Logika Noise Air Quality CONSULTANTS

Implications of extended pollutant coverage within E-PRTR – Assessment of relevance and significance of air emissions from mineral oil and gas refineries

for Concawe

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1 Abstract

A 2020 ICF review of the completeness of the European Pollutant Release and Transfer Register (E-PRTR) activities, pollutants and thresholds identified 38 new air and water pollutants for potential inclusion in the E-PRTR. Of these, 17 air pollutants and 11 water pollutants were highlighted as indicative to the mineral oil and gas refining sector. A number of policy options are currently being considered as part of the ongoing revision of the E-PRTR Regulation, including the introduction of an expanded suite of pollutants informed by the 2020 review.

This aim of this report was to undertake a desk-based literature review to assess the contribution of the refining sector to emissions to air of 18 pollutants – the 17 pollutants identified by the 2020 ICF review plus hydrogen sulphide (H_2S) – against the backdrop of a potential expansion of the pollutant scope of the E-PRTR. Each pollutant was assessed according to two criteria: (i) its relevance to the refining sector, and (ii) the significance of the contribution of the refining sector to pollutant emissions.

Of the 18 air pollutants assessed, two (thallium and acrylonitrile) were determined to be 'not relevant' to the refining sector. Based on the data available, mineral oil and gas refining was judged to be a significant emissions source of five pollutants, a potentially significant source of emissions of one pollutant, and a potentially not significant emissions source of five pollutants. Finally, the refining sector was found to be a not significant source of emissions of a further five pollutants.

2 Introduction

2.1 Project background

In 2020, a review was undertaken (ICF, 2020) of the completeness of the European Pollutant Release and Transfer Register (E-PRTR) activities, pollutants and thresholds. The review compared the current situation with the Industrial Emissions Directive (IED), with the requirements of other European environmental legislation, with recent work by the OECD to harmonise international PRTR definitions of sectors and pollutant lists (OECD, 2013), and with emerging evidence on new activities and pollutants. The aim of the review was to improve the E-PRTR's alignment with other policy and emerging environmental concerns. The review identified a total of 38 new air and water pollutants proposed for inclusion in the E-PRTR pollutant list to enable more comprehensive monitoring of environmental initiatives including the IED and other EU legislation. Of these 38 pollutants, the review highlighted 17 air pollutants and 11 water pollutants as indicative for mineral oil and gas refineries (sector 1.(a)) and for thermal power stations and other combustion installations (sector 1.(c)). The ongoing revision of the E-PRTR Regulation (now proposed to be renamed as the "Industrial Emissions Portal Regