Concawe
Environmental Science for European Fuel Manufacturing

Report

Report no. 12/23

A Survey on European Refineries Waste with Focus on Waste Sludges 2019-2021

ISBN 978-2-87567-179-0

9 782875 671790

A Survey on European Refineries Waste with Focus on Waste Sludges 2019-2021

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Thanks for their contribution to:

Concawe Special Task Force on Fuel Manufacturing Waste (WQ/STF-36)

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ABSTRACT

This report provides a statistical analysis of waste production by Concawe member company refineries in the years 2019, 2020 and 2021, based on survey data returned from 68 member company refineries (70.1% response rate) situated in the EU-27 countries + UK, 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). Given the identification of tank bottom sludges and waste water effluent sludges in the previous survey of 2013 waste data (Concawe; 12/17), this report also provides a focus on the sources and management options for refinery oily sludges. The findings from this survey, together with those of previous Concawe waste surveys for 1986 (Concawe; 5-89), 1993 (Concawe; 1-95), and 2013 (Concawe; 12/17), 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.

KEYWORDS

Waste, European refinery waste, waste survey, waste framework directive, waste

production, waste management options, waste classification codes, waste hazard codes, waste sludges, refinery sludges.

INTERNET

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

CONTENTS

			Page
SUMMARY			**VI**
1.	**INTRODUCTION**		**1**
2.	**SURVEY DESIGN**		**3**
	2.1.	INTRODUCTION	3
	2.2.	WASTE WORKSHEET (DATA INPUT)	3
	2.3.	DATA QA/QC	6
3.	**SURVEY RESPONSE**		**7**
4.	**DATA AGGREGATION AND THROUGHPUT**		**9**
5.	**WASTE QUANTITIES AND SOURCES**		**12**
	5.1.	TOTAL AND RELATIVE WASTE PRODUCED AND ITS SOURCES	12
	5.1.1.	Total and Relative Waste Produced	12
	5.1.2.	Total Waste Produced by Source	15
	5.1.3.	Types of Wastes Produced	16
	5.2.	TOTAL AND RELATIVE SLUDGE WASTE PRODUCED AND ITS SOURCES	17
	5.2.1.	Total and Relative Sludge Waste Produced	17
	5.2.2.	Total Sludge Waste Produced by Source	19
	5.2.3.	Waste Sludge Categories	20
	5.3.	SOURCES OF OTHER “TOP FIVE” WASTE CATEGORIES	23
	5.3.1.	Soil and Stones	23
	5.3.2.	Aqueous liquid wastes containing hazardous wastes (EWC 16 10 01*)	25
	5.3.3.	Iron and Steel	26
6.	**WASTE MANAGEMENT OPTIONS**		**28**
	6.1.	INTRODUCTION	28
	6.2.	MANAGEMENT OPTIONS FOR TOTAL HAZARDOUS AND NON-HAZARDOUS WASTES	29
	6.3.	MANAGEMENT OPTIONS FOR WASTE SLUDGES	34
	6.3.1.	Management Options for Hazardous and Non-hazardous Waste Sludges	34
	6.3.2.	Relationship between Sludge Separation Techniques and Management Options	41
	6.3.3.	Separation and Management Options for Sludges from Crude and Non-Crude Throughputs	43
	6.4.	MANAGEMENT OPTIONS FOR OTHER TOP WASTE CATEGORIES	44
	6.4.1.	Soils and Stones	44
	6.4.2.	Aqueous Liquid Wastes Containing Hazardous Substances	46
	6.4.3.	Management Options of Iron and Steel	47
7.	**CONCLUSIONS**		**48**
	7.1.	ANALYSIS OF SURVEY DATA	48
	7.2.	WASTE QUANTITIES AND SOURCES	48
	7.3.	TOTAL WASTE MANAGEMENT	49
	7.4.	SLUDGES WASTE MANAGEMENT	49

8. GLOSSARY 51

9. REFERENCES 52

APPENDIX A: SLUDGE TREATMENT TO DISPOSAL SANKEY DIAGRAMS. 53

LIST OF FIGURES

Figure 1. Responses per Concawe Country Groupings 7
Figure 2. Concawe Country Groupings 8
Figure 3. Number of responding refineries per throughput feedstock type 10
Figure 4. Total Throughput in Tonnes for 2013, 2019, 2020 and 2021 11
Figure 5. Total Throughput for refineries that responded to both the 2013 and 2019-2021 surveys. 11
Figure 6. Total Waste Produced in Tonnage (2013, 2019, 2020 and 2021) 12
Figure 7. Relative Waste Produced by Tonnage (2013, 2019, 2020 and 2021) 13
Figure 8. Total Amount of Waste per Country Groupings and Survey Year 13
Figure 9. Relative Waste Tonnage per Country Grouping 14
Figure 10. Relative Hazardous Waste 2019-2021 15
Figure 11. Total Hazardous and Non-Hazardous Waste by Source 2019-2021 15
Figure 12. Top Ten EWC Waste Categories by Tonnage (2019-2021) 16
Figure 13. Top Ten EWC Waste Categories by Tonnage for 2019, 2020 and 2021 17
Figure 14. Tonnage of non-sludge and sludge wastes 2019, 2020 and 2021 18
Figure 15. Total Hazardous and Non-Hazardous Waste Sludges per Country Group 18
Figure 16. Relative Hazardous and Non-Hazardous Waste Sludges per Country Group 19
Figure 17. Total Sludge Waste Produced by Source 20
Figure 18. Top Ten Waste Sludges per Tonnage 2019-2021. 21
Figure 19. Top Three Total Waste Sludges per Country Grouping (EWC 05 01 09*: Waste water treatment sludges; EWC 05 01 06*: Sludges from refinery operations; EWC 05 01 03: Tank Bottoms sludges). 22
Figure 20. Top Three Relative Waste Sludges per Country Grouping (EWC 05 01 09*: waste water treatment sludges; EWC 05 01 06*: sludges from refinery operations; EWC 05 01 03: tank bottoms sludges). 22
Figure 21. Sources of non-hazardous soils and stones 24
Figure 22. Sources of hazardous soils and stones 25
Figure 23. Sources of Aqueous Liquids containing hazardous substances 26
Figure 24. Sources of Iron and Steel per Country Group 27
Figure 25. EU Waste Hierarchy 28
Figure 26. Total Hazardous and Non-Hazardous Waste per Recovery and Disposal Management Options (quantities in tonnes) 30
Figure 27. Waste Quantity by Disposal Type per Year 31
Figure 28. Total Waste Tonnage by Management Location 32
Figure 29. Total Waste by Management Option 2019-2021 33
Figure 30. Hazardous and Non-Hazardous Sludge Wastes by Management Option 35
Figure 31. Total Hazardous Sludge Waste by Management Option and Country Groupings 36
Figure 32. Relative Hazardous Sludge Waste by Management Option and Country Groupings 36
Figure 33. Total Non-Hazardous Waste per Management Option and Country Groupings 37
Figure 34. Relative Non-Hazardous Waste per Management Option and Country Groupings 37
Figure 35. Hazardous and Non-Hazardous Sludge Waste Separation Technologies 38
Figure 36. Percentage of Oil Treatment Options after Sludge Separation 39
Figure 37. Management Options of Water After Separation form the Sludge Waste 39
Figure 38. Sludge Waste Further Treatment After Separation 40
Figure 39. Management Options for Top Three Sludge Wastes for Crude and Non-Crude Throughputs 43

Figure 40. Separation Techniques and Management options for tank bottoms, wastewater effluent and maintenance sludges associated with non-fossil throughputs. 44
Figure 41. Management Options for Soils and Stones Waste Category (EWC 17 05 04)....................... 45
Figure 42. Management Options for Soils and Stones Containing Hazardous Substances Waste Category (EWC 17 05 03*) 46
Figure 43. Management Options for Aqueous Liquid Wastes Containing Hazardous Substances (EWC 16 10 01*).. 46
Figure 44. Management Options for Iron and Steel per Country Group 47

LIST OF TABLES

Table 1. List of Wastes Categories 4
Table 2. Waste Sources Categories... 5
Table 3. Generic Recovery and Disposal Route Categories 5
Table 4. List of available selection options for sludge waste pre-treatment....................................... 6
Table 5. Crude and Non-Crude Throughputs per Concawe Country Groupings................................. 9
Table 6. Estimated average refineries capacity/throughput ratios for crude and non-crude feedstocks 10
Table 7. Normalised sludges tonnage for 2013, 2019, 2020 and 2021 for three largest waste sludges categories produced (in tonnes of sludge waste per kiloton of total throughput)............... 23
Table 8. Waste Management Options Groupings... 29
Table 9. Percentages of Total Waste by Management Options for 2013 and 2019-2021.................. 33

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 the years 2019, 2020 and 2021. The report includes a statistical analysis of waste production, waste types, waste sources and management options reported under different 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 waste survey was constructed in the form of an Excel spreadsheet that was sent to 87 Concawe member refinery companies. 68 refineries responded to the questionnaire which gave a response rate of 78.16% (70.1 % when considering all operating Concawe member refinery companies in Europe). Total waste production reported by the refining sector in the 2019-2021 period was 3.6 million tonnes, of which 47.3% was classified as hazardous. The vast majority (95%) of refinery wastes were disposed within the country of origin.

When relative tonnage is considered (tonne of waste produced by kiloton of throughput) Germany Country Group presented the highest relative waste with an average of 4.85 t/kt, while Iberia Country Group had the lowest relative tonnage with 1.83 t/kt for the average of the three years period.

The top 3 reported wastes types by tonnage are soil and stones not containing hazardous substances, sludges from on-site effluent treatment containing hazardous substances and soil and stones containing hazardous substances. The top 3 reported waste sludges by tonnage were sludges from on-site effluent treatment containing hazardous substances, sludges from maintenance operations and tank bottom sludges, all three representing approximately 62.8% of all waste sludges reported for the three-year period. Most waste (62.6%) originated from refinery operations, followed by re-construction works (11.5%) and diverse sources (10%).

Approximately 60% of the total waste generated underwent some form of recovery, while the remaining of the waste was managed by disposal options. Recycling comprised the largest amount of waste in every year of the survey period with over 300,000 tonnes of waste handled through this option each year. The second largest reported waste management category was landfilling. Incineration and incineration with energy recovery were the two largest management options for waste sludges. These were followed by landfill, recycling and treatment, all with similar tonnages of hazardous sludges and less amounts of non-hazardous sludges.

Approximately 35% of the sludge waste did not undergo any form of pre-treatment prior to disposal, while for another 20% data on pre-treatment was not provided. Centrifugal thickening was the main separation technique used, followed by decantation and gravity and flotation thickening. Water separated from the sludge waste was treated primarily onsite by biological treatment (42%). No clear management preferences were observed for individual sludge separation techniques.

Sludges derived from non-crude feedstock used less management options than those from crude feedstock. Incineration and recovery-energy were the predominant management options for non-crude waste water sludges while landfill, followed by incineration and treatment constituted the main management options for non-crude tank bottoms and maintenance sludges.

1. INTRODUCTION

Concawe and its members want to proactively contribute to the circular economy as well as to prepare for an upcoming revision/proposal of the Water Framework Directive and other legislative activities regarding 'zero pollution', and the adoption by the European Commission of the Circular Economy package' aimed to develop a more circular economy.

The circular economy refers to an economic model whose objective is to produce goods and services in a sustainable manner, limiting the waste of resources and the production of waste. It involves breaking with the traditional model of a linear economy (extract, manufacture, consume, throw away) and transforming what was once considered 'inevitable' waste into a valuable resource.

A previous review of European refineries waste data (Concawe Report 12/17) showed that Waste Water Treatment (WWT) and hydrocarbon sludges were the most significant part of refinery waste sludges in terms of tonnages. With a view to understand how Concawe members can contribute further to the circular economy, this project aimed to collect more recent waste data, via a survey, regarding total refinery waste management with particular focus on sludge waste management. In addition, Concawe also seeks to take advantage of this survey to understand if there is a difference in waste sludge management depending on if non-fossil feedstock(s) are (co)-processed at plant, notably vegetable oils and used cooking oils.

While the 2013 (published in November 2017) waste survey utilised data from the 2013 reporting year, the survey discussed in this report collected and analysed data for a three- year period (2019 to 2021) to account for the variability of the quantities of waste produced from one year to the next, often do to large one-off projects.

This 2023 report provides a summary of the industry management of total wastes and sludges based on questionnaire responses, and it complements and updates the 2013 waste survey by addressing the following analyses:

- Total refineries waste and their breakdown into hazardous and non-hazardous waste.
- Waste tonnage sent to different management options as per the Waste Framework Directive defined options (landfill, recovery, treatment).
- Types of waste (per EWC codes)[1] routinely sent to landfill.
- The amounts of waste sludge produced in tonnes & rate of waste generation 'normalised' by feedstock throughput).
- Management options for hazardous and non-hazardous waste sludges including pre-treatment methods.
- The amounts of waste sludge sent to landfill and treatment, respectively, per EWC code in tonnes and by feedstock throughput.
- The main barriers for not having the waste sludge going to treatment.

[1] EWC stands for European Waste Codes, a hierarchical list of waste descriptions established by Commission decision 2000/532/EC2

- Any difference in waste and waste sludge management depending on if non-fossil feedstock(s) are (co)-processed at plant, notably vegetable oils and used cooking oils.
- Relevant comparisons with previous Concawe Waste Survey Report (2013 data) to show if/how the industry performance has changed.

2. SURVEY DESIGN

2.1. INTRODUCTION

The waste survey was constructed in the form of an Excel spreadsheet that was sent to the participating refineries for completion. The excel survey form contained questions on types and quantities of wastes generated in the years 2019, 2020 and 2021, including their EWC codes. If a sludge waste type was selected, the form allowed the user to unlock additional cells with pull down options to collect additional pertinent detail information such as the pre-treatment technologies used, barriers to the treatment of sludges, location of sludges treatment (onsite/offsite), and whether treatment was carried out in country or abroad.

The waste survey consisted of one information worksheet, two data input worksheets, a submissions worksheet and a summary worksheet, as follows:

- Information worksheet: provided instructions how to fill in the survey.
- Site Identification Form: to be filled in with site name, contact name and refinery crude and non-crude throughput for 2019, 2020 and 2021.
- Waste Worksheet: allowed entry of each waste type reported per EWC code and per year.
- Submission worksheet: listing all entries per EWC code and including total amount of waste and additional responses if the waste was a sludge.
- Summary worksheet: showing total amount of hazardous and non-hazardous waste per year and corresponding amount per disposal and recovery (D or R Code).

2.2. WASTE WORKSHEET (DATA INPUT)

Respondents were requested to provide data on all refinery wastes, whether produced directly by the reporting member company or by contractors undertaking work on their behalf. The “Waste” worksheet comprised a 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 from a dropdown list including the 20 main categories of waste represented by the first two digits of the EWC code[2] (**Table 1**). Waste Type selected from a dropdown list including the four last digits of the EWC Code.
- Year of waste reported (2019, 2020 or 2021).
- 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 in units of tonnes).
- Final Recovery or Disposal route (selected from a list, as shown in **Table 3**).

[2] Commission notice on technical guidance on the classification of waste (2018/C 124/01). 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 individual six digits codes. Wastes suffixed with an asterisk (*) are always hazardous wastes.

Based on the selection of the EWC Code the spreadsheet identifies if the waste is hazardous or non-hazardous.

While the waste categories in **Table 1** and the generic recovery and disposal categories in **Table 3** are the same as those used in the 2013 survey, two more waste source categories (**Table 2**) were added to the 2019-2021 survey, “decommissioning activities” and “construction works”.

Table 1. List of Wastes Categories

Wastes Categories	
1	Wastes resulting from exploration, mining, quarrying, and physical and chemical treatment of minerals
2	Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing
3	Wastes from wood processing and the production of panels and furniture, pulp, paper and cardboard
4	Wastes from the leather, fur and textile industries
5	Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal
6	Wastes from inorganic chemical processes
7	Wastes from organic chemical processes
8	Wastes from the manufacture, formulation, supply and use (mfsu) of coatings (paints, varnishes and vitreous enamels), adhesives, sealants and printing inks
9	Wastes from the photographic industry
10	Wastes from thermal processes
11	Wastes from chemical surface treatment and coating of metals and other materials, non-ferrous hydro- metallurgy
12	Wastes from shaping and physical and mechanical surface treatment of metals and plastics
13	Oil wastes and wastes of liquid fuels (except edible oils, and those in chapters 05, 12 and 19)
14	Waste organic solvents, refrigerants and propellants (except 07 and 08)
15	Waste packaging, absorbents, wiping cloths, filter materials and protective clothing not otherwise specified
16	Wastes not otherwise specified in the list
17	Construction and demolition wastes (including excavated soil from contaminated sites)
18	Wastes from human or animal health care and/or related research (except kitchen and restaurant wastes not arising from immediate health care)
19	Wastes from waste management facilities, off-site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use
20	Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions

Table 2. Waste Sources Categories

Waste Source
Refinery Operations
Turnaround
Remediation
Decommissioning Activities
Construction Works
Diverse Sources
Other

Table 3. Generic Recovery and Disposal Route Categories

Generic Final Recovery or Disposal Routes
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
D3 - Deep Injection
D8 - Biological Treatment
D9 - Physico- Chemical Treatment
D10 - Incineration on Land
D12 - Permanent Storage

The survey also asked respondents to indicate if the waste disposal or recovery for each waste category is done within the country of origin, outside the country of origin but within the European Union or outside the European Union.

When an EWC code selected identified waste sludges, additional questions were made available to respondents regarding sludges pre-treatment prior to disposal or recovery, and any additional treatment of the water and oily fractions resulting from sludge separation. **Table 4** lists the selected treatment options available to the respondents.

Table 4. List of available selection options for sludge waste pre-treatment

Sludge Separation	Water Treatment	Oil Treatment
Gravity Thickening	Biological Wastewater treatment onsite	Oil water separation onsite
Centrifugal Thickening	Biological wastewater treatment offsite	Oil and water are treated together (onsite)
Flotation Thickening	No treatment	Other treatment onsite (specify)
Gravity Belt Thickening	Other treatment offsite	Other treatment offsite (specify)
Rotary Drum Thickening		No treatment
Decantation		
Dewatering Belt Filter Presses		
Reuse of oil in cooking process		
No treatment		
Other		

Several refineries did not respond to the survey using the excel spreadsheet provided, sending instead the requested data in their own formats (identified in the report as "manual" data). This resulted in some data omissions/gaps. While further questions were sent to the refineries involved, at the time of preparing this report some data was still missing. Where relevant, this issue is discussed in the analysis sections.

2.3. DATA QA/QC

The survey results were compiled into a single unified data format to facilitate the analysis and creation of tables and figures. Historic throughput was requested for the three survey years to normalize the waste quantities reported. Seven refineries did not provide throughput data. The incorporation of these data into the overall analysis is discussed later in the report.

Quality assurance and quality control (QA/QC) of the data was carried out by construction of Q-Q plots to identify and investigate outliers for total throughput and each EWC waste code reported. Some respondents sent back manually filled data instead of using the provided excel spreadsheet requiring additional QA/QC checks and edits.

3. SURVEY RESPONSE

The questionnaire was distributed to Concawe member companies in 2022 for the collection of 2019, 2020 and 2021 waste data, representing a wide geographical scope and range of refinery types and complexities. Sixty-eight (68) refineries responded to the survey. The response rate, i.e., the number of refineries that responded to the survey out of the total number of refineries that confirmed their participation was 78.16%. The response rate when considering total available (operating) refineries, was 70.1%, similar to the response rate of 71% in the 2013 waste survey.

Figure 1 shows the number of responses per Concawe Country Groupings. To ensure anonymity and prevent the identification of individual companies or installations regional country groupings were established, with a large enough geographic scope such that each group contained at least 5 refineries. Due to the low number of refineries that responded in UK/Ireland and Northern Europe, these were merged together (**Figure 2**). The lower response for UK/Ireland and Northern Europe in 2020 and 2021 is likely the result of a refinery ceasing operations and therefore not reporting after this date.

Figure 1. Responses per Concawe Country Groupings

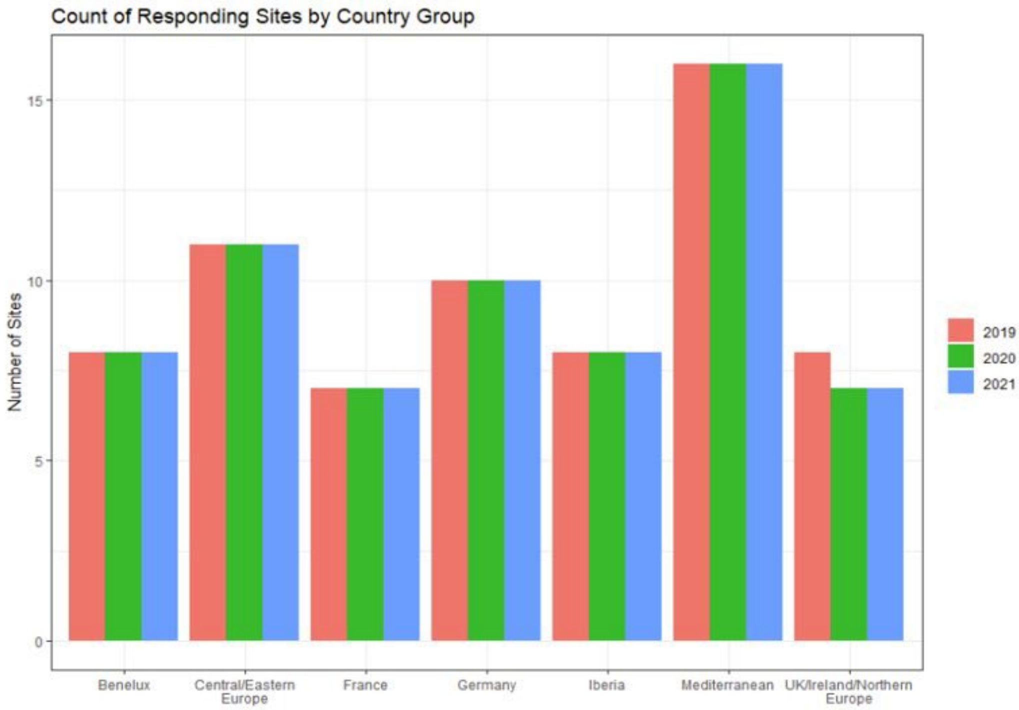


Figure 2. Concawe Country Groupings

4. DATA AGGREGATION AND THROUGHPUT

Waste data is presented in this report 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.

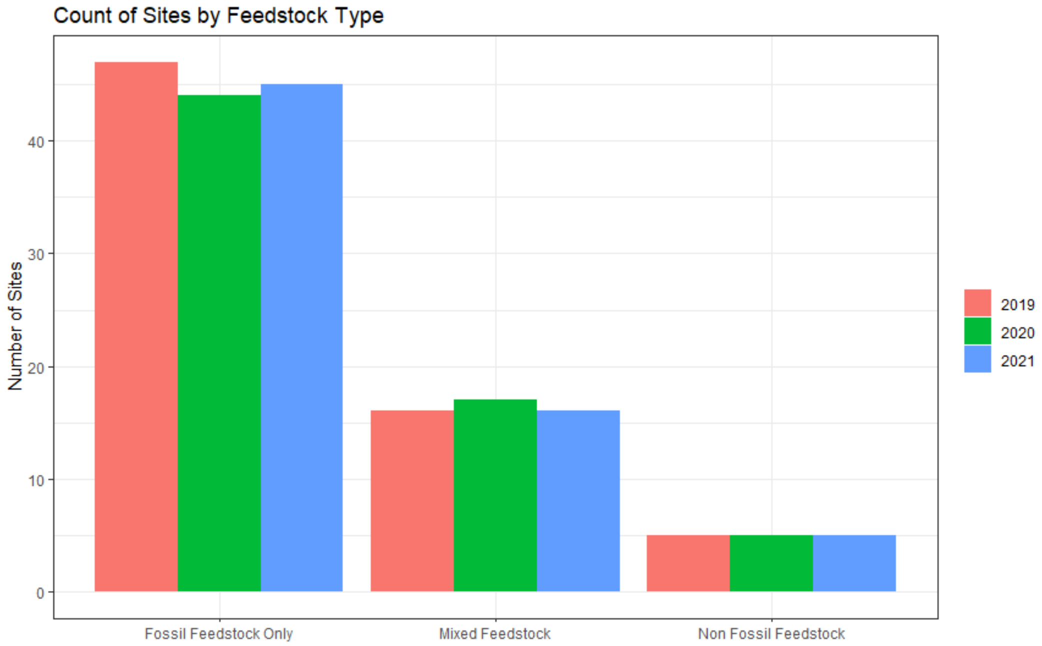
Table 5 shows the total crude and non-crude throughput per country grouping and the total throughput for the three survey years (2019-2021), for the 68 refineries that responded the waste survey.

Table 5. Crude and Non-Crude Throughputs per Concawe Country Groupings

Country Group	Number of Refineries	Crude Through-put	Non-Crude Through-put	Total Through-put
		kt	kt	kt
Benelux	8	251778.92	121.88	251900.80
Central/Eastern Europe	11	151000.27	1961.88	152962.16
France	7	109342.84	0.00	109342.84
Germany	10	158383.64	4129.28	162512.92
Iberia	8	151389.03	424.91	151813.94
Mediterranean	16	172394.11	12982.10	185376.21
UK/Ireland/Northern Europe	8	130662.08	4756.52	135418.61
Totals 2019-2021	**68**	**1124950.89**	**24376.58**	**1149327.47**

One of the survey's objectives was to understand differences in the management of waste sludges depending on the type of refinery feedstock involved. **Figure 3** shows the number of refineries responses to the survey by feedstock type. While most refineries processed fossil fuels only, some 16 refineries (17 in 2020) processed both crude and non-crude feedstock. Five (5) refineries processed only non-crude feedstock.

Figure 3. Number of responding refineries per throughput feedstock type



Some refineries failed to provide throughput data in their responses. To avoid excluding throughput (and consequently) waste data from the analysis, missing throughputs were estimated by calculating the average ratio of the three reporting years between refineries reported throughputs and their reported capacities. This ratio was then used to estimate actual throughputs for the refineries with missing data. A similar approach was used for non-crude throughput where data was missing. In this case the average ratio of the known non-crude throughput of two refineries and their reported capacities was used to estimate non-crude throughputs for those refineries that did not report this data. **Table 6** includes the ratios between reported throughputs and refineries capacities for the three years of the survey.

Table 6. Estimated average refineries capacity/throughput ratios for crude and non-crude feedstocks.

	2019	2020	2021
Crude Through-put	0.861	0.770	0.813
Non-Crude Through-put	0.694	0.650	0.600

Figure 4 compares total throughput of survey years 2019-2021 with the 2013 survey. The 2013 data is not directly comparable to the 2019-2021 data. Seventy-four (74) refineries participated in the 2013 survey while 68 refineries were included in 2019-2021. However, a reduction in throughput is markedly noticeable in 2020 and 2021 most likely due to the global reduction of economic activity during the Covid pandemic. While the 2013 throughput data included only crude, the 2019, 2020 and 2021 surveys included also non-crude sources, albeit in significant less amounts

(some 24,000,000 tonnes for the 2019-2021 period). When the same refineries that participated in both surveys are considered, then the feedstock throughput reductions in 2020 and 2021 are much more noticeable.

Figure 4. Total Throughput in Tonnes for 2013, 2019, 2020 and 2021

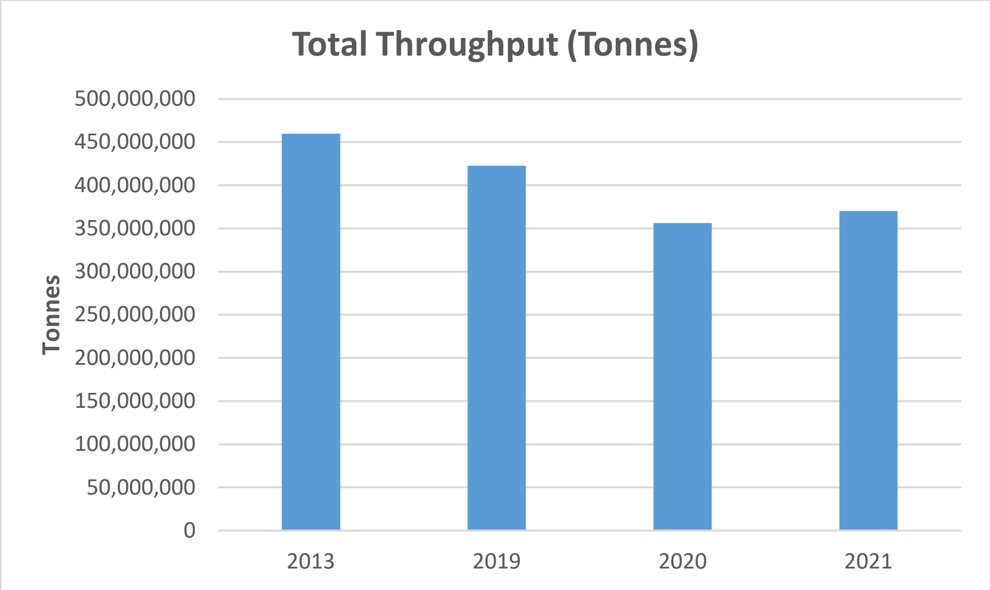
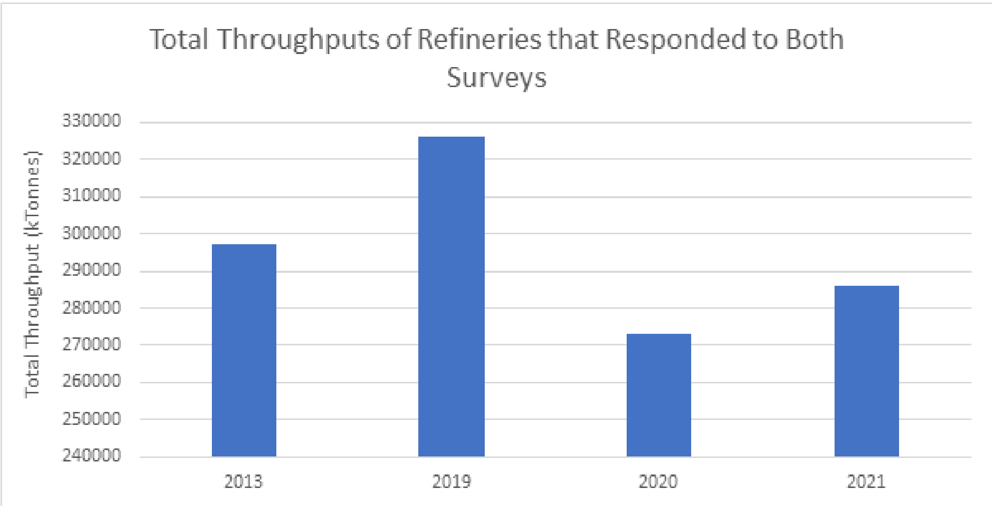


Figure 5. Total Throughput for refineries that responded to both the 2013 and 2019-2021 surveys.



5. WASTE QUANTITIES AND SOURCES

5.1. TOTAL AND RELATIVE WASTE PRODUCED AND ITS SOURCES

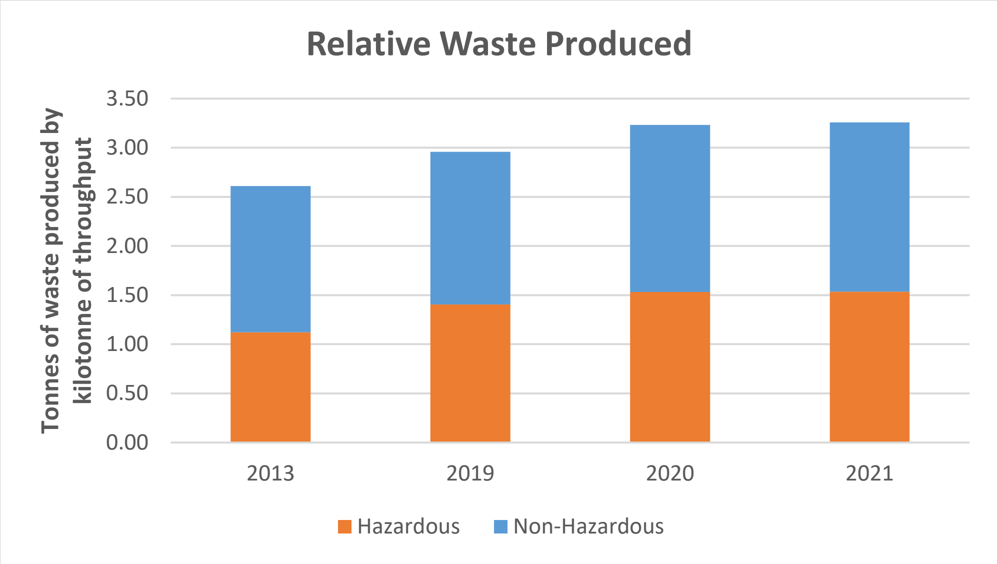
5.1.1. Total and Relative Waste Produced

Of the 68 survey questionnaires returned, all included waste data for the three survey years 2019, 2020 and 2021, with the exception of one refinery that presented waste data only for 2019. **Figure 6** shows the total amount of waste produced (in metric tonnes) in each survey year by the 68 refineries that responded to the survey, discriminated between hazardous and non-hazardous wastes. In total, some 3.6 kt of hazardous and non-hazardous waste was produced in the period 2019-2021. The figure also includes data from 2013 for comparison purposes. It should be noted that the total waste tonnage in 2013 was produced by 74 refineries while on this survey 68 refineries responded.

Figure 6. Total Waste Produced in Tonnage (2013, 2019, 2020 and 2021)

Figure 7 shows the relative hazardous and non-hazardous waste produced in the three survey years, normalised by the total feedstock throughput from each year. The normalised waste data show an increase in waste production per unit of throughput from 2013 to 2019. The further increase in relative waste produced in 2020 and 2021 is likely the result of lower throughput (due to Covid) while waste generation remained constant or decrease at a lower rate.

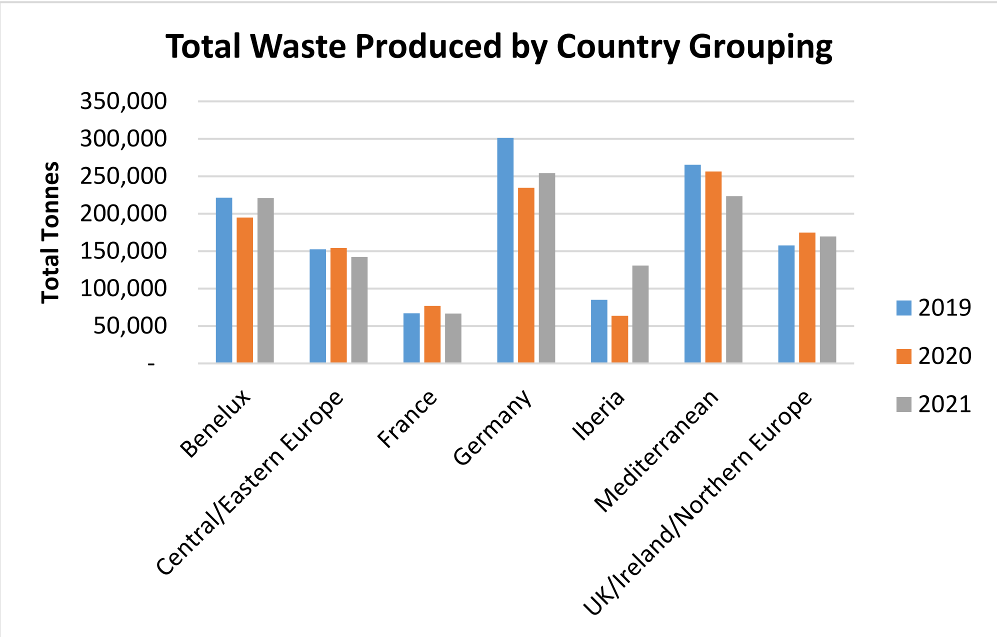
Figure 7. Relative Waste Produced by Tonnage (2013, 2019, 2020 and 2021)



Note: While normalised data over the three-year period provide useful information as to the rate of waste production per throughput, it doesn't fully represent refineries efficiencies regarding waste production, as some wastes are the result of one off projects or of activities that are not carried out on a regular basis. This statement is valid for subsequent figures and data of normalised waste production.

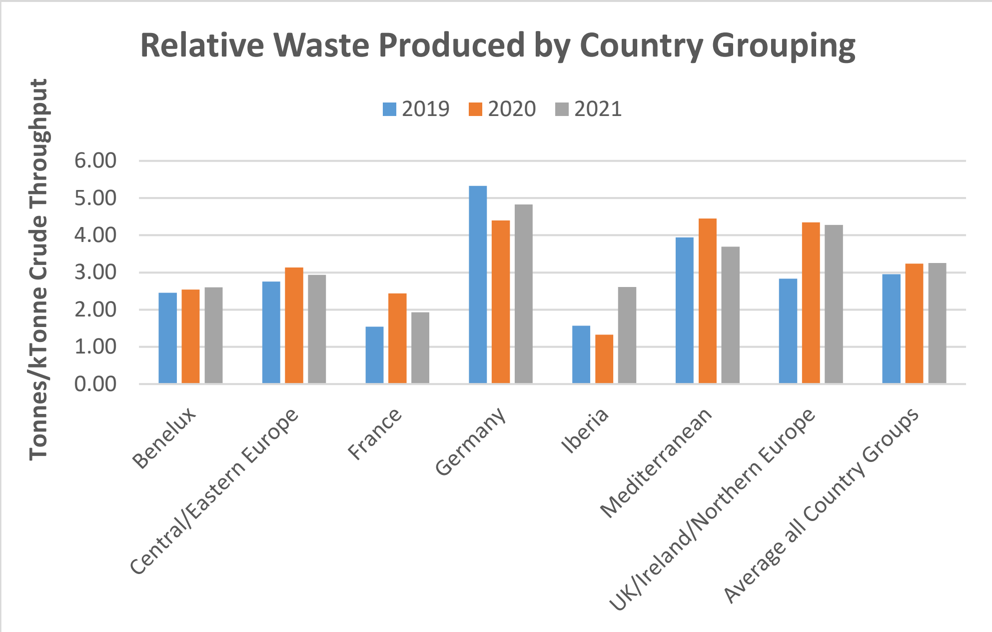
Figure 8 shows the total amount of waste (in metric tonnes) per Country Grouping and survey year. Germany produced the largest total amount of waste in 2019 (301 kt) and 2021 (254.1 kt), while the Mediterranean region produced the largest amount in 2020 (256.5 kt).

Figure 8. Total Amount of Waste per Country Groupings and Survey Year



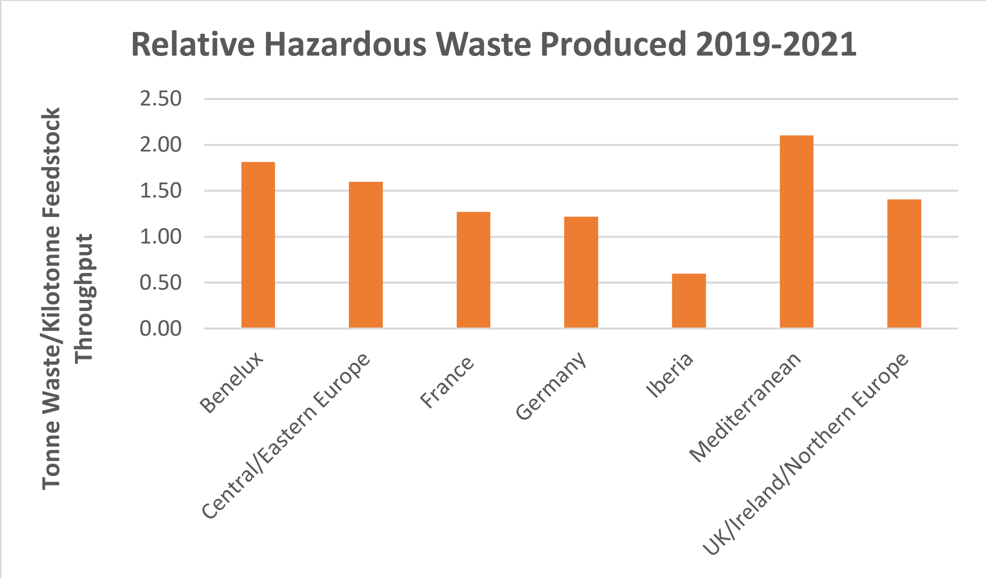
The effect of normalising total waste production to refinery feedstock throughput per Country Grouping is shown in **Figure 9**. It shows significant variation in relative waste production averages for the three survey years with a minimum average of 1.83 tonnes of waste per kilotonne (t/kt) of feedstock throughput for the Iberia region, to a maximum average of 4.85 t/kt for Germany. The normalised total waste to feedstock throughput average for all waste produced by the participating refineries for the three survey years was 3.15 t/kt.

Figure 9. Relative Waste Tonnage per Country Grouping



When only hazardous wastes are considered, the highest normalized relative waste for the three survey years was produced by the Mediterranean Region with 2.1 t/kt of throughput while the lowest corresponds to Iberia with 0.6 t of waste per kt of feedstock throughput (**Figure 10**).

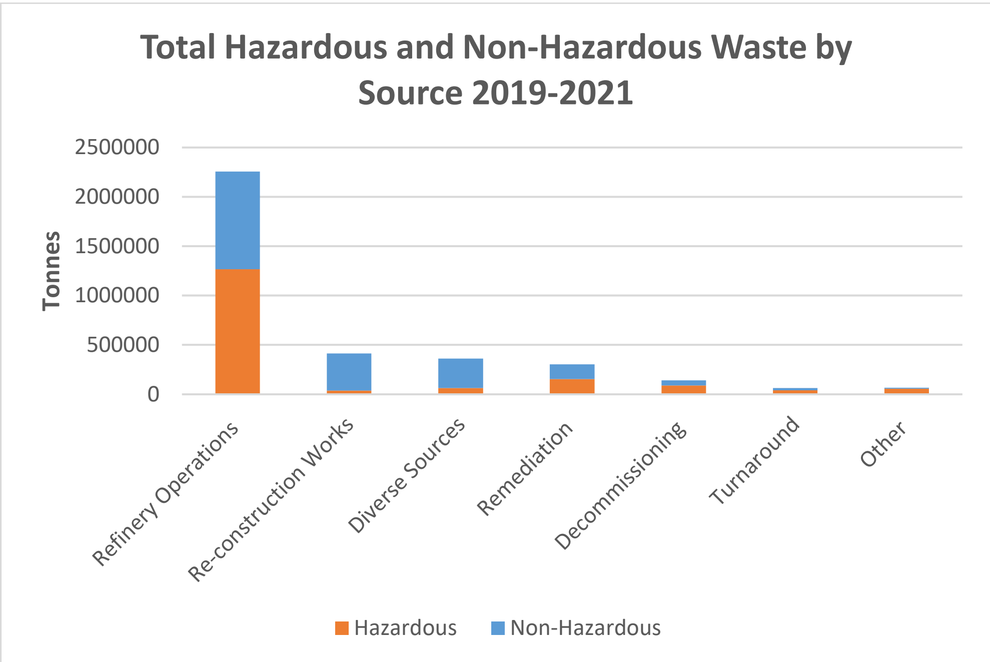
Figure 10. Relative Hazardous Waste 2019-2021



5.1.2. Total Waste Produced by Source

As shown in **Figure 11**, the largest amount of total waste (and hazardous waste) originates from refinery operations, followed by re-construction works, diverse sources and remediation, all with similar reported total amounts of waste over the 2019-2021 period. Sources were not provided for a significant amount of reported waste. This was split proportionally into the other categories following the calculated ratios between sources and hazardous and non-hazardous wastes.

Figure 11. Total Hazardous and Non-Hazardous Waste by Source 2019-2021

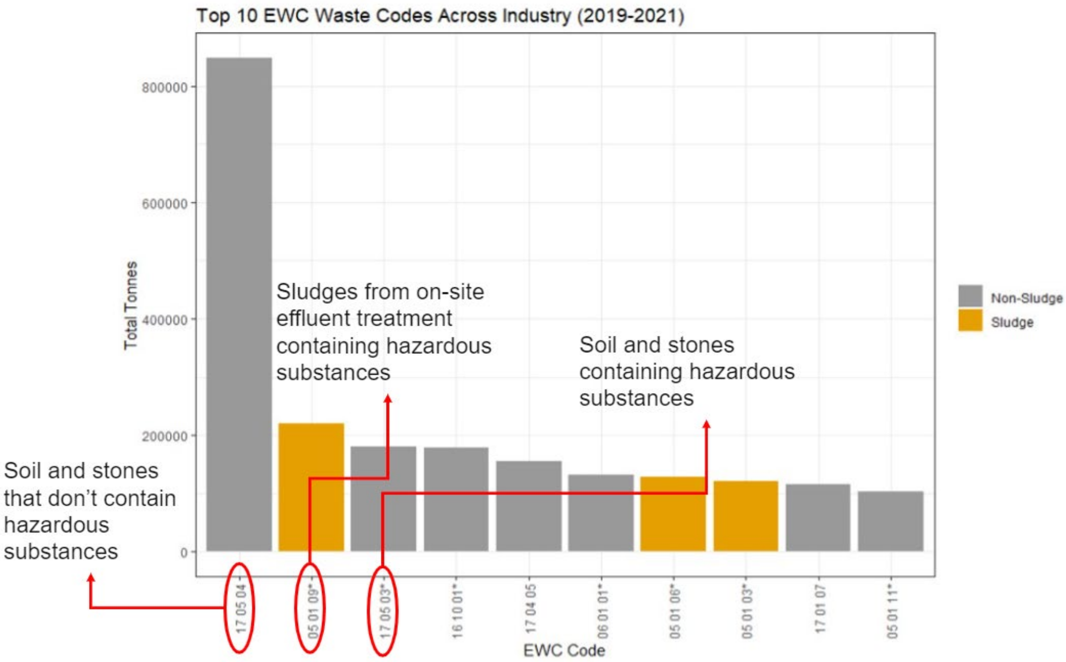


Diverse sources included more than 160 different waste types mostly with relatively low reported tonnage. The “Other (please specify)” category included dozens of different sources. However, the majority of this category (about 65%) was composed of acid tars, oily residues and sludge from sewage treatment, historically stored in lagoons which were emptied and cleaned and thus the need to manage their disposal.

5.1.3. Types of Wastes Produced

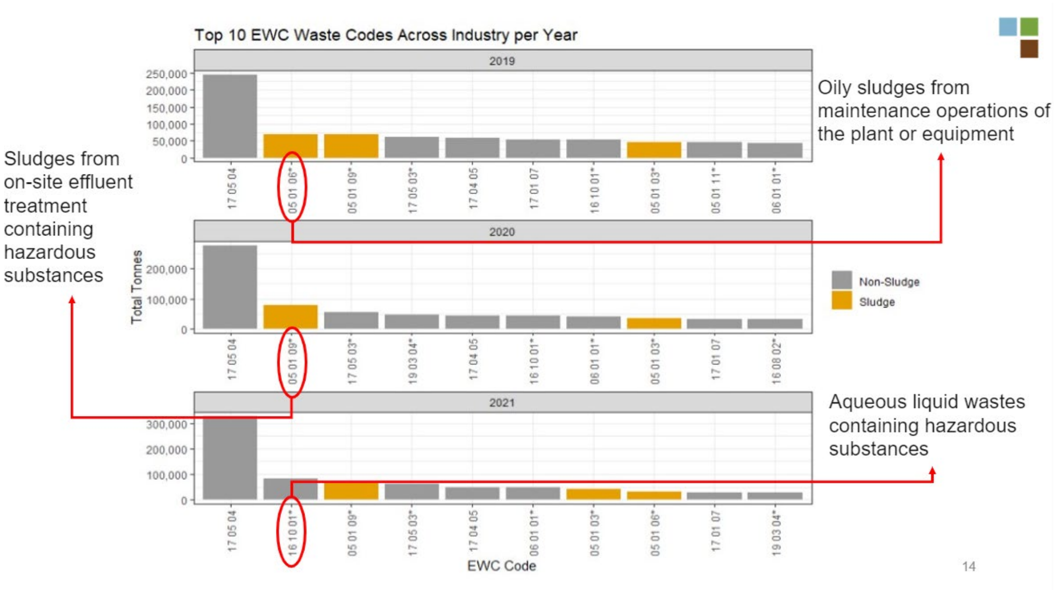
Figure 12 provides a breakdown of waste for the ten waste (EWC) codes with the largest tonnage produced during the three years of the survey (i.e., total waste tonnage for 2019, 2020 and 2021). The figure also identifies sludges and non-sludges waste by use of a different colour. The largest amount produced between 2019 and 2021 corresponded to soils and stones not containing hazardous substances (appr. 850 kt), typically associated with construction work. Sludges from waste water treatment containing hazardous substances (approx. 240 kt), and soil and stones also containing hazardous substances (approx. 180 kt), constitute the second and third largest categories overall for the 2019 to 2021 period.

Figure 12. Top Ten EWC Waste Categories by Tonnage (2019-2021)



Differences exist year on year with oily sludges from maintenance operations constituting the second largest waste produced by tonnage in 2019 and aqueous liquid wastes containing hazardous substances constituting the second largest waste category by tonnage in 2021 as shown in **Figure 13**.

Figure 13. Top Ten EWC Waste Categories by Tonnage for 2019, 2020 and 2021



When sludges and non-sludges wastes are analysed separately, soil and stones containing non-hazardous substances (approx. 850 kt) and hazardous substances (approx. 180 kt) constitute the first and second largest category respectively on non-sludge waste for the 2019-2021 period overall.

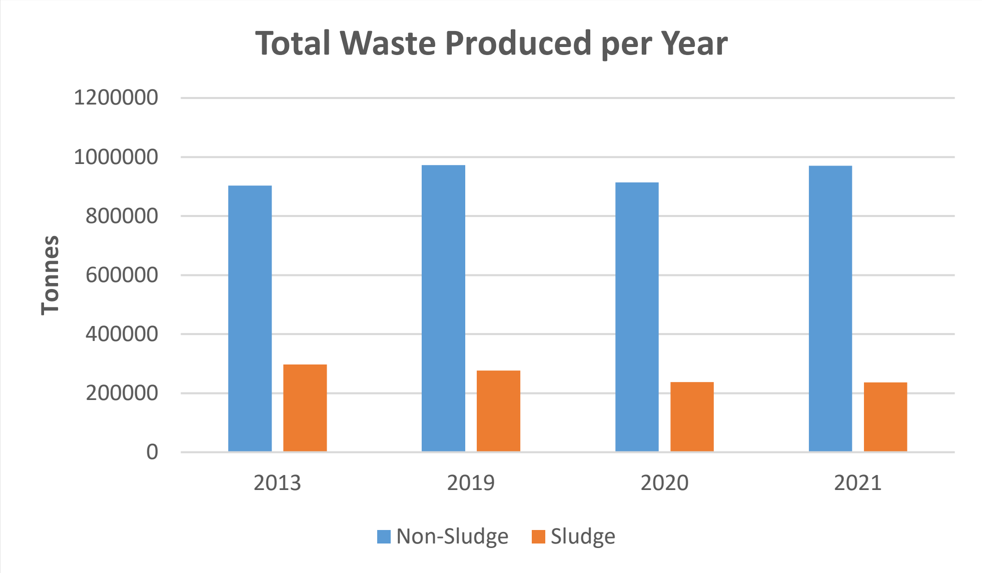
5.2. TOTAL AND RELATIVE SLUDGE WASTE PRODUCED AND ITS SOURCES

This section discusses in more detail the data collected for waste sludges, both hazardous and non-hazardous, in terms of volumes generated, their sources and their characterisation based on the EWC codes reported.

5.2.1. Total and Relative Sludge Waste Produced

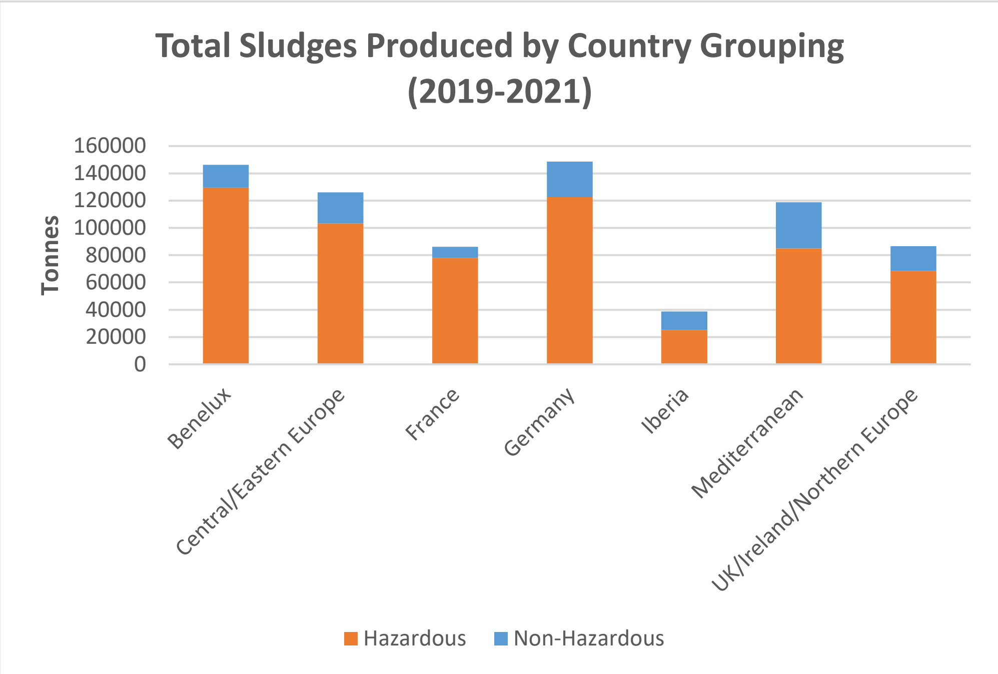
As discussed earlier, total waste produced was approximately 1,250 kt in 2019, 1,152 kt in 2020 and 1,207 kt in 2021. The percentages of sludges in relation to the total amounts of wastes produced are shown in **Figure 14** and were respectively 22.17% (277,137 t), 20.61% (237,466 t) and 19.61 % (236,647 t). In 2013, sludges constituted some 24% of the total waste produced.

Figure 14. Tonnage of non-sludge and sludge wastes 2019, 2020 and 2021



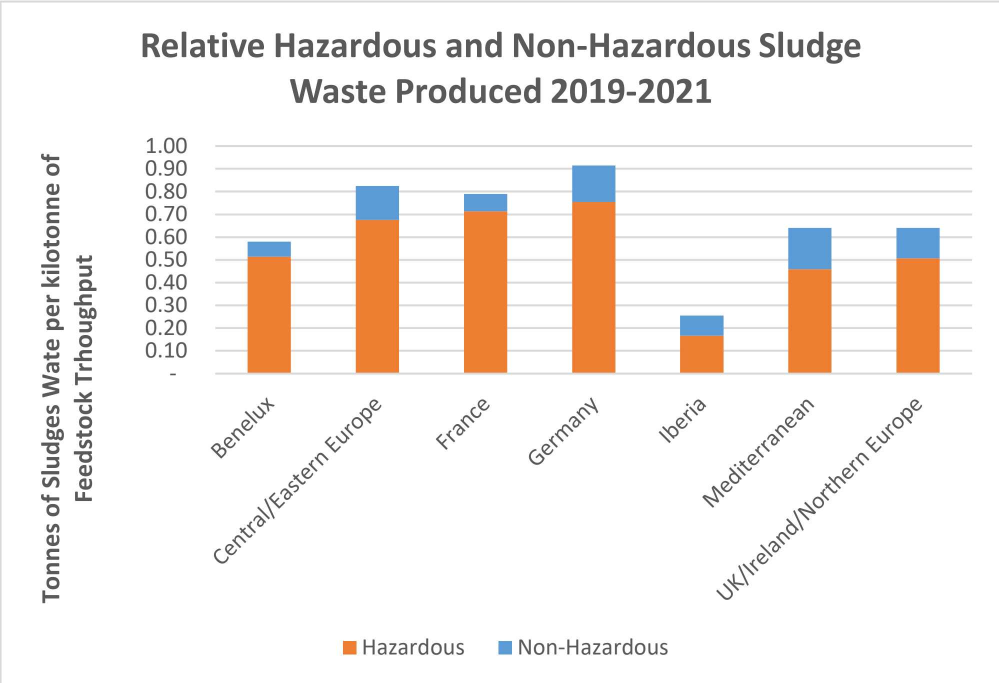
The total tonnage of sludge waste produced per Country Group is shown in **Figure 15**. Germany, followed by Benelux and Central/Eastern Europe generated the three largest tonnages in the 2019-2021 period, with Iberia producing the smallest amount. As shown in the figure, the majority of the sludge waste produced (81.5%) was classified as hazardous.

Figure 15. Total Hazardous and Non-Hazardous Waste Sludges per Country Group



When the normalised sludge waste production is considered, relative waste production across the country groupings varied between 0.26 t/kt (Iberia) and 0.91 t/kt (Germany), with an average of 0.66 t/kt when considering total sludge production for the 2019-2021 period (**Figure 16**).

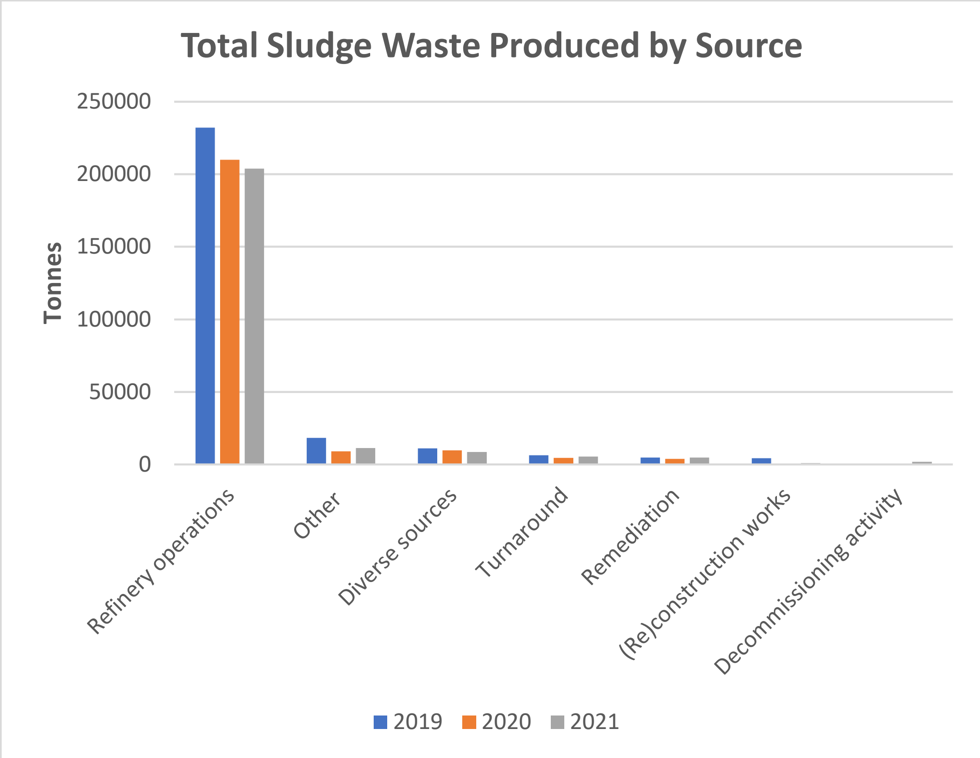
Figure 16. Relative Hazardous and Non-Hazardous Waste Sludges per Country Group



5.2.2. Total Sludge Waste Produced by Source

The greatest tonnage (approx. 85%) of sludge wastes reported originated from refinery operations (**Figure 17**). As indicated earlier, sources were not provided for a significant amount of reported waste. Therefore, the tonnage of waste with no reported sources was split proportionally into the other categories using calculated ratios between the reported sources.

Figure 17. Total Sludge Waste Produced by Source

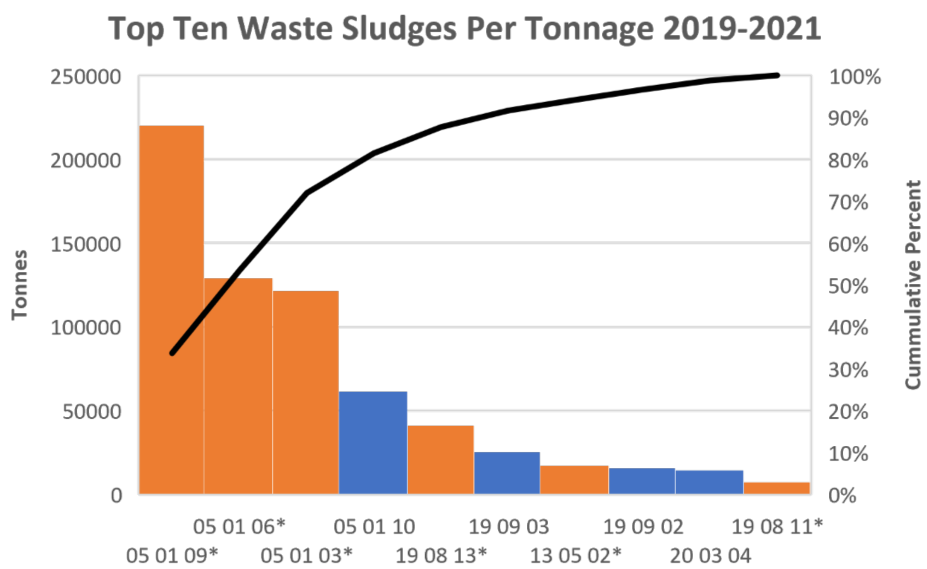


The second category, “other” includes a variety of wastes as described earlier for total waste sources, and as before, more than half of this source category (approx. 56%) corresponds to sludges from sewage treatment that were historically placed in lagoons which were emptied and cleaned, and the removed sludge sent to disposal or recovery.

5.2.3. Waste Sludge Categories

Figure 18 shows the top ten waste sludge categories by EWC code for the 2019-2021 period. The three largest waste sludge categories reported were sludge from waste water treatment plants, oily sludges from maintenance operations and tank bottom sludges and represent 72% of the top ten waste sludge categories. Tank bottom sludges and waste water treatment sludges were also among the three largest categories of waste produced by weight in 2013.

Figure 18. Top Ten Waste Sludges per Tonnage 2019-2021.



EWC Code	Waste Description	Waste Tonnes
05 01 09*	Sludges from on-site effluent treatment containing hazardous substances	220,289
05 01 06*	Oily sludges from maintenance operations of the plant or equipment	129,023
05 01 03*	Tank bottom sludges	121,578
05 01 10	Sludges from on-site effluent treatment other than those mentioned in 05 01 09	61,522
19 08 13*	Sludges containing hazardous substances from other treatment of industrial waste water	41,357
19 09 03	Sludges from decarbonation	25,351
13 05 02*	Sludges from oil/water separators	17,190
19 09 02	Sludges from water clarification	15,757
20 03 04	Septic tank sludge	14,565
19 08 11*	Sludges containing hazardous substances from biological treatment of industrial waste water	7,513

The distribution of the top three sludge waste tonnage produced in 2019-2021 per Country Grouping is shown in **Figure 19** and correspond to sludges from waste water treatment (EWC: 05 01 09*), sludges generated during maintenance operations (EWC: 05 01 06*) and tank bottom sludges (EWC: 05 01 03*), all classified as hazardous wastes. **Figure 20** shows the same top three EWC waste categories normalised using total throughput for 2019-2021.

Figure 19. Top Three Total Waste Sludges per Country Grouping (EWC 05 01 09*: Waste water treatment sludges; EWC 05 01 06*: Sludges from refinery operations; EWC 05 01 03: Tank Bottoms sludges).

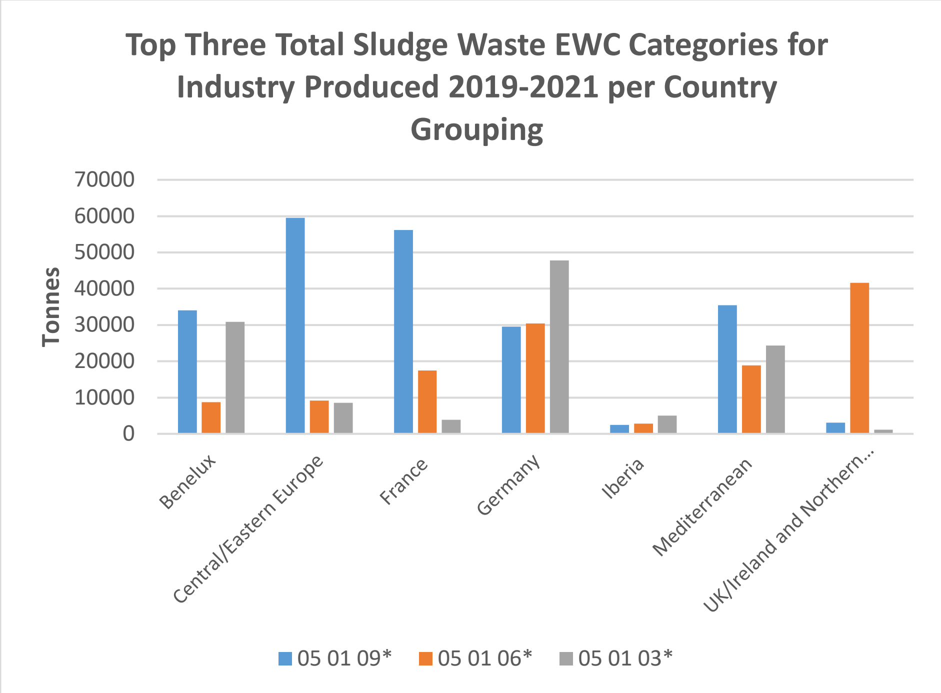
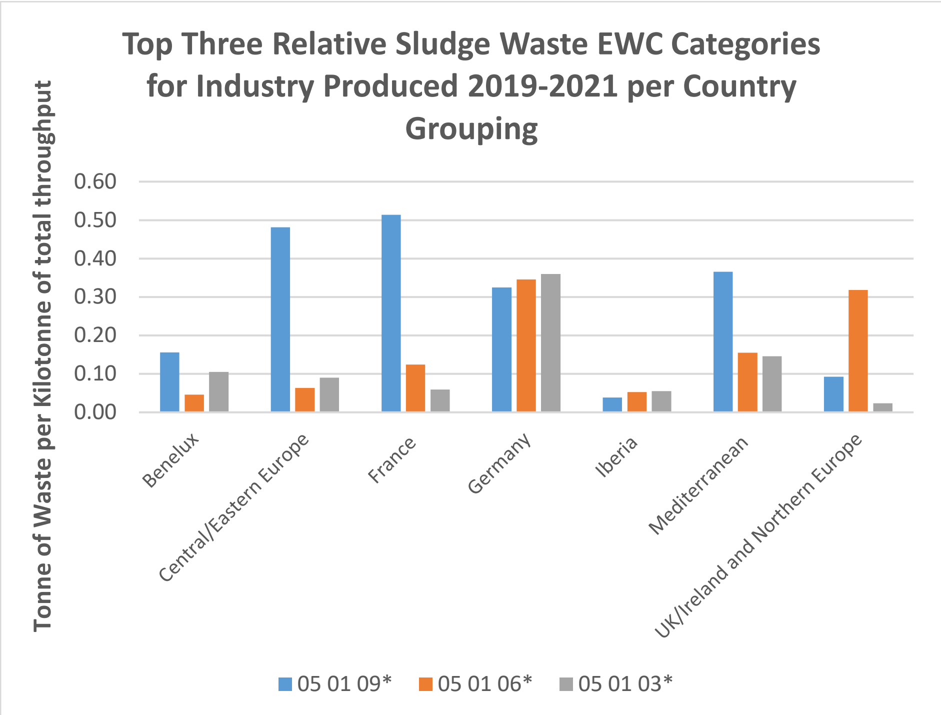


Figure 20. Top Three Relative Waste Sludges per Country Grouping (EWC 05 01 09*: waste water treatment sludges; EWC 05 01 06*: sludges from refinery operations; EWC 05 01 03: tank bottoms sludges).



Sludges from waste water treatment are the largest category in Benelux, Central/Eastern Europe, France and Mediterranean Country Groupings. Sludges from maintenance activities are the largest waste sludges in UK/Ireland and Northern Europe whilst tank bottom sludges are the largest category in Germany. Normalised waste water sludges amounts varied between 0.04 t/kt in Iberia to a maximum of 0.51 t/kt in France, with an average of 0.28 t/kt. Sludges from maintenance activities had an average normalised weight production of 0.16 t/kt and varied between a minimum of 0.05 in Benelux and Iberia and a maximum of 0.35 in Germany. Finally, the tank bottom sludges had an averaged normalised production of 0.11 with a minimum of 0.02 in UK/Ireland /Northern Europe and a maximum of 0.36 in Germany (see Note on **Figure 7** regarding normalised data).

Table 7 is a comparison of normalised sludge tonnage against total throughput between 2013 and 2019-2021. It shows very similar normalized tonnage between the two periods with a slight increase for waste water sludges and sludges from refinery operations in the 2019-2021 period.

Table 7. Normalised sludges tonnage for 2013, 2019, 2020 and 2021 for three largest waste sludges categories produced (in tonnes of sludge waste per kiloton of total throughput)

	2013	2019	2020	2021	2019-2021
Sludges from waste water treatment (05 01 09*)	0.18	0.16	0.22	0.19	0.19
Sludges from refinery operations (05 01 06*)	0.10	0.16	0.07	0.09	0.11
Tank bottom sludges (05 01 03*)	0.10	0.10	0.09	0.11	0.10

5.3. SOURCES OF OTHER “TOP FIVE” WASTE CATEGORIES

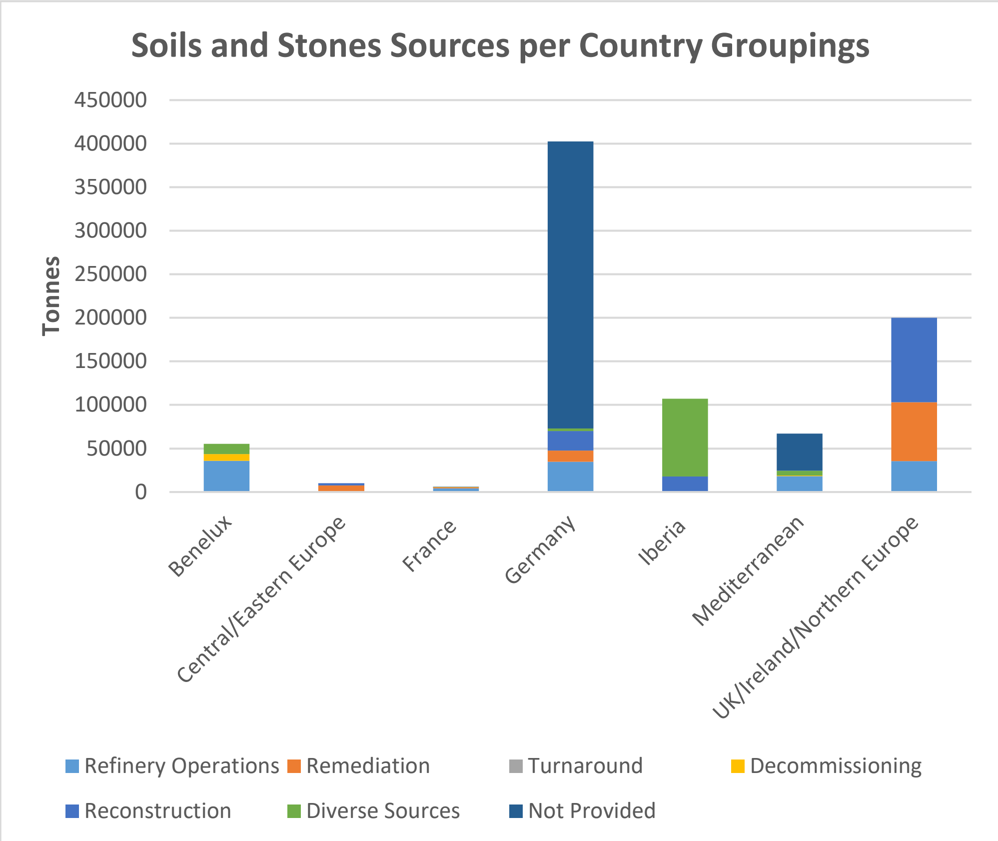
Sludges from waste water treatment containing hazardous substances is one of the top five wastes produced by tonnage and was discussed in Section 5.1.3 together with other sludge wastes. This Section provides an overview of the sources of the other waste categories in the top five waste types; they include:

- EWC 17 05 04: Soil and stones other than those mentioned in 17 05 03*.
- EWC 17 05 03*: soils and stones containing hazardous substances.
- EWC 16 10 01*: aqueous liquid wastes containing hazardous wastes.
- EWC 17 04 05: iron and steel.

5.3.1. Soil and Stones

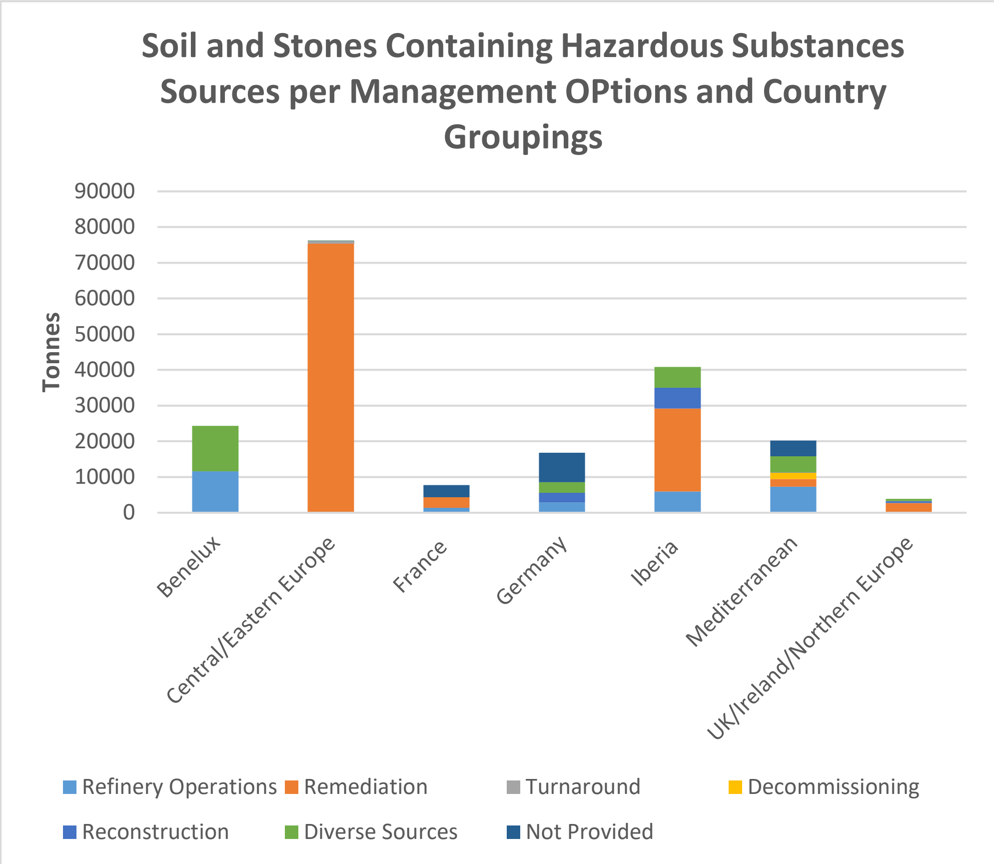
The largest amount of soil and stones not containing hazardous substances was produced in Germany (some 370,000 tonnes), however, the source of this material was not provided in the survey (**Figure 21**). Reconstruction, refinery operations and diverse sources are the next source categories by tonnage, occurring primarily in UK/Ireland/Northern Europe, Iberia and Benelux. The total amount of non-hazardous soil and stones in 2019-2021 was approximately 848,000 tonnes.

Figure 21. Sources of non-hazardous soils and stones



Some 190,000 tonnes of soil and stones containing hazardous substances were produced in 2019-2021 (**Figure 22**). The largest amount was produced in Central/Eastern Europe and Iberia as a result of remediation activities. This category was followed by wastes originating from refinery operations and diverse sources (not specified).

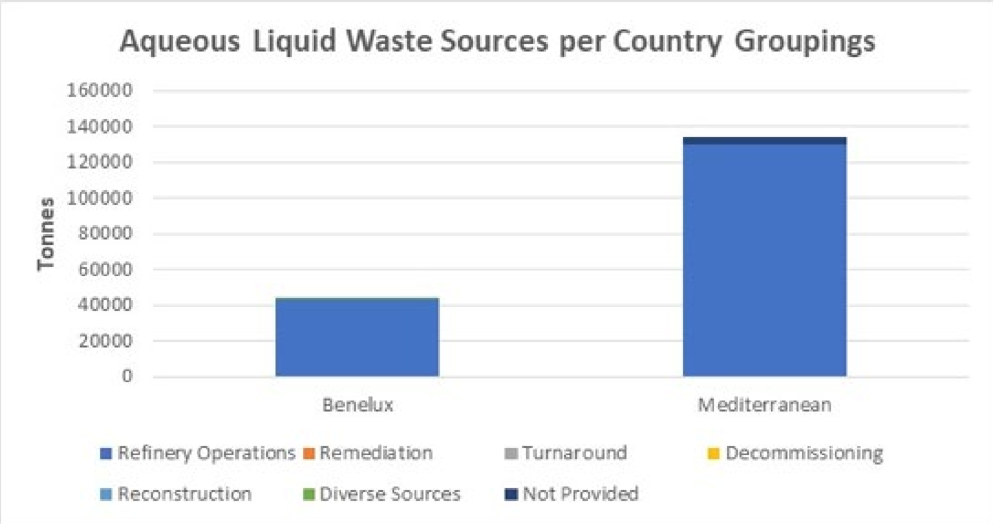
Figure 22. Sources of hazardous soils and stones

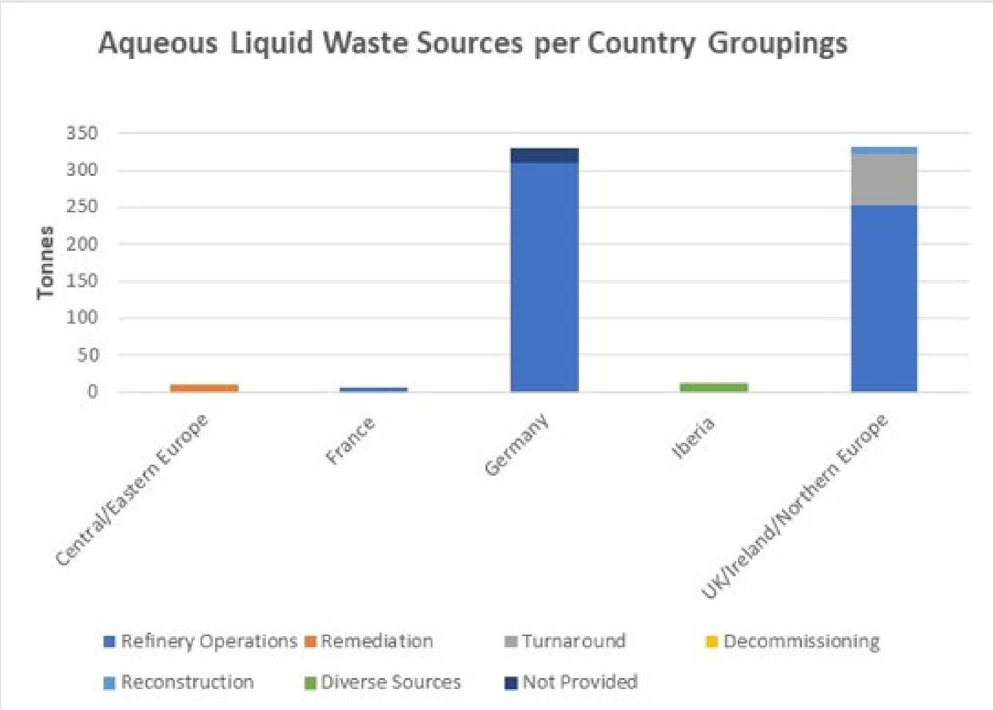


5.3.2. Aqueous liquid wastes containing hazardous wastes (EWC 16 10 01*)

Two Country Groups, Mediterranean and Benelux were the primary producers of this type of waste with an approximate total production of 173,000 tonnes (**Figure 23**). Very small amounts were also produced in other regions. The reported source of this waste was primarily refinery operations.

Figure 23. Sources of Aqueous Liquids containing hazardous substances

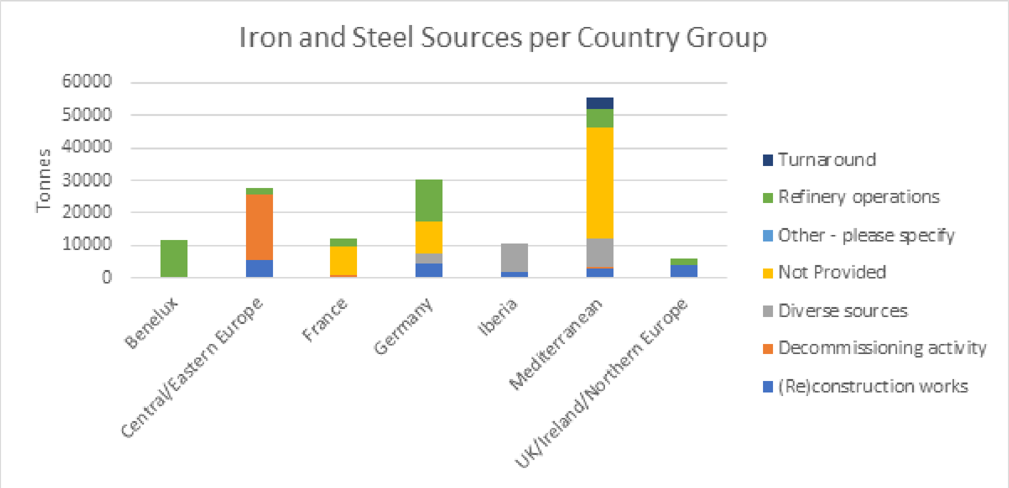




5.3.3. Iron and Steel

Iron and steel (EWC 17 04 05) produced in the 2019- 2021 period is shown in **Figure 24**. The Mediterranean Country Group produced the largest tonnage followed by Germany and Central/Eastern Europe. Sources were not provided for a large amount of the reported iron and steel waste. The largest sources reported were refinery operations and decommissioning activities.

Figure 24. Sources of Iron and Steel per Country Group

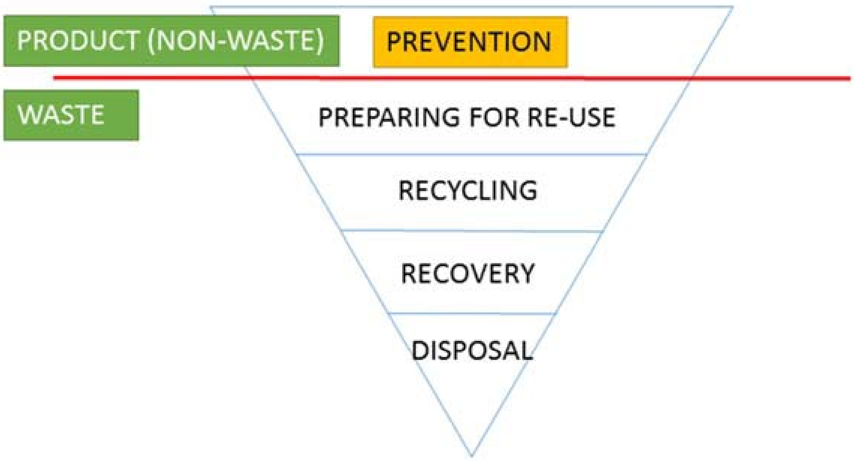


6. WASTE MANAGEMENT OPTIONS

6.1. INTRODUCTION

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 25** below.

Figure 25. 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 case of disposal, the final treatment is primarily thermal treatment or the final deposit in a landfill. In the case of recovery, the final treatment step is either the incineration of waste for energy recovery, or a treatment step where the waste ceases to be waste because it is turned into a product or used in another way where it replaces primary material.

As for the 2013 waste report, waste management options reported in this survey have been grouped to reflect the above hierarchy, as shown in **Table 8** below. The groupings are the same as those used in 2013 to facilitate comparisons.

Table 8. Waste Management Options Groupings

Waste Management Option Group	Waste Management Options	
Incineration	D10	Incineration on land
Landfill	D1/5 D4 D12 D15*	Landfill Surface Impoundment Permanent Storage Storage pending any further operations (D1 to D14)
Multiple Disposal/Other	D14* Other Multiple disposal /recovery methods	Repackaging prior to submission to further operations (D1 to D13) Please specify Please specify
Recovery-Energy	R1	Energy recovery
Recovery – Other	R2/R6 R6 R7/R8 R10 R11 R12** R13**	Regeneration Regeneration of acids and bases Recovery of components Agriculture/ecological benefit Uses of waste for submission to any of the operations R1 to R11 Exchange of waste for submission to any of the operations R1 to R11 Storage prior to recovery
Recycling	R3/R4/R5 R9	Recycle/reclaim Reuse
Treatment	D2 D8* D9* D13*	Land treatment Biological treatment Physico-chemical treatment Blending or mixing prior to submission to any of the operations D1 to D12
Not specified		Null Missing

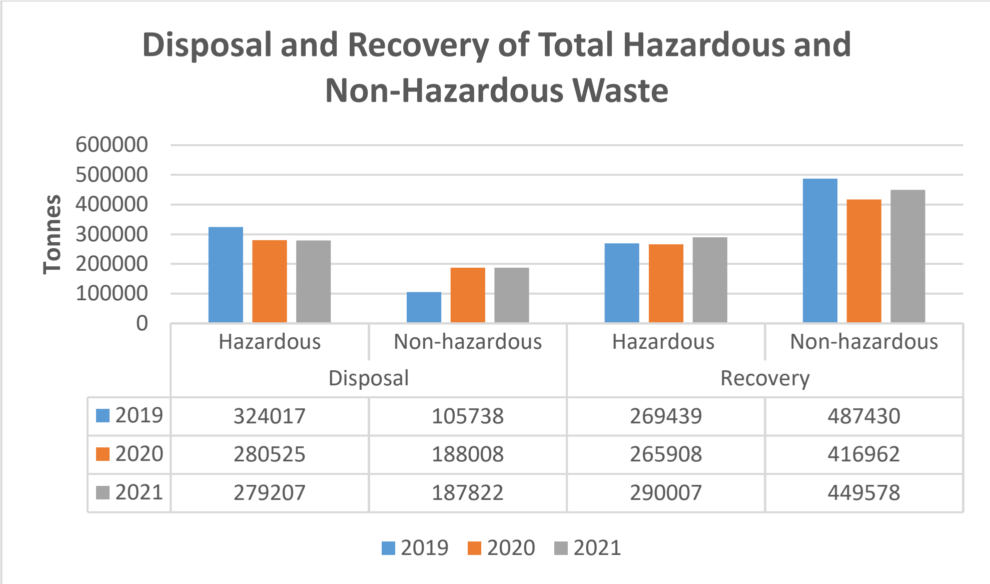
*These codes refer to pre-treatment operations which must be followed by one of the other disposal operations.
**These codes refer to pre-treatment operations, which must be followed by one of the other recovery operations.

This Section discusses the management options for the wastes discussed in Section 5 that were produced by the respondent refineries in the years 2019, 2020 and 2021. Generic disposal and recovery route categories are listed in **Table 3** in Section 2.

6.2. MANAGEMENT OPTIONS FOR TOTAL HAZARDOUS AND NON-HAZARDOUS WASTES

Figure 26 provides the general distribution of total wastes generated in the 2019-2021 period between disposal and recovery options. The wastes are further discriminated between hazardous and non-hazardous types. Aproximately 60% of the total waste generated underwent some form of recovery, while the remaining of the waste was managed by disposal options. While the amount of hazardous waste was similar in both management options (disposal and recovery) the total tonnage of non-hazardous waste undergoing recovery was much higher than undergoing disposal.

Figure 26. Total Hazardous and Non-Hazardous Waste per Recovery and Disposal Management Options (quantities in tonnes)



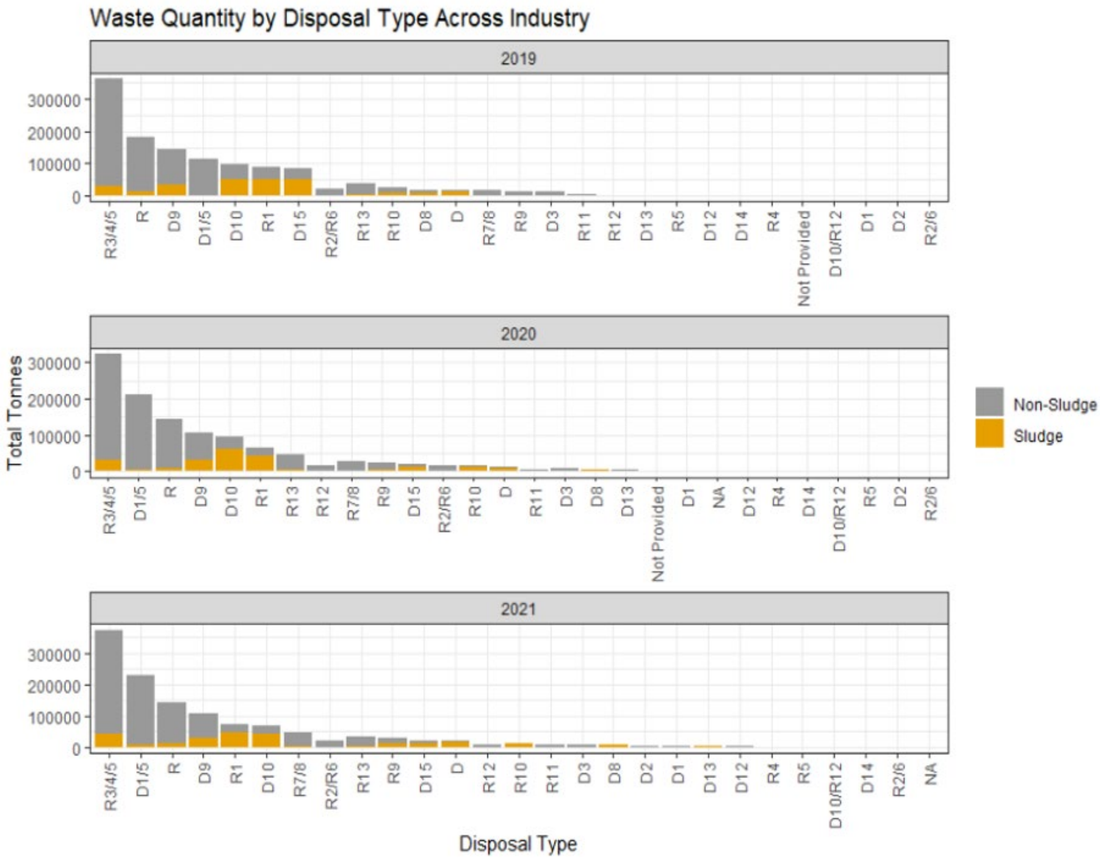
	Disposal – Hazardous	Disposal – Non-hazardous	Recovery – Hazardous	Recovery – Non-hazardous
2019	324017	105738	269439	487430
2020	280525	188008	265908	416962
2021	279207	187822	290007	449578

Management option R3/4/5 comprised the largest amount of waste in every year of the survey period with over 300,000 tonnes of waste handled through this option each year (**Figure 27**). R3/4/5 includes the recycling/reclamation of organic substances (R3), metals (R4) and inorganic substances (R5). A review of the data indicates the Recovery option R3/4/5 includes dozens types of waste of which the top three categories by weight are soil and stones with and without hazardous substances (17 05 03*/17 05 04), sulphurus and sulphuric acid (06 01 01*) and spent fluids (16 08 06).

The secong largest waste managent category is D1/5 (landfilling) in 2020 and 2021, and R in 2019, a generic recovery term provided in the manual returns and without specific recovery method identified. The three top wastes assigned to this generic Recovery option in 2019 and constituting 85% of the waste in this category are soils and stones (17 05 04), mixtures of concrete, bricks, tiles and ceramics (17 01 07) and sludges from onsite effluent treatment plants (05 01 10).

D1/D5 is a combined option including disposal of waste into or on land (such as a landfill) and disposal in a specially engineered landfill. The largest waste category in 2020 and 2021 disposed by this method was soils and stones with and without hazardous substances (17 05 03* and 17 05 04), followed by generic hazardous waste (19 03 04*) and bottom ash waste (10 01 01).

Figure 27. Waste Quantity by Disposal Type per Year



In terms of the location of disposal/recovery options the majority of the waste produced in 2019-2021was managed within the same country of origin with a very small amount (approximately 5%) managed outside the country of origin but within the European Union (**Figure 28**), a location distribution similar to the 2013 survey. Benelux and Central/Eastern Europe had the largest amount of waste managed outside their country of origin but within the EU. There were gaps in the data provided, in particular in the Mediterranean Country Grouping, where some 300,000 tonnes were not assigned a location. It is safe to assume the majority of this waste would have been handled within the country of origin.

Figure 28. Total Waste Tonnage by Management Location

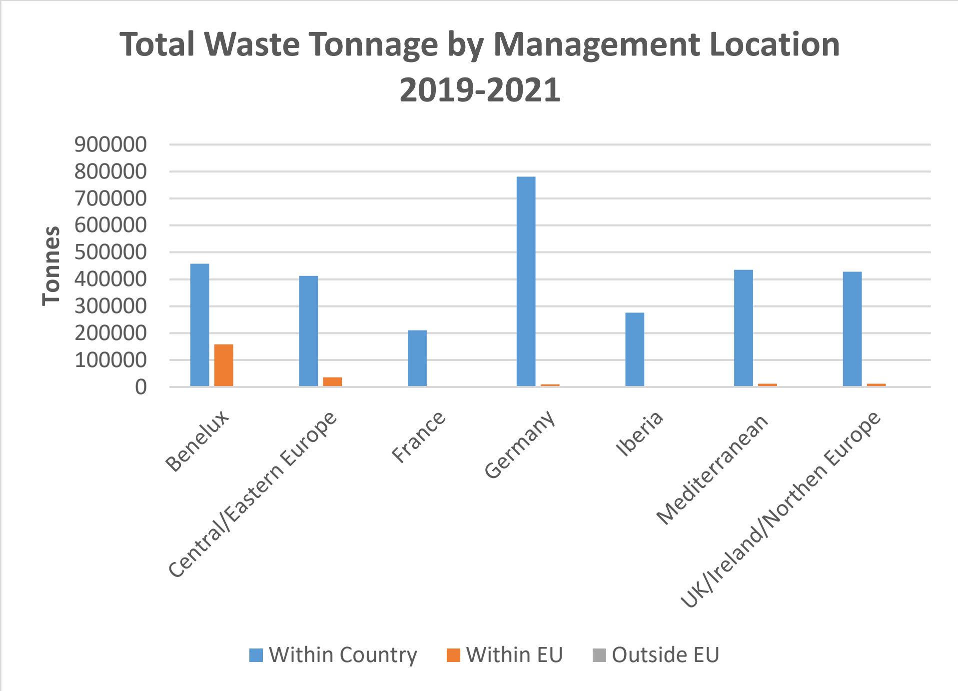


Figure 29 shows the tonnage of hazardous and non-hazardous wastes assigned to the selected management option groups. These management options are those included in **Table 9** and are the same as those used in the 2013 survey to allow comparison. The following observations can be made concerning the results of the 2019-2021 survey:

- All management options were used for both hazardous and non-hazardous wastes with the exception of "Multiple Other" involving a small amount of hazardous waste only.
- Recycling was the method involving the largest tonnage of waste, followed by recovery-other and landfill.
- Incineration, recovery energy and treatment methods were mainly applied to hazardous waste.
- While recovery, recycling and landfill were used to managed both hazardous and non-hazardous wastes, they handled more than 60% of the total amount of non-hazardous waste generated during the 2019-2021 period.

Figure 29. Total Waste by Management Option 2019-2021

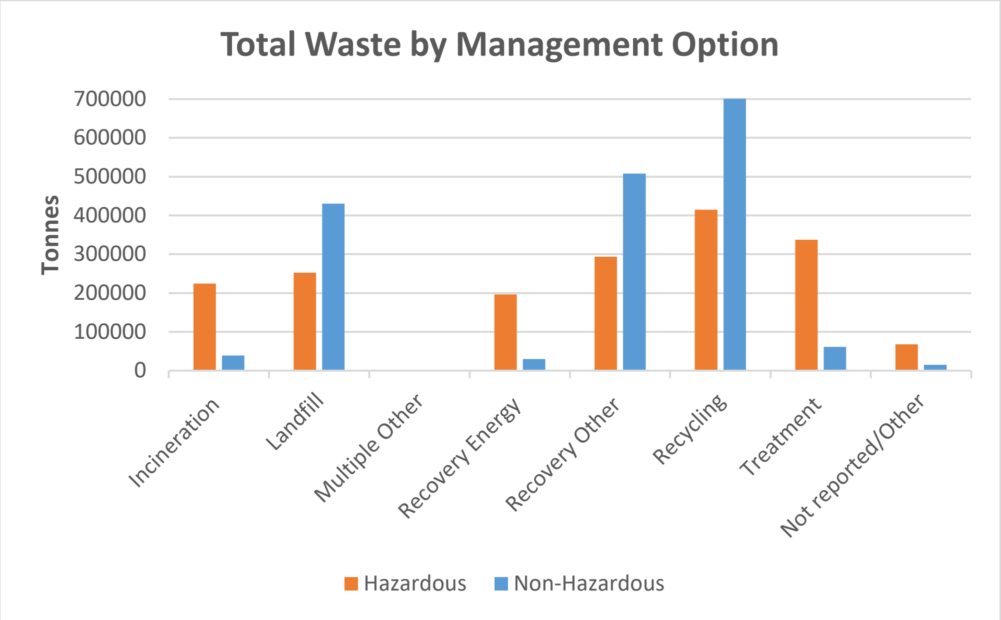


Table 9 includes the percentages of waste assigned to these management option groups in both the 2013 and 2019-2021 surveys, thus allowing a comparison of management options used in both surveys.

Table 9. Percentages of Total Waste by Management Options for 2013 and 2019-2021

Waste Management Option Group	Hazardous waste split (%) 2013	Non-Hazardous Waste Split (%) 2013	Total Waste Split (%) 2013	Hazardous waste split (%) 2019-2021	Non-Hazardous Waste Split (%) 2019-2021	Total Waste Split (%) 2019-2021
Incineration	11.9	1.7	6.1	12.6	2.1	7.3
Landfill	7.6	29.3	19.9	14.1	23.7	19.1
Multiple/Other	16.8	8.3	12.0	0.03	0.00	0.01
Recovery Energy	13.9	1.7	7.0	11	1.65	6.3
Recovery-Other	10.1	5.9	7.7	16.4	28.3	23
Recycling	15.3	49.1	34.4	23.2	39.3	31.4
Treatment	23.5	3.9	12.4	18.9	3.4	11.1
Not reported/ Other	0.9	0.00	0.4	3.8	0.83	1.63

Other includes: not provided, generic category D and Not applicable
A generic category R of 465950 tonnes was included in the Recovery-Other category

The following observations can be drawn from **Table 9**.

- The percentage of waste handled by incineration increased slightly from 6.1 to 7.3 % involving a small increase for both hazardous and non-hazardous waste.
- The overall percentage of waste going to landfill remained fairly constant, but the amount of hazardous waste managed by this option increased between 2013 and 2019-2021.
- Recovery energy saw a very small decrease in waste amounts in 2019-2021. This option continues to be used primarily for hazardous waste.
- Recovery other saw a significant increase, from 7.7% in 2013 to 23 % in 2019-2021, with a larger increase in the handling of non-hazardous waste. It should be noted that not all of the waste assigned to category R in 2019-2021 may be associated with the Recovery other category.
- Recycling and treatment saw a small decrease of 3% and 1.4% respectively in the use of this option in 2019-2021 with respect to 2013.

6.3. MANAGEMENT OPTIONS FOR WASTE SLUDGES

6.3.1. Management Options for Hazardous and Non-hazardous Waste Sludges

As discussed earlier in Section 5.2.1, approximately 80% of all sludges produced in 2019-2021 were classified as hazardous. **Figure 30** shows the management options for both hazardous and non-hazardous waste sludges. For most management options, hazardous sludges constituted the majority of the waste sludge. Incineration and incineration with energy recovery were the two largest management options by weight. Only 2.6 % of the sludges managed by these options were classified as non-hazardous. These two incineration options were followed by landfill, recycling and treatment, all with similar tonnages of hazardous sludges and less amounts of non-hazardous sludges. The recovery-other option is the only option with a larger quantity of non-hazardous sludges in relation to the hazardous fraction.

Figure 30. Hazardous and Non-Hazardous Sludge Wastes by Management Option

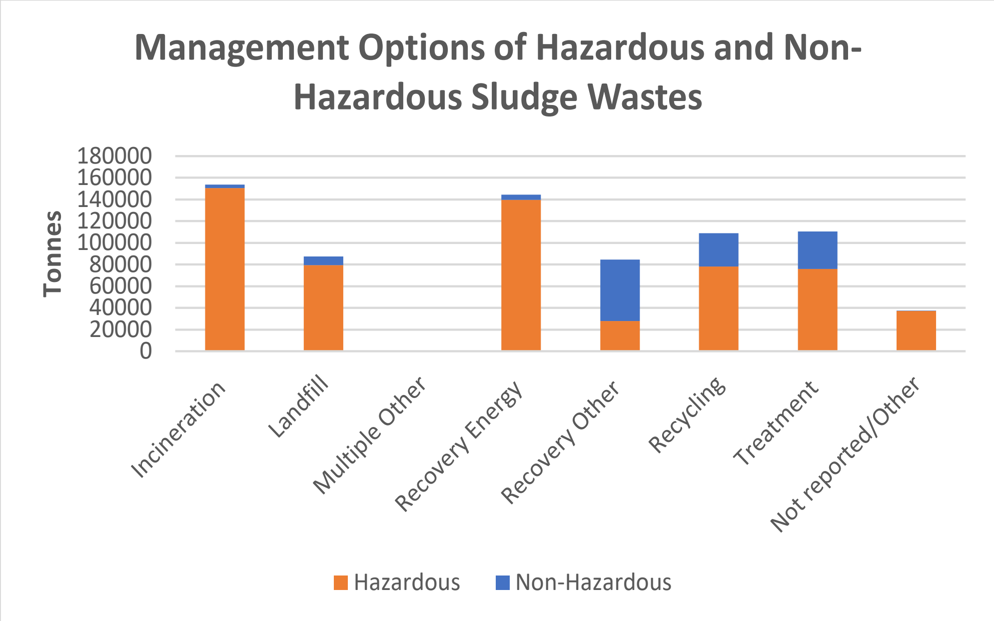


Figure 31 shows that there are regional differences in the management options for hazardous waste sludges, which could reflect the availability of waste management options and local policy differences. For example, landfill disposal is more important in the Mediterranean, Germany and the UK/Ireland/Northern Europe Country Groupings, whilst incineration and recovery-energy constitute the main management options in Benelux, Central/Eastern Europe and France. Treatment is a significant management option in Benelux and is also used in Iberia and Mediterranean Country Groupings. **Figure 32** shows the same management options per Country Groupings but for relative (normalised) hazardous waste. As per earlier figures (i.e., **Figure 10**), Iberia shows the lowest relative hazardous waste sludge tonnage (tonne of hazardous waste sludge per kiloton of throughput) of all Country Regions.

Figure 31. Total Hazardous Sludge Waste by Management Option and Country Groupings

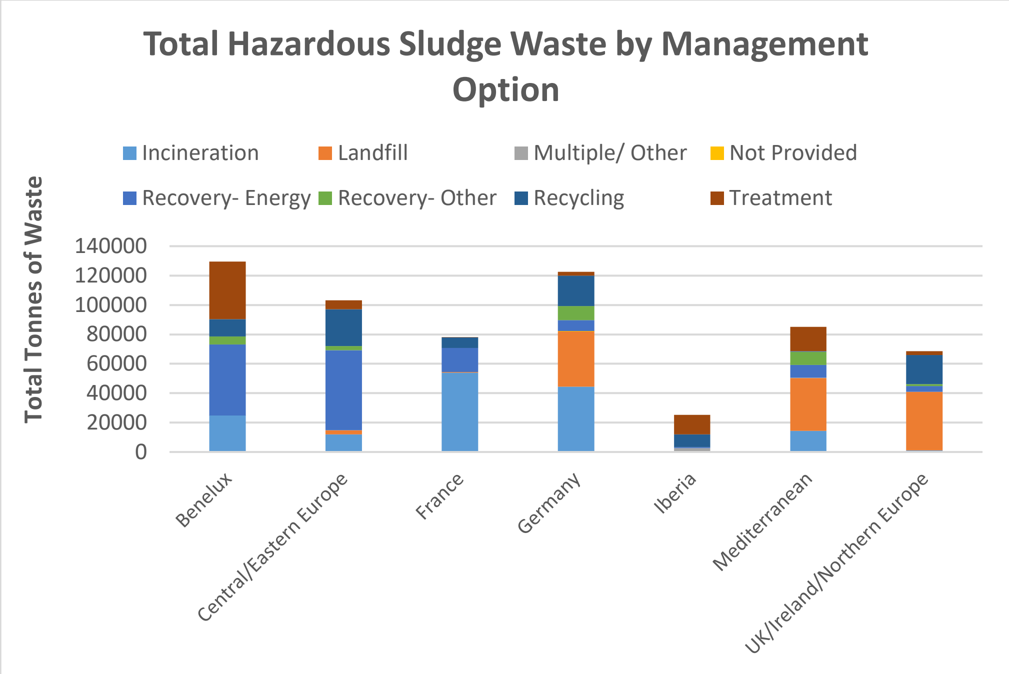
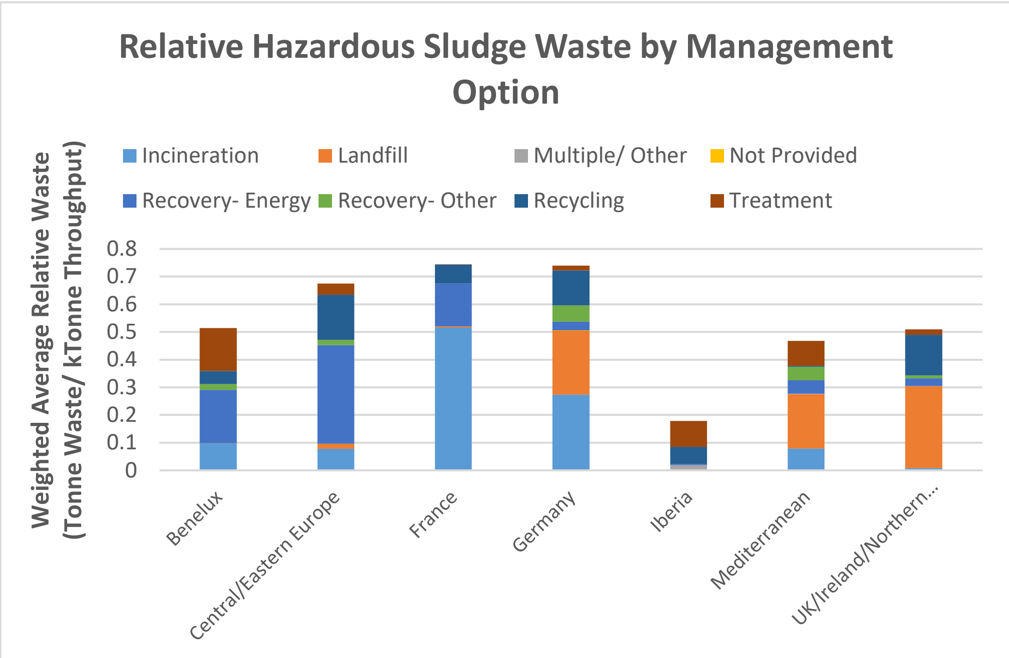


Figure 32. Relative Hazardous Sludge Waste by Management Option and Country Groupings



The geographical distribution of management options for non-hazardous waste presents less variation (**Figure 33**). Treatment is almost the only management option in Benelux and is also important in the Mediterranean and France regions. Recycling is almost the only management option in Iberia and is significantly used in the Mediterranean and France regions. Recovery-other predominates in Central and Eastern Europe, Germany and UK/Ireland and Northern Europe. Landfilling is the second management option in UK/Ireland and Northern Europe and used in small proportions in Mediterranean and Germany Country Regions.

Figure 33. Total Non-Hazardous Waste per Management Option and Country Groupings

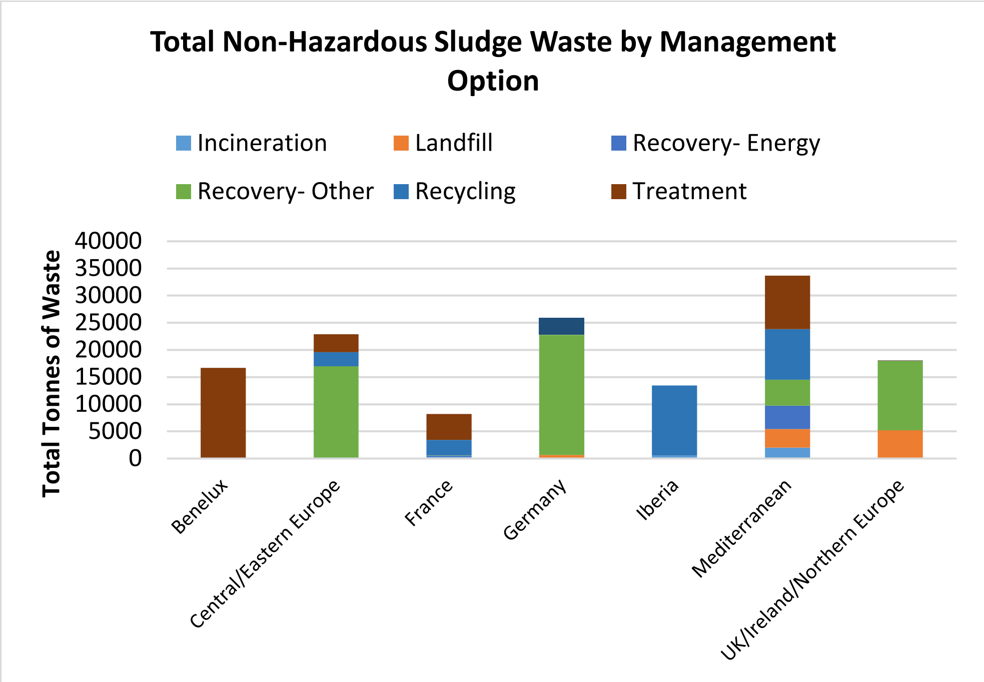
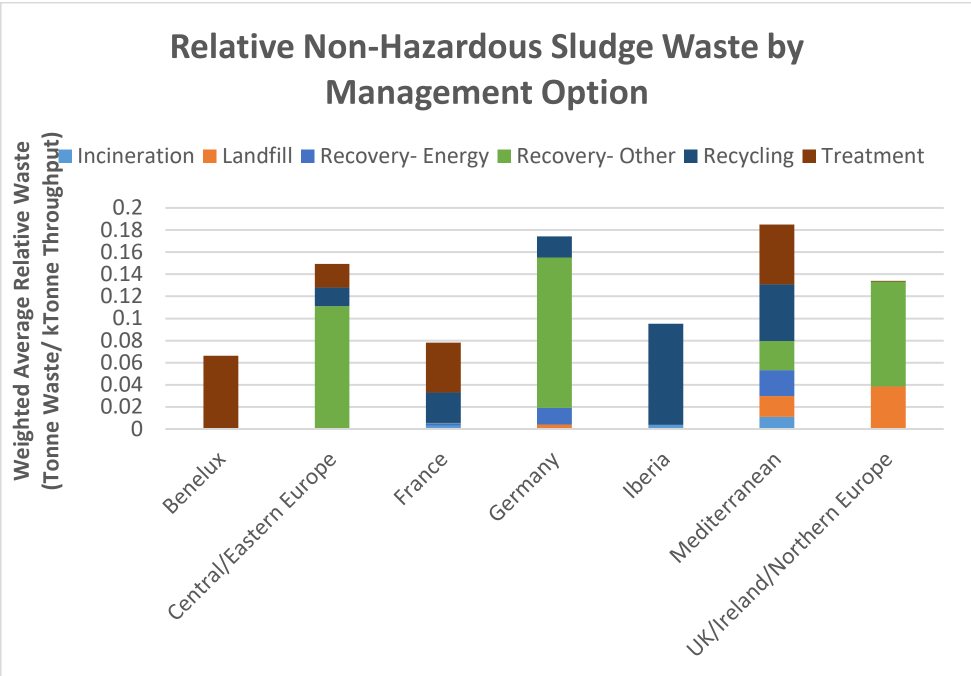
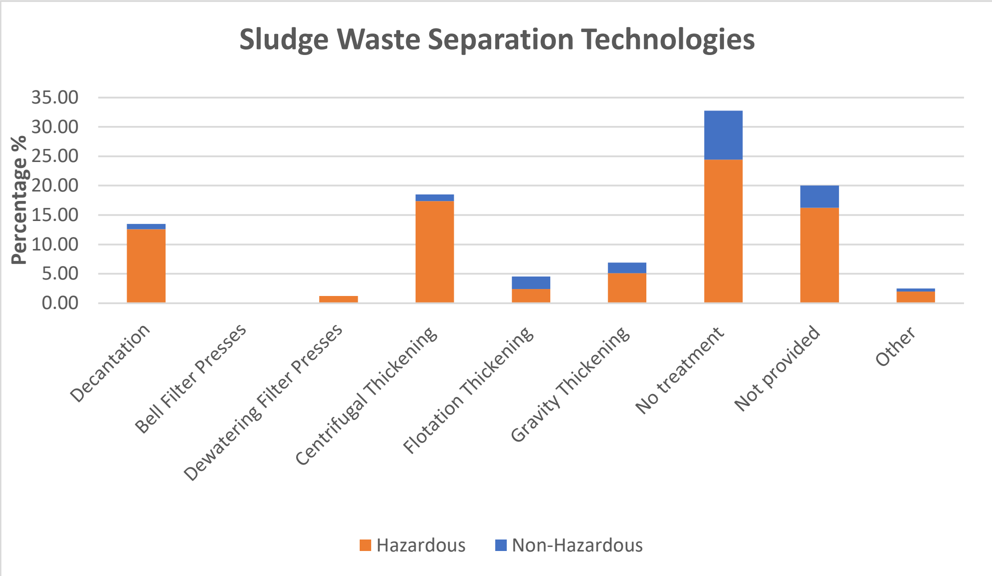


Figure 34. Relative Non-Hazardous Waste per Management Option and Country Groupings



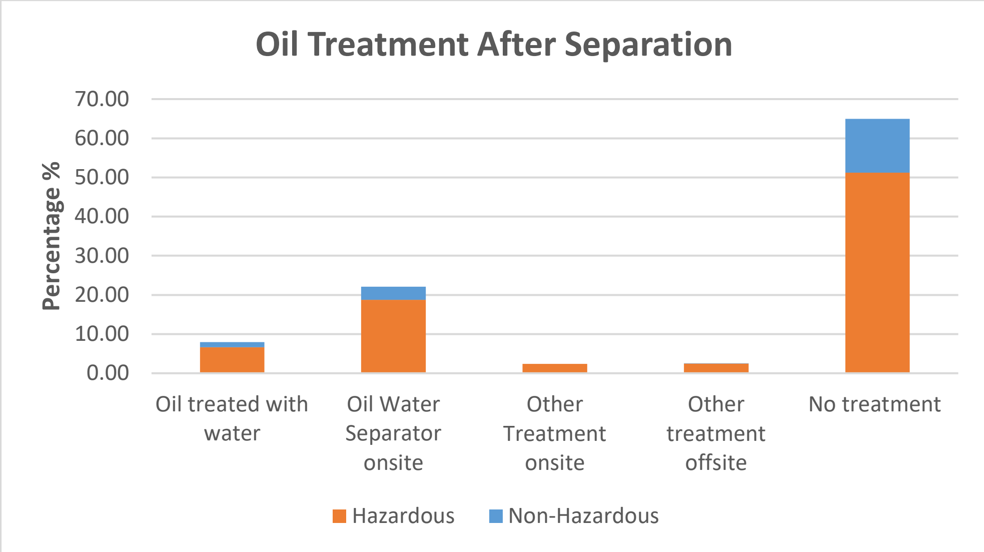
Respondents to the survey were also requested to answer questions as to the methods and techniques used in the pre-treatment of sludges prior to final disposal of the waste. These questions focused on initial separation of the liquid and solid phases and their further treatment. **Figure 35** shows that approximately 35% of the sludge waste did not undergo any form of pre-treatment, while for another 20% data on pre-treatment was not provided. Centrifugal thickening was the main separation technique used, followed by decantation and gravity and flotation thickening.

Figure 35. Hazardous and Non-Hazardous Sludge Waste Separation Technologies



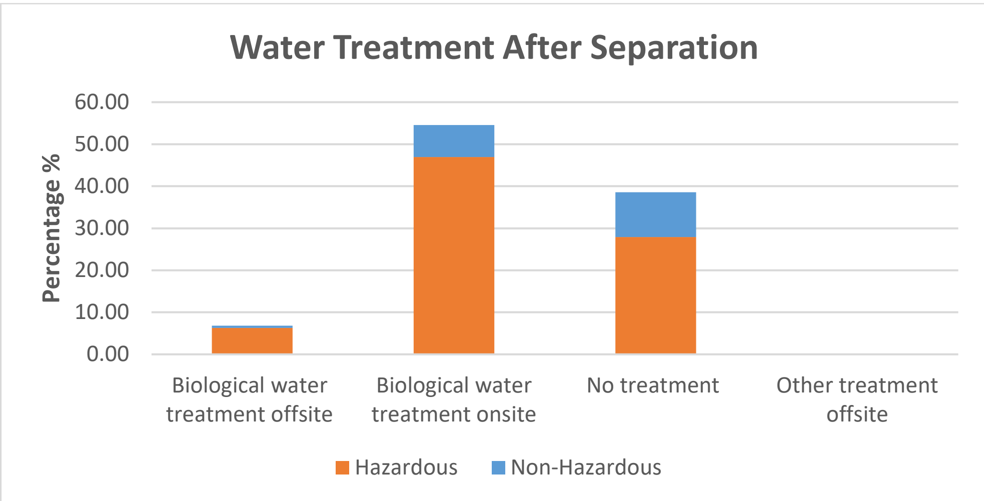
Respondents indicated that the majority of the oil in sludges received no treatment reflecting the responses related to sludge separation (**Figure 36**). When oil was separated from the liquid phase this was undertaken mainly with oil/water separators. In some cases, oil was treated together with the water phase. Only a small percentage (approximately 2%) was treated offsite.

Figure 36. Percentage of Oil Treatment Options after Sludge Separation



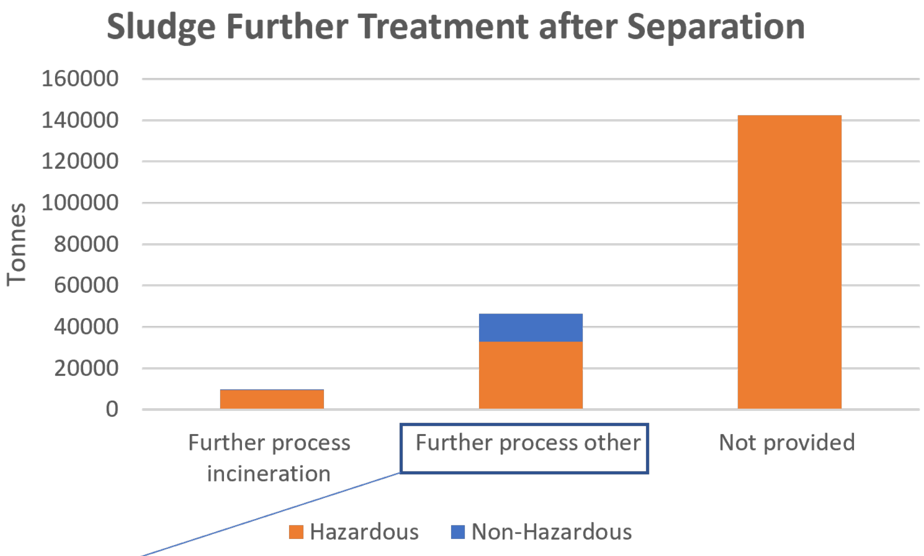
Water separated from the sludge waste was treated primarily onsite by biological treatment (42%) with a small quantity treated also biologically but offsite (5%). Approximately 27% of the water separated from hazardous sludge waste and 10% separated from non-hazardous sludge waste did not undergo any form of treatment (**Figure 37**). It is assumed from the questionnaire that this water is the water contained in the sludge waste that did not have any pre-treatment/separation and therefore was disposed by the management options shown in **Figure 30**.

Figure 37. Management Options of Water After Separation form the Sludge Waste



For the majority of pre-treated waste sludge, no information was provided as to whether it received further treatment. We assume in this report that this means the waste was sent to final disposal or recovery without further treatment. Some 25 % of the reported waste in this item was sent for further processing including a variety of methods with most of the sludge waste undergoing treatment according to BAT (best available techniques), oil re-refining and recycling of organic substances not used as solvent (**Figure 38**).

Figure 38. Sludge Waste Further Treatment After Separation



Sludge Further Processed (Other)	Hazardous (Tonnes)	Not-Hazardous (Tonnes)
BAT (Best Avalable Technique)	11566	13478
Biological	45	0
Oil re-refining or other reuses of oil	13523	0
Recycling reclamation of organic substances not used as solvents	5344	0
Reuse in distillation process	273	0
Land treatment	0	56

Answers including the use of BAT techniques can refer to several of the techniques described earlier, or more generally to the use of pre-treatment to reduce the volume of waste sludges. For example, BAT Conclusion 15, in the REF BREF, includes the pre-treatment of waste sludges with centrifugal decanters or steam dryers and the reprocessing of certain sludges in units, such as coking units, as part of the feed due to their oil content. The CWW BREF also provides BAT Conclusions for wastewater sludges. BAT Conclusion 14 states that in order to reduce the volume of wastewater sludges requiring treatment or disposal, one or a combination of techniques should be used including conditioning techniques (chemical, thermal conditioning), thickening techniques (decanting, flotation and gravity thickening) and dewatering (with the use of belt presses for example).

The survey asked respondents to identify barriers to treating sludge wastes that were sent to landfill for final disposal. Only a few answers were received in relation to less than 10% of the total amount of waste sludges generated during the three-year period of the survey. The response involving the largest amount of waste sludge referred to “sludge contamination” as a reason for not treating the sludge prior to disposal/recovery, probably referring to the hazardous nature of the sludge. Limited site capacity and the use of third-party companies were the second and third reasons provided in terms of associated tonnage. Insufficient volume of sludge was also cited as a barrier to treatment.

6.3.2. Relationship between Sludge Separation Techniques and Management Options

As discussed in previous Sections, incineration (D10) and energy recovery (R1), are the main management options for oily sludges generated at refinery operations, followed by landfilling (management options D1/5, D4, D12 and D15), recycling (R3/4/5) and treatment (D2, D8, D9 and D13)[3]. Thickening (centrifugal, gravitational and flotation) and decantation are the main separation techniques used onsite to condition oily sludges prior to final disposal or recovery offsite.

The relationship between the sludge separation techniques used by refineries and the final disposal or recovery options is more difficult to elucidate. To help visualise this relationship for the three main oily sludges discussed, Sankey diagrams have been used. Sankey diagrams are useful visualization tools to depict a flow from one set of values to another and they are best used to show the mapping of multiple paths through and between, in this case, Country Regions, separation techniques and management options for each sludge waste type. Sankey diagrams for all Country Groups and for individual Country Groups have been constructed and are included in Annex A. Based on these Sankey diagrams, the following observations can be made for each oily sludge type.

Tank Bottom sludges

Most of the Country Regions responses indicated that almost half (app. 47%) of all tank bottom sludges received no separation/treatment prior to disposal or a response was not provided. France was the only country region that reported no separation/treatment of tank bottom sludges prior to final management which included primarily incineration (D10) and energy recovery (R1). All other Country Regions have a mixture of no treatment/separation prior to final disposal. For Benelux, more than 50% of the tank bottom sludges that did not undergo separation were recycled (R3/4/5) although the actual recycle process used is unknown.

There doesn't appear to be consistency between sludge that underwent separation and sludge that didn't, and disposal options, with both treated (separated), and not treated (not separated) sludge both resulting in incineration with or without energy recovery (R1, D10), physico- chemical treatment (D9) and recycling (R3/4/5). Of particular attention are treated sludges sent to landfill in UK/Ireland/Northern Europe (about 30% of all tank bottom sludge) and the approximately 30% of sludges sent to deep injection (D3) in the Iberia Region.

Overall, energy recovery was the management option most used (app. 24.5%), followed by incineration (app. 22%), physico-chemical treatment (app.13.3%) and recycling (app. 8%). Only 1.8% of the tank bottom sludges where disposed of in a landfill.

Maintenance sludges

For maintenance oily sludges (EWC 05 01 06*), there doesn't seem to be a pattern between Country Regions with regards to the final management options and sludge separation or no separation onsite. For more than 40% of the maintenance sludges, separation prior to final disposal was not provided by the respondents or received no treatment. Similarly, Country Regions reported different management options for this type of sludges. Overall, management options were not provided for over 25% of the maintenance sludges reported. The largest management option

[3] Refer to Table 8 for waste management options groupings.

(app. 15%) was physico-chemical treatment (D9), followed in decreasing volume by recycling (R3/4/5), energy recovery (R1), incineration (D10) and oil re-refining (R9) with percentages of between approximately 10% and 13%.

Different management options were primarily used in some Country Regions with Germany using recycling (R3/4/5) and incineration (D10) as their main option and Central/Eastern Europe using biological treatment (D8), the only region to use it as the main waste management options for this type of sludge. Similarly, Iberia and Benelux's most used option was physico-chemical treatment (D9) while energy recovery (R1) was the main option used in France.

The disposal into landfill (D1/5) was low, with approximately 1.8% of the total maintenance sludge managed by this option (in UK/Ireland/Northern Europe, Central/Eastern Europe and Iberia Country Regions). Maintenance sludges in Benelux were sent to physico-chemical treatment (D9) with and without prior treatment/separation, probably indicating the production of different sludges qualities in terms of water or solids content. Finally, UK/Ireland/Northern Europe did not report final management options for the majority of the maintenance sludges produced in this Country Region.

Wastewater Treatment sludges

Several EWC codes were included in this category that includes sludges from on-site effluent treatment containing hazardous and non-hazardous substances: 05 01 09*, 05 01 10, 07 01 11*, 07 07 11*, 10 01 20* and 19 11 05). Approximately 44% of the wastewater treatment (WWT) sludges received no treatment prior to final disposal or the information was not provided by the respondents. All Country Regions reported a mixture of treatment/separation and no treatment prior to final disposal with the exception of UK/Ireland/Northern Europe which reported all WWT sludges treated by thickening (centrifugal, flotation and gravity thickening).

Energy recovery (R1) was the main management option for this type of sludge waste with a reported 25.2% of the total volume. This was followed by physico-chemical treatment (app. 14.4%) and recycling (app. 6.8%). Disposal into landfill constituted only 1.7% of the total.

While it is difficult, with the available data, to draw conclusions as to the use of separation techniques associated with specific management options, the following observations can be made. More volume of sludge was treated than not treated prior to incineration (D10) and energy recovery (R1), while more sludge volume was not treated than treated when the management option selected was physico-chemical treatment (D9). Recycling (R3/4/5) seemed to have similar volumes of WWT sludges managed by this option with both treatment and no treatment prior to recycling.

The above discussion regarding the three main types of oily sludges seems to indicate that the selection of management option is dependent on the availability of these management options within the country where the sludges are generated, with little waste sludges sent to countries outside the country of origin, as discussed earlier in the report. The separation techniques used, or the lack of any separation or pre-treatment, seem to be a function of the quality of the sludge needing disposal/recovering in terms of the amount of water, solids and the quality of the oil present in the sludge. This is based on the fact that the same type of oily sludge that is treated in a Country Region prior to disposal by a type of management option, does not required treatment in another Country Region when the same management option is used.

6.3.3. Separation and Management Options for Sludges from Crude and Non-Crude Throughputs

Figure 39 shows a comparison of management options for the three largest sludge types by relative weight when non-fossil and fossil/mixed throughputs are considered. The main three types of sludge wastes are sludges from wastewater treatment plants, sludges from maintenance operations and tank bottom sludges. To make the comparison more relevant only refineries with non-crude feedstock were selected and compared against crude-only and mixed- feedstock refineries that overall processed no more than 7% non-crude feedstock.

