardous waste) was added to codes associated with hazardous waste types, where it was clear that this had been accidentally omitted.
  - In some instances, when filling in the questionnaire, responders inadvertently added an asterisk "*" to codes reserved for non-hazardous wastes. If the waste stream indicated hazardous material via the notes or hazardous code listing then the code was adjusted to the appropriate hazardous code. If the waste stream did not indicate any hazardous material, then the asterisk was removed from the reported code.
  - If a reported code did not match with an actual existing code then, where possible, the correct code was chosen based on the waste stream type and additional notes or information provided by the refinery. If the correct code could not be determined the data was excluded from the analysis.

All data changes resulting in the QA/QC procedure were fully documented in the database.

3.2. DEFINITION OF COUNTRY GROUPS

To ensure anonymity and prevent the identification of individual companies or installations regional country groupings were established, with a large enough

[12] The historical conversion rates for each currency to US dollars were obtained from the following on-line resource: http://www.usforex.com/forex-tools/historical-rate-tools/historical-exchange-rates

[13]Source:http://www.lampspecs.co.uk/Light-Bulbs-Tubes/835-White_4/6-Foot-70-Watt-835-White-Philips

[14]Source:http://www.engineeringtoolbox.com/specific-gravity-liquids-d_336.html, and http://www.csgnetwork.com/specific_gravity_viscosity_liquids.html. As "waste oils" could be a mixture of different oil types, the value 0.88 was used as an estimate.

[15] Source: https://en.wikipedia.org/wiki/Polystyrene

geographic scope such that each group contained at least 5 refineries. **Figure 1** shows the geographic extent of these country groups and **Table 5** the number of refinery respondents in each country group together with their total reported feedstock throughput.

Figure 1: Geographic extent of country groupings

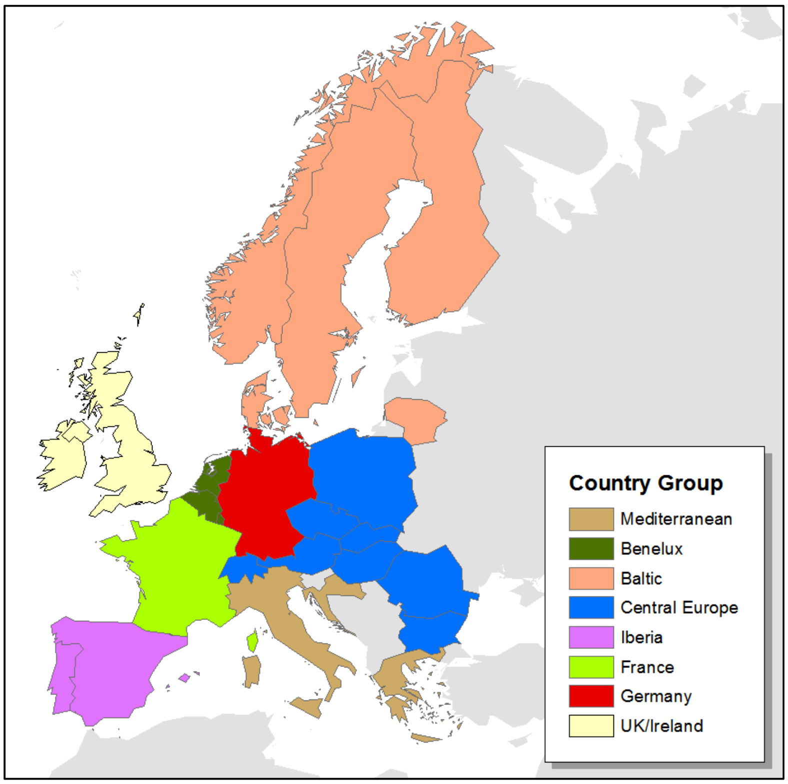


Table 5: Summary of refinery waste respondents in 2013

Country Group	Number Refinery Respondents	Total Feedstock Throughput Reported (Tonne/year)
Baltic	9	49,611,647
Benelux	7	56,078,341
Central Europe	12	58,529,163
France	9	57,921,613
Germany	10	64,334,690
Iberia	10	69,544,241
Mediterranean	12	62,546,542
UK and Ireland	5	41,225,726
TOTAL	**74**	**459,791,963**

Regional differences in the production of hazardous and non-hazardous wastes from major events (e.g. turnarounds, refinery operations, remediation and other sources) were investigated by plotting the tonnages of different waste types aggregated by country group, in accordance with the data analysis structure shown in **Figure 2** below. Plots were also produced showing waste management options for the top 10 hazardous and non-hazardous waste types by total tonnage (see **Appendix 2**).

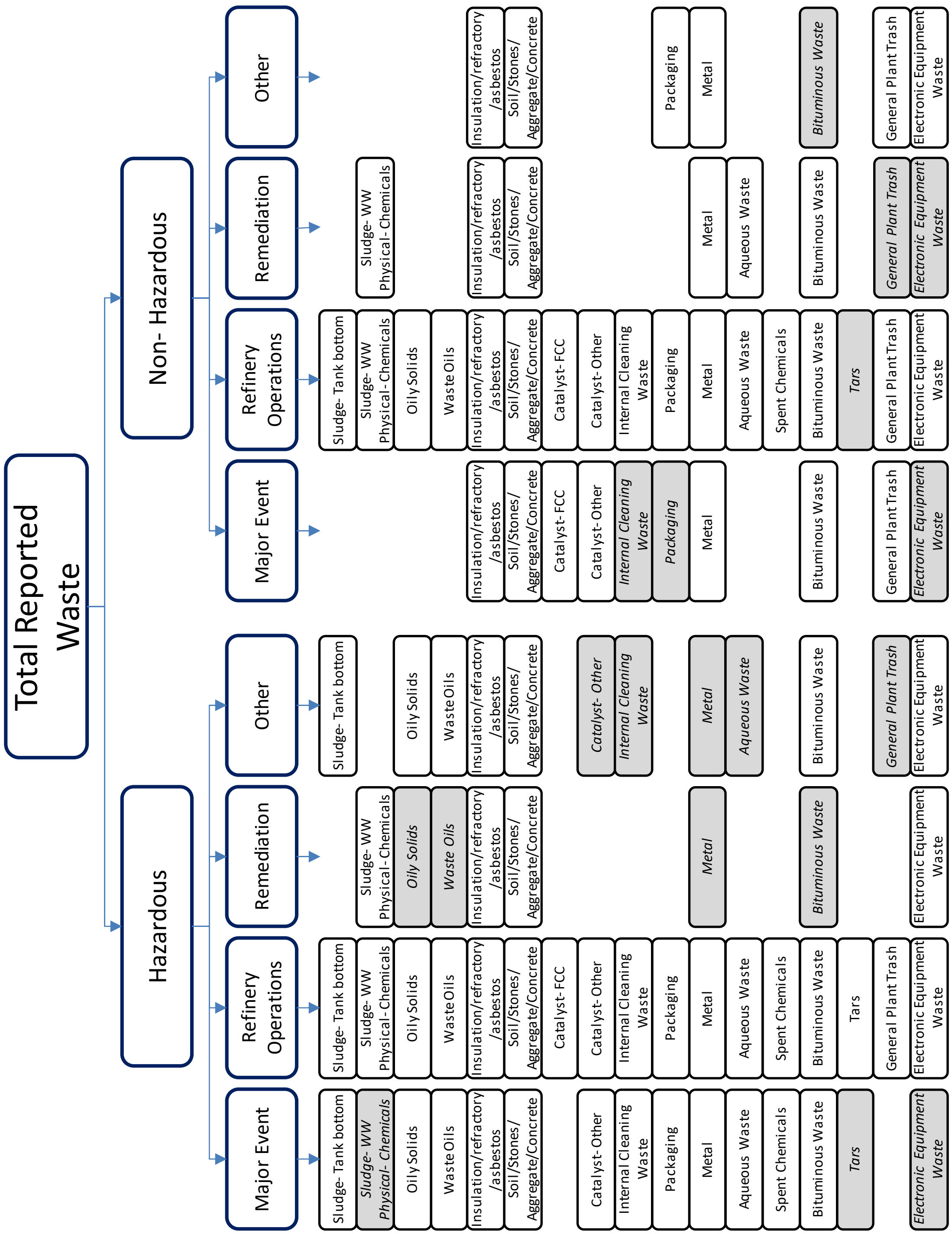
Note**:** Where no tonnage was reported for certain waste category/ waste source/ waste type combinations, the corresponding box on the flowchart (**Figure 2**) has been removed and no plot is provided in **Appendix 2**.

Note**:** Waste category/ waste source/ waste type combinations represented by only 1 tonnage record are shaded light grey in **Figure 2**, with the writing in italics.

3.3. DATA AGGREGATION

Waste data is presented both in terms of total waste tonnage (reflecting the environmental burden) and also tonnes per kilotonne of feedstock throughput (as a measure of efficiency). Where relative waste production data has been aggregated, data from individual refineries has been weighted according to their feedstock throughput.

Figure 2: Tiered organizational structure of waste charts analysed



4. WASTE QUANTITIES AND SOURCES

Of the 77 survey questionnaires returned, all included data on non-hazardous waste tonnage and 71 included data on hazardous waste tonnage. A total of 68 refineries provided tonnage data for both hazardous and non-hazardous waste (three questionnaires were not taken into account in the number of total refineries, since for two refineries sub-facilities reported independently; in the first case three sub-facilities were merged into one refinery and in the second case two sub-facilities were merged into one refinery).

4.1. WASTE PRODUCTION (TONNES)

Total reported waste production by the sector in 2013 was 1.2 million tonnes, of which 43% was classified as hazardous (**Figure 3**). Reported waste production across the country groups was broadly similar, although the ratio of hazardous to non-hazardous waste was somewhat lower for the country groups Benelux, UK & Ireland and Central Europe. Various factors may account for this, for example regional differences in how waste legislation is implemented. Future surveys may show if this is a meaningful trend that merits further analysis.

Figure 3: Total hazardous and non-hazardous waste partitioned by country grouping

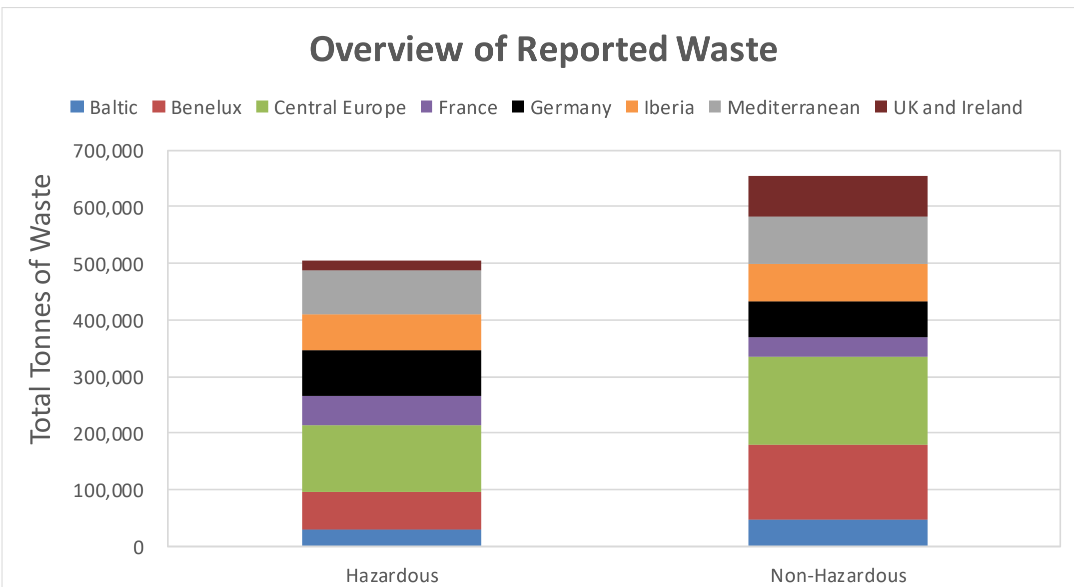
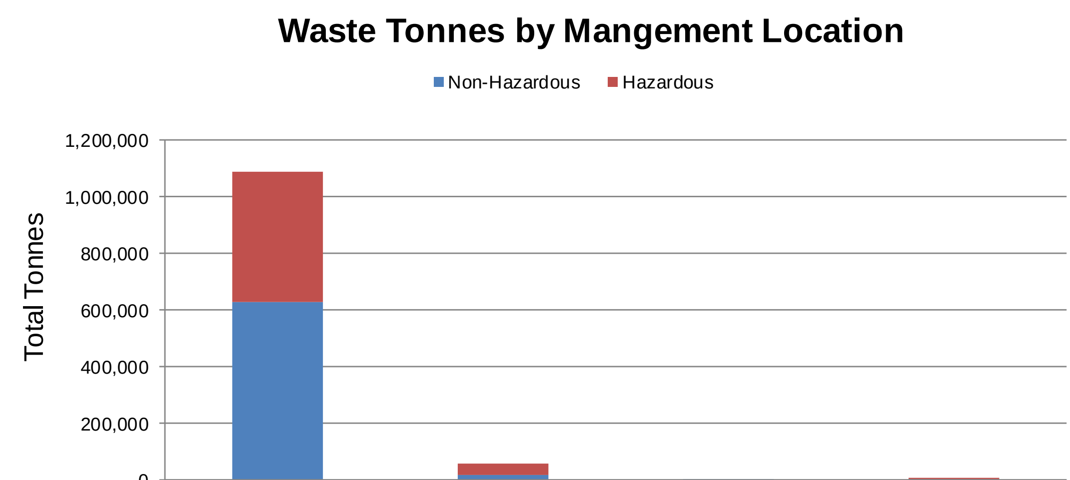


Figure 4 shows the final waste management location of wastes, whether disposed in country, exported within the European community, or exported outside of the EU. The vast majority (94%) of refinery wastes were disposed of within the country of origin. The only waste exported outside the EU was non- hazardous spent catalyst.

Figure 4: Tonnages of hazardous and non-hazardous waste managed within country of origin or exported



	Within country	Exported within European Community	Exported outside the European Community	Not reported
Hazardous	462,812	42,725		7
Non-Hazardous	628,206	18,993	5,146	2,208

Figures 5 and **6** show total hazardous and non-hazardous waste segregated by source and country group. Waste derived from refinery operations accounts for a higher proportion of hazardous waste (59% vs 43% for total waste), whereas other waste sources are associated with a higher proportion of non-hazardous waste.

Figure 5: Total hazardous waste separated by source partitioned by country grouping

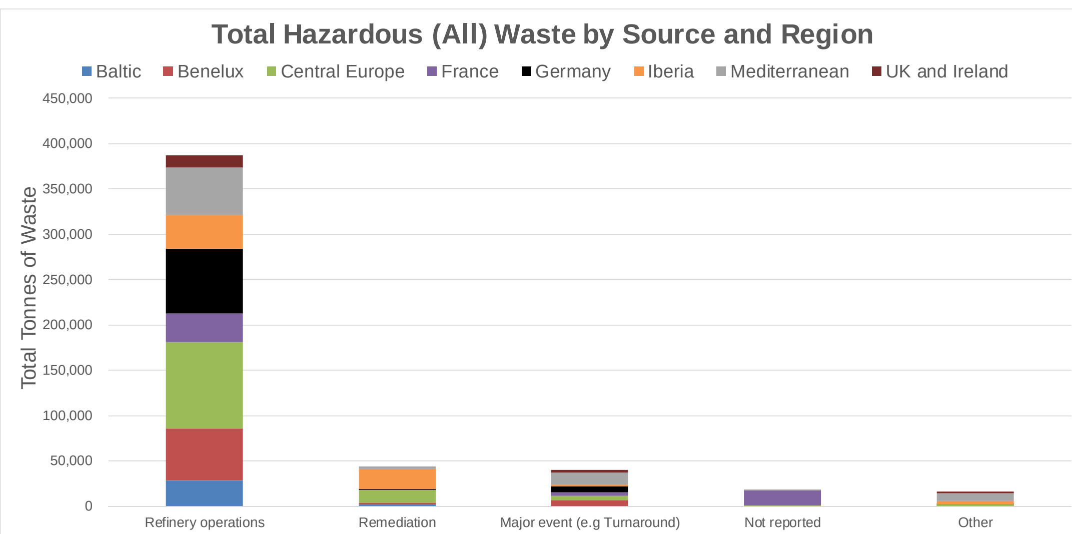
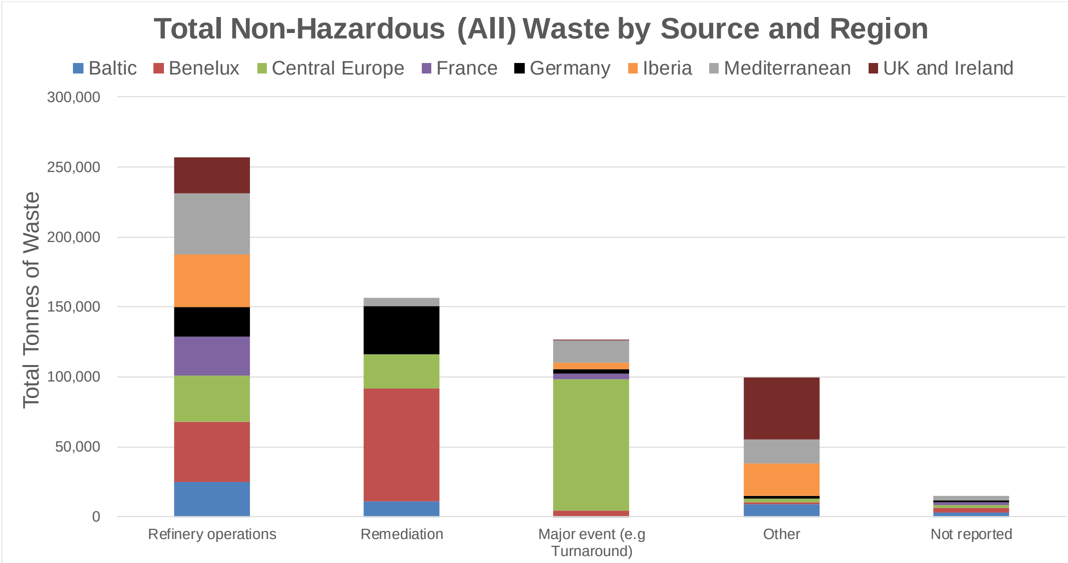


Figure 6: Total Non-Hazardous Waste separated by source partitioned by country grouping



Based on the reported Waste Classification (EWC) codes, non-hazardous waste production in Central Europe was dominated by dredging spoil and soils/stones, which accounted for 81,000 tonnes (52%) of the total. Waste reported from "Other" sources is primarily soil and construction waste from investment projects or reconstruction works, as shown in **Table 6**. The "Other" category was chosen to reflect that these wastes are from civil engineering projects (e.g. railway renovation), and not remediation or turnaround events[16].

[16] The "Other" waste source category contains some EWCs that may belong to a more specific category. For example, in some questionnaires EWC 050103* (Tank bottom sludges) are reported under "Other", however sludges can usually only be extracted after emptying the tank. This being the case, it may be that these would be better reported under the "Major events (e.g. Turnaround)" category. Similarly, EWC 100101 (bottom fly ash and dust) and 100105 (calcium-based reaction from FGD system) may be better reported under the "Refinery operation" category.

Table 6: Top five EWC codes composing the “Other” waste source category

Waste Category	EWC Code	EWC Code Description	Total Tonnes Waste
Hazardous	170503*	Soil and stones containing dangerous substances	8187
	170903*	Other construction and demolition wastes (including mixed wastes) containing dangerous substances	4071
	050103*	Tank bottom sludges	1942
	100101	Bottom ash, slag and boiler dust (excluding boiler dust mentioned in 100104)	577
	130401*	Bilge oils from inland navigation	274
Non-Hazardous	170504	Soil and stones other than those mentioned in 170503	78804
	170101	Concrete	10918
	170904	Mixed construction and demolition wastes other than those mentioned in 170901, 170902 and 170903	3854
	170405	Iron and steel	1646
	100105	Calcium-based reaction wastes from flue-gas desulphurisation in solid form	987

4.2. RELATIVE WASTE PRODUCTION (TONNES/ KTONNE FEEDSTOCK THROUGHPUT)

The effect of normalising hazardous and non-hazardous waste production to refinery feedstock throughput is shown on **Figures 7** and **8**. While the degree of variation in relative waste production is less than that in total waste tonnage, significant differences remain between the country groups. For hazardous wastes the range in relative waste production across the country groups is 0.44 to 1.99 tonnes/ kilotonne feedstock throughput, with a sector average of 1.07 tonnes/ kilotonne feedstock throughput. For non-hazardous wastes the range in relative waste production across the country groups is 0.59 to 2.66 tonnes/ kilotonne feedstock throughput, with a sector average of 1.45 tonnes/ kilotonne feedstock throughput.

It is important to note that because the survey is a snapshot in time, waste totals for certain country groups may be dominated by large one-off projects. This is especially the case for wastes associated with construction, demolition and remediation. For this reason, differences in relative waste production between country groups do not reflect differences in overall waste management efficiency. For example, at the high end of the range for relative non-hazardous waste production is Benelux, which reported 96000 tonnes of non-hazardous soil/stone/rock wastes from remediation and refinery operations (>50% of total reported waste for the Benelux country group).

Figure 7: Relative hazardous and non-hazardous waste per country grouping. Total number of refineries reported per country grouping are also provided (68 refineries provided tonnage data for hazardous waste and 74 for non-hazardous waste).

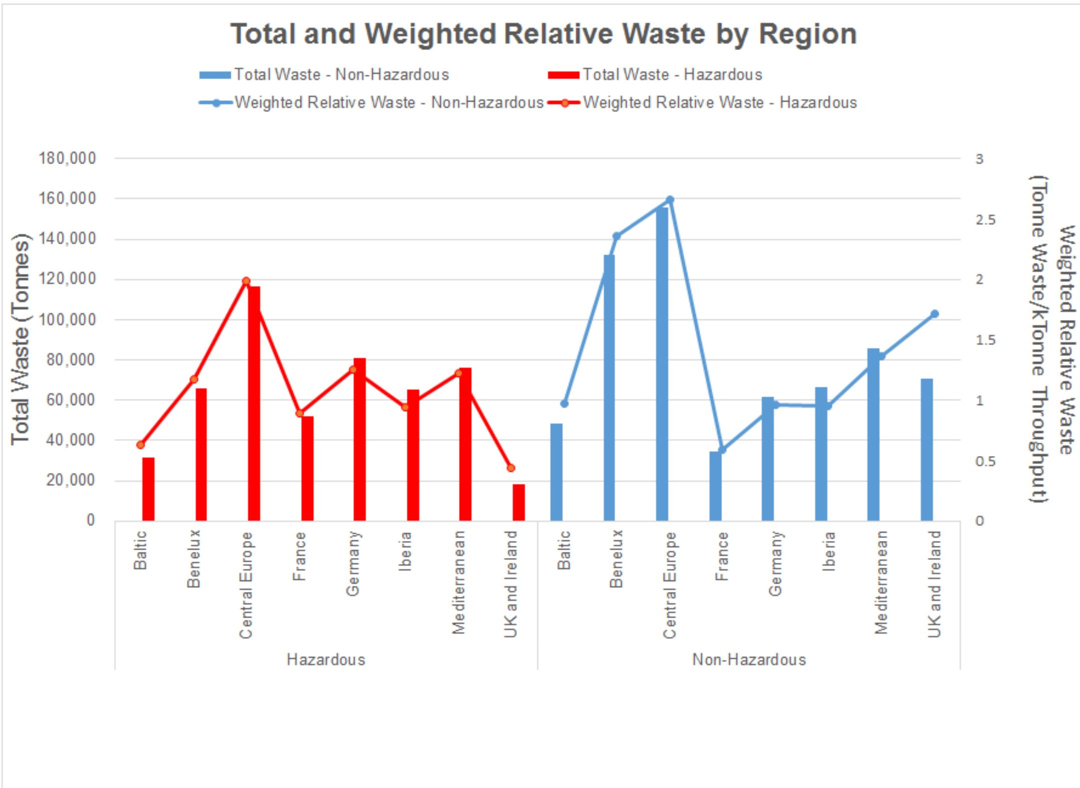


Figure 8: Relative weighted average hazardous and non-hazardous waste by region and source

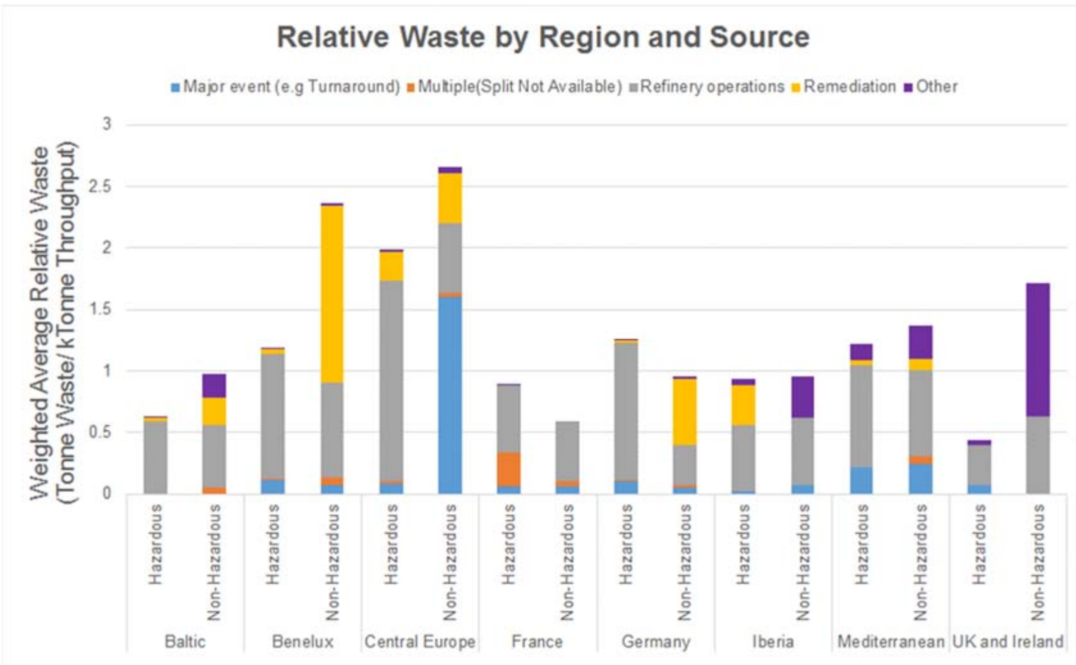


Figure 9 shows that the top 10 hazardous waste types account for 83% of both total and relative waste production. **Figure 10** shows the same for the top 10 non-hazardous wastes, however for non-hazardous wastes the top 10 waste types account for 91% of both total and relative waste production. Wastes on the left-hand side of the plots are most important in terms of mass produced and therefore potential candidates for further research into waste reduction.

The top 3 reported hazardous wastes types are sludges (45%, comprising tank bottoms, physical/chemical treatment, biological treatment and other), followed by spent chemicals/acids/bases (14%) and then contaminated soil/stones/aggregate/ concrete (12%, with approximately 4% arising from remediation activities). The focus upon minimising emissions to water soil remediation is evident in the fact that sludges from wastewater treatment and oil-impacted soil/stone/aggregate/concrete wastes together account for 53% of total reported hazardous waste.

The top 3 non-hazardous wastes comprise soils/stones/aggregate/concrete (65%) from construction and demolition activities and remediation, followed by metal (9%) from major events, demolition and ongoing maintenance, and biological wastewater treatment sludges (4%).

Figure 9: Pareto chart of top ten waste types and their sources. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput

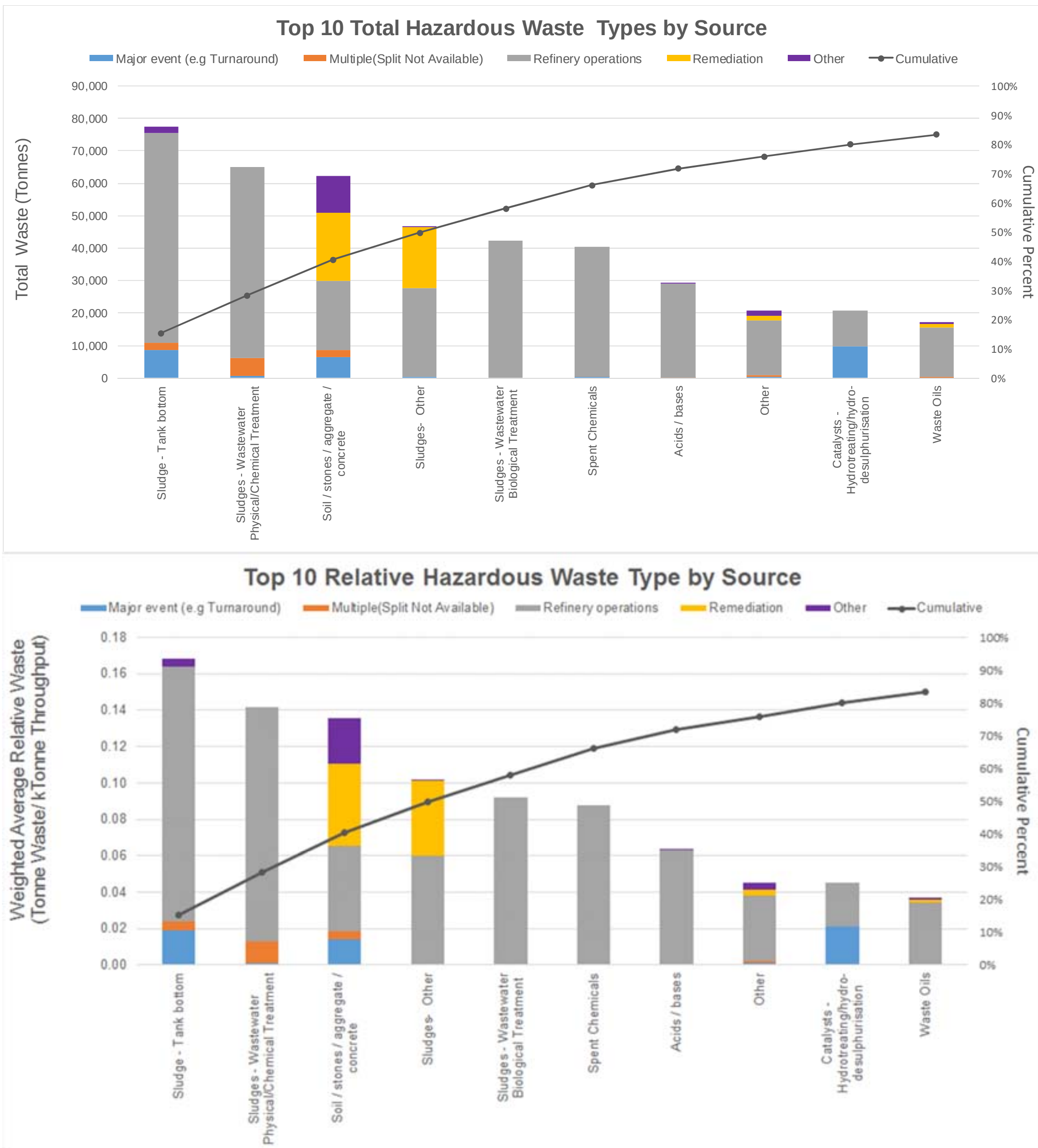
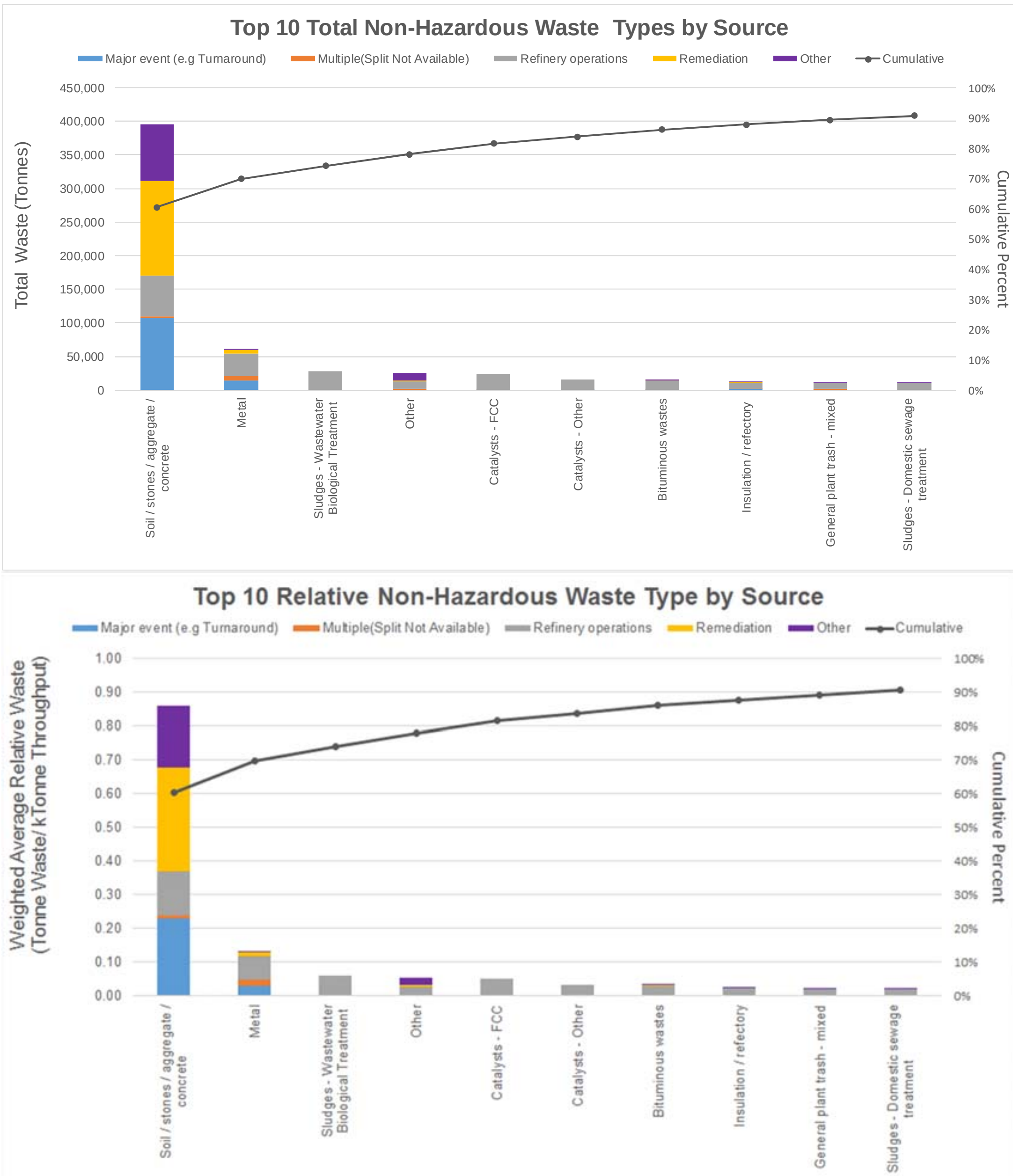


Figure 10: Pareto chart of top ten waste types and their sources. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput

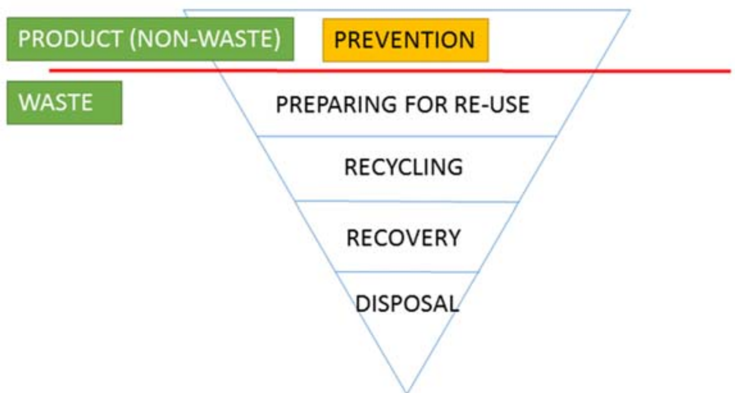


5. WASTE MANGEMENT

5.1. WASTE HIERARCHY

The Waste Framework Directive (2008/98/EC) sets out a waste hierarchy, or priority order of what constitutes the best overall environmental option in waste legislation and policy. This hierarchy is illustrated in **Figure 11** below.

Figure 11: EU waste hierarchy



A key objective of the EU legislation is that member states implement measures to encourage waste producers to move waste streams up the waste hierarchy, such that the percentage prevented, re-used or recycled is increased. In the analysis of the 2013 waste data the reported waste management options have been grouped to reflect this hierarchy, as shown in aforementioned **Table 4**. The groupings also permit comparison with the 1993 waste survey, which used a similar (though not identical) grouping.

5.2. MANAGEMENT OPTIONS FOR HAZARDOUS AND NON-HAZARDOUS WASTES

Figure 12 and **Table 7** show the tonnage and percentage of hazardous and non-hazardous wastes assigned to the management option groups. **Table 7** also shows the percentage of total waste assigned to these management option groups in the 1993 and 2013 surveys. It should be noted that accurate comparisons are not possible because slightly different method grouping were used in the 1993 and 2013 surveys. For example, waste management by "treatment", which accounted for 12% of total waste in 2013, was not an option in the 1993 survey. Also, the 1993 survey had the waste management options "alternate fuel use" and "landfarm", which accounted for 1.7% and 4.9%, respectively, in the 1993 survey. While acknowledging the difference in the 1993 vs 2013 waste management option groups, some observations can be made concerning apparent changes in waste management practices:

- Landfill use has reduced significantly, from 40% of total waste in 1993 to 20% in 2013. Even if all waste sent for treatment was assumed to be landfilled (and not composted or incinerated with/ without energy recovery) this still represents a significant reduction. In parallel, the percentage of waste recycled has increased from 21% to 34% over the same period, showing the progress made by the refining sector over the past 20 years towards moving waste management up the waste hierarchy.

- The percentage of waste used for energy recovery has reduced from 15% in 1993 to 7% in 2013, while the percentage of waste disposed of by incineration has reduced slightly from 8% to 6%. It should be noted, however, that these figures may be distorted if wastes sent for treatment are ultimately disposed of by another route, such as energy recovery. More detailed information would be required in future survey questionnaires to provide a breakdown of the final waste management options utilizes post 'treatment'.

For hazardous waste, the main management option in 2013 was treatment (24%), with the remaining tonnage split fairly evenly across the other management options. For non-hazardous waste recycling was the dominant management option (49%), followed by landfill (29%).

Figure 12: Hazardous and non-hazardous waste tonnage by management option

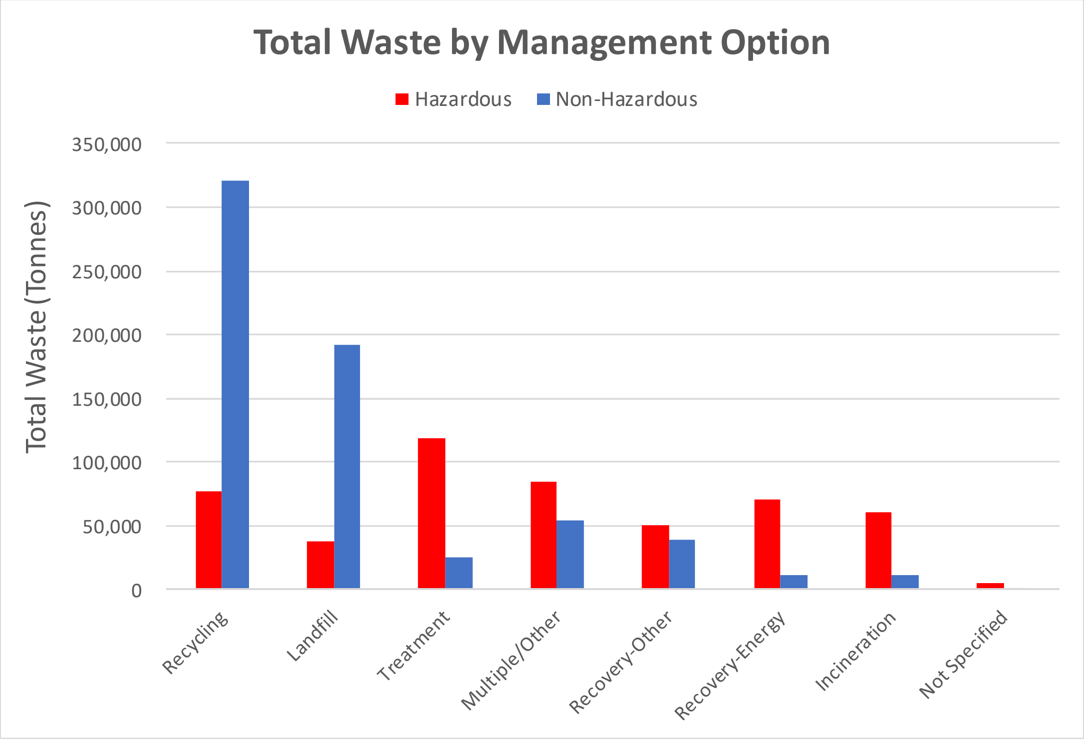


Table 7: Percentages of waste by management option and comparison to 1993 survey results

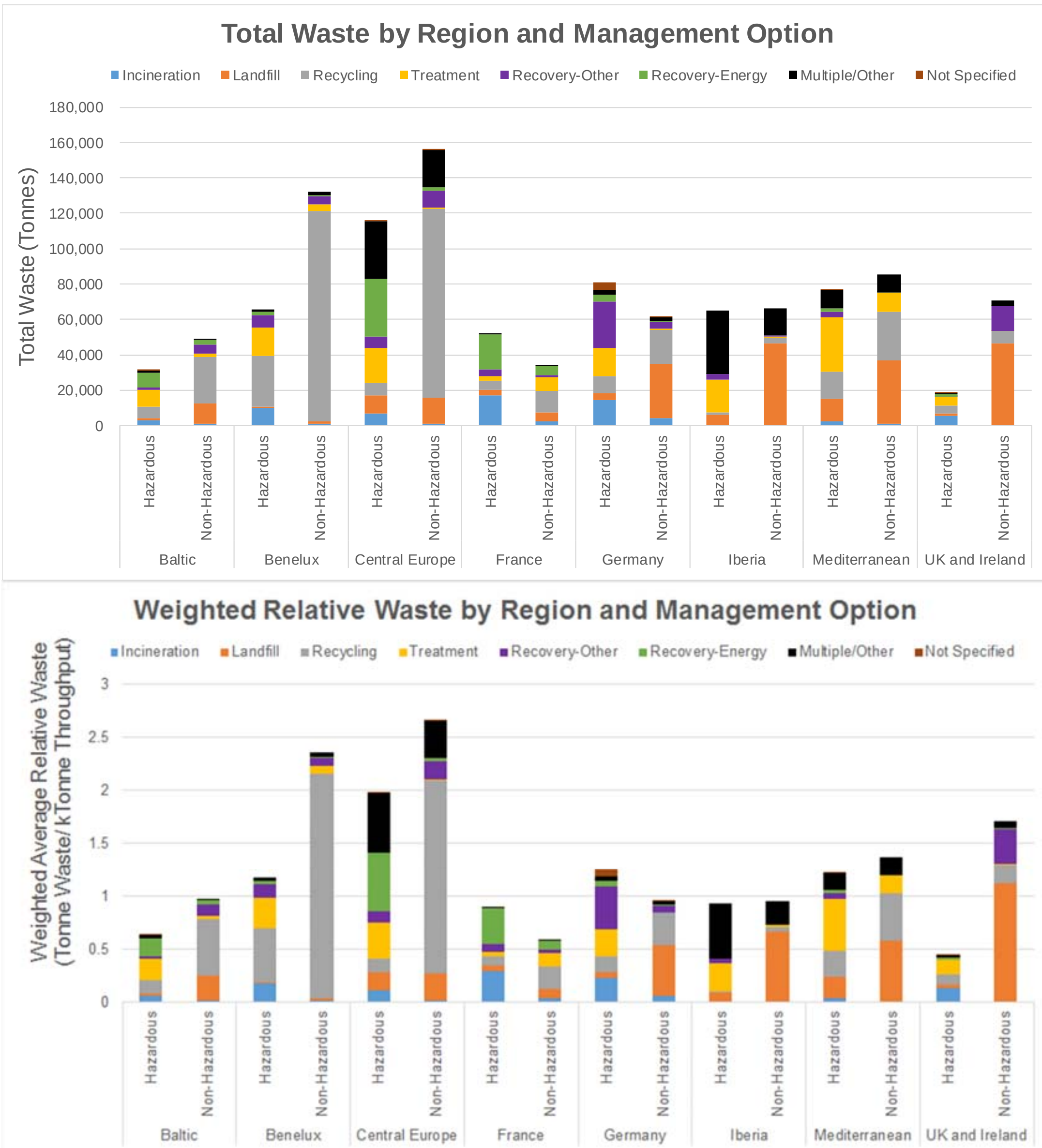
Waste management option group	Hazardous waste split (%) per management option (2013 data)	Non-hazardous waste split (%) per management option (2013 data)	Total waste split (%) per management option (2013 data)	Total waste split (%) per management option (1993 data)
Incineration	11.9	1.7	6.1	8.4
Landfill	7.6	29.3	19.9	39.9
Multiple/ Other	16.8	8.3	12.0	8.1
Recovery-Energy	13.9	1.7	7.0	14.9
Recovery-Other	10.1	5.9	7.7	1.7*
Recycling	15.3	49.1	34.4	21.4
Treatment	23.5	3.9	12.4	4.9**
Not Reported	0.9	0.0	0.4	0.6

* = % of "alternate fuel use" is given since the management option "recovery-other" did not exist in the 1993 survey.
** = % of "landfarm" is given since the management option "treatment" did not exist in the 1993 survey.

5.2.1. Geographic variation in hazardous and non-hazardous waste management options

Figure 13 shows that there are regional differences in the management option for major waste types, which could reflect the availability of waste management options and local policy differences. For example, landfill disposal is more important for non-hazardous waste in Iberia, Germany, Mediterranean and UK & Ireland country groups. Options to divert non-hazardous waste away from landfill require that additional recycling facilities are available locally to make this feasible. In France and Central Europe energy recovery is more utilised, but initiatives on raw materials could further promote this option.

Figure 13: Relative hazardous and non-hazardous waste management, split by management option and country group. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput



5.3. VARIATION IN WASTE MANAGEMENT OPTION ACCORDING TO WASTE TYPE

The reported management options for the top 10 waste types (in terms of tonnage) were analysed to establish the extent to which refineries may be reliant on particular management options. The results of this analysis for hazardous and non-hazardous wastes are shown in **Figures 14** and **15**.

Additional plots are provided in **Appendix 2** showing the management options for the top 10 hazardous and non- hazardous wastes types, split by country group. Note that the interpretation of this data is sometimes difficult due to the high tonnages reported under the ambiguous “treatment” and “multiple/ other” management options (e.g. hazardous tank bottom sludges, hazardous soil/ aggregate/ concrete, hazardous sludges (other) and also non- hazardous domestic sewage treatment sludges). Where this is not an issue, the plots in **Appendix 2** provide insight into the dominant waste management options per waste type.

5.3.1. Hazardous wastes

A number of management options are reported for the top 10 hazardous wastes, with energy recovery, multiple/other and treatment being the main management options and smaller tonnages sent for incineration or to landfill (**Figure 14**). The percentage sent to landfill exceeds 5% for only 2 out of the top 10 hazardous wastes, these being soils/stones/aggregate/concrete (20%; corresponding to 2.4% of total hazardous waste tonnage) and “other” (25%; corresponding to 1% of total hazardous waste tonnage).

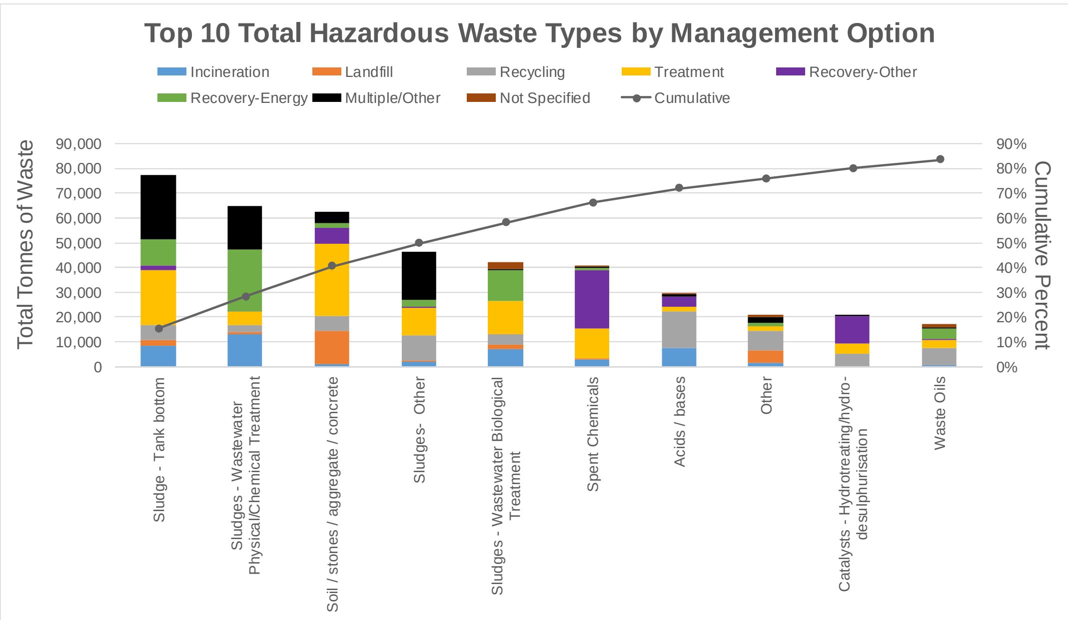
Recovery options dominate for materials where significant value can be realised such as catalysts, oils, acids, chemicals and higher calorific value sludges.

5.3.2. Non-hazardous wastes

The top 10 non-hazardous wastes are dominated by soils/stones/aggregate/concrete and metal, which together account for 69% of the total tonnage (**Figure 15**). 54% of soils/stones/aggregate/concrete waste was recycled, with 38% sent to landfill and 8% to multiple/other management options. Metal waste was either recycled (>95%) or sent for treatment (possibly prior to recycling).

With reference to Section 5.1.1, the single largest waste tonnage sent for landfill disposal, which could potentially move up the hierarchy, is non-hazardous soils/stones/aggregate/concrete. Additional work would be required, however, to better understand the opportunity for increased re-use of this material, taking into account legislative constraints and the infrastructure available in member states.

Figure 14: Pareto charts of top ten hazardous waste types and their management option. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput



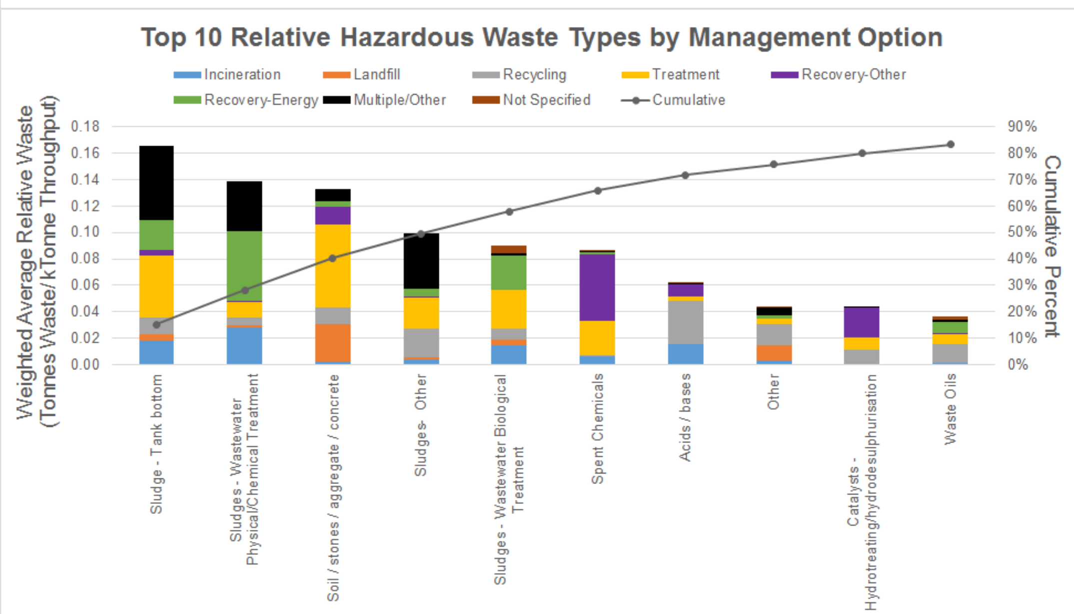
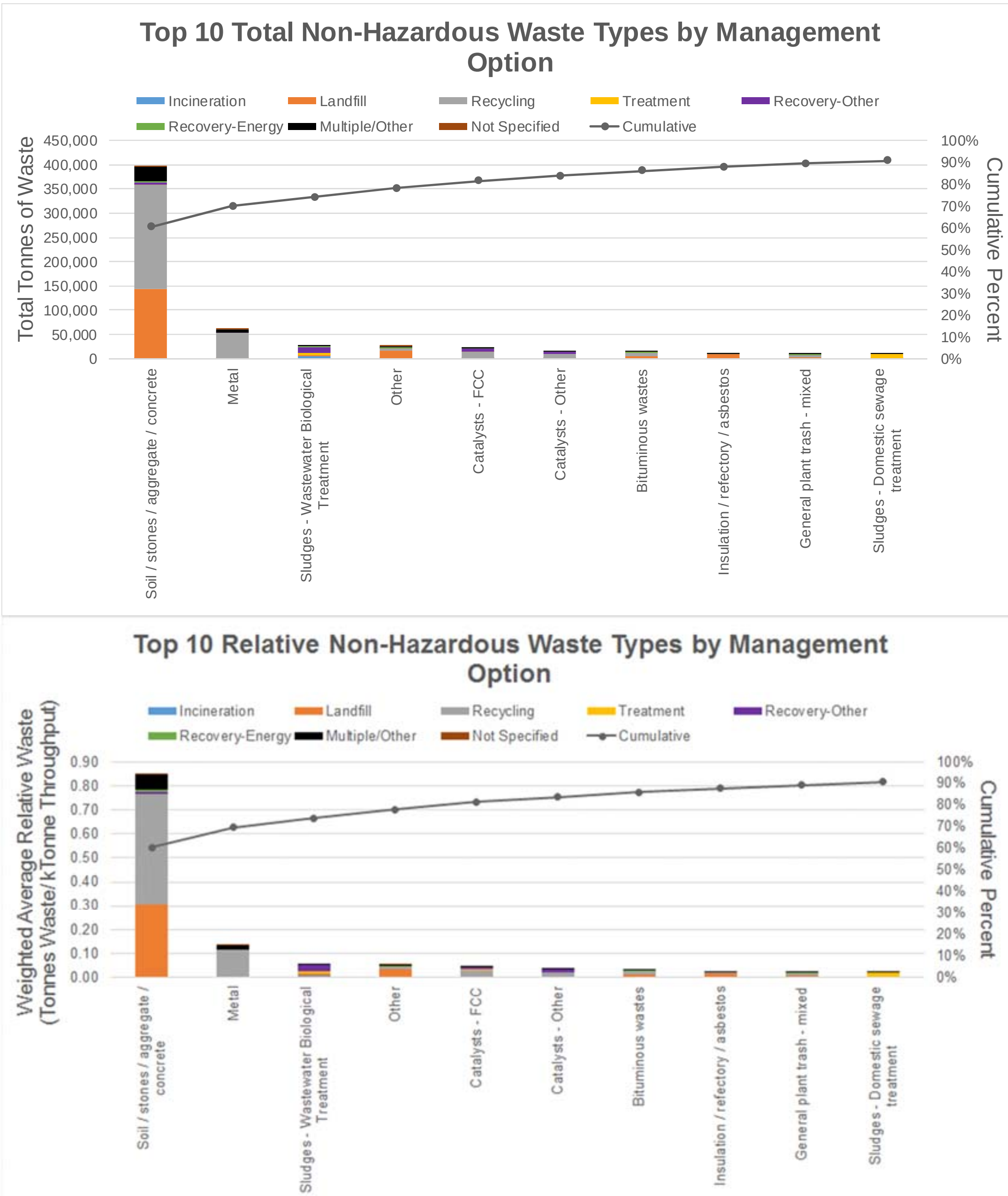


Figure 15: Pareto charts of top ten non-hazardous waste types and their management option. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput



6. WASTE CLASSIFICATION CODES AND WASTE HAZARD CODES

The European List of Waste, often referred to as the European Waste Catalogue (EWC) is a hierarchical list of waste descriptions established by Commission Decision 2000/532/EC for use in waste characterization prior to waste management. Individual wastes are assigned a unique six figure code, with each having a description to match with the waste. Waste codes suffixed by an asterisk "*" are always hazardous waste. Survey questionnaire respondents were asked to report the EWC code and also the applicable Waste Hazard codes in place during 2013 (see Section 1.1) for each reported waste type, as shown in **Table 8**. The full List of Waste is available at:

http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.370.01.0044.01.ENG

Table 8: EC Waste Hazard codes (2000/532/EC)[17]

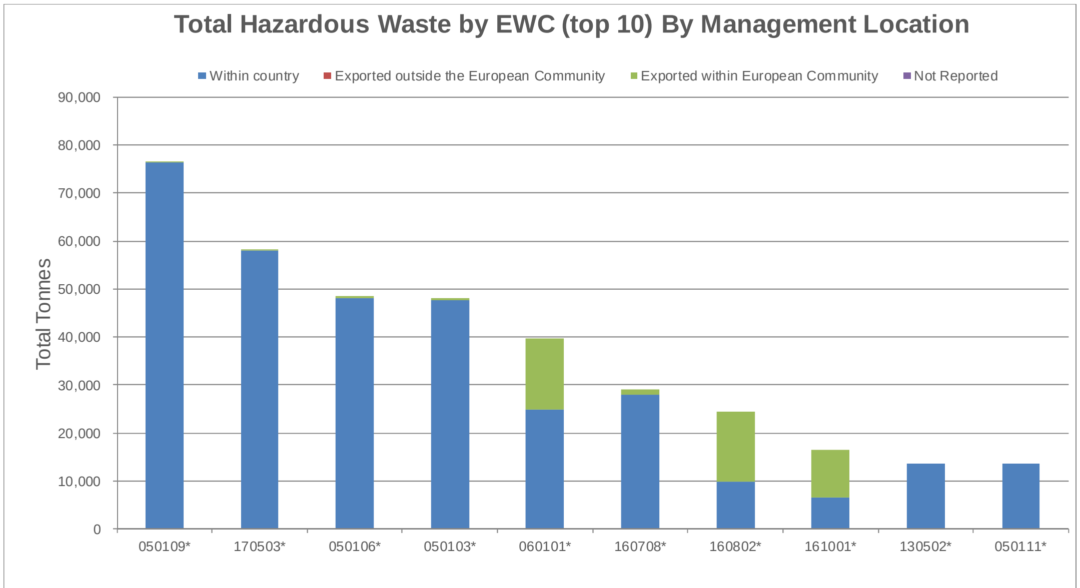
Hazardous Waste Code (2013)	Waste Hazard Property Description
H1	Explosive
H2	Oxidising
H3	Highly Flammable (H3A) / Flammable (H3B)
H4	Irritant
H5	Harmful
H6	Toxic
H7	Carcinogenic
H8	Corrosive
H9	Infectious
H10	Toxic for Reproduction
H11	Mutagenic
H12	Releases toxic gas in contact with water, air or acid
H13	Sensitizing
H14	Ecotoxic
H15	Waste capable by any means, after disposal, of yielding another substance, e.g. a leachate, which possesses any of the characteristics listed above.

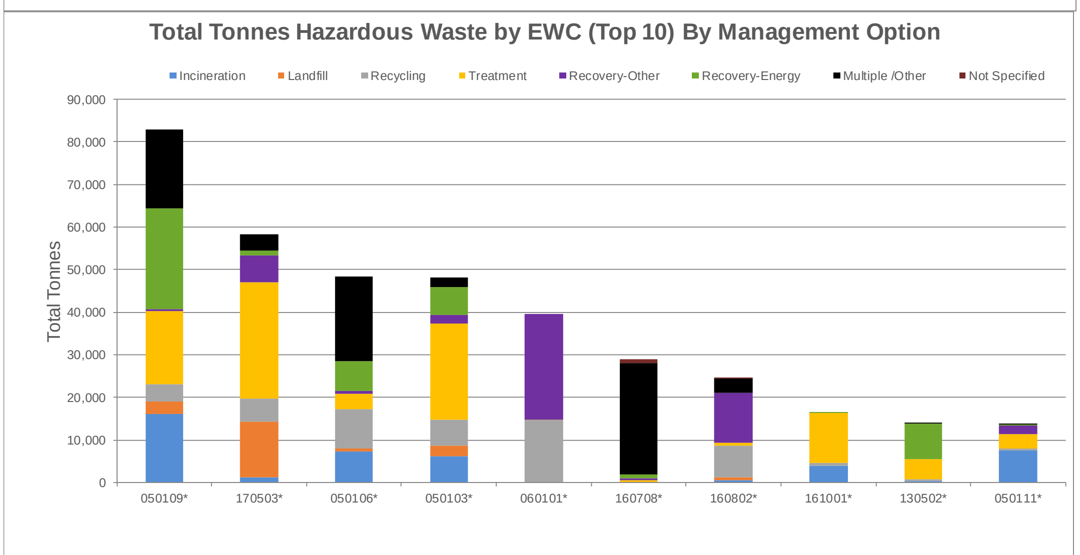
Figure 16 shows the top 10 hazardous waste EWC codes by waste management location and then broken down by management option. **Figure 17** shows the same for the top 10 non-hazardous waste codes. For both hazardous and non-hazardous wastes, the top 10 EWC codes represent 74% and 77% respectively of the total amounts of these wastes produced. The majority of the top 10 EWC codes were disposed in the country of origin, and none of the top 10 EWC codes were exported outside of the European community. Significant transfer between EU member states was only reported for three hazardous waste types: sulphuric/sulphurous acid, aqueous liquid wastes and spent catalyst. For these waste streams, it is likely that the

[17] As in force at the time of data collection, prior to the adoption of an updated list of waste hazard codes in the Directive introduced by Commission Regulation (EU) 1357/2014.

specialist infrastructure required for its waste management is not present in all EU Member States. With exception of asbestos (hazardous waste landfill), there were no instances of EWC codes for special types of waste being restricted to one management option. Items marked as having a "Multiple/Other" management option were most often managed with a combination of recycling and energy recovery. In addition, some waste streams in this category were managed through incineration.

Figure 16: Waste management details for top 10 hazardous waste according to EWC code. Upper plot splits by location and lower plot by management option.

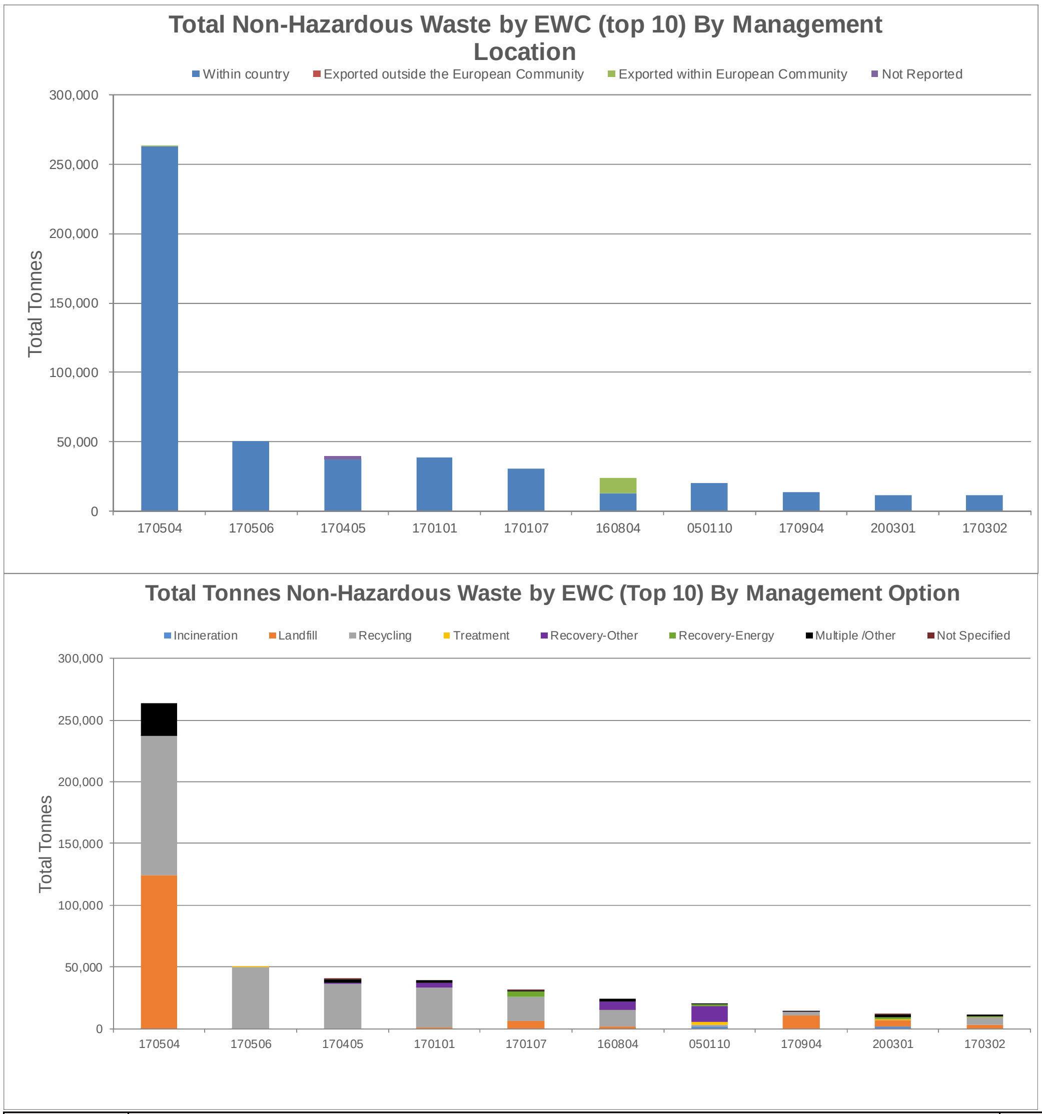




EWC Code	EWC Code Description	Tonnes Waste
050109*	Sludges from on-site effluent treatment containing dangerous substances	82,827
170503*	Soil and stones containing dangerous substances	58,366
050106*	Oily sludges from maintenance operations of the plant or equipment	48,446
050103*	Tank bottom sludges	48,108
060101*	Sulphuric acid and sulphurous acid	39,654
160708*	Wastes containing oil (from transport tank, storage tank and barrel cleaning)	29,075
160802*	Spent catalysts containing dangerous transition metals or dangerous transition metal compounds	24,538
161001*	Aqueous liquid wastes containing dangerous substances (destined for off-site treatment)	16,429
130502*	Sludges from oil/water separators	13,744
050111*	Wastes from cleaning of fuels with bases	13,727

Note: the top 10 Hazardous EWC codes represents 74% of the total Hazardous waste reported

Figure 17: Waste management details for top 10 non-hazardous waste according to EWC code. Upper plot splits by location and lower plot by management option.



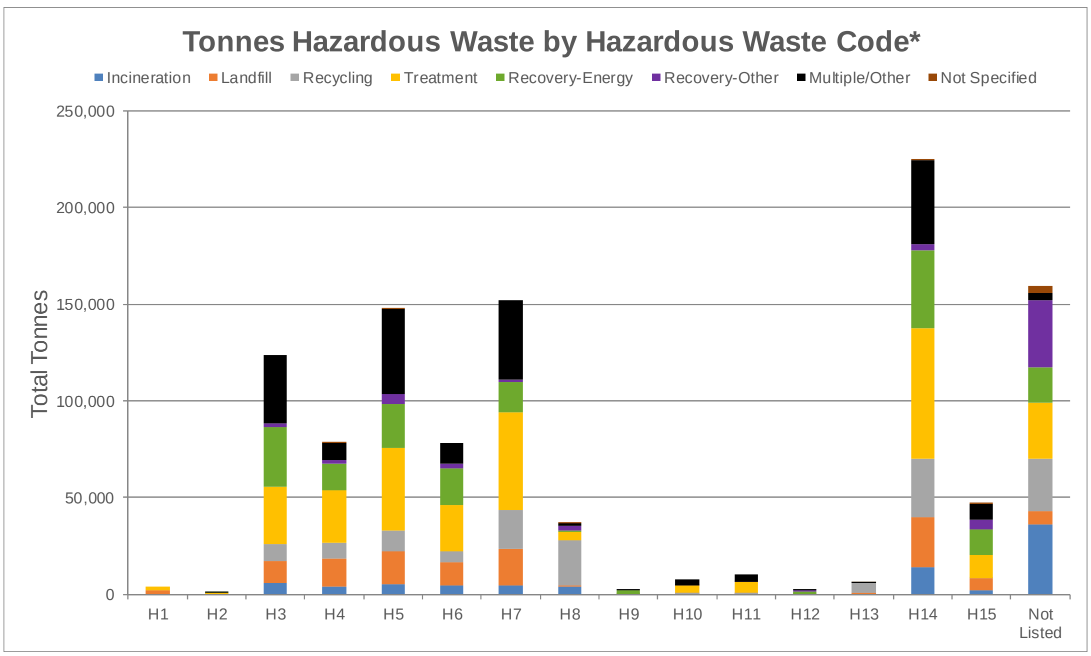
EWC Code	EWC Code Description	Waste Tonnes
170504	Soil and stones other than those mentioned in 170503 (i.e. non-hazardous)	263,337
170506	Dredging spoil other than those mentioned in 170505 (i.e. non-hazardous)	50,360
170405	Iron and steel	39,791
170101	Concrete	39,196
170107	Mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 170106 (i.e. non-hazardous)	30,748
160804	Spent fluid catalytic cracking catalysts (except 160807, i.e. non-hazardous)	24,327
050110	Sludges from on-site effluent treatment other than those mentioned in 050109 (i.e. non-hazardous)	20,518
170904	Mixed construction and demolition wastes other than those mentioned in 170901, 170902 and 170903 (i.e. not containing mercury, non-hazardous and not containing PCB, respectively)	13,894
200301	Mixed municipal waste	11,532
170302	Bituminous mixtures other than those mentioned in 170301 (i.e. not containing coal tar)	11,407

Note: the top 10 Non-Hazardous EWC codes represents 77% of the total Non-Hazardous waste reported

Figure 18 shows the tonnes of hazardous waste that were assigned a specific Hazardous Waste code by the survey respondent (H1-H15 at the time the survey was carried out). Many respondents listed multiple hazardous waste codes for their wastes. The graph applies the total waste tonnage to each of the multiple listed codes. Therefore, the sum of individual waste tonnages was larger than the actual total waste quantity. The hazard category "Not listed" reflects the fact that not all countries require Hazardous Waste codes to be listed on the transport document (requiring only a distinction between hazardous vs non-hazardous).

Hazardous Waste code H14 (ecotoxic) is applied to more waste than any other Hazardous Waste code. Work being undertaken by the European Commission to develop and implement common criteria at EU level to determine whether waste possesses an ecotoxic hazard may impact the amount of waste assigned this hazard. In addition, implementation of updated hazardous waste definitions and threshold limits for certain hazardous waste properties introduced by Commission Decision Regulation (EU) 1357/2014 may further impact the distribution shown.

Figure 18: Tonnes of hazardous waste by assigned Hazardous Waste Code



*Note: many respondents listed multiple hazard codes per waste stream. Graph assumes that total waste stream tonnage is applied to each of the multiple listed hazard codes.

7. WASTE MANAGEMENT COSTS

In the 2013 survey refineries were asked to provide data on the total annual cost (in K$) of hazardous and, separately, non-hazardous waste management. A breakdown of total costs was not requested due to the commercial sensitivity of such information, and as such significant variation is likely in the approach used for the cost calculation (especially the extent to which indirect costs are included). For these reasons the findings from the cost data analysis are considered indicative rather than absolute.

7.1. TOTAL REPORTED COST OF WASTE MANAGEMENT

Of the 77 survey questionnaires returned, 57 included data on hazardous waste costs and 58 data on non-hazardous waste costs. In addition, 5 questionnaires were returned with aggregate waste costs (hazardous + non-hazardous). 63 questionnaires (representing 61 refineries) were therefore available for the summation of EU refining sector waste management costs.

Total reported waste management costs in 2013 were 137.2M$, with hazardous waste management accounting for 91.7M$, non-hazardous waste management for 34.7M$ and undifferentiated (aggregated hazardous + non-hazardous) for 10.8M$.

7.2. VARIATION IN HAZARDOUS AND NON-HAZARDOUS WASTE MANAGEMENT COSTS

Figures 19 and **20** show the rank order of the hazardous and non-hazardous waste management costs per tonne of waste, respectively, for individual refineries. For these graphs, the cost provided by each site for the given hazardous or non-hazardous category was divided by the computed total tonnage of waste in the same category. Refineries were then ranked from lowest to highest cost per tonne waste and plotted on a logarithmic scale. Not all reporting refineries provided cost information, as noted above. A high outlier in the hazardous plot that does not fit the main cost distribution is indicated in red. This has been excluded from subsequent box plots as it is considered to reflect unresolved errors in the reported data (average hazardous waste management cost of > 25,000 $ per tonne is unrealistically high).

Figure 19: Hazardous waste management cost per tonne waste ($ per tonne). Note that the high outlier point shown in red has been excluded from subsequent box plots as it is considered to reflect unresolved errors in the reported data.

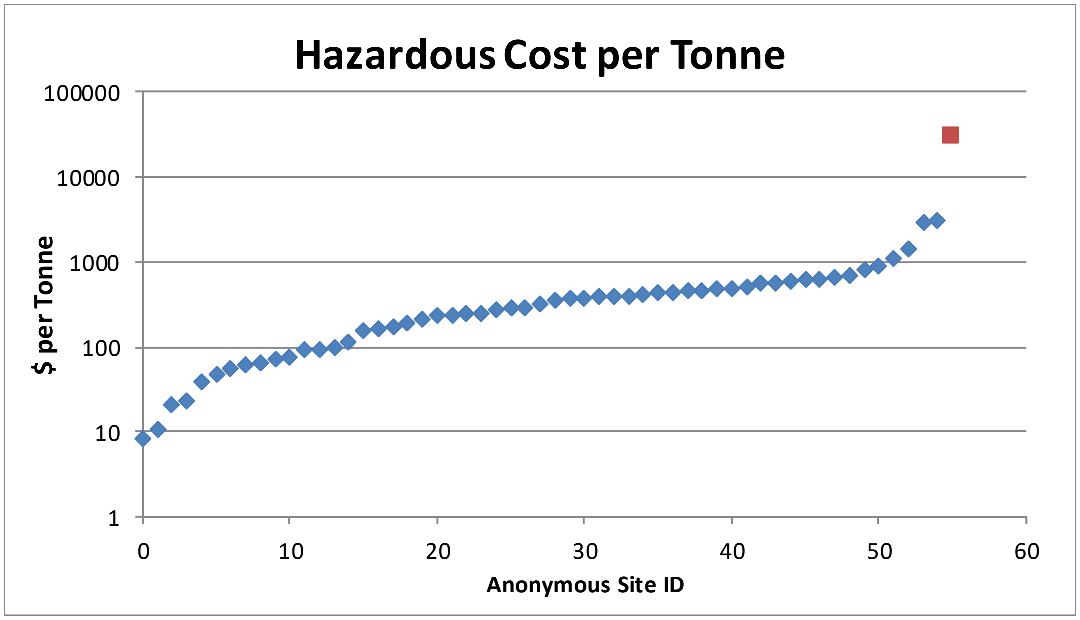


Figure 20: Non-hazardous waste management cost per tonne waste ($ per tonne)

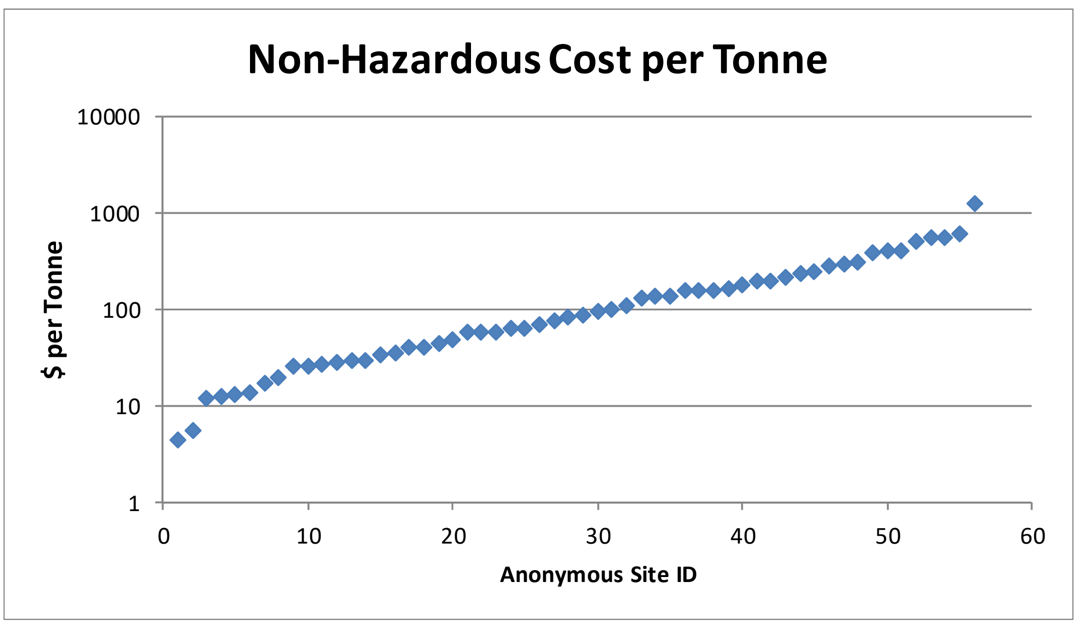
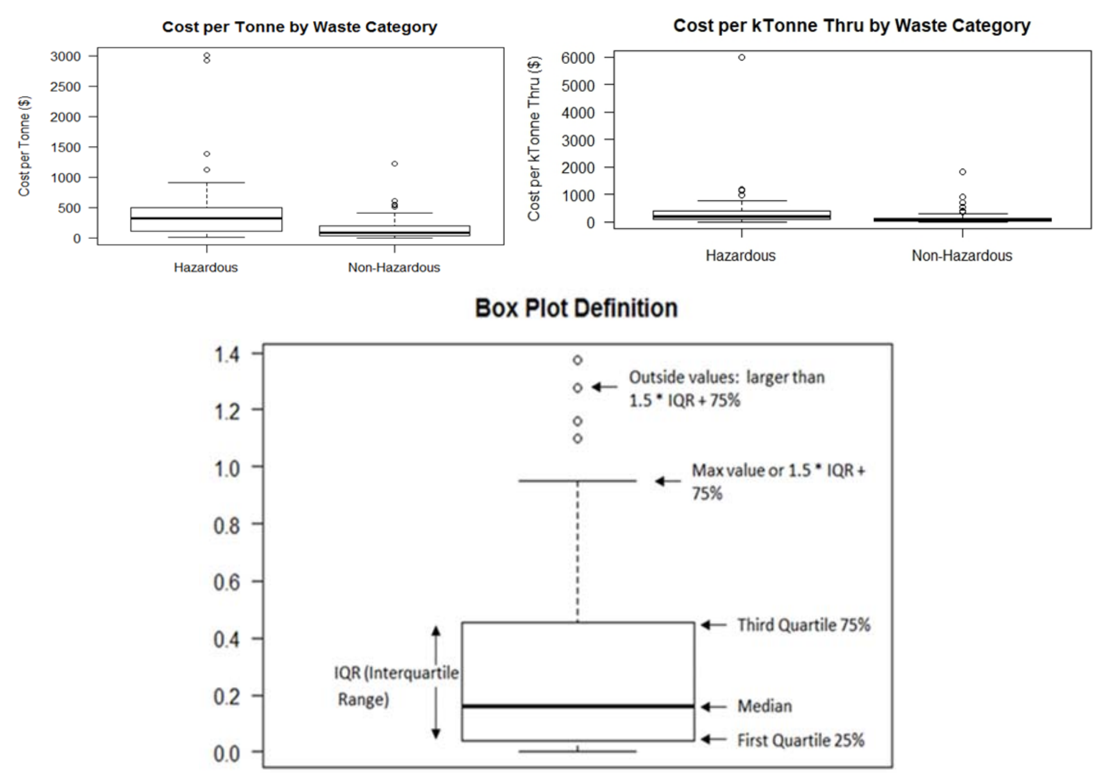


Figure 21 shows a box-and-whisker plot of the distribution in hazardous and non-hazardous waste costs per tonne (left hand plot), and per ktonne feedstock throughput (right-hand side plot), respectively. **Figure 21** also includes the legend to all box-and-whisker plots shown in this chapter. Two sites had a relatively high cost per tonne for hazardous waste management (~3000 $/tonne). Comments returned in the questionnaire indicated that for one of these sites the cost includes the dewatering of waste water treatment sludge. Sludge dewatering represents an additional cost and could also increase the cost per tonne, if the dry rather than wet sludge mass was reported. For this site the cost normalized to feedstock throughput is below the industry median, which is consistent with this hypothesis. For the other site no supporting data was provided, and so the reason for the high cost per tonne is not clear. However, in this case also the cost normalized to feedstock throughput is below the industry median.

An analysis of the one site on the right hand plot that had relatively high cost per ktonne feedstock throughput for hazardous waste management (~6000 $/ktonne feedstock throughput) indicated that the largest waste stream from this site was related to fly ash due to electrostatic precipitator (ESP) abatement of the pet-coke firing combustion plant. It cannot be determined, however, if this waste stream is responsible for the high cost per tonne feedstock throughput.

Figure 21: Waste management costs in $ per tonne, and $ per kilotonne of tonne feedstock throughput, for all refineries. Legend to box-and-whisker plots included below plots.



7.3. WASTE MANAGEMENT COSTS BY COUNTRY GROUP

For hazardous waste, the median cost of waste management (316 $/tonne) is similar to the median country group cost for Baltic, Benelux and France. In Central Europe and Iberia the median cost is lower at 63 $/tonne and 85 $/tonne respectively, whereas in Germany, Mediterranean and UK & Ireland the median cost is closer to 500 $/tonne (**Figure 22**). Possible explanations for these differences include different levels of availability of each waste management option between countries, country policy and economic instruments concerning specific waste management options and location of refineries relative to waste management facilities.

The Baltic and Germany country groups exhibit much wider variations in hazardous waste management cost than other country groups, whereas the variations in relative waste management cost is clearly the widest in the Mediterranean area. For some countries the prevalence of a specific waste management option is shown in **Figure 24**; in Central Europe and France there is high utilisation of energy recovery, in Benelux recycling, in Germany material recovery and in UK & Ireland incineration.

For non-hazardous waste the median cost of all waste management (83 $/tonne) is similar to the median country group cost for Baltic, Central Europe and Iberia. In Benelux and Germany the median cost is lower at 20 $/tonne, whereas in France, Mediterranean and UK & Ireland the median cost is closer to 200 $/tonne (**Figure 23**). Possible explanations are similar to those provided for hazardous waste (see above).

The Baltic and Mediterranean country groups exhibit the widest variations in non-hazardous waste management cost, whereas the median relative waste management costs are generally in the range 10-90 $/ktonne, except where influenced by high outliers (e.g. the Mediterranean area at 200 $/ktonne). **Figure 25** shows significant recycling in Benelux, Central Europe, France, Baltic and Mediterranean and use of landfill in Germany, Iberia, Mediterranean and UK & Ireland.

Further to show the management options for hazardous and non-hazardous wastes in different areas, **Figures 24** and **25** show the 25th and 75th percentile of the cost per tonne indicated above each bar. Detailed cost information for each waste management option would be a valuable addition to future surveys, to provide insight into factors driving the wide variation in waste management costs

Figure 22: Hazardous waste management cost in $ per tonne, and $ per ktonne of tonne of feedstock throughput, per country group. For legend to box-and-whisker plots see **Figure 21**.

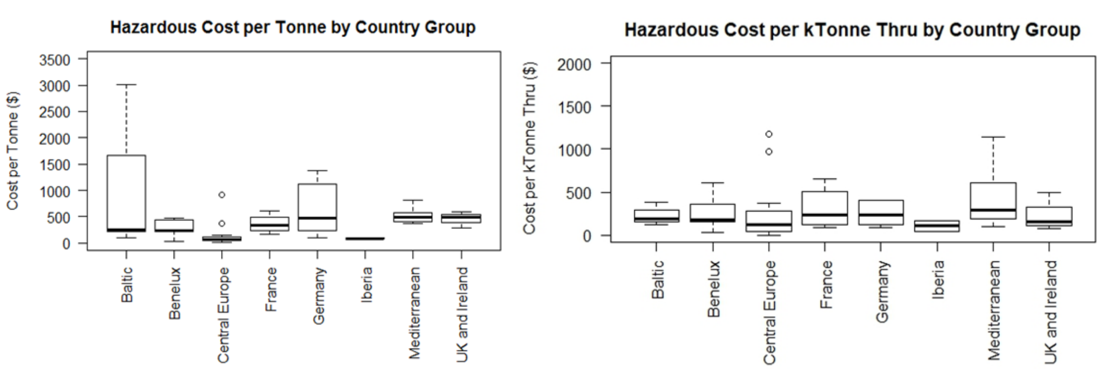


Figure 23: Non-hazardous waste management cost in $ per tonne, and $ per kilotonne of tonne of feedstock throughput, per country group. For legend to box-and-whisker plots see **Figure 21**.

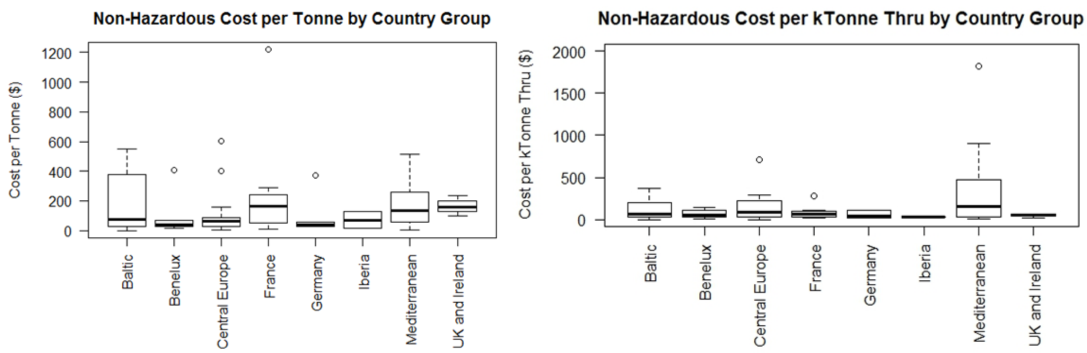


Figure 24: Total hazardous waste by region and management option with 25th and 75th percentile of waste management costs per tonne indicated above bar.

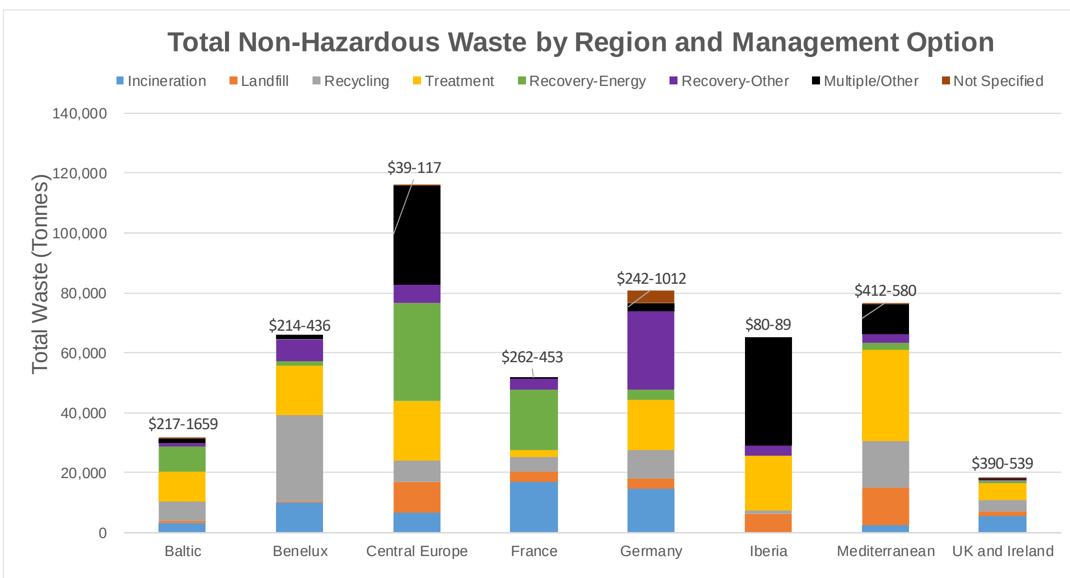
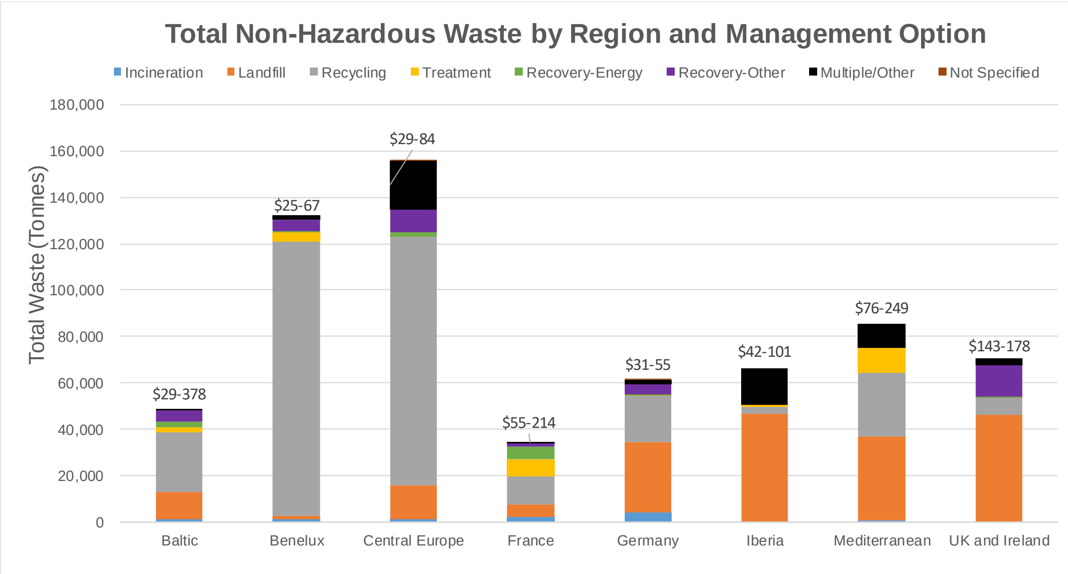


Figure 25: Total non-hazardous waste by region and management option with 25th and 75th percentile of waste management costs per tonne indicated above bar.



8. VARIATION IN WASTE MANAGEMENT OPTIONS FOR MAJOR WASTE TYPES

This section considers in greater detail regional variation in waste management options for selected high tonnage wastes.

8.1. SLUDGES

Refineries produce large quantities of sludge, principally from tank cleaning and wastewater treatment, as described in Section 4.2. The total mass of sludge produced by the 74 refineries reporting in 2013 was 296,809 tonnes; a percentage breakdown of this tonnage is provided in **Table 9** below. Given the high tonnage, there is a potential for further research into cost effective waste minimisation and/or to move the waste management option higher up the waste hierarchy. This, however, would require a detailed analysis of sludge production and management, which is not possible based on the data collected in this study.

The total sludge mass is equivalent to an average of 1 tonne of sludge for 1390 tonnes (i.e. 0.07%) of refinery feedstock throughput, which is 2.8 times lower than the sludge production reported in 1993 (1 tonne per 492 tonnes feedstock throughput; 0.2%). This apparent reduction could be due to a number of factors, for example increased dewatering of sludges prior to waste management (no data was collected on sludge water content). With reference to **Table 9** below, the majority of the sludge tonnage is derived from tank bottoms and physical/ chemical/ biological treatment of waste waters.

Table 9: Percentage contribution of reported sludge types to the total reported sludge tonnage in 2013.

Sludge type	Sludges (%)	All Waste (%)
Sludges - Tank bottom	26.2	6.7
Sludges - Desalter	1.7	0.4
Sludges - Alkylation	1.0	0.3
Sludges - Boiler feed water	2.4	0.6
Sludges - Domestic sewage treatment	3.6	0.9
Sludges - Interceptor (API, CPI, etc.)	1.8	0.5
Sludges - Wastewater physical/chemical treatment (DAF, IAF, etc.)	23.3	6.0
Sludges - Wastewater biological treatment	23.5	6.0
Sludges - Other	16.5	4.2

The sludge types recorded in the 2013 survey, as shown in the table above, together account for 45% of total hazardous waste and 10% of total non-hazardous waste. The majority of the total sludge tonnage (79%) was classified as hazardous waste, although a proportion of WWTP physical/chemical and biological sludges were classified as non-hazardous.

In the case of physical/chemical treatment sludges, 6% of the total tonnage was reported as non-hazardous. This comprised mainly boiler feedwater sludge (EWC 050113). 11% of biological wastewater treatment sludges were reported as non-hazardous, comprising sludges from on-site effluent treatment [non-hazardous]

(EWC 050110) and sludges from other treatment of industrial waste water [non-hazardous] (EWC 190814).

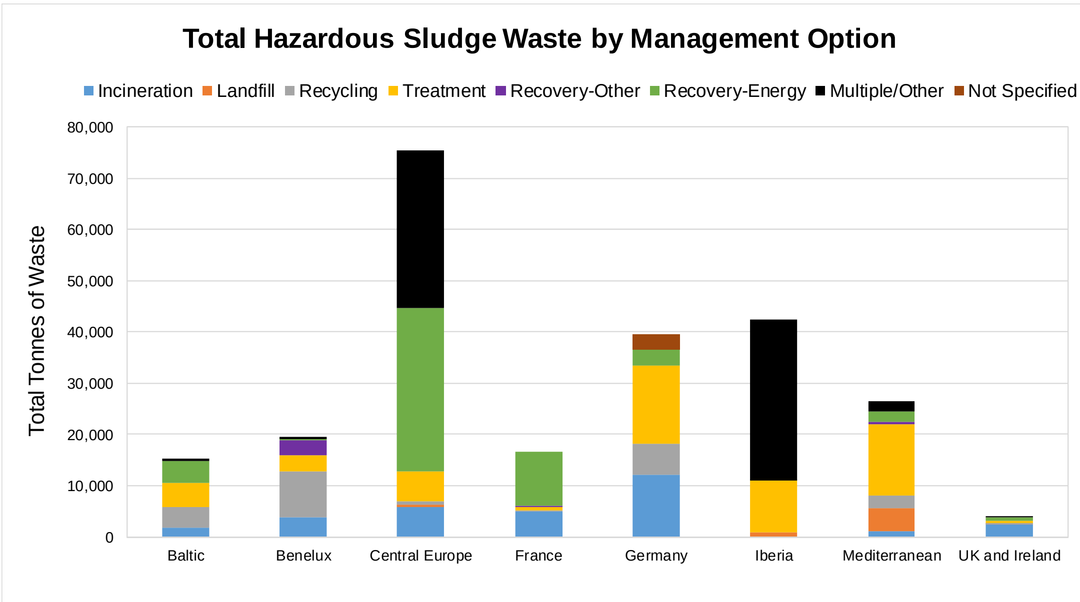
8.1.1. Geographical variation in waste management options for different sludge types

Figures 26 and **27** show the variation in waste management options for hazardous and non-hazardous sludges, split by country group. Incineration and energy recovery are widely used for both hazardous and non-hazardous sludges. Landfill is a significant waste management option for hazardous sludges in the Mediterranean, and for non-hazardous sludges in the Mediterranean and Iberia. The reported "recovery-other" management option for non-hazardous sludges in Germany and UK & Ireland is "R10 - Agriculture/ecological benefit" (i.e. use of sludges for land improvement).

A significant fraction of hazardous sludges in the Baltic, Benelux and Germany areas is recycled. While not explicit in the survey returns, sludge recycling appears to correlate with refineries operating coking units, which can use oily dewatered sludge as a feedstock. For example, sludges with high oil content may be injected into a delayed coking unit during the coking phase so that they are converted to coke and liquid coking products. High water content sludges can then be used to quench the coke during the quench phase of the coking cycle.

As previously mentioned, where waste management is by "treatment" or "multiple/other", information on the final management option was not collected in the survey. This situation may be encountered when waste is taken away by a contractor for treatment prior to waste management. Addressing this issue will be important for future surveys but is acknowledged to be difficult as it may, at least in some cases, require access to the records of refinery waste management contractors.

Figure 26: Management options for hazardous sludge waste, partitioned by country group. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput



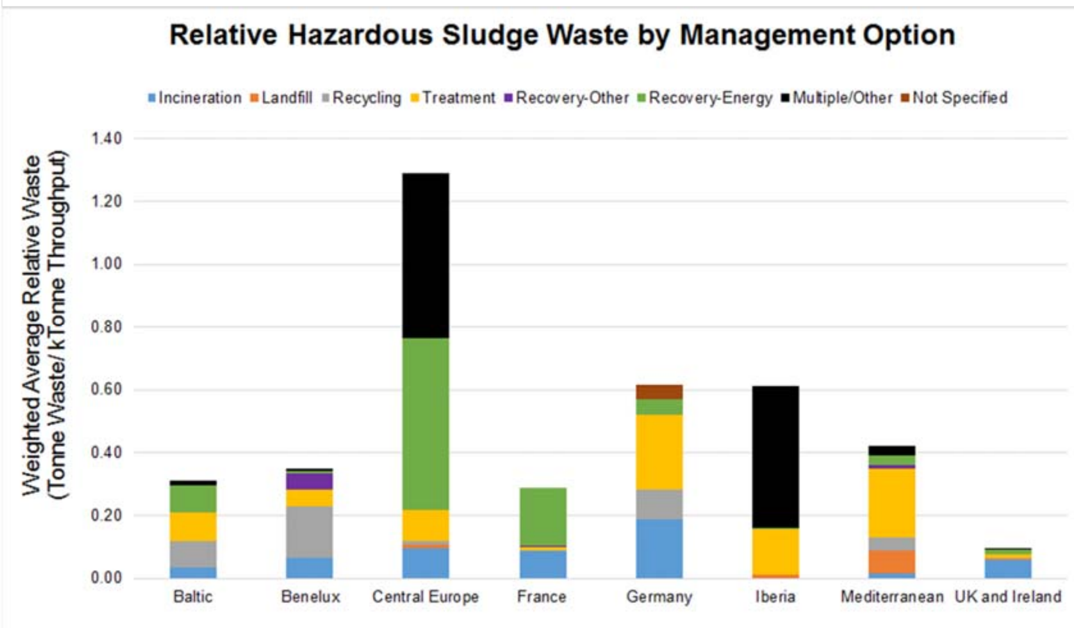
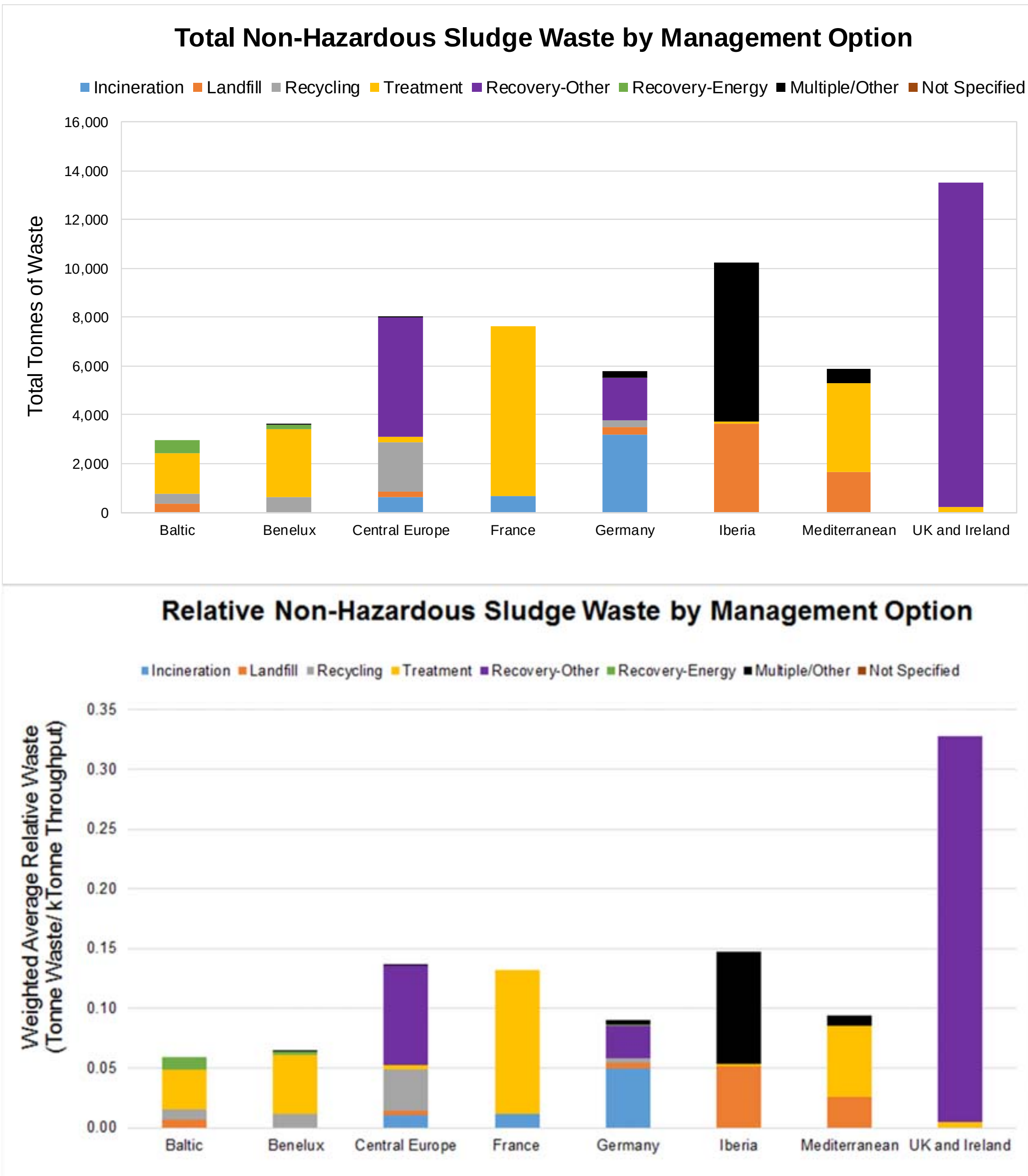


Figure 27: Management options for non-hazardous sludge waste, partitioned by country group. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput.



8.2. OILS

Table 10 shows the tonnage of each EWC code used for the reporting of waste oils. It is apparent that a large part of the total tonnage may reflect waste containing only a small amount of oil (e.g. “wastes containing oil”; “water from oil/water separators”). A more explicit definition of waste oils would help to avoid this confusion in future surveys.

Table 11 compares the total tonnage of waste oil in each geographical region to the corresponding tonnes of feedstock throughput. Only a very small percentage of the total refinery feedstock throughput (0.0045% on average over all country groups) was disposed of as waste oil.

Figure 28 shows the waste management options of reported hazardous waste oils in different country groups, in units of tonnes and also tonnes waste/ktonne feedstock throughput. The dominant waste management option in absolute and relative terms was recycling, closely followed by energy recovery. A minor component of the total tonnage (approximately 500 tonnes) was sent for incineration. The remaining tonnage was reported under the treatment/ multiple (other)/ not specified categories, whereby the final waste management option was not captured by the survey.

Table 10: Tonnage of each EWC code used for reporting waste oil.

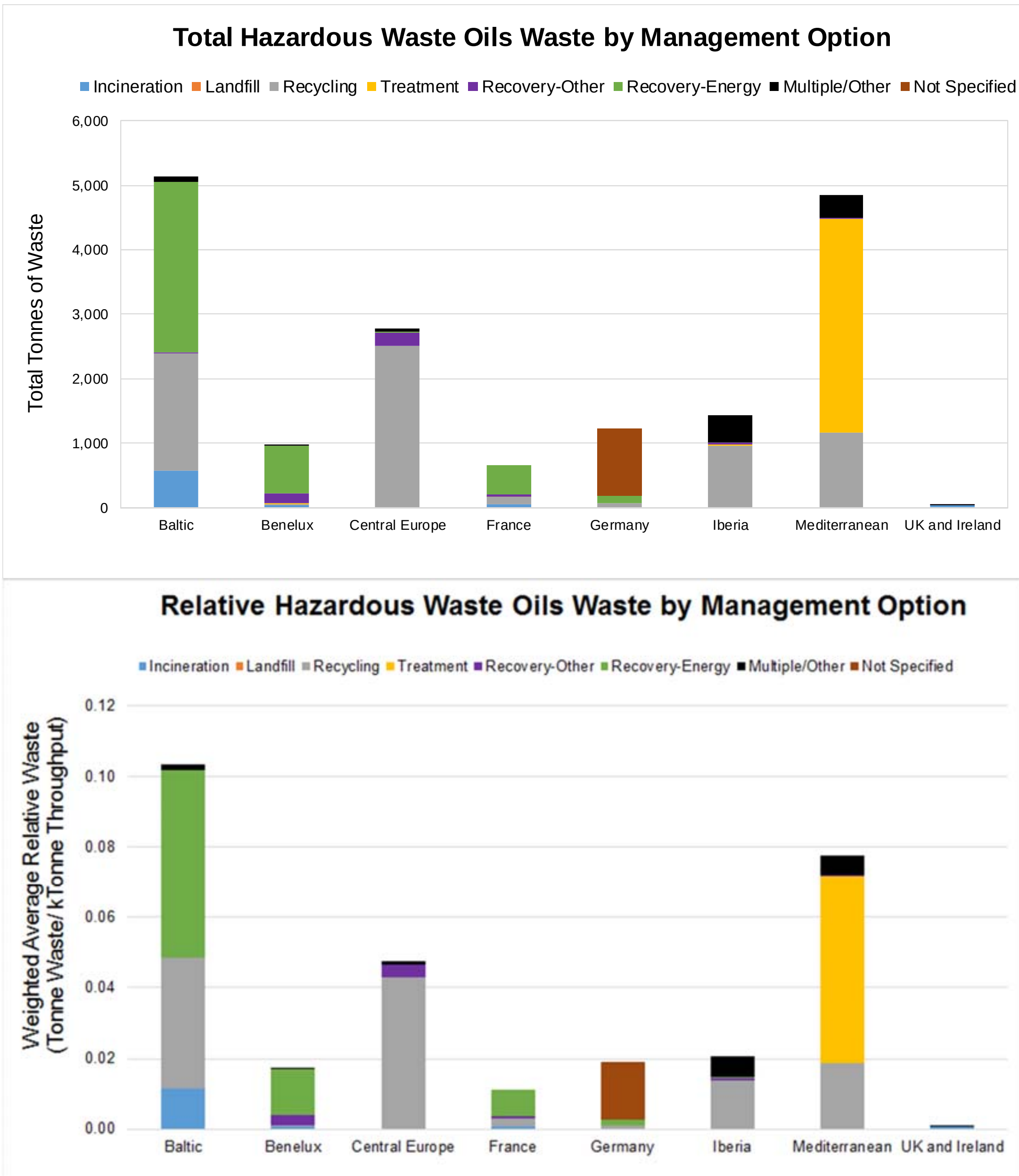
Waste Category	EWC Code	EWC Description	Total Tonnes Reported
Hazardous	050105*	oil spills	4212
	130506*	oil from oil/water separators	3932
	160708*	wastes containing oil	1543
	130205*	mineral-based non-chlorinated engine, gear and lubricating oils	1441
	130703*	other fuels (including mixtures)	1336
	130402*	bilge oils from jetty sewers	918
	050106*	oily sludges from maintenance operations of the plant or equipment	771
	130208*	other engine, gear and lubricating oils	665
	130899*	wastes not otherwise specified	618
	130507*	oily water from oil/water separators	438
	130502*	sludges from oil/water separators	381
	130401*	bilge oils from inland navigation	274
	130307*	mineral-based non-chlorinated insulating and heat transmission oils	142
	130110*	mineral based non-chlorinated hydraulic oils	75
	050111*	wastes from cleaning of fuels with bases	53
	130310*	other insulating and heat transmission oils	44
	130701*	fuel oil and diesel	43
	150202*	absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by dangerous substances	37
	130113*	other hydraulic oils	33
	050112*	oil containing acids	26
	160305*	organic wastes containing dangerous substances	19

Waste Category	EWC Code	EWC Description	Total Tonnes Reported
Hazardous	161001*	aqueous liquid wastes containing dangerous substances	11
	140603*	other solvents and solvent mixtures	8
	130802*	other emulsions	8
	120112*	spent waxes and fats	6
	160508*	discarded organic chemicals consisting of or containing dangerous substances	4
	200126*	oil and fat other than those mentioned in 20 01 25	4
	130308*	synthetic insulating and heat transmission oils	4
	120109*	machining emulsions and solutions free of halogens	4
	130206*	synthetic engine, gear and lubricating oils	3
	110113*	degreasing wastes containing dangerous substances	3
	130702*	petrol	2
	130301*	insulating or heat transmission oils containing PCBs	1
Non-Hazardous	050199	wastes not otherwise specified	3672
	160306	organic wastes other than those mentioned in 16 03 05	15
	200125	edible oil and fat	2

Table 11: Waste oil tonnes as a percent of feedstock throughput.

Country Group	Total Waste Oil (tonne)	Total feedstock throughput (tonnes/year)	Percent waste oil of feedstock throughput
Baltic	5,437	49,611,808	0.0110%
Benelux	955	56,078,341	0.0017%
Central Europe	2,772	58,529,163	0.0047%
France	797	57,921,613	0.0014%
Germany	1,226	64,334,690	0.0019%
Iberia	1,431	69,544,241	0.0021%
Mediterranean	8,159	62,546,542	0.0130%
UK and Ireland	62	41,225,726	0.0002%

Figure 28: Management options for hazardous waste oils, partitioned by country group. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput.

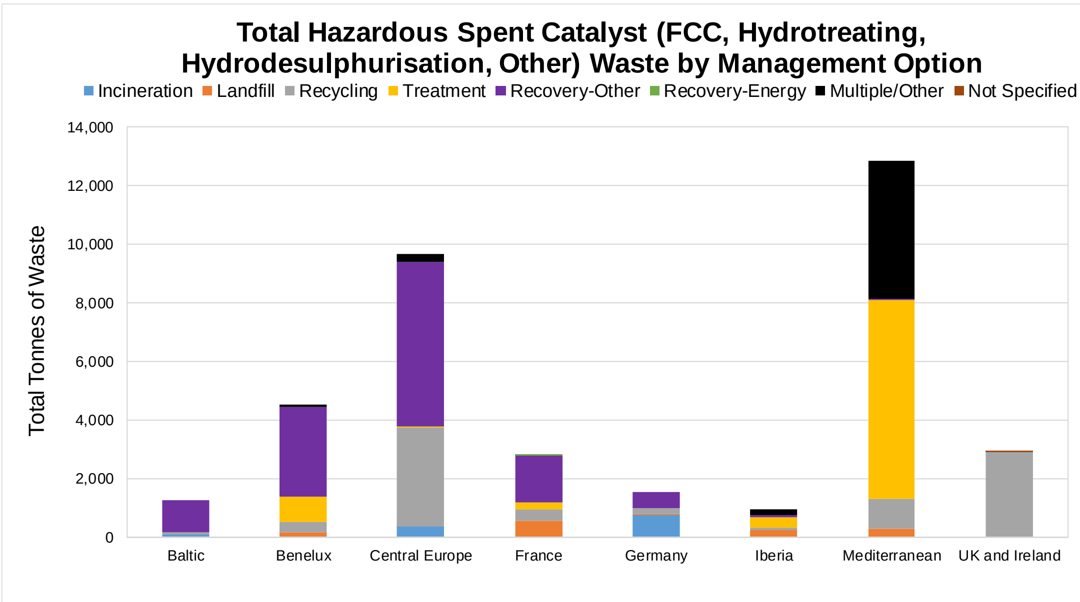


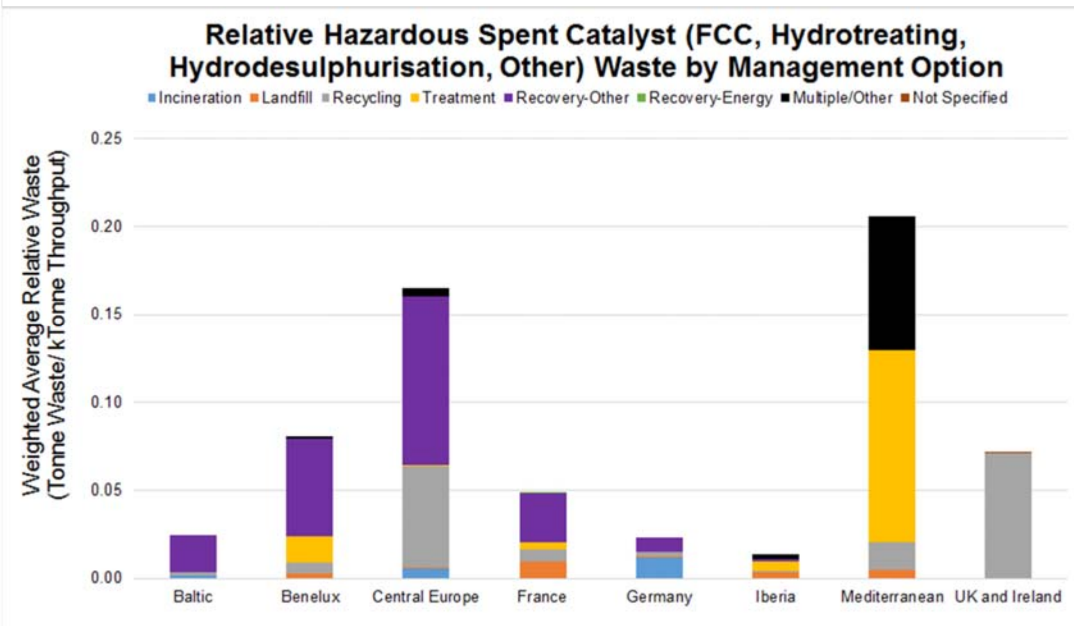
8.3. CATALYST

The regeneration and recovery of spent catalyst requires specialist facilities that may not be available in the country of origin. Accordingly, hazardous and non-hazardous waste catalyst accounts for 25% and 29% of the refining waste that was exported within the European community in 2013.

Figure 29 shows the waste management options for hazardous and non-hazardous spent catalyst, split by country group. The majority of spent catalyst is sent for recycling, treatment or recovery, with a small amount (4788 tonnes; 6%) sent to landfill or for incineration.

Figure 29: Management options for hazardous spent catalyst, partitioned by country group. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput.





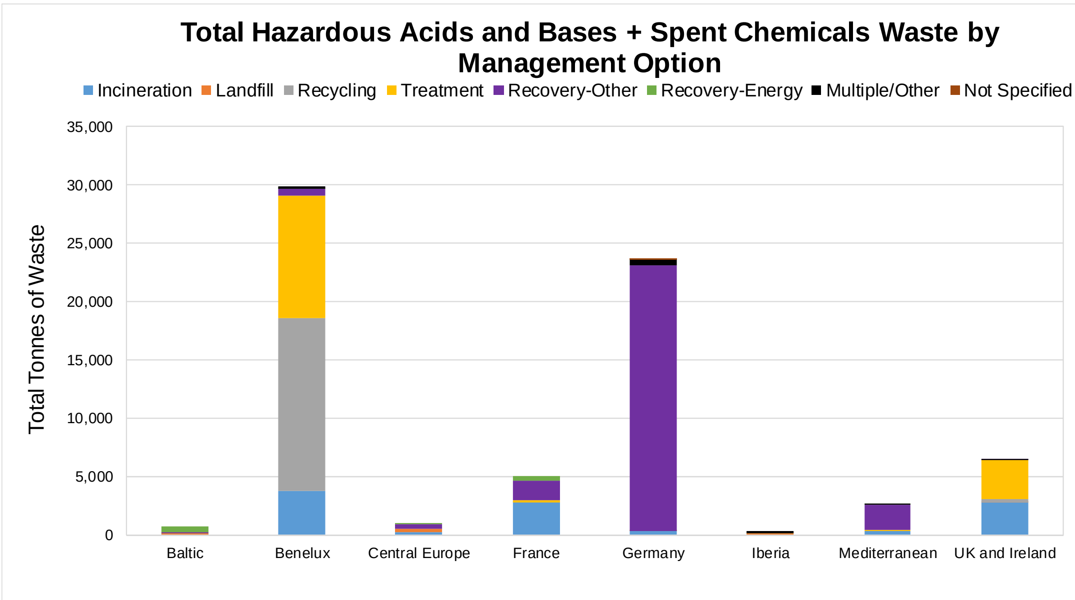
8.4. ACIDS/ BASES AND SPENT CHEMICALS

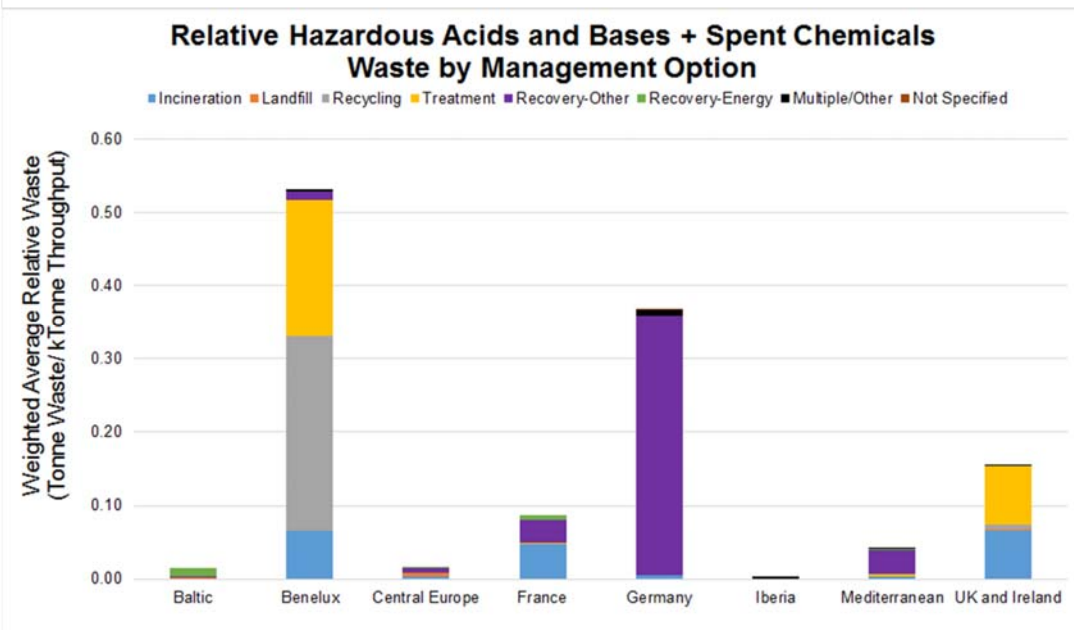
Figure 30 shows the waste management options of reported hazardous acids/bases and spent chemicals, split per country groups. Refineries in the Benelux and Germany area, which generated the majority of this waste, reported that it was sent for treatment and recycling, or “recovery-other”. Acids, bases and spent chemicals, also require specialised regeneration and recovery facilities that may not be available in the country of origin. Accordingly these wastes account for 46%.of the refining waste that was exported within the European community in 2013.

The 14,811 tonnes reported sent for recycling and 9,784 tonnes reported sent for treatment in Benelux all came from individual refineries. The same holds for the 22,694 tonnes reported as sent for “recovery-other” in Germany. This indicated that the high tonnages for Benelux and Germany is more related to specific operations of individual refineries than representative for a whole country group.

The category spent chemicals was identified to be a non-optimal category naming since different survey respondents interpreted it differently. For the next survey questionnaire the category referring to chemical waste needs to be more clearly defined and explained.

Figure 30: Hazardous acids, bases and spent chemicals waste by management option and partitioned by country group. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput.

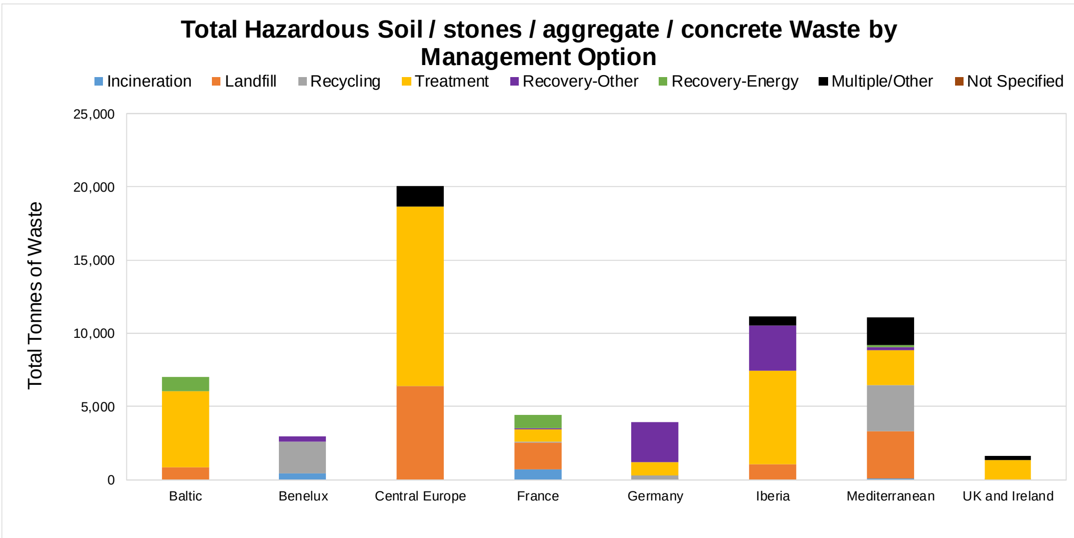




8.5. SOIL/ STONES/ AGGREGATE/ CONCRETE

Figure 31 shows the management options of reported hazardous soil/stones/aggregate/concrete waste, split per country groups. As previously discussed (see Section 4.2), the reported tonnage of this waste type is highly dependent on the site-specific timing of remediation, major turnaround events, and investment projects. **Figure 32** indicates that the majority of soil/stones/aggregate/concrete waste is from non-hazardous remediation and major turnaround events. The main management options for this waste type were “recovery-other”, “recycling”, and “multiple/other”. Hazardous soil/stones/aggregate/concrete waste is typically treated for the purpose of reuse or to remove the hazardous properties to enable waste management via other options. A small tonnage of this waste type was used for energy recovery; from the reported EWC codes it can be seen that this fraction comprised hazardous soil and earth (90% dredging spoils and 4% soils; no further detail was provided).

Figure 31: Hazardous soil/stones/aggregate/concrete waste by management option and partitioned by country group. Upper plot shows total tonnage and lower plot shows tonnes/ ktonne feedstock throughput



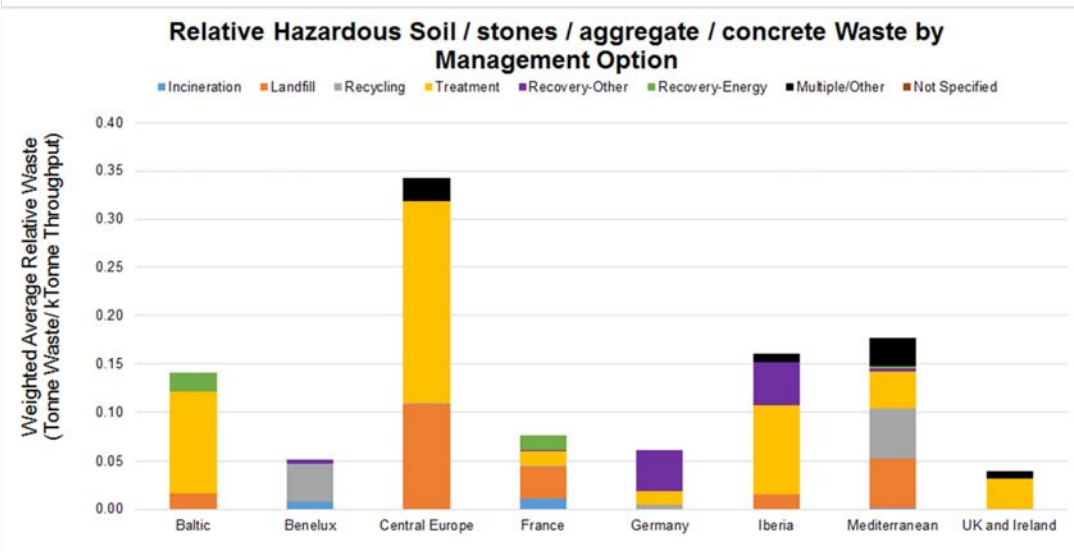
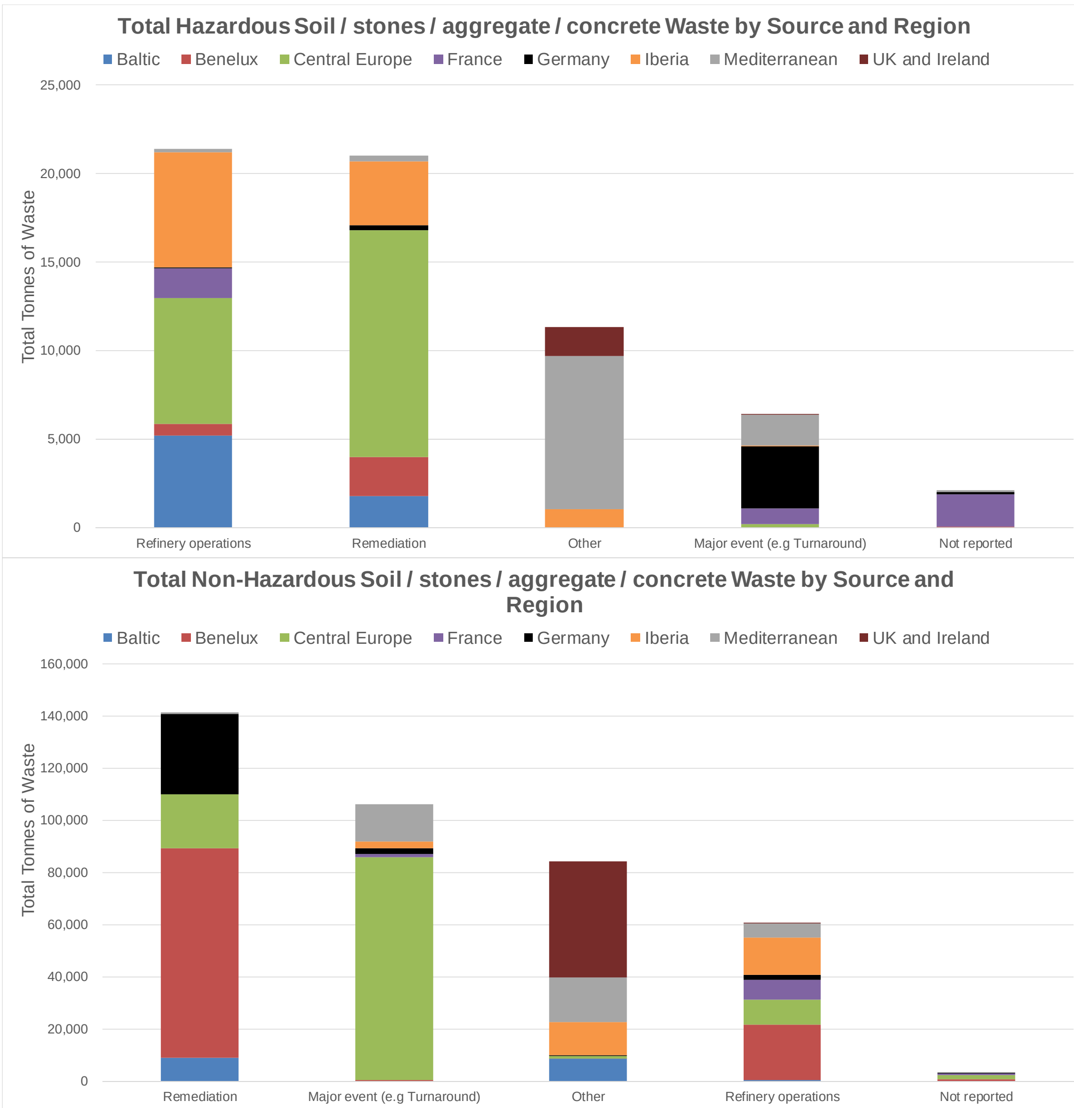


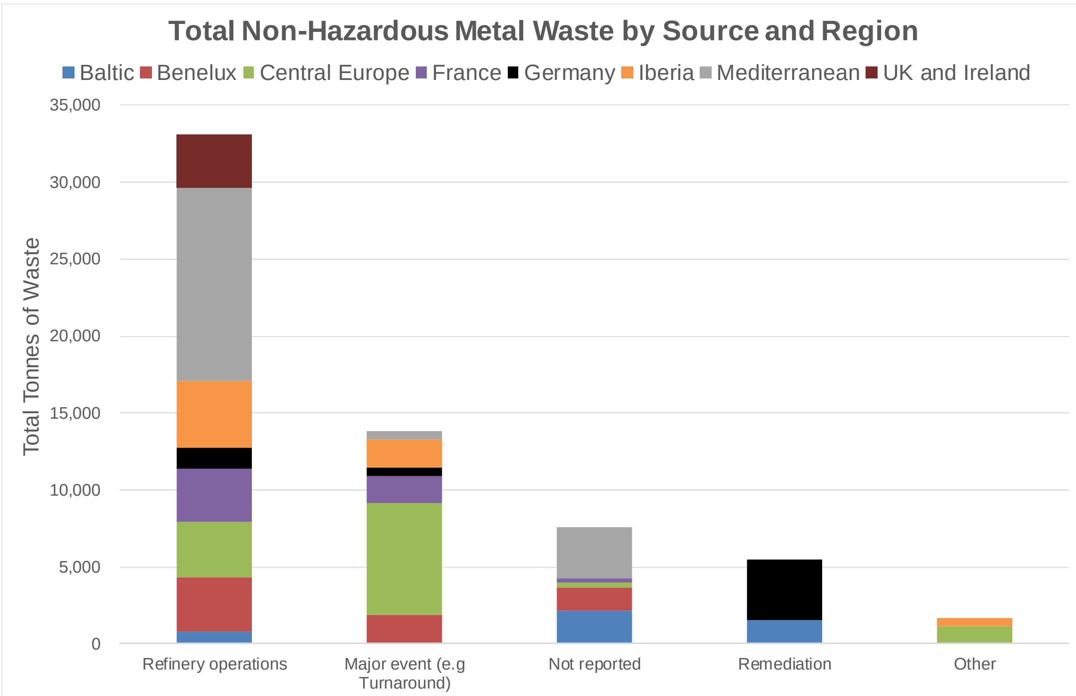
Figure 32: Hazardous and Non-hazardous soil/stones/aggregate/concrete waste by waste source and partitioned by country group.



8.6. METAL

Over 97% of the metal waste was classified as non-hazardous. **Figure 33** indicates that the majority of the metal waste comes from refinery operations and major turnaround events. The vast majority (> 85%) of waste metal was recycled.

Figure 33 Non-hazardous metal waste by source and partitioned by country group.



9. COMPARISON OF REPORTED WASTE TONNAGE AND MANAGEMENT COSTS IN 1986, 1993 AND 2013 SURVEYS

Table 12 provides a comparison of the 1986, 1993 and 2013 waste surveys in terms of the number of reporting sites, total and relative waste tonnage and cost.

A high level comparison of waste tonnage indicates an increase in total and, in particular, relative waste production from 1993 to 2013 despite the number of reporting refineries decreasing from 89 to 74. The increase may be associated with a higher tonnage of material being classified as waste under current EU legislation (e.g. E-PRTR (Regulation EC No. 166/2006) and the Waste Framework Directive (2008/98/EC)). It may also reflect a real increase in waste production due to enhanced emission control measures (e.g. increased use of three-stage wastewater treatment and consequent rise in biological sludge production, increased use of ESP to remove dust from flue gases or an increase in the tonnage of material removed during remediation activities). In parallel, the total cost of refinery waste management also appears to have increased, from an inflation-adjusted figure of approximately 80 M$ in 1986 to 137.2 M$ in 2013.

An in-depth comparison of the 2013 survey and previous survey data is not possible due to changes in the reporting metrics used. For example, hazardous and non-hazardous wastes were not separately classified in the 1986 and 1993 surveys. The 2013 survey also includes significantly more detail on sources of wastes, waste management options and waste types. To protect confidentiality, only total costs of waste management were requested in the survey. Consequently detailed comparisons of costs is not possible as the scope of the cost calculation may vary between sites (for example, whether waste transport costs are included).

Table 12: Summary of past waste surveys

Year of Survey	Number of Responses	% Response	Total Waste in Millions of tonnes/yr	Relative waste production (tonnes/ktonne feedstock throughput)	Total Cost in Millions ($, unadjusted)[1]	Total Cost in Millions ($, approx. adjusted to 2013)[2]
1986	75	78	0.50	1.3	37.5	80
1993	89	93	1.16	1.9	72.7	117
2013	74	71	1.20[3]	2.6	137.2[4]	137.2[4]

[1] The reported waste management and costs do not include indirect costs, such as taxation, tank cleaning etc. As such, these totals should be considered minimum values.
[2] Indicative only: adjusted using Index: USCPI 31011913, United States
[3] 68 refineries provided hazardous and non-hazardous waste tonnage data for 2013
[4] 63 refineries provided data on waste management costs for 2013

10. CONCLUSIONS

10.1. ANALYSIS OF SURVEY DATA

The 2013 survey questionnaire was distributed to all 104 refineries operated by Concawe member companies. 74 refineries responded questionnaire which gave a response rate of 71%.

10.2. WASTE QUANTITIES AND SOURCES

Total reported waste production by the sector in 2013 was 1.2 million tonnes, of which 43% was classified as hazardous. The ratio of hazardous to non-hazardous waste was somewhat lower for the country groups Benelux, UK & Ireland and Central Europe. The reasons for it being lower in some country groups can be plenty (e.g. regional differences in how legislation is implemented), and future surveys may show if this is a meaningful trend that needs to be further analysed. However, it is important to note that because the survey is a snapshot in time, waste totals for certain country groups may be dominated by large one-off projects.

- The vast majority (94%) of refinery wastes were disposed of within the country of origin. The only waste exported outside the EU was non-hazardous spent catalyst.
- For hazardous wastes the range in relative waste production across the country groups is 0.44 to 1.99 tonnes/ kilotonne feedstock throughput, with a sector average of 1.07 tonnes/ kilotonne feedstock throughput. The highest relative waste production is reported in Central Europe, while the lowest is in UK & Ireland. For non-hazardous wastes the range in relative waste production across the country groups is 0.59 to 2.66 tonnes/ kilotonne feedstock throughput, with a sector average of 1.45 tonnes/ kilotonne feedstock throughput. The highest is again reported in Central Europe, while the lowest is in France. It is important to note that because the survey is a snapshot in time, waste totals for certain country groups may be dominated by large one-off projects. This is especially the case for wastes associated with construction, demolition and remediation.
- The top 3 reported hazardous wastes types are sludges (comprising tank bottoms, physical/chemical treatment, biological treatment and other), followed by spent chemicals/acids/bases and then contaminated soil/stones/aggregate/concrete (with approximately one third of these arising from remediation activities). Sludges constitutes 45% of the total hazardous waste reported, while spent chemicals/acids/bases and contaminated soil/stones/aggregate/concrete constitutes 14% and 12%, respectively.
- The top 3 non-hazardous wastes comprise soils/stones/aggregate/concrete, followed by metal and biological wastewater treatment sludges. Soils/stones/aggregate/concrete constitutes 65% of the total non-hazardous waste reported, while metal and biological wastewater treatment sludges constitutes 9% and 4%, respectively. The effort made by refineries to control emissions to land and water is evident in the fact that sludges from wastewater treatment and oil-impacted soil/stone/aggregate/concrete wastes together account for 53% of total reported hazardous waste.

An in-depth comparison of the 2013 survey and previous survey data is not possible due to changes in the reporting metrics used. For example, hazardous and non-hazardous wastes were not separately classified in the 1986 and 1993 surveys. However, a few observations can be made, such as that landfill use has reduced significantly, from 40% of total waste in 1993 to 20% in 2013. In parallel, the percentage of waste recycled has increased from 21% to 34% over the same period, showing the progress made by the refining sector over the past 20 years The percentage of waste used for energy recovery has reduced from 15% in 1993 to 7% in 2013, while the percentage of waste disposed of by incineration has reduced slightly from 8% to 6%. It should be noted that these figures may be distorted if wastes sent for treatment are ultimately disposed of by another route, such as energy recovery.

10.3. WASTE MANAGEMENT

The main management option for hazardous waste is treatment (24%), with the remaining tonnage split fairly evenly across the other management options. For non-hazardous waste, recycling is the dominant management option (49%), followed by landfill (29%). The single largest waste tonnage sent for landfill disposal, which could potentially move up the waste hierarchy, is non-hazardous soils/stones/ aggregate/concrete.

10.4. EWC CODES AND HAZARDOUS CODES

The top 10 EWC codes represent approximately 75% of the total hazardous or non-hazardous waste, and therefore represent the majority of the waste classifications used in the industry.

Significant transfer between EU member states was only reported for 3 three hazardous waste types: sulphuric & sulphurous acid; aqueous liquid wastes and spent catalyst. For these waste streams, it is likely that the specialist infrastructure required its waste management is not present in all EU Member States.

10.5. WASTE MANAGEMENT COSTS

The median cost of all hazardous waste management (316 $/tonne) is similar to the median country group cost for Baltic, Benelux and France. In Central Europe and Iberia the median cost is lower, at 63 $/tonne and 85 $/tonne, respectively, whereas in Germany, Mediterranean and UK & Ireland the median cost is closer to 500 $/tonne.

The median cost of all non-hazardous waste management (83 $/tonne) is similar to the median country group cost for Baltic, Central Europe and Iberia. In Benelux and Germany the median cost is lower at 20 $/tonne, whereas in France, Mediterranean and UK & Ireland the median cost is closer to 200 $/tonne.

10.6. COMPARISON OF REPORTED WASTE TONNAGE AND MANAGEMENT COSTS IN 1986, 1993 AND 2013 SURVEYS

A high level comparison of waste tonnage indicates an increase in total and, in particular, relative waste production from 1993 to 2013 despite the number of reporting refineries decreasing from 89 to 74. The increase may be associated with a higher tonnage of material being classified as waste under current EU legislation (e.g. E-PRTR (Regulation EC No. 166/2006) and the Waste Framework Directive (2008/98/EC)). It may also reflect a real increase in waste production due to enhanced emission control measures (e.g. increased use of three-stage wastewater treatment and consequent rise in biological sludge production, increased use of ESP to remove dust from flue gases or an increase in the tonnage of material removed during remediation activities).

In parallel, the total cost of refinery waste management also appears to have increased, from an inflation-adjusted figure of approximately 80 M$ in 1986 to 137.2 M$ in 2013.

11. OPPORTUNITIES FOR IMPROVEMENT IN FUTURE WASTE SURVEYS

In general, any future surveys would benefit from reduced use of categories that are ambiguous with regard to the final management option of wastes e.g. "multiple/other" and "treatment". The challenge, however, in addressing this is that refineries would have to retrieve this data from their waste management contractors, which would add to the complexity of the exercise.

The category referring to chemical waste needs to be more clearly defined and explained in the next survey questionnaire, because different survey respondents interpreted it differently.

Information on activities included in the reported costs was only provided by 32% of survey respondents, and respondents provided a written description of which costs were included. This varied greatly from one site to another and so a statistical analysis of cost vs. waste management options was not feasible. In future surveys this could be addressed by providing a checklist of activities included the total cost (e.g. tank cleaning, taxation, etc.) to increase the response rate and align the cost metrics.

As mentioned above, the collection of more detailed information on waste management is difficult because this data is often held by waste management contractors. In future this could be addressed by reducing the scope of surveys to address specific areas of interest (e.g. how the definition of "treatment" varies between member states), with the current report being used as a reference point.

12. GLOSSARY

API = American Petroleum Institute

CH = Switzerland

CLP = Classification, Labelling and Packaging

CPI = Corrugated Plate Interceptor

DAF = Dissolved Air Flotation

E-PRTR = European Pollutant Release and Transfer Register

ESP = Electrostatic Precipitator

EU-28 = Abbreviation of European Union (EU) which consists a group of 28 countries

EWC = European Waste Catalogue

FCC = Fluid Catalytic Cracking

FGD = Flue Gas Desulphurisation

HP = Hazardous Properties

IAF = Induced Air Flotation

JV = Joint Venture

NO = Norway

PCB = Polychlorinated biphenyl

PLN = Polish Zloty

QA/QC = Quality Assurance and Quality Control

WEEE = Waste Electrical & Electronic Equipment

WsFD = Waste Framework Directive

WWTP = Waste Water Treatment Plant

13. ACKNOWLEDGEMENTS

The project team would like to acknowledge the support received from refineries in assembling the waste data, and in particular the refinery focal points.

We would also like to acknowledge the contribution of the member company experts for their detailed review and critique of the report.

14. REFERENCES

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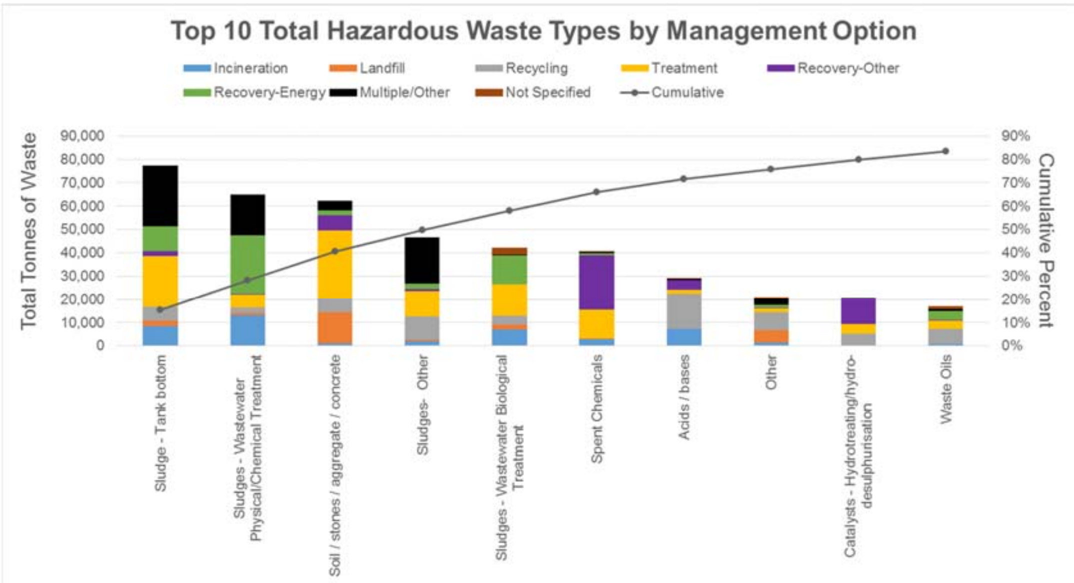
APPENDIX 1: 2013 WASTE SURVEY QUESTIONNAIRE

APPENDIX 2: TOP 10 WASTE TYPES PER WASTE MANAGEMENT OPTION

Figure A2.1. Top ten hazardous and non-hazardous waste types partitioned by management option



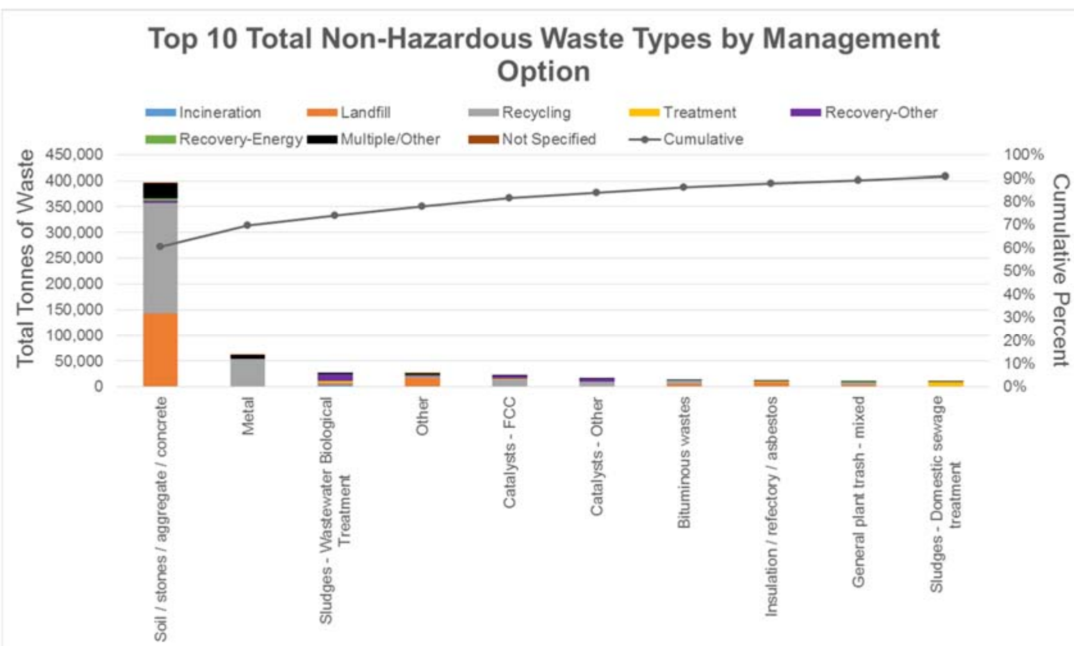


Figure A2.2. Hazardous sludge tank bottom by management option partitioned by country group.