While relative amounts of sludges originating from wastewater treatment were similar for non-crude and crude/mixed feedstocks, higher relative amounts of tank bottom sludges and higher still of sludges from maintenance operations were produced by non-crude refining processes. It should be noted that the throughput of non-crude feedstock in non-crude refineries is very small (approximately 3,500 kt) when compared to a total crude feedstock of over 1 million kilotonne that may benefit from efficiencies of scale.

In terms of differences in management options, sludges derived from non-crude feedstock have used less management options than those from crude feedstock. This could be a result of the small volume of non-crude feedstock generated in the period necessitating less options or a result of more uniformity in the quality of the sludges.

Incineration and recovery-energy were the predominant management options for non-crude wastewater sludges while landfill, followed by incineration and treatment constituted the main management options for non-crude tank bottoms and maintenance sludges.

Figure 39. Management Options for Top Three Sludge Wastes for Crude and Non-Crude Throughputs

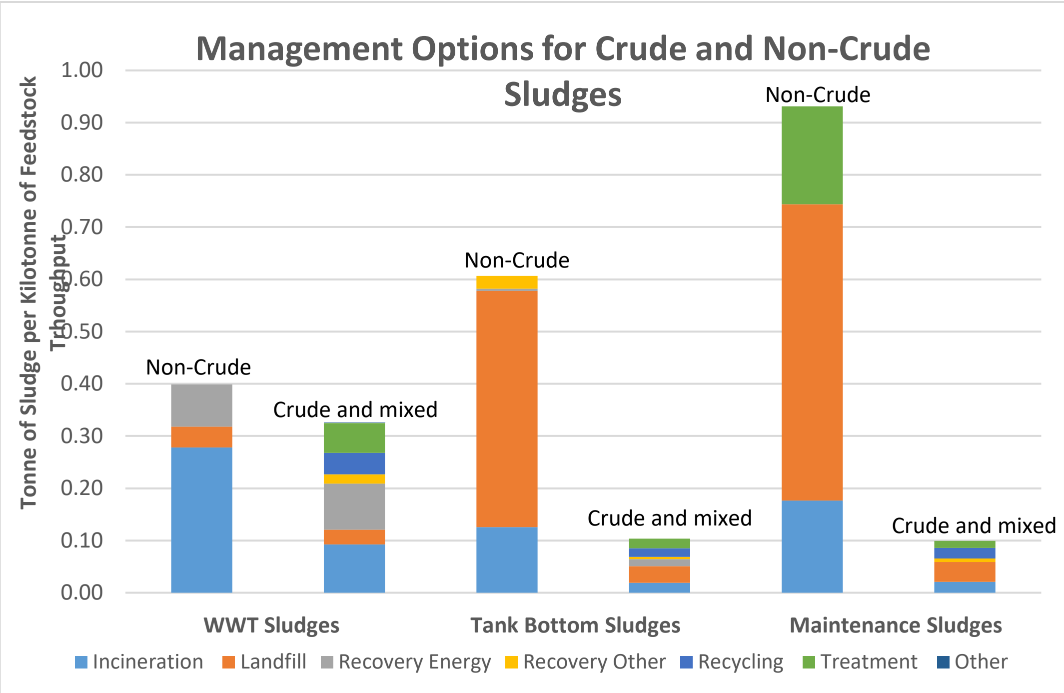
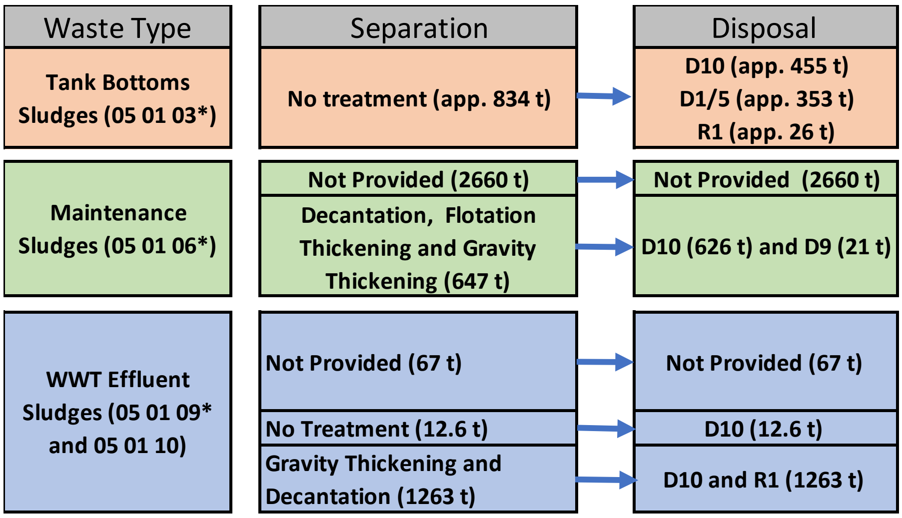


Figure 40 shows the separation techniques and final management options for the three largest sludge waste types reported associated only to sludges produced from the processing of non-crude feedstock in an attempt to identify correspondence between separation techniques and management options. No separation was undertaken on tank bottom sludges which were disposed of mainly by incineration and landfilling. As mentioned earlier, one respondent indicated pollution as a barrier for not pre-treating the sludges sent to landfill, presumably referring to the hazardous classification of this sludge type.

Where provided, maintenance sludges were separated by decantation, flotation and gravity thickening followed primarily by incineration. Wastewater treatment sludges were sent primarily to incineration and incineration with energy recovery whether they were pre-treated or not prior to final disposal. When a response was given, oil was separated using oil/water separation technique and water underwent biological treatment. No answers were given for non-crude maintenance sludges regarding barriers to treatment for sludge sent to landfill.

Figure 40. Separation Techniques and Management options for tank bottoms, wastewater effluent and maintenance sludges associated with non-fossil throughputs.



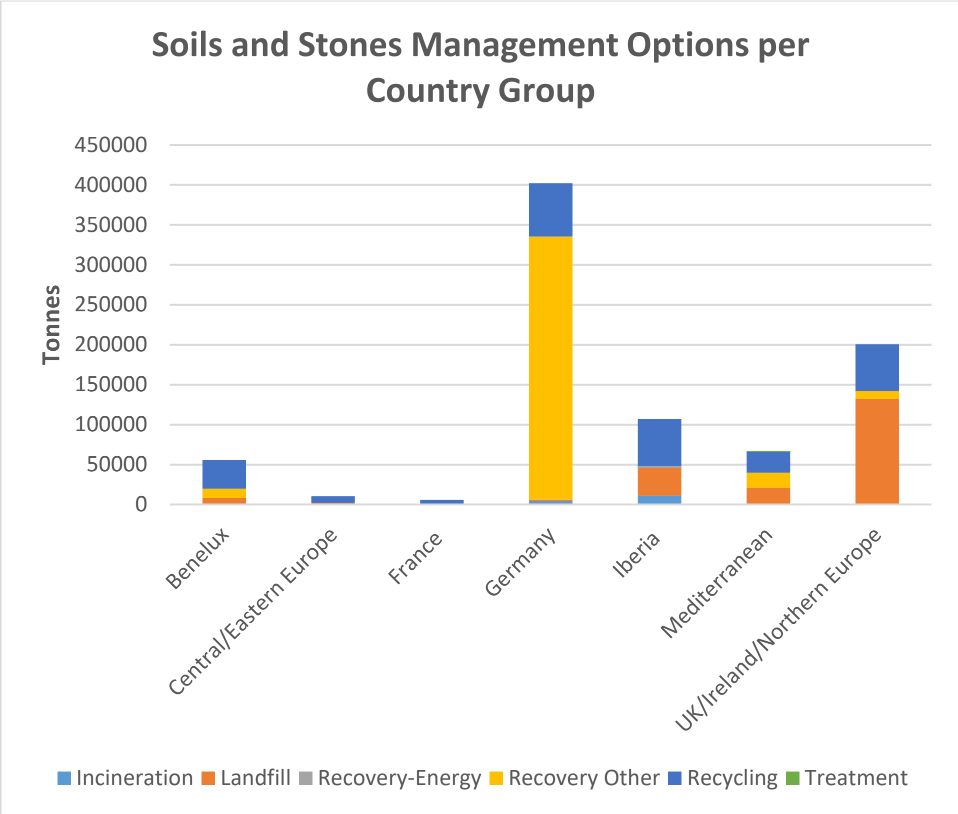
D1/5	**Landfill/engineered landfill**
D10	**Incineration**
D9	**Physico-chemical treatment**
R1	**Incineration with energy recovery**

6.4. MANAGEMENT OPTIONS FOR OTHER TOP WASTE CATEGORIES

6.4.1. Soils and Stones

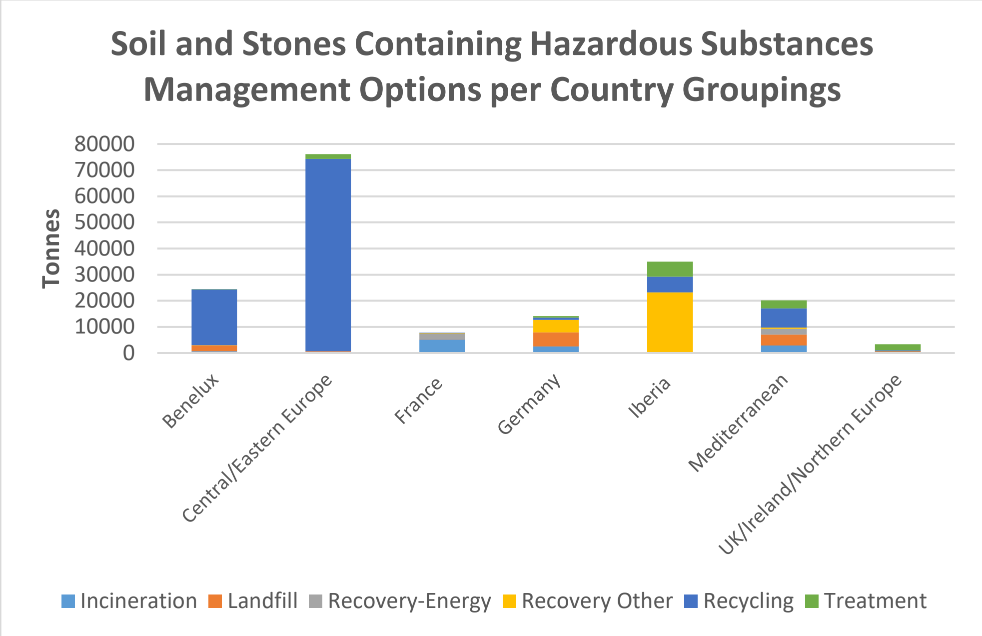
Germany was the largest producer of soil and stones waste in the 2019-2021 period (**Figure 41**). Most of this waste was handled by Recovery-Other which constituted the most used management option for this type of waste (43%). Recovery-other was also used in Mediterranean and in Benelux and UK/Ireland/Northern Europe in small quantities. Recycling was used by all Country Groups and was the second management option in terms of tonnage (30%). Landfill was primarily used in the UK/Ireland/Northern Europe and was the third largest management option in terms tonnage (23%).

Figure 41. Management Options for Soils and Stones Waste Category (EWC 17 05 04)



Recycling was the main management option for soils and stones containing hazardous substances (**Figure 42**). Approximately 60% of all the waste was handled by this option and was primarily used by Central/Eastern Europe (the main producer of this waste type) and Benelux. Recovery-Other was the second largest management option by tonnage (16%) used primarily in Iberia. France managed this waste mainly by incineration while Germany and Mediterranean Country Groups used a variety of options to manage this waste.

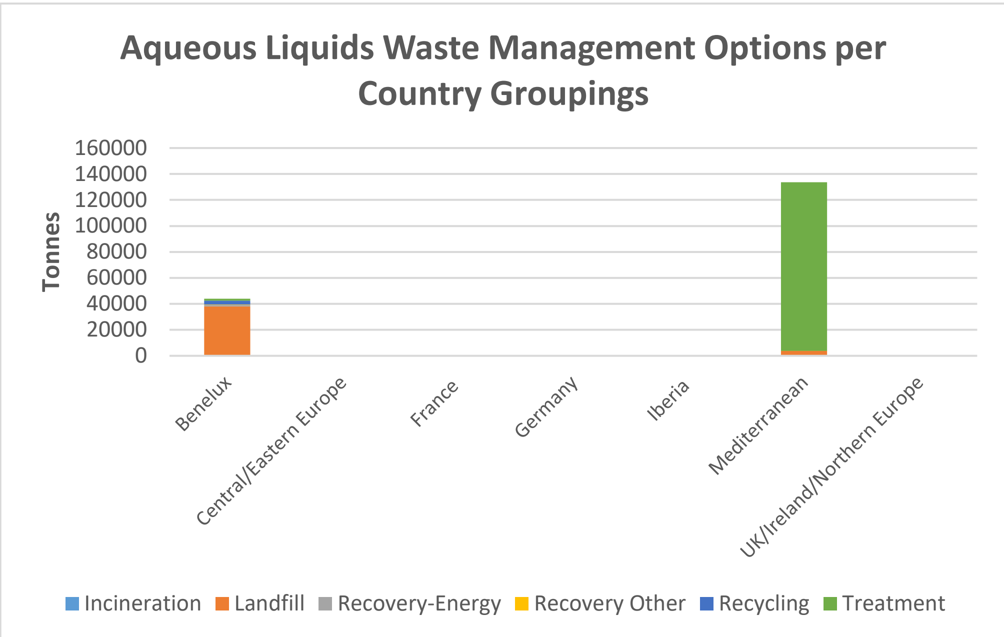
Figure 42. Management Options for Soils and Stones Containing Hazardous Substances Waste Category (EWC 17 05 03*)



6.4.2. Aqueous Liquid Wastes Containing Hazardous Substances

As shown in **Figure 43**, most of this waste was reported by Mediterranean and Benelux (97% of the total waste). Treatment was the preferred option by the Mediterranean Group, with Landfill the preferred management option in the Benelux Group.

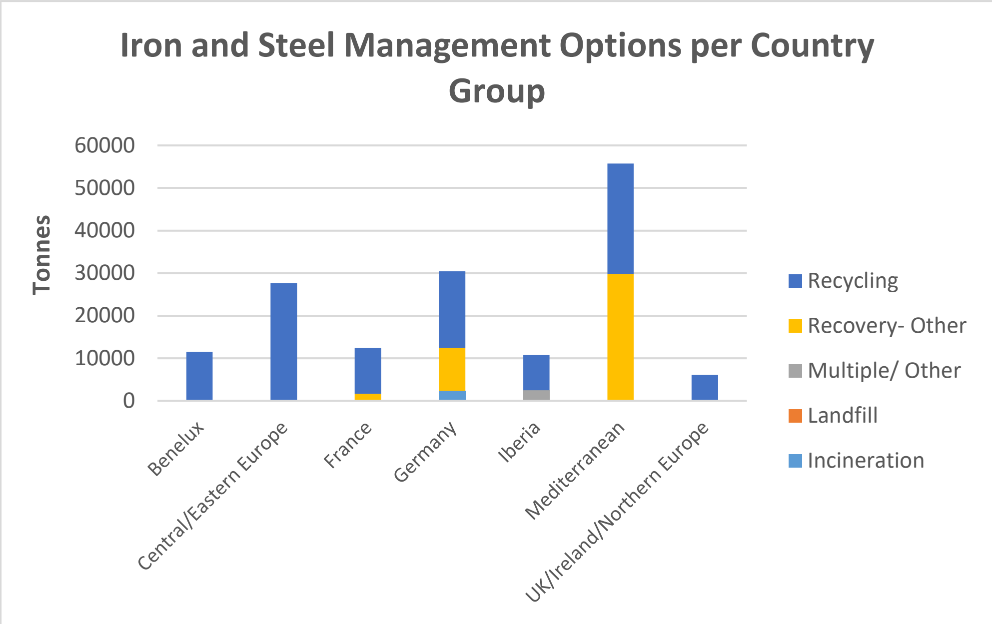
Figure 43. Management Options for Aqueous Liquid Wastes Containing Hazardous Substances (EWC 16 10 01*)



6.4.3. Management Options of Iron and Steel

Recycling, followed by recovery-other were the main management options for this waste category (**Figure 44**). The largest amount of iron and steel was produced in the Mediterranean Country Group area and it was managed with both management options almost in equal measure. Germany also used both management options with a small portion sent to incineration. All other Country Groups used recycling as the main management option.

Figure 44. Management Options for Iron and Steel per Country Group



7. CONCLUSIONS

7.1. ANALYSIS OF SURVEY DATA

The survey questionnaire for the years 2019, 2020 and 2021 was distributed to 87 refineries operated by Concawe member companies that agreed to participate in the survey. 68 refineries responded questionnaire which gave a response rate of 70.1%. The waste survey asked questions about wastes types and their sources, waste management options for the different types of wastes and had a focus on waste sludges sources and management including questions about pre-treatment techniques

7.2. WASTE QUANTITIES AND SOURCES

Total reported waste production by the sector in the 2019-2021 period was 3.6 million tonnes, of which 47.3% was classified as hazardous. The highest tonnage of total waste was produced by Germany while the lowest was produced by Iberia. When waste generation is normalised by total throughput, Germany, Mediterranean and UK/Ireland/Northern Europe have the highest relative waste tonnage (in tonnes of waste per Kilotonne of throughput), with Iberia and France presenting the lowest relative waste tonnage. While overall total annual waste generation was similar in the 2019-2021 period to that reported in 2013 (i.e., approximately 1.2 million tonnes/year), relative waste tonnage increased steadily from 2013 (2.61 t/kt) to 2021(3.26 t/kt). This is likely the result of lower throughput (due to Covid) while waste generation remained constant or decrease at a lower rate.

When only hazardous wastes are considered, the range in relative waste production across the country groups was from 0.6 (Iberia) to 2.1 (Mediterranean) tonnes of hazardous waste/ kilotonne of feedstock throughput, with a sector average of 1.4 t/kt for the three years period. This is slightly higher than the 1.07 t/kt reported in 2013. For non-hazardous wastes the average relative waste production across the 2029-2021 period was 1.65 tonnes of waste/ kilotonne feedstock throughput.

The top 3 reported wastes types by tonnage are soil and stones not containing hazardous substances, sludges from on-site effluent treatment containing hazardous substances and soil and stones containing hazardous substances. Soils and stones (hazardous and non-hazardous) represented approximately 28% of all waste produced in the 2019-2021 period. Approximately 61% of the total hazardous or non-hazardous waste are accounted for by the top 10 waste classification codes reported. Sludges represented approximately 20.8% of all waste produced and sludges classified as hazardous constituted 81.5% of all sludges. The top 3 reported waste sludges by tonnage were sludges from on-site effluent treatment containing hazardous substances, sludges from maintenance operations and tank bottom sludges, all three representing approximately 62.8% of all waste sludges reported for the three-year period. Aqueous liquid wastes containing hazardous substances was the third largest hazardous waste by tonnage representing 5% of all waste. Most waste (62.6%) originated from refinery operations, followed by re-construction works (11.5%) and diverse sources (10%).

7.3. TOTAL WASTE MANAGEMENT

Approximately 60% of the total waste generated underwent some form of recovery, while the remaining of the waste was managed by disposal options. Recycling comprised the largest amount of waste in every year of the survey period with over 300,000 tonnes of waste handled through this option each year. Recycling included several types of waste of which the top three categories by weight were soil and stones with and without hazardous substances, sulphurus and sulphuric acid and spent fluids.

The secong largest reported waste management category was landfilling. The largest waste category disposed by this method was soils and stones with and without hazardous substances, followed by generic hazardous waste and bottom ash waste. A generic recovery term "R" was reported as the third largest management option. Wastes assigned to this category were soils and stones, mixtures of concrete, bricks, tiles and ceramics and sludges from onsite effluent treatment plants.

Similar waste tonnages where managed by incineration, landfill and recycling between 2013 and the 2019-2021 period. However, a significant increased of waste managed by the "recovery-other" category was reported in 2019-2021 (from 7.7% in 2013 to 22.4% in 2019-2022), likely emcompassing several management options previously assigned to a "multiple disposal-other" category which in 2019-2021 was reported as almost zero (0.01%).

7.4. SLUDGES WASTE MANAGEMENT

For most management options, hazardous sludges constituted the majority of the waste sludge. Incineration and incineration with energy recovery were the two largest management options by weight. Only 2.6 % of the sludges managed by these options were classified as non-hazardous. These two incineration options were followed by landfill, recycling and treatment, all with similar tonnages of hazardous sludges and less amounts of non-hazardous sludges. The recovery-other option is the only option with a larger quantity of non-hazardous sludges in relation to the hazardous fraction.

Approximately 35% of the sludge waste did not undergo any form of pre-treatment prior to disposal, while for another 20% data on pre-treatment was not provided. Centrifugal thickening was the main separation technique used, followed by decantation and gravity and flotation thickening. Water separated from the sludge waste was treated primarily onsite by biological treatment (42%) with a small quantity treated also biologically but offsite (5%). When oil was separated from the liquid phase this was undertaken mainly with oil/water separators. In some cases, oil was treated together with the water phase. Only a small percentage (approximately 2%) was treated offsite. No clear management preferences were observed for individual sludge separation techniques with most pre-treated sludge managed by incineration, landfilling and physico-chemical processing.

The selection of management option is dependent on the availability of these management options within the country where the sludges are generated, with little waste sludges sent to countries outside the country of origin, as discussed above. The separation techniques used, or the lack of any separation or pre-treatment, seem to be a function of the quality of the sludge needing disposal/recovering in terms of the amount of water, solids and the quality of the oil present in the sludge.

A comparison of management options for the three largest sludge types by relative weight (in tonnes waste/kiloton of throughput) was undertaken for non-crude and crude/mixed throughputs. While relative tonnages of sludges originating from waste water treatment were similar for non-crude and crude/mixed feedstocks, higher relative amounts of tank bottom sludges and higher still of sludges from maintenance operations were produced by non-crude refining processes. In terms of differences in management options, sludges derived from non-crude feedstock used less management options than those from crude feedstock. Incineration and recovery-energy were the predominant management options for non-crude waste water sludges while landfill, followed by incineration and treatment constituted the main management options for non-crude tank bottoms and maintenance sludges.

8. GLOSSARY

DIN	German National Standard
EN	European Standard
EU	European Union
EU-27	Abbreviation of European Union (EU) which consists of a group of 27 countries
EWC	European Waste Catalogue
ISO	International Organisation for Standardisation

9. REFERENCES

1. Concawe (2017). 2013 Survey of Waste Production and Management at European Refineries. Concawe Report No 12/17.

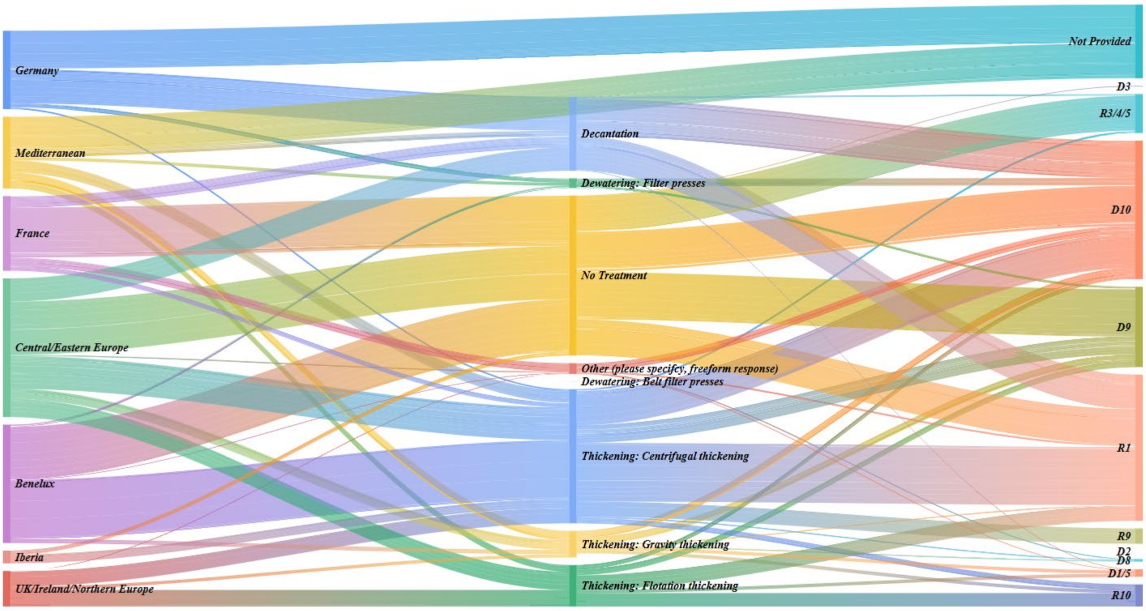
2. Commission notice on technical guidance on the classification of waste (2018/C 124/01). European Union, 2018.

3. Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas, 2015, and its accompanied BATc, 2014.

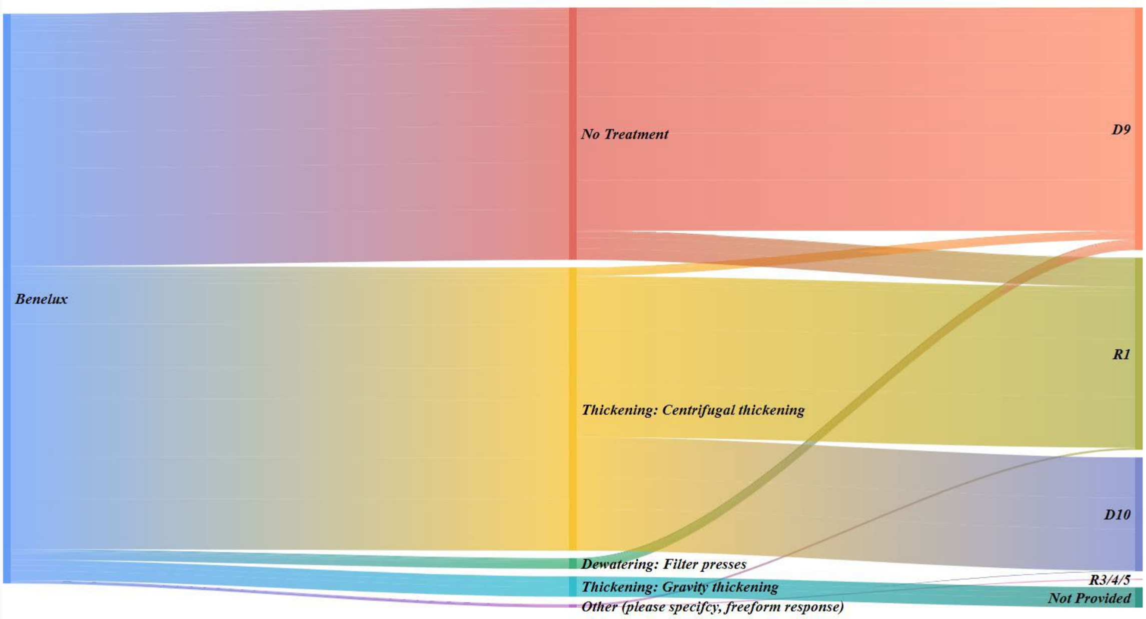
4. Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector, 2010.

APPENDIX A: SLUDGE TREATMENT TO DISPOSAL SANKEY DIAGRAMS.

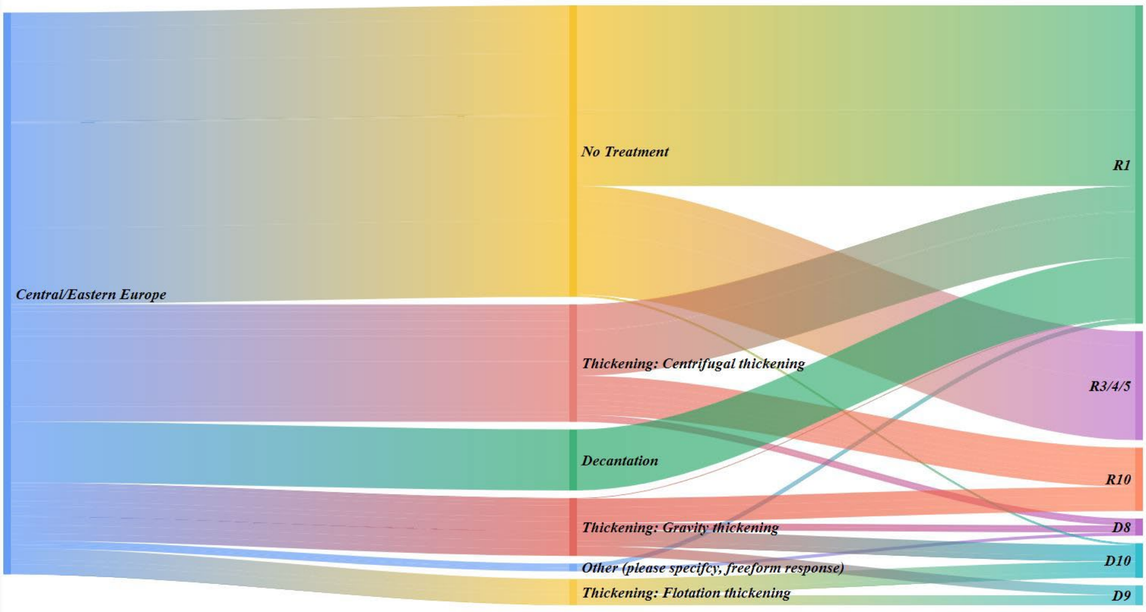
Sankey Diagrams of Wastewater Sludges per Country Region, Separation Techniques and Disposal Options (2019-2021)



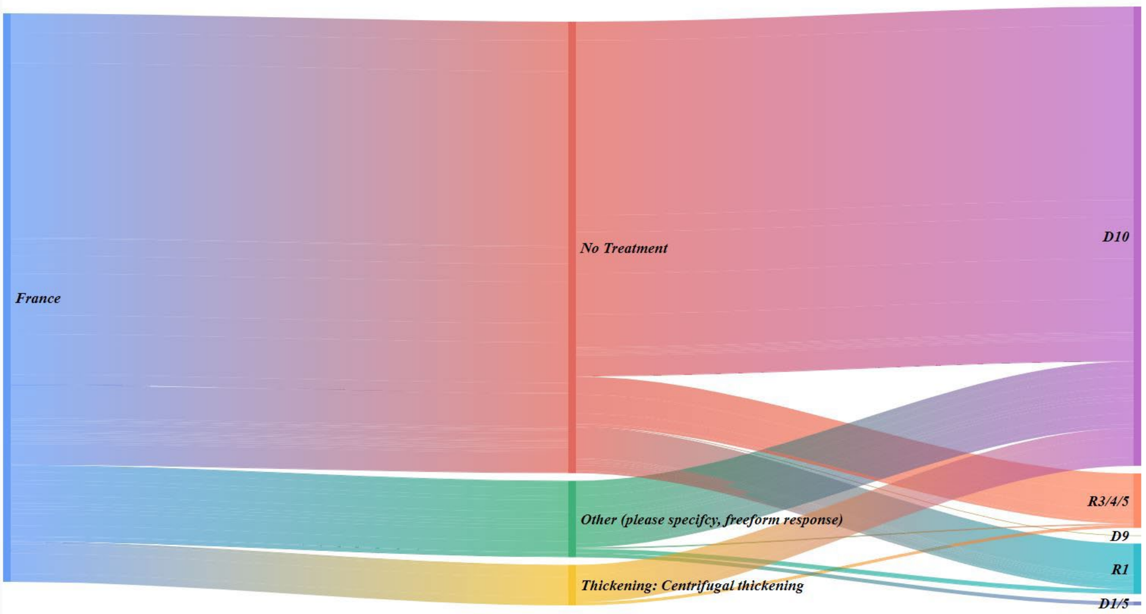
Benelux WWT Sludges (2019-2021)



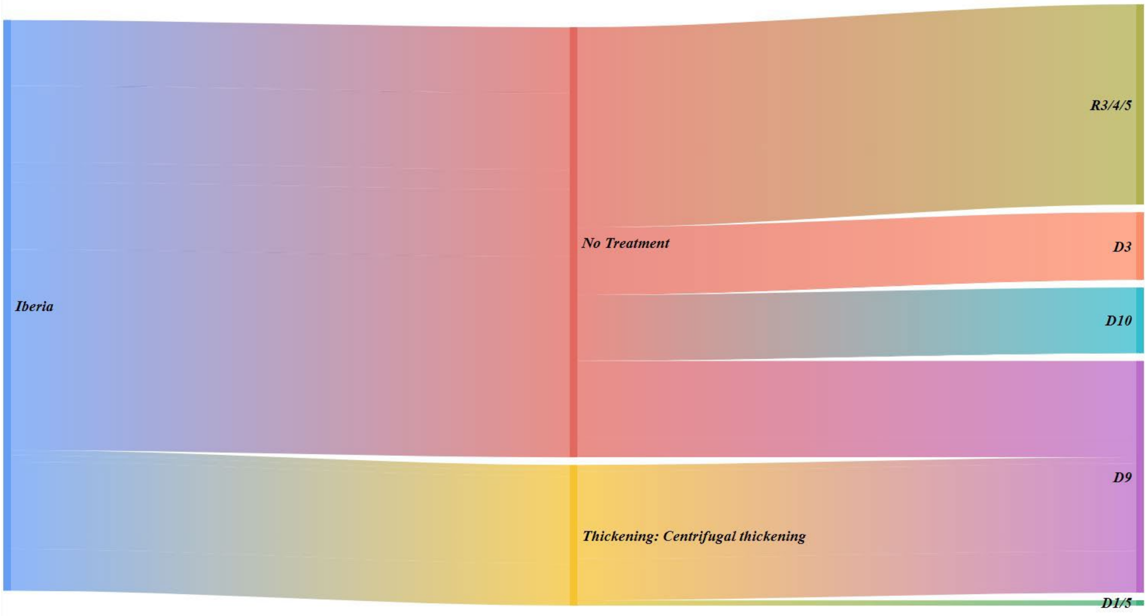
Central/Eastern Europe WWT Sludges (2019-2021)



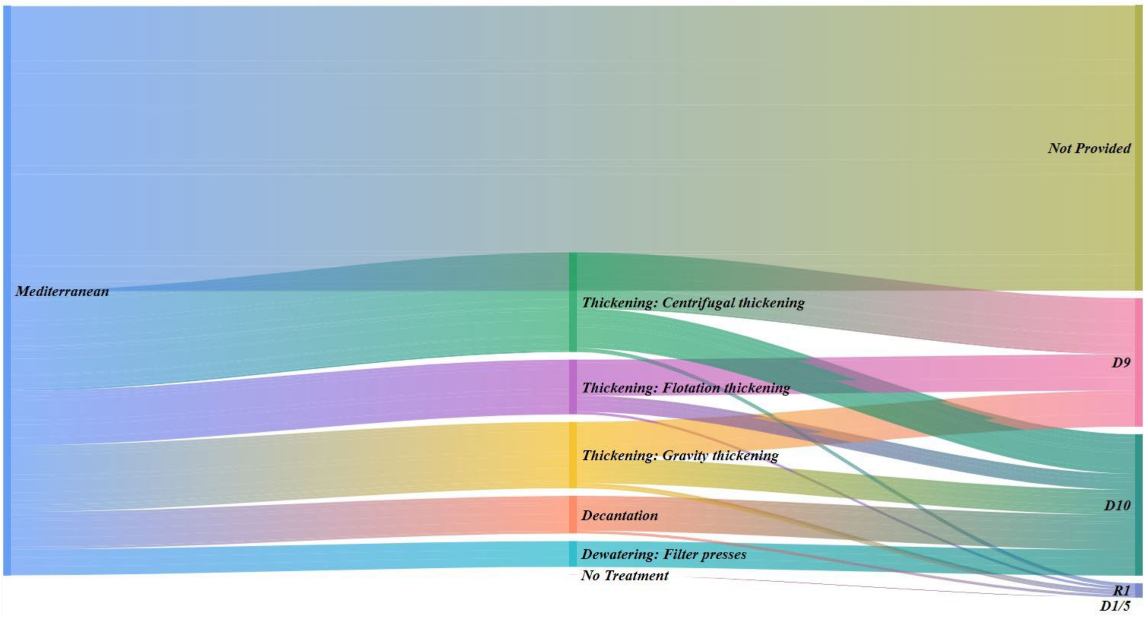
France WWT Sludges (2019-2021)



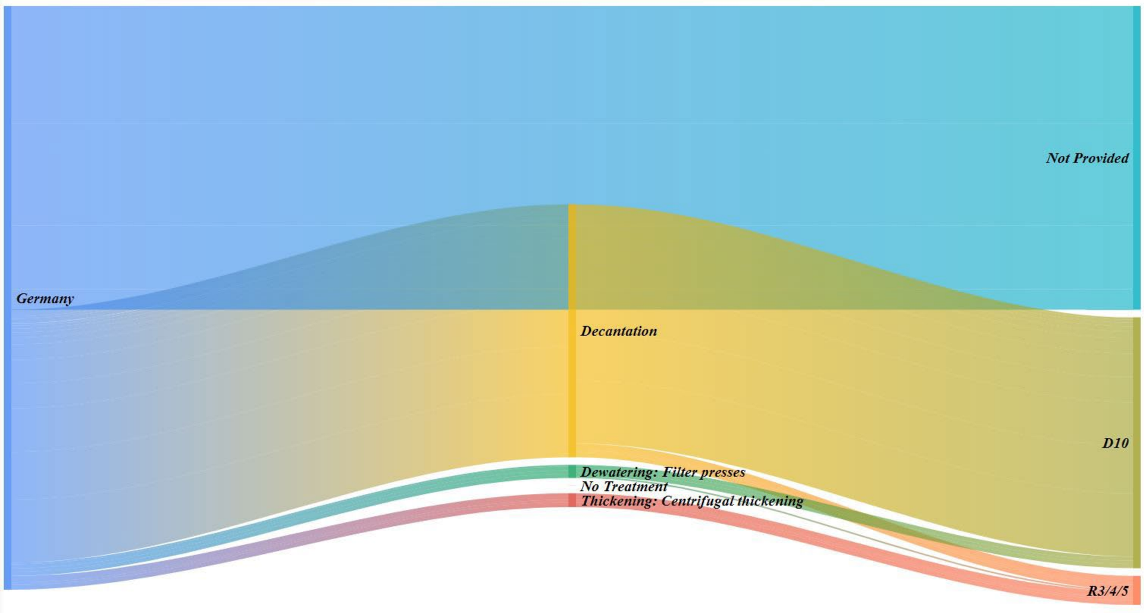
Iberia WWT Sludges (2019-2021)



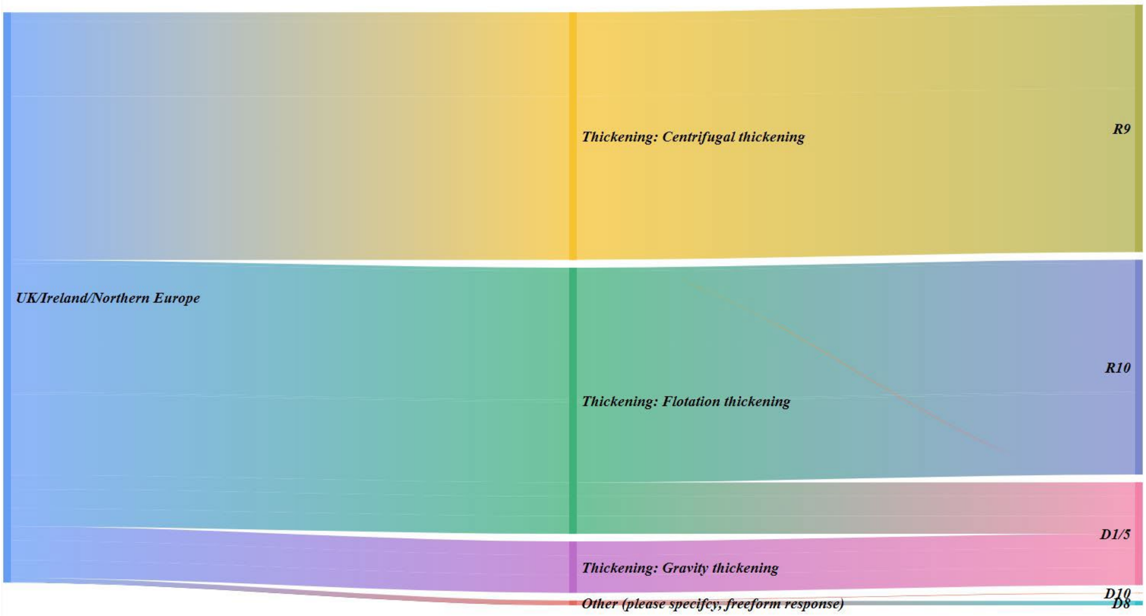
Mediterranean WWT Sludges (2019-2021)



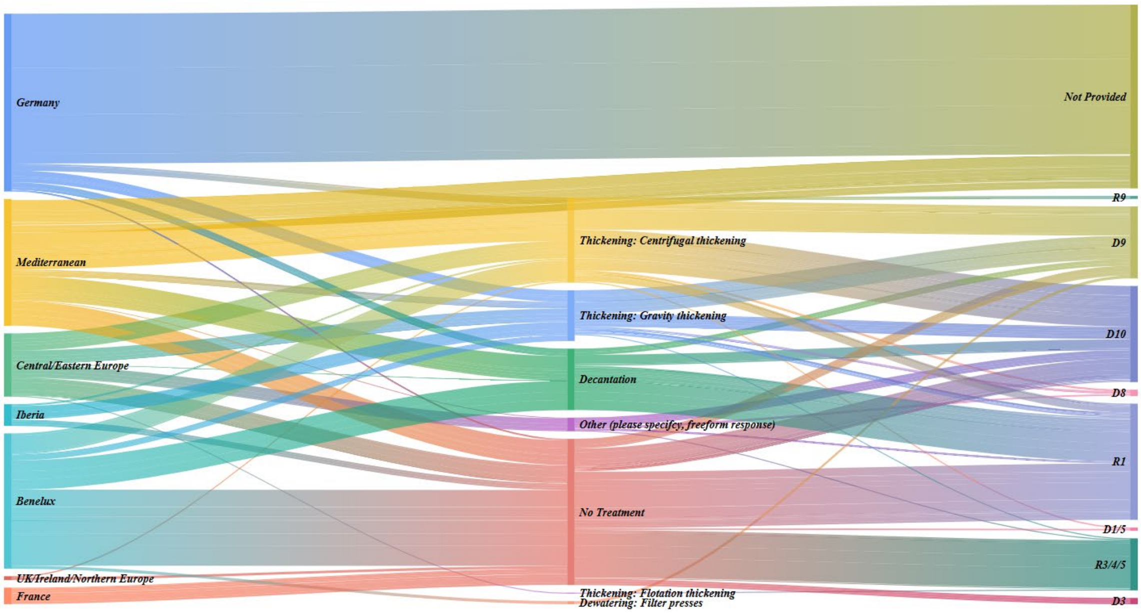
Germany WWT Sludges (2019-2021)



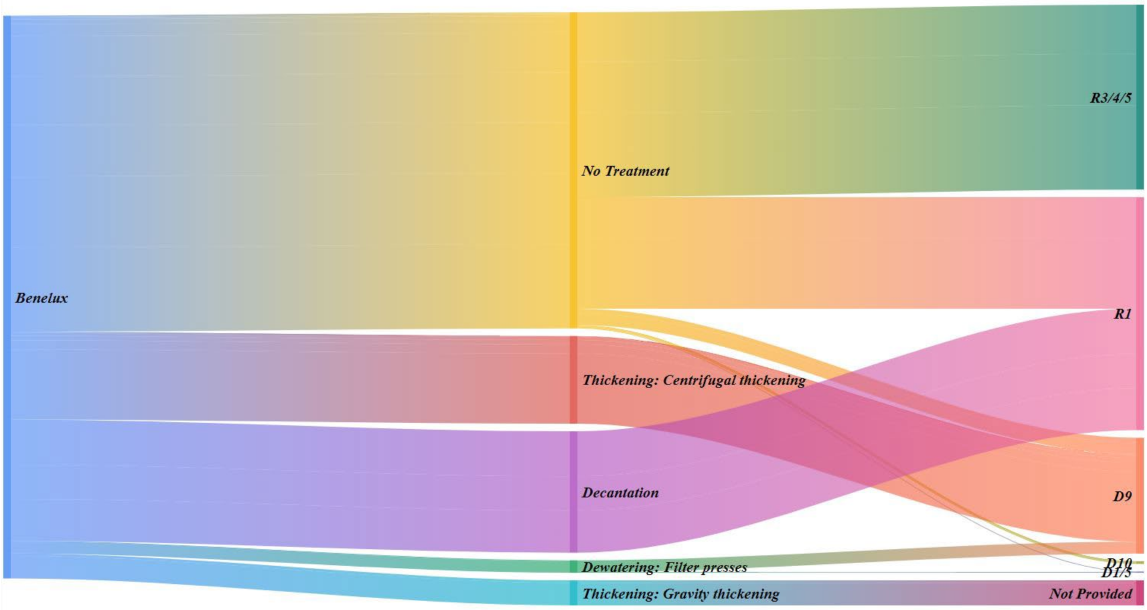
UK/Ireland/Northern Europe WWT Sludges (2019-2021)



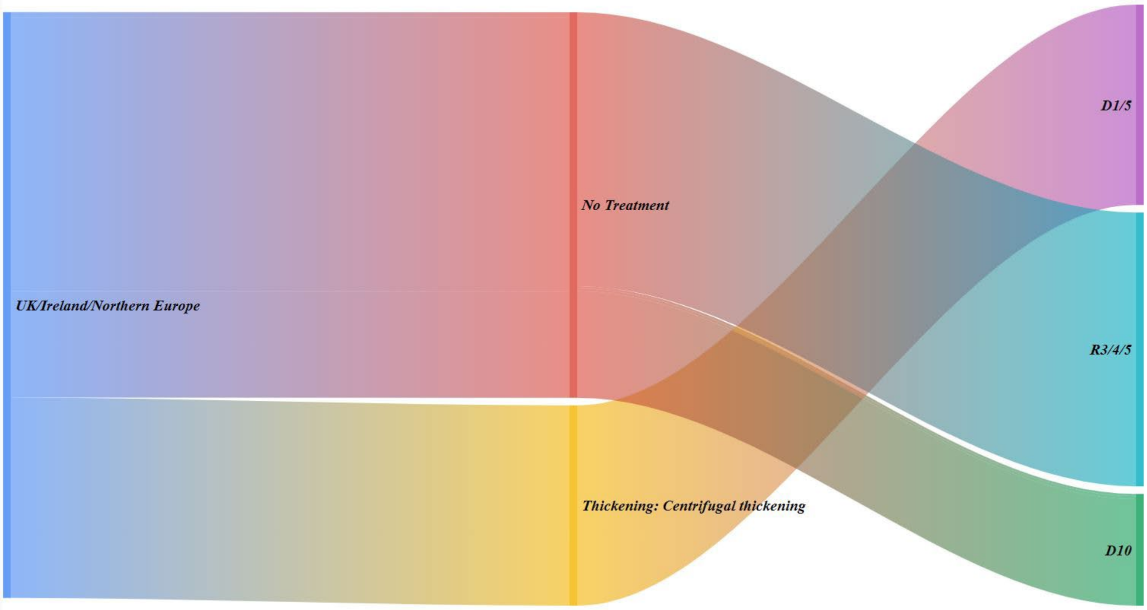
Sankey Diagram of Tank Bottom Sludges per Country Region, Separation Techniques and Disposal Options (2019-2021)



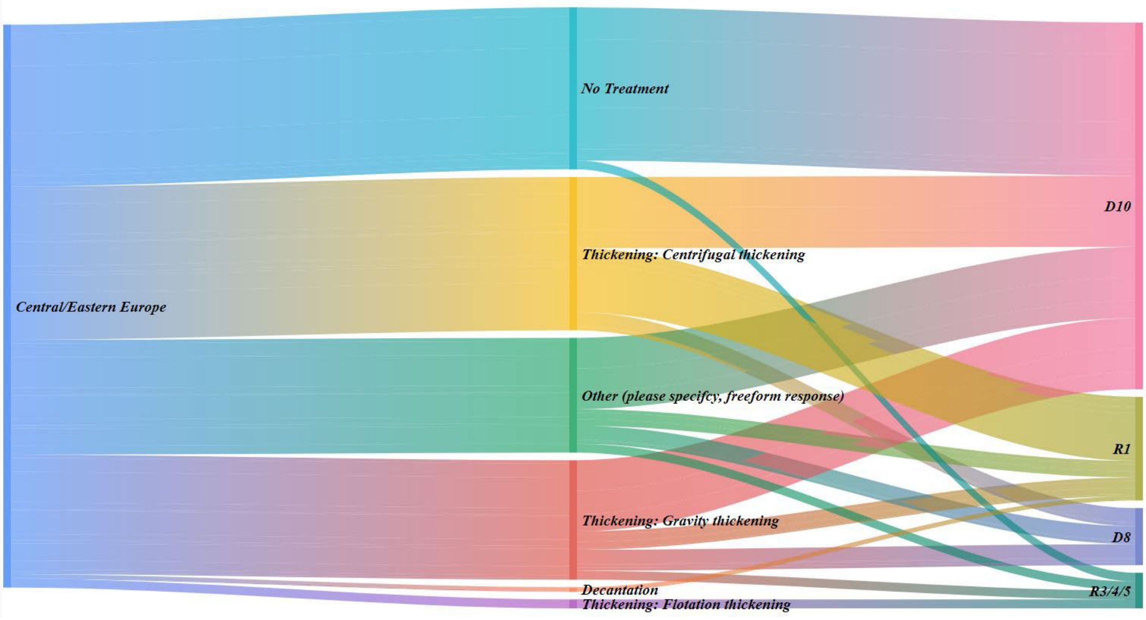
Benelux Tank Bottom Sludges (2019-2021)



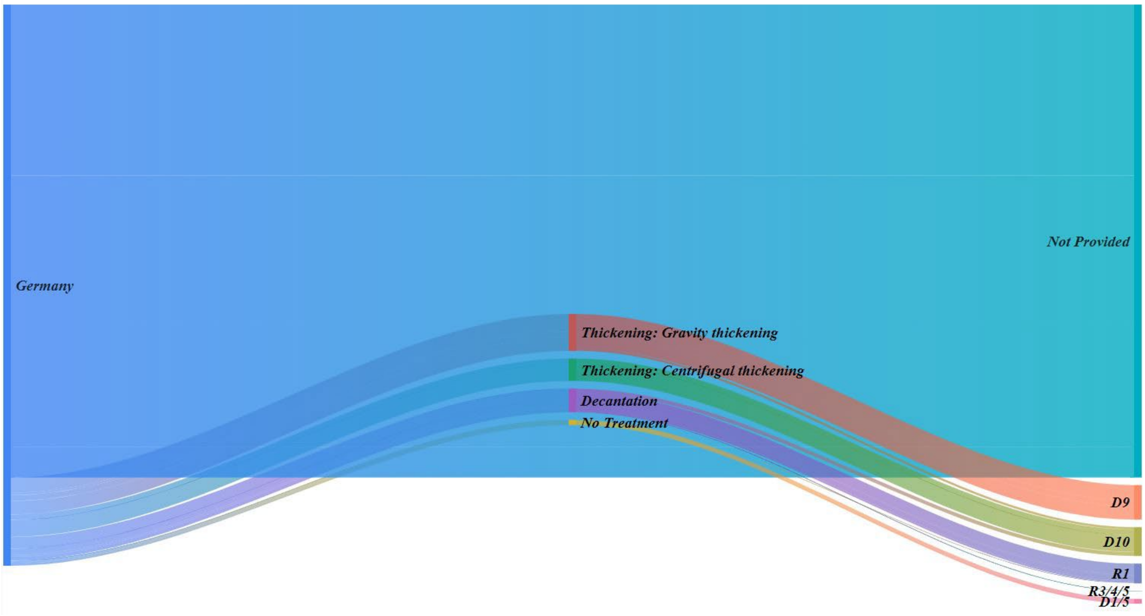
UK/Ireland/Northern Europe Tank Bottom Sludges (2019-2021)