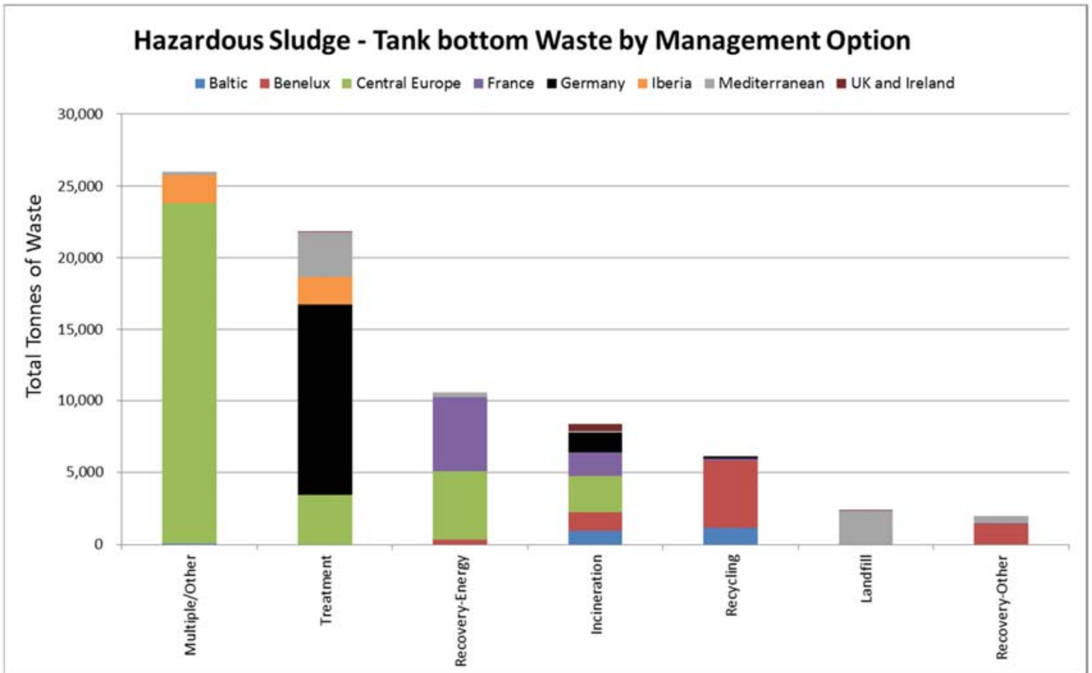


Figure A2.3. Hazardous physical treatment wastewater sludge by management option partitioned by country group.

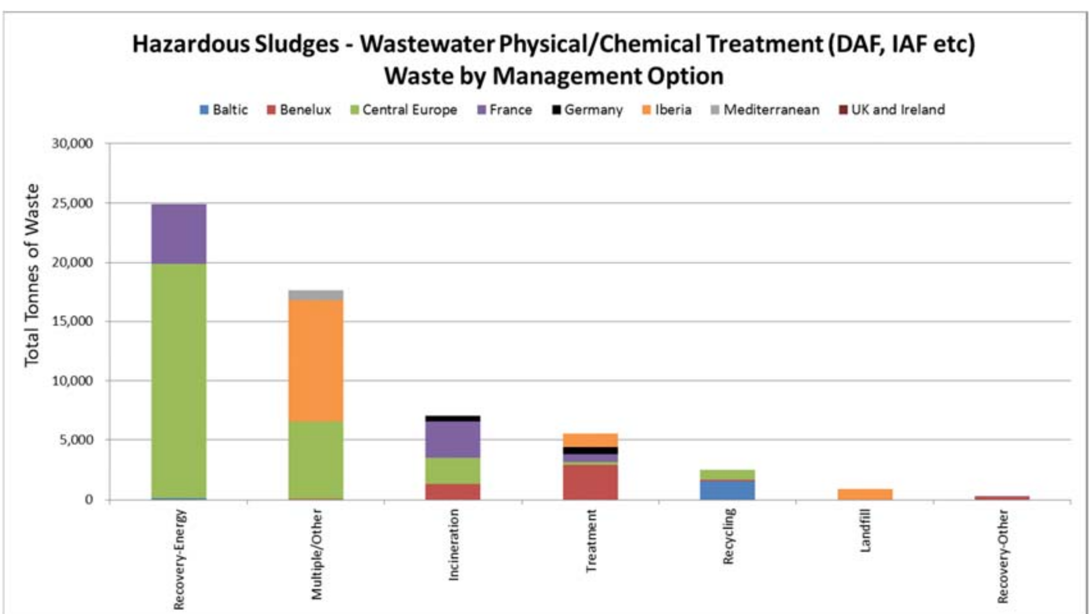


Figure A2.4. Hazardous Soil / stones / aggregate / concrete waste by management option partitioned by country group.

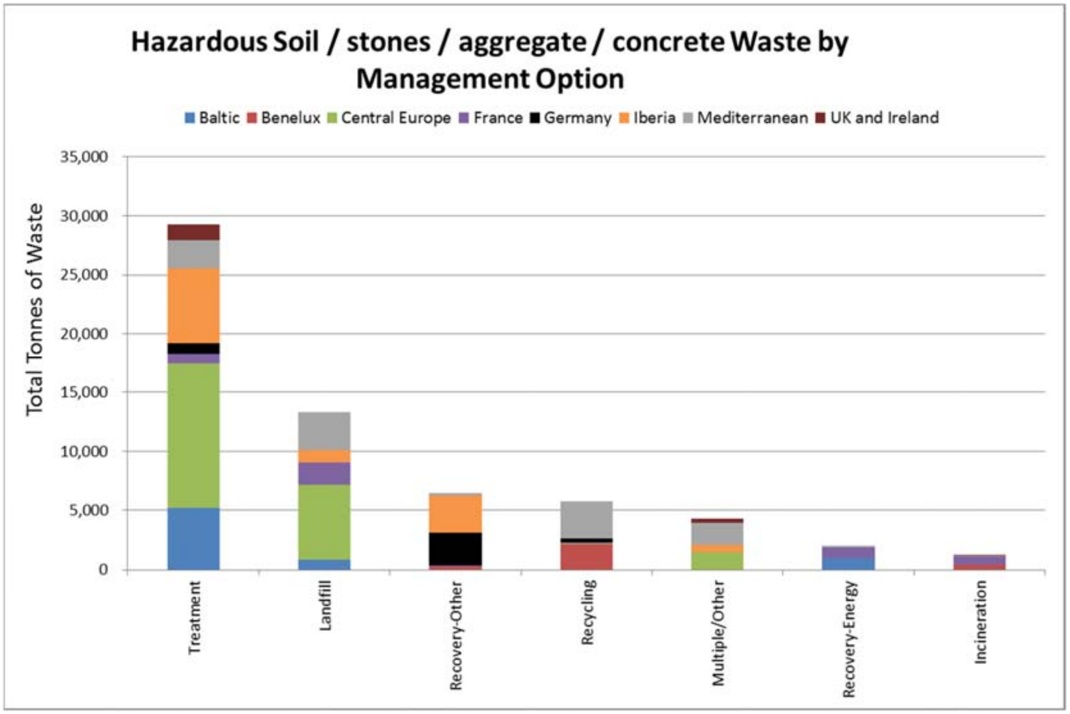


Figure A2.5. Hazardous sludges-other waste by management option partitioned by country group.

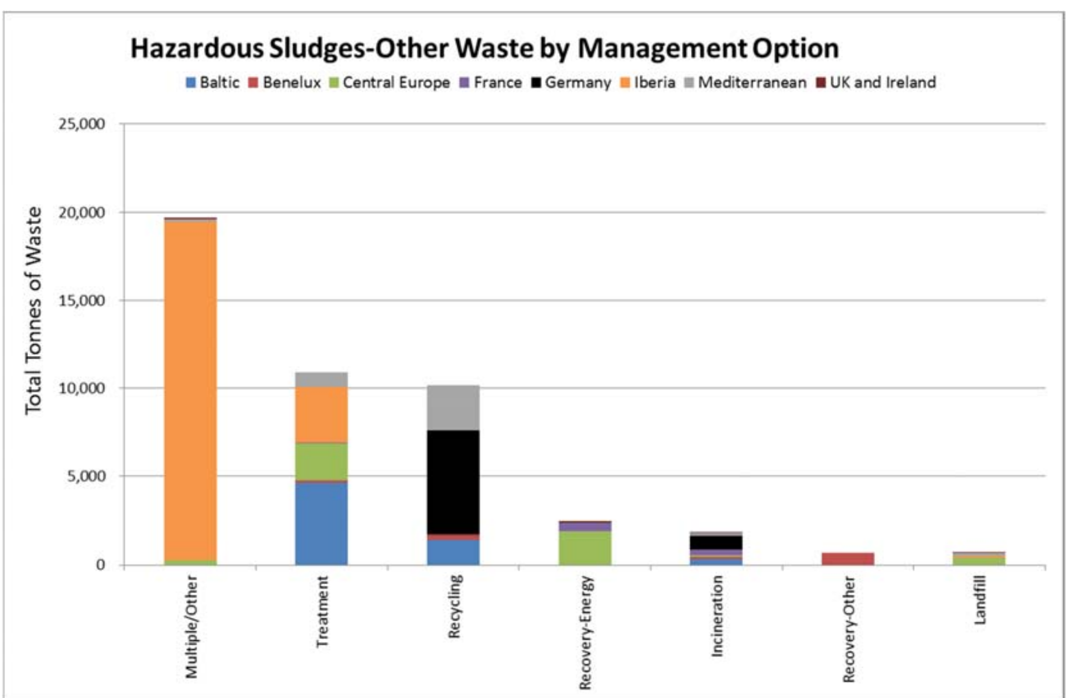


Figure A2.6. Hazardous sludges-biological wastewater treatment waste by management option partitioned by country group.

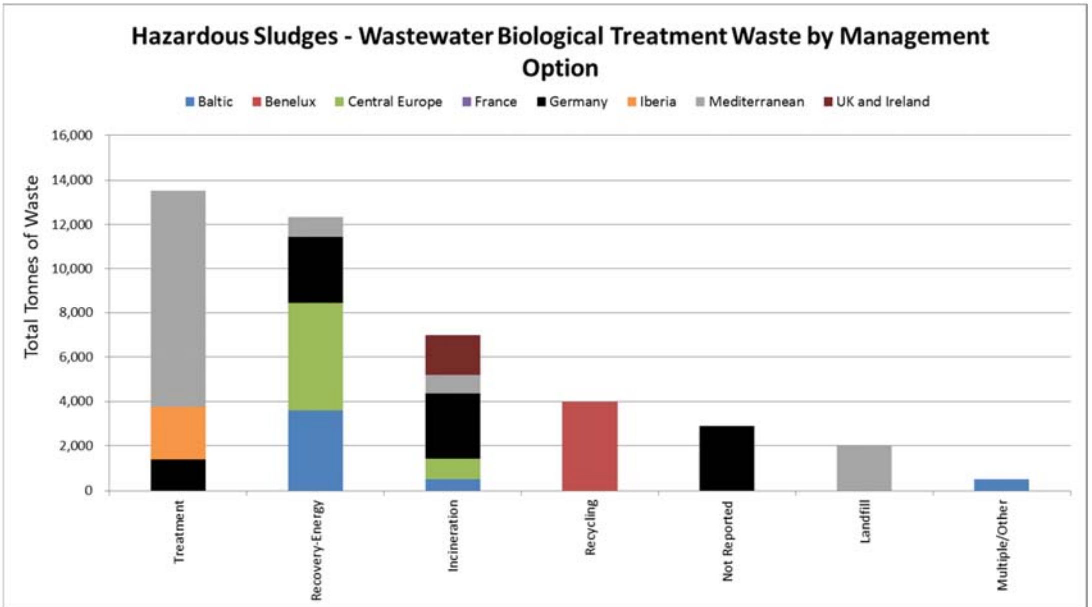


Figure A2.7. Hazardous spent chemical waste by management option partitioned by country group.

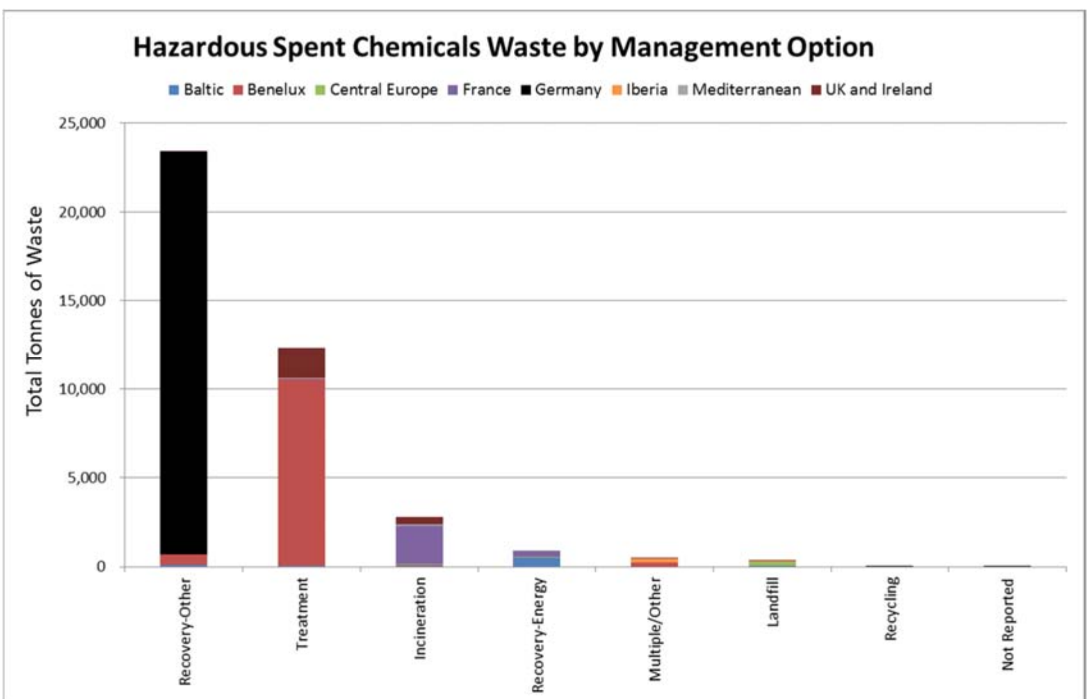


Figure A2.8. Hazardous acid and base waste by management option partitioned by country group.

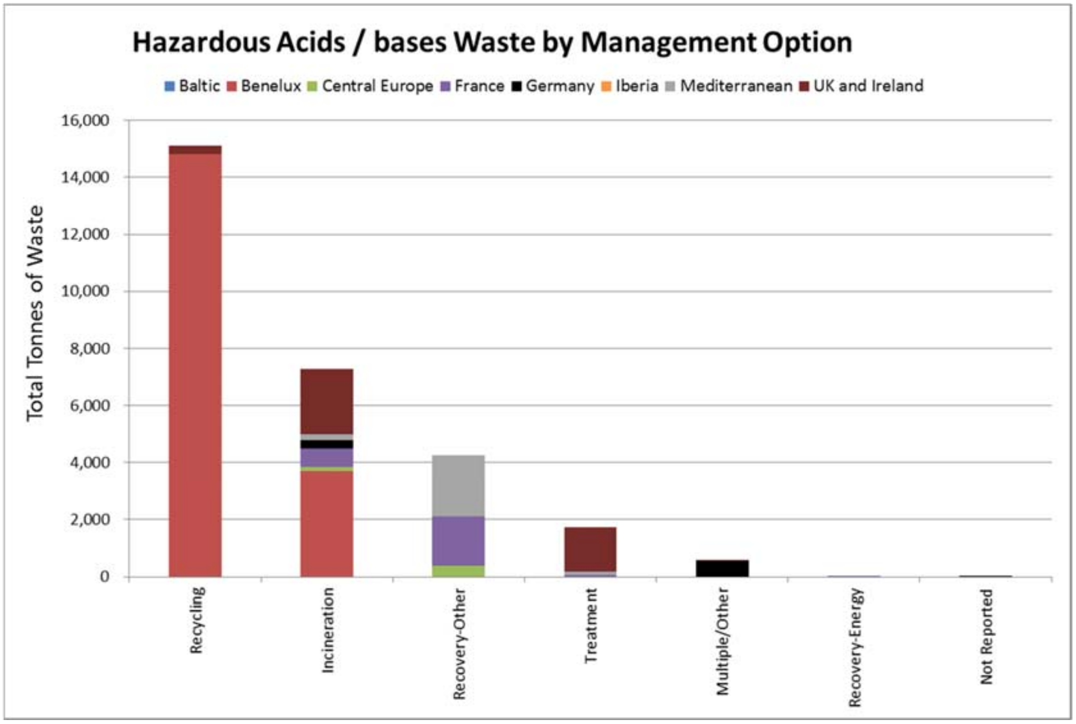


Figure A2.9. Hazardous other waste by management option partitioned by country group.

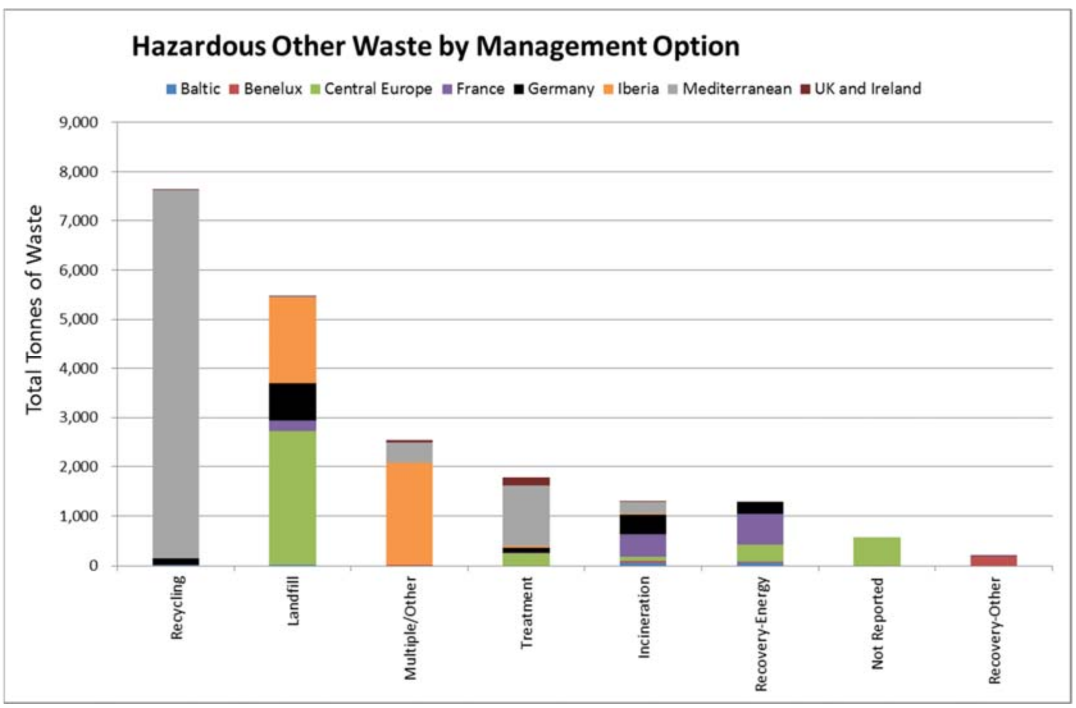


Figure A2.10. Hazardous Catalysts - Hydrotreating/hydrodesulphurization waste by management option partitioned by country group.

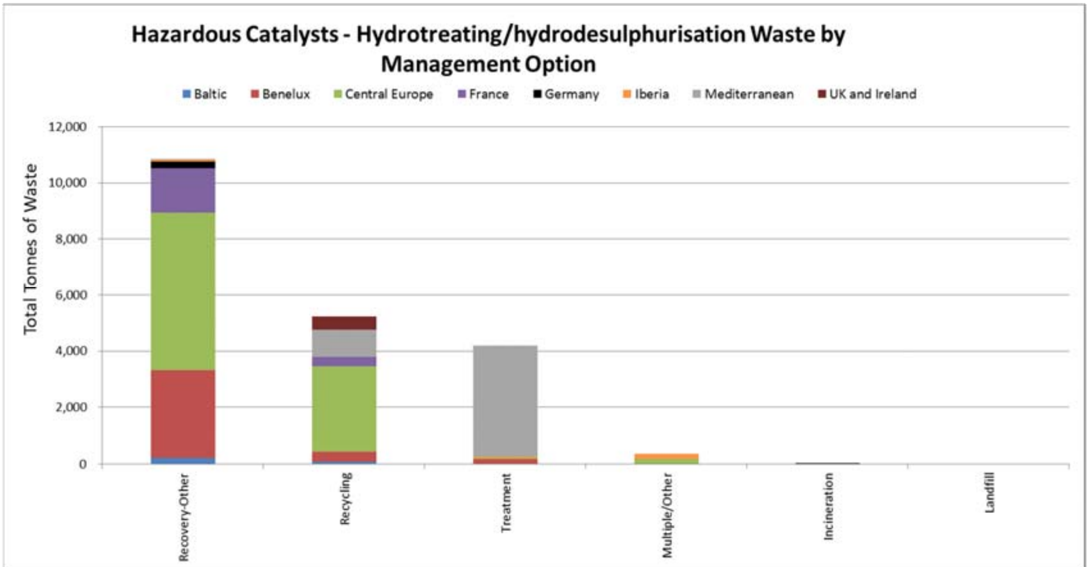


Figure A2.11. Hazardous waste oils waste by management option partitioned by country group.

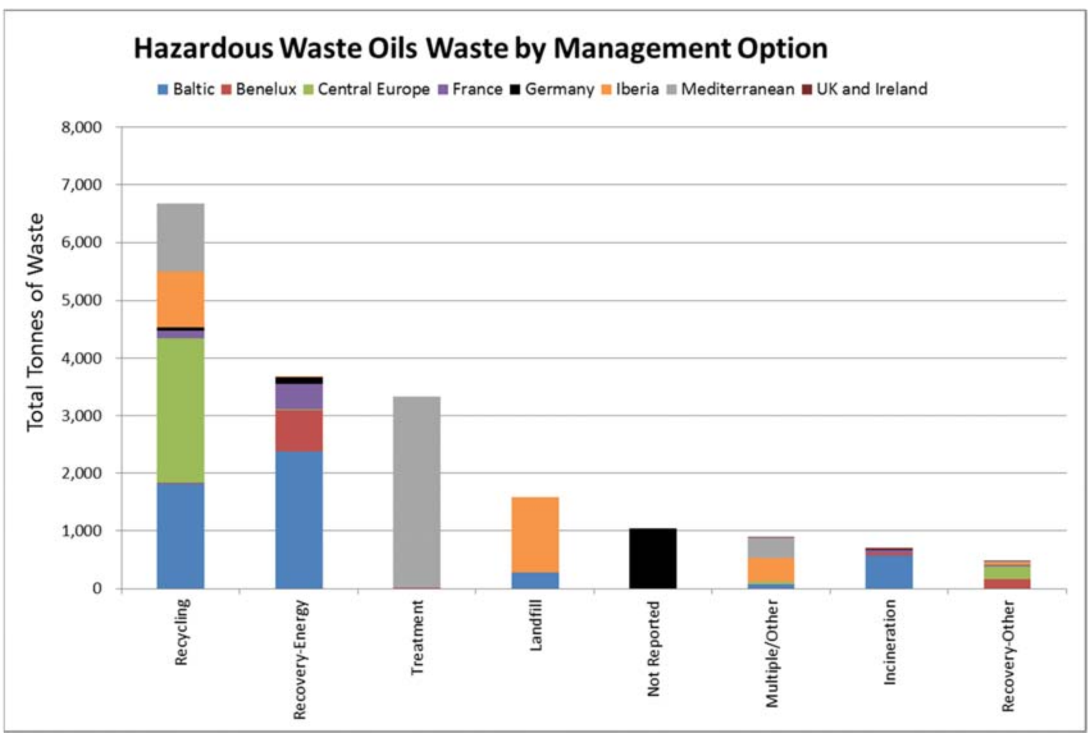


Figure A2.12. Non-hazardous Soil / stones / aggregate / concrete waste by management option partitioned by country group.