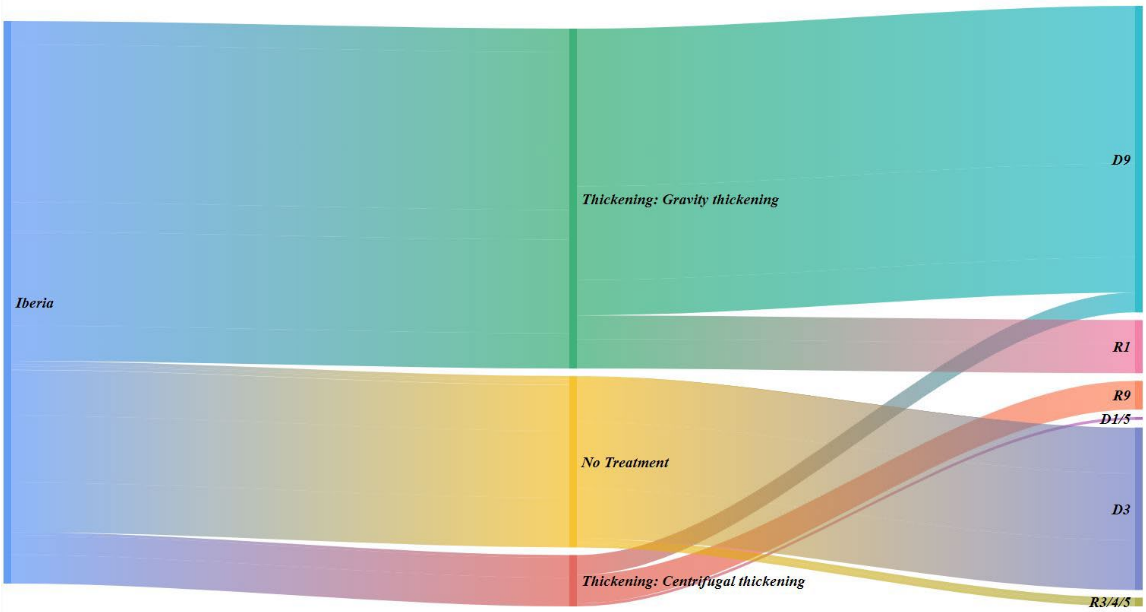
Central/Eastern Europe Tank Bottom Sludges (2019-2021)



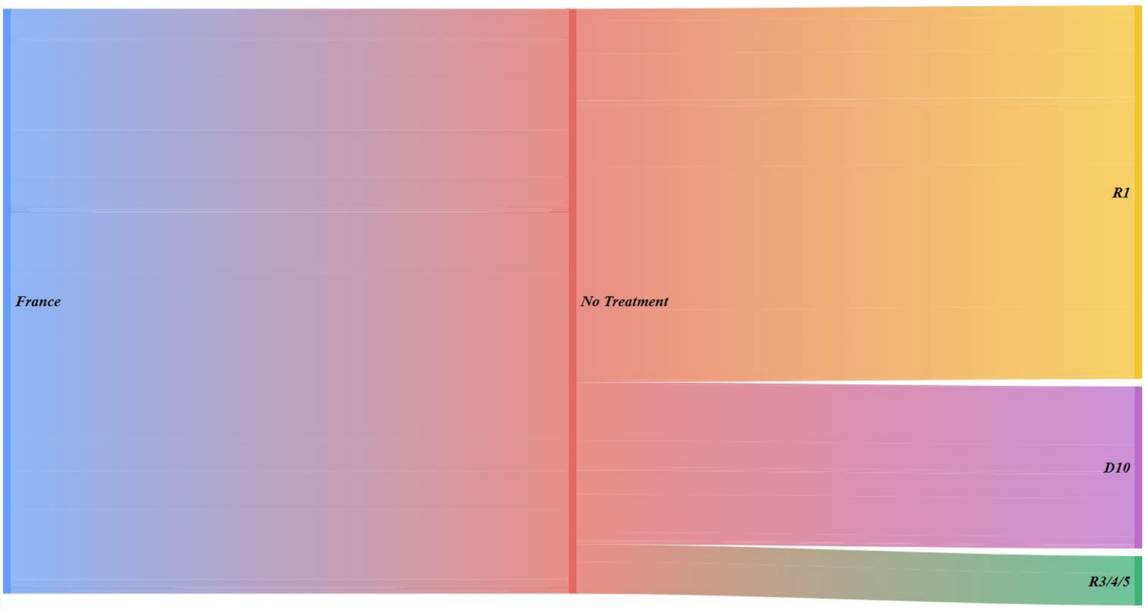
Germany Tank Bottom Sludges (2019-2021)



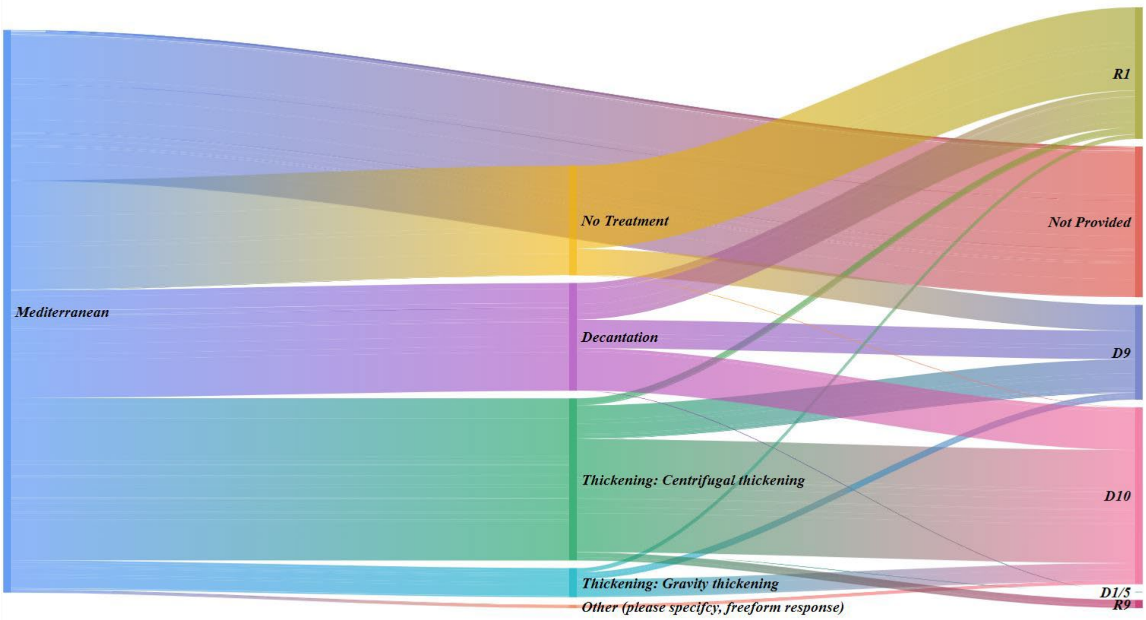
Iberia Tank Bottom Sludges (2019-2021)



France Tank Bottom Sludges (2019-2021)

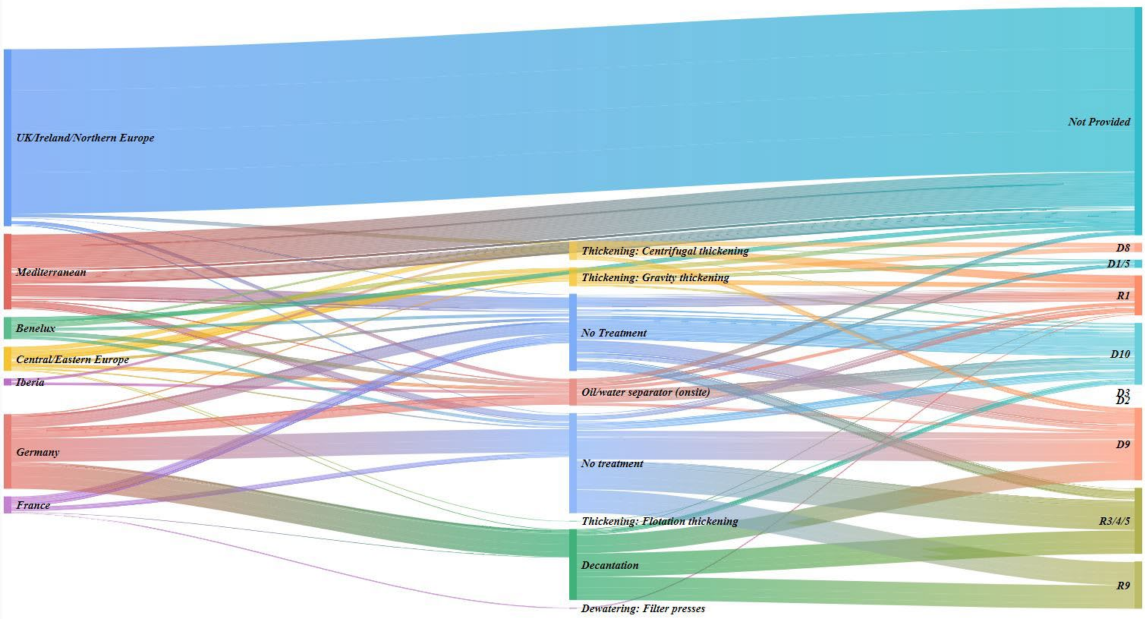


Mediterranean Tank Bottom Sludges (2019-2021)

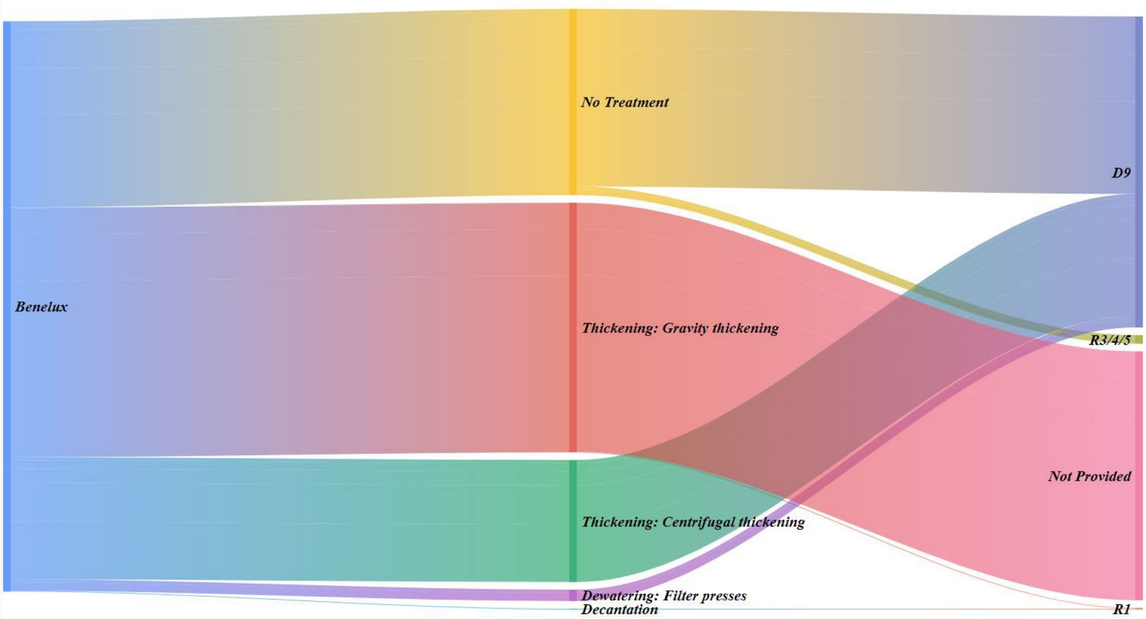


Sankey Diagrams of Maintenance Sludges per Country Region, Separation Techniques and Disposal Options (2019-2021)

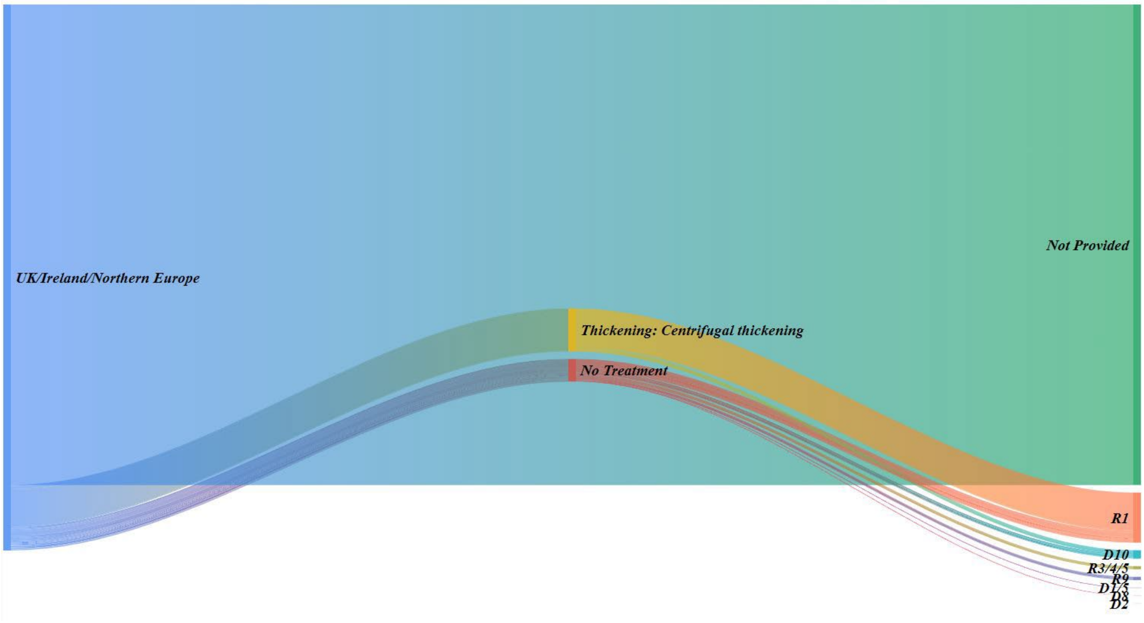
Maintenance Sludges (2019-2021)



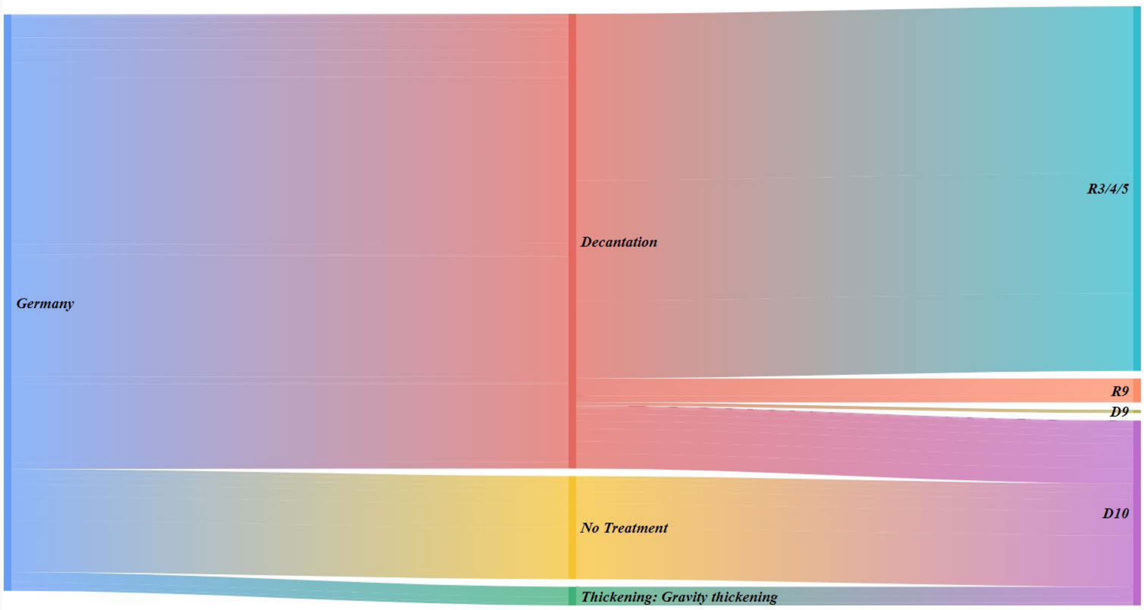
Benelux Maintenance Sludges (2019-2021)



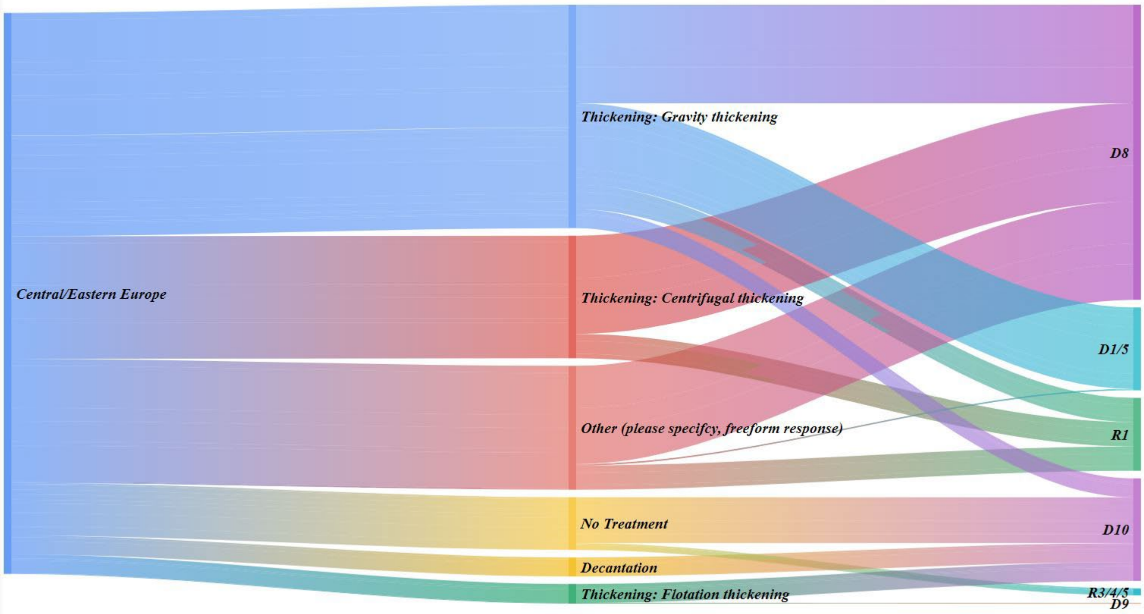
UK/Ireland/Northern Europe Maintenance Sludges (2019-2021)



Germany Maintenance Sludges (2019-2021)



Central/Eastern Europe Maintenance Sludges (2019-2021)



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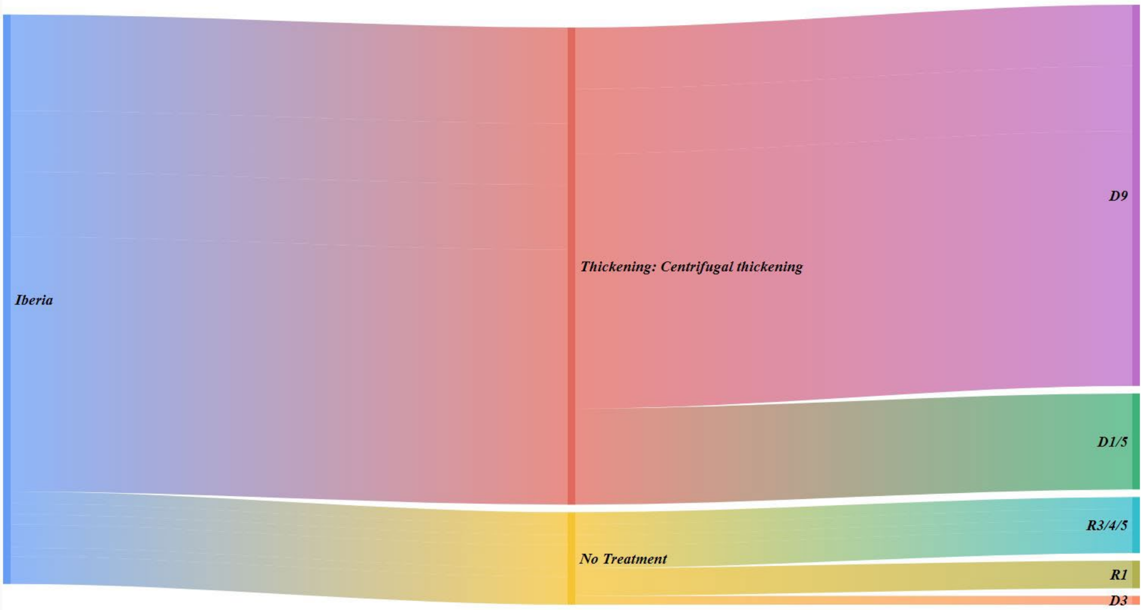
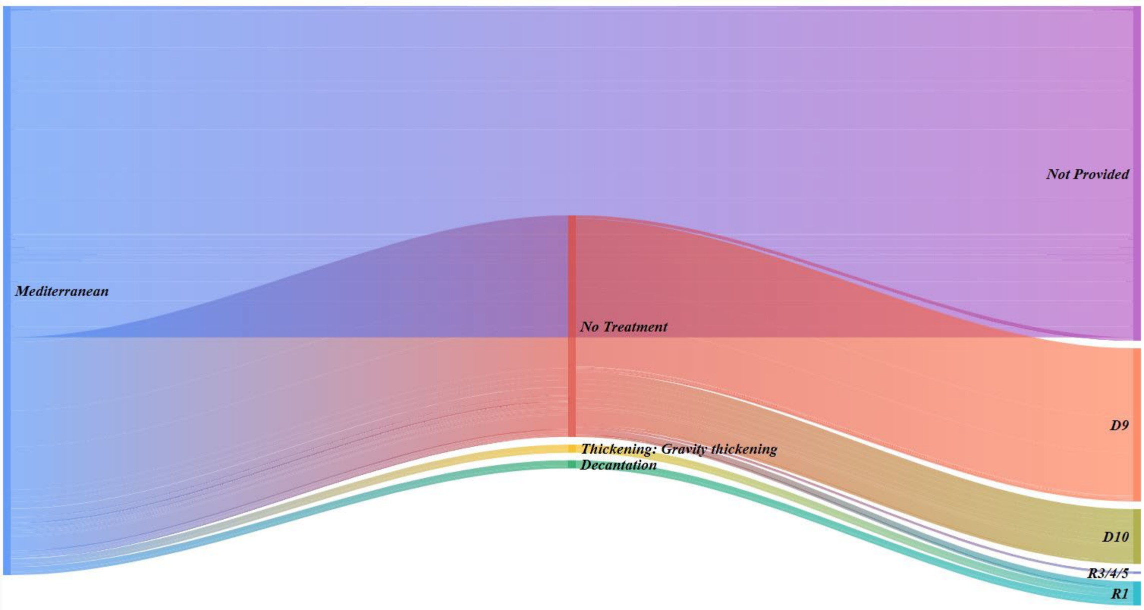
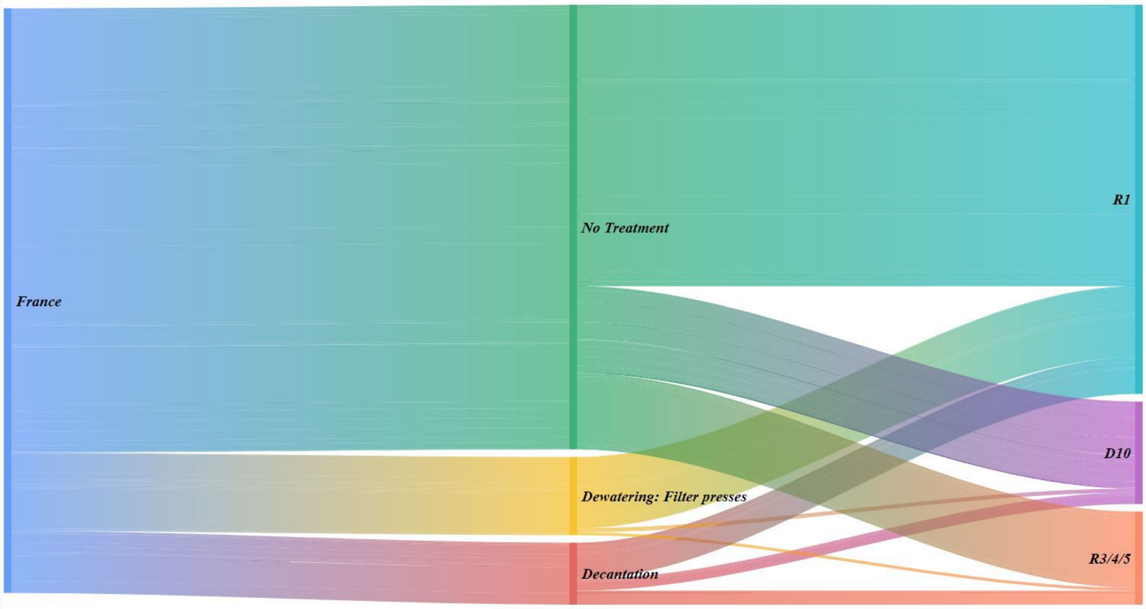


Mediterranean Maintenance Sludges (2019-2021)



France Maintenance Sludges (2019-2021)



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ISBN 978-2-87567-179-0
9 782875 671790