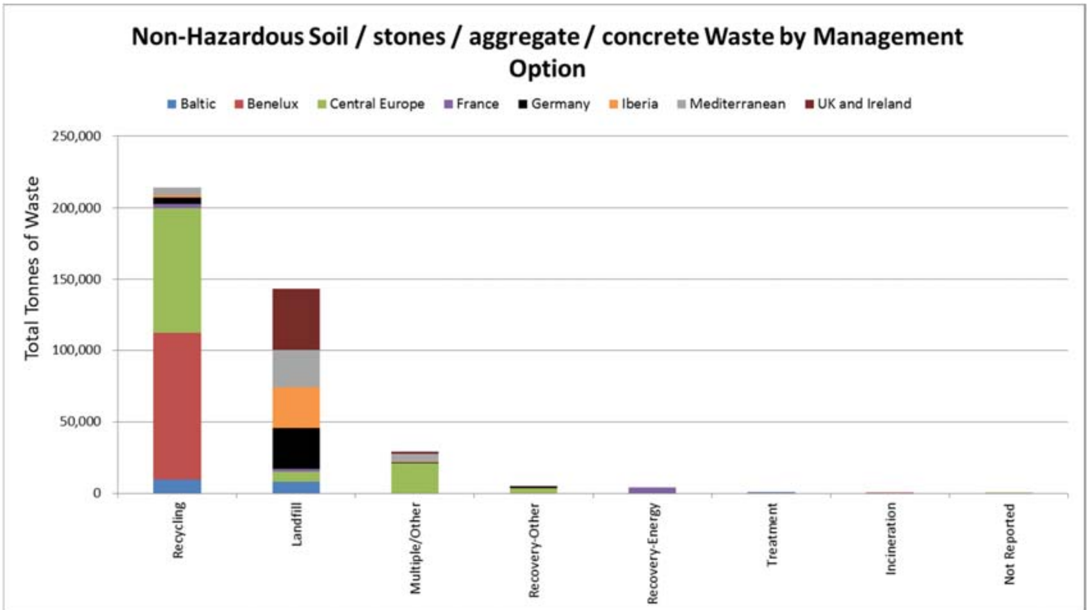


Figure A2.13. Non-hazardous metal waste by management option partitioned by country group.

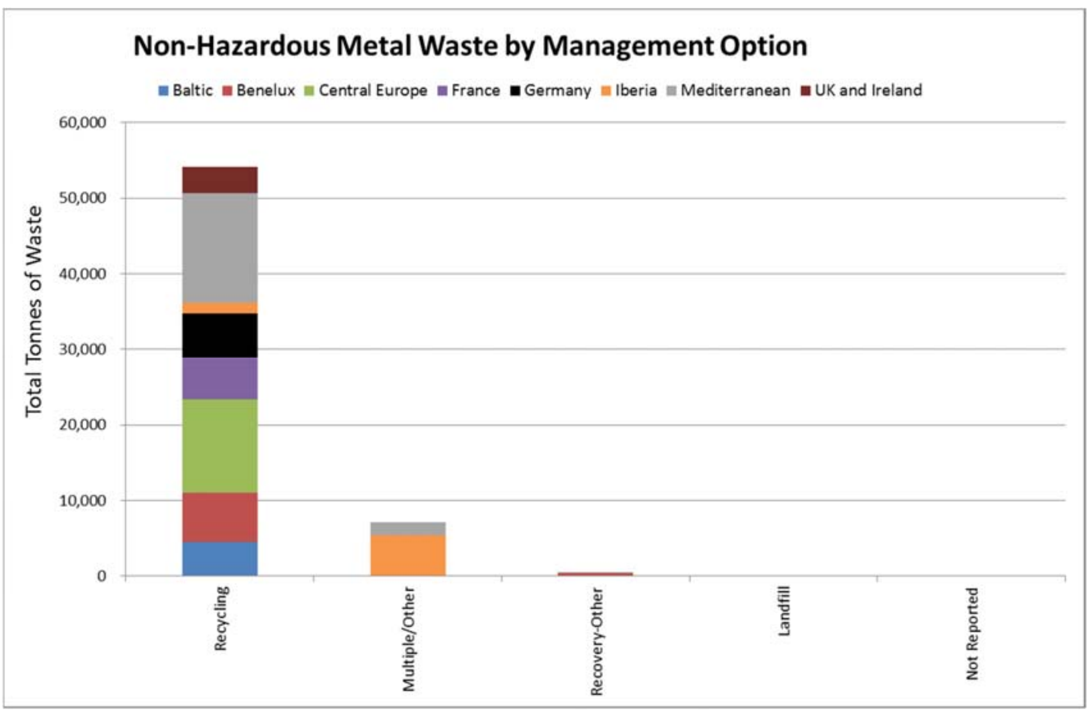


Figure A2.14. Non-hazardous Sludges - Wastewater Biological Treatment waste by management option partitioned by country group.

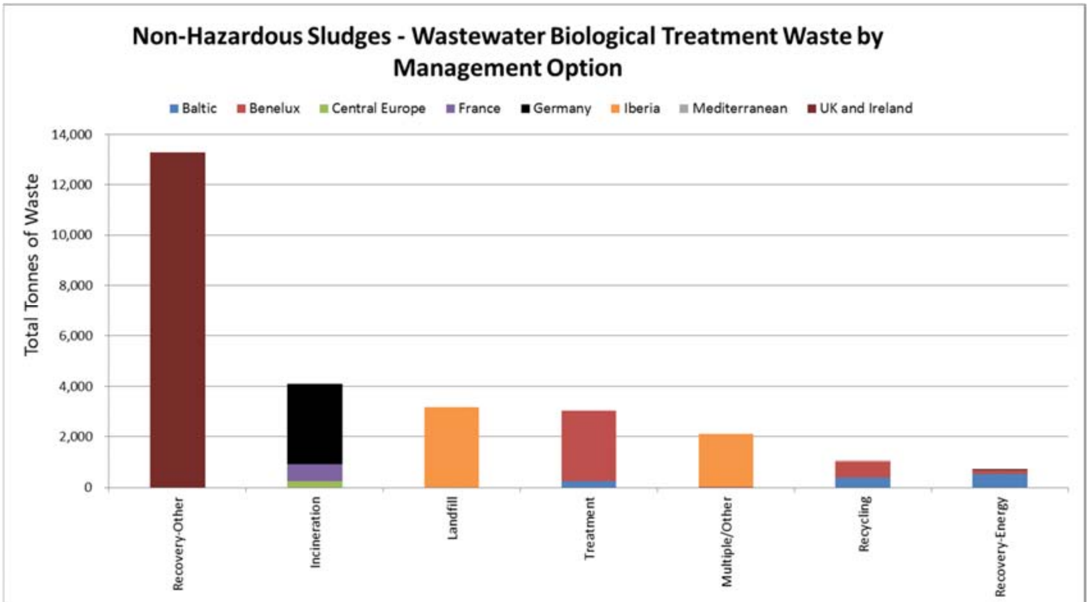


Figure A2.15. Non-hazardous other waste by management option partitioned by country group.

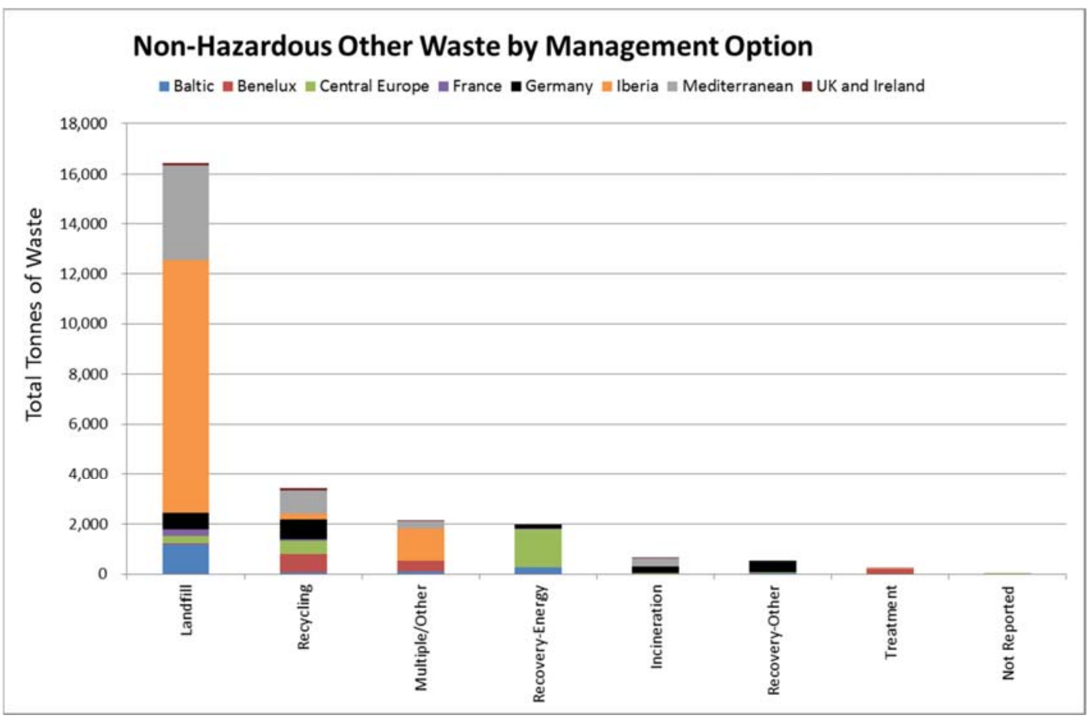


Figure A2.16. Non-hazardous Catalysts – FCC waste by management option partitioned by country group.

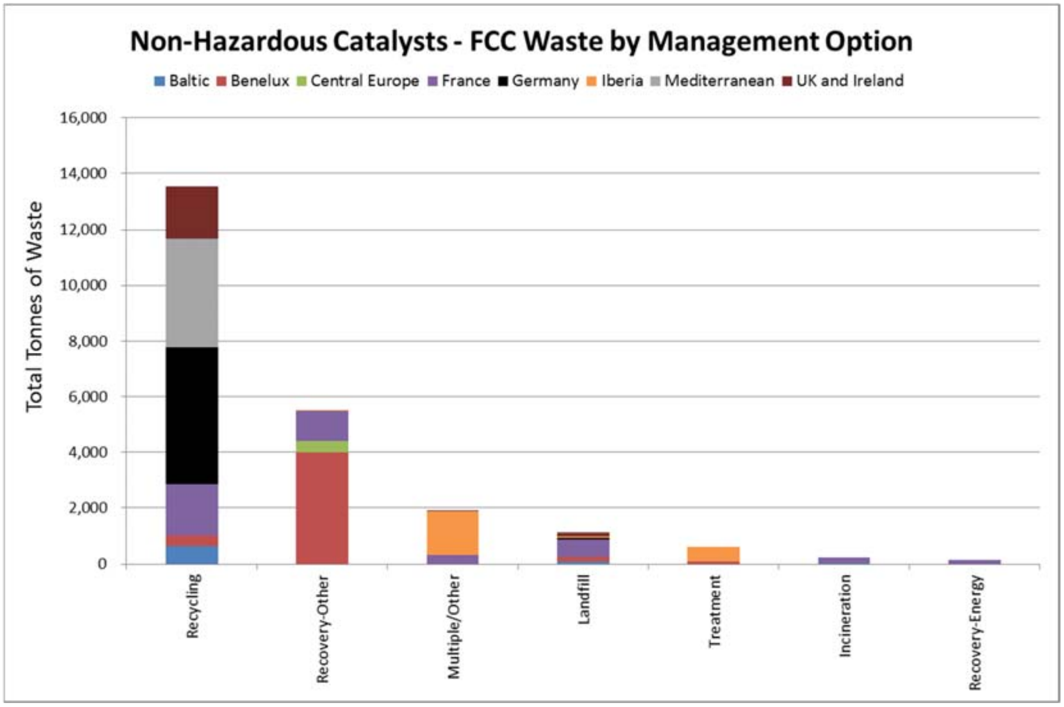


Figure A2.17. Non-hazardous Catalysts – other waste by management option partitioned by country group.

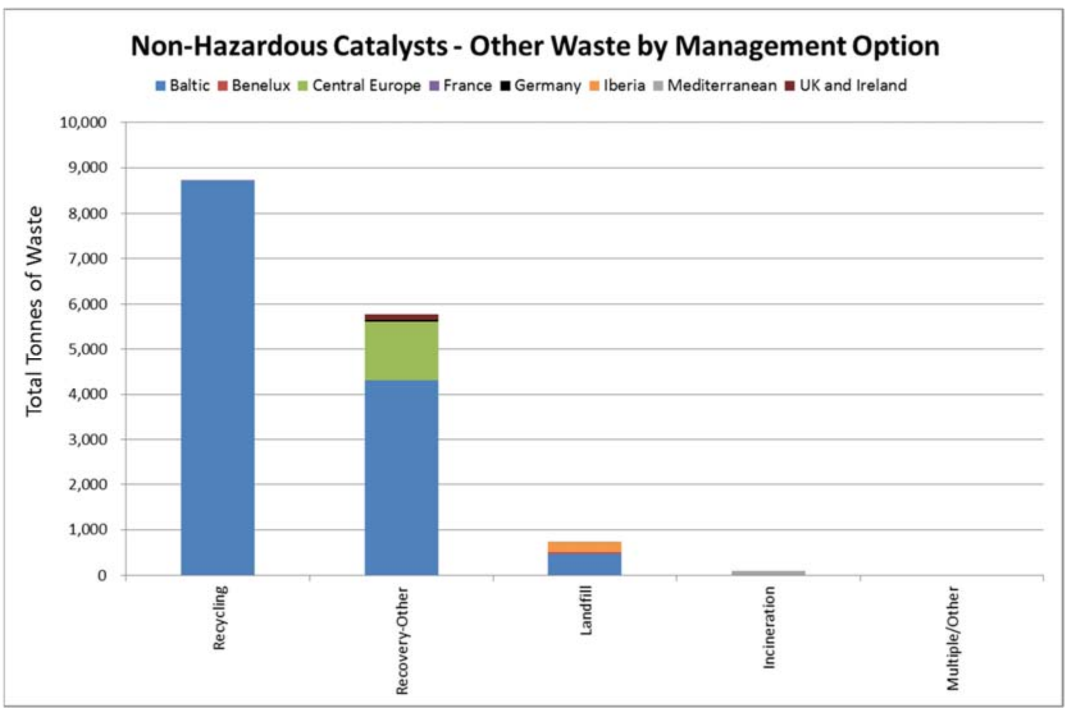


Figure A2.18. Non-hazardous Bituminous wastes by management option partitioned by country group.

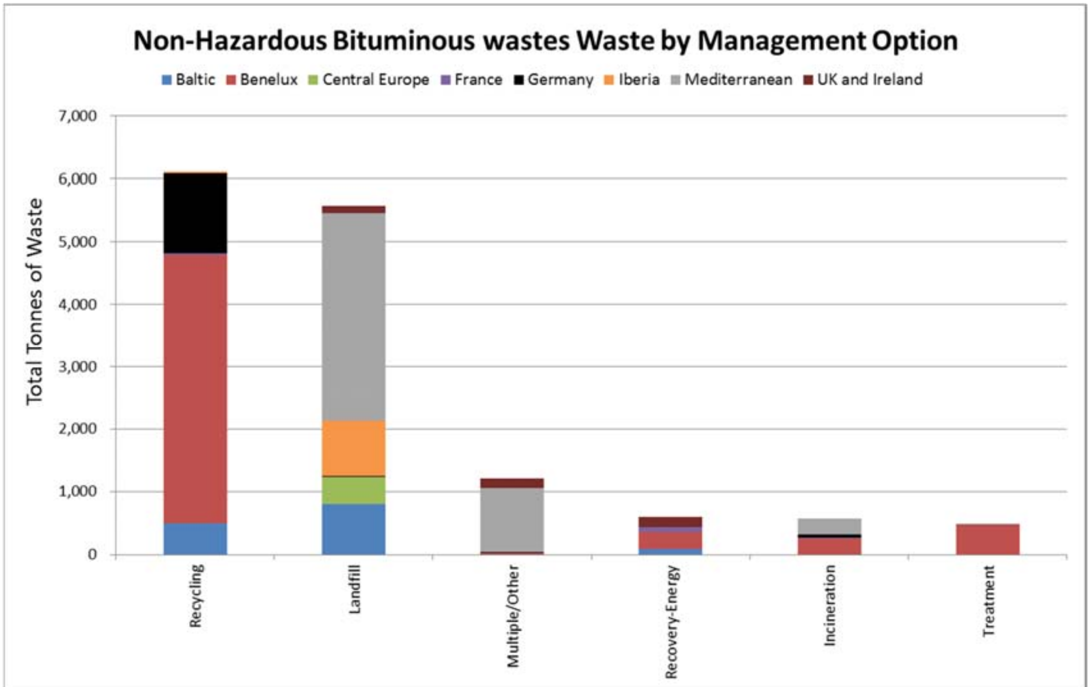


Figure A2.19. Non-hazardous Insulation / refectory / asbestos waste by management option partitioned by country group.

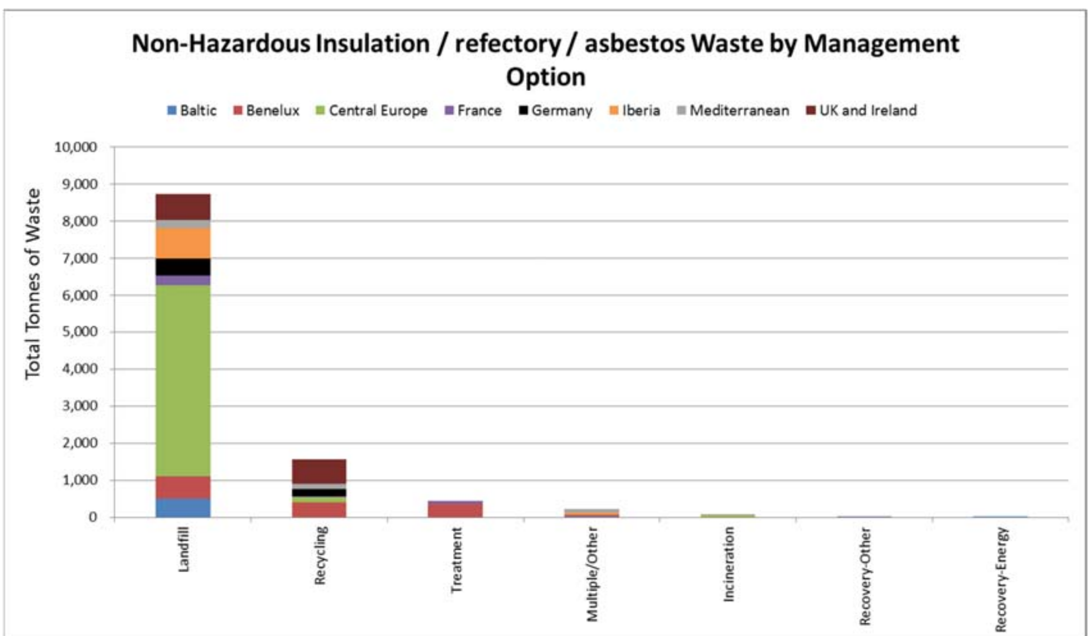


Figure A2.20. Non-hazardous general plant trash waste by management option partitioned by country group.

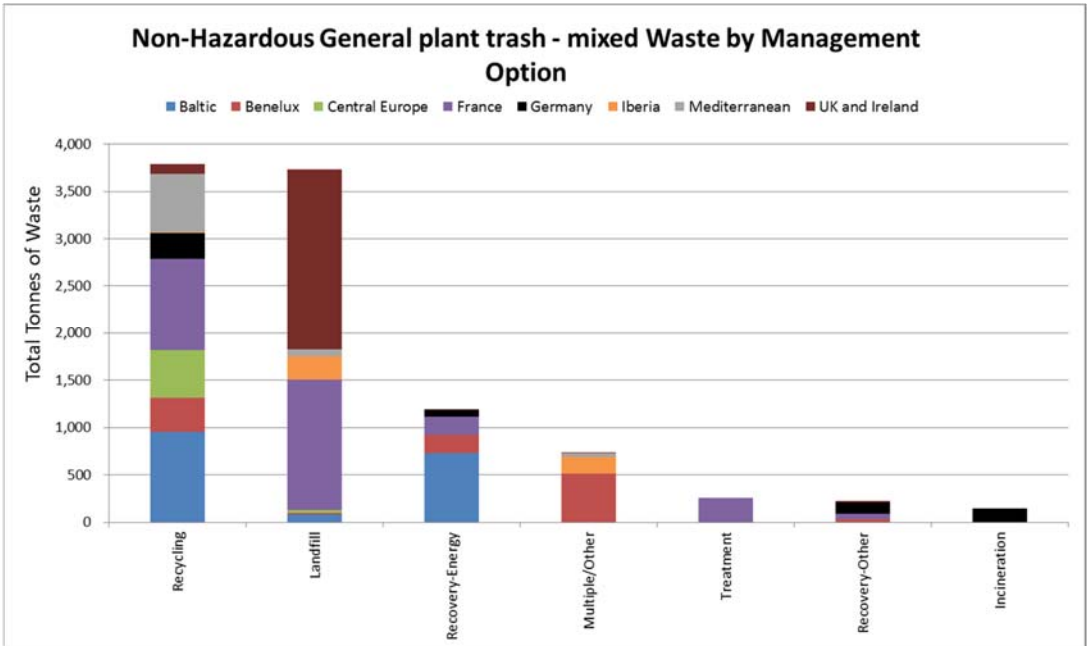
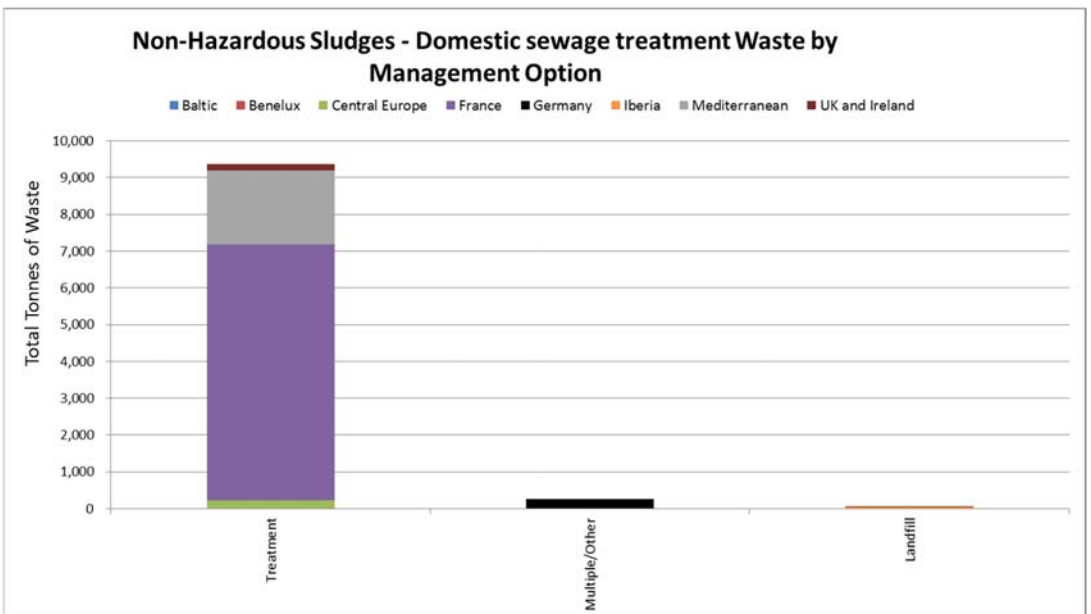


Figure A2.21. Non-hazardous domestic sewage treatment sludge waste by management option partitioned by country group.



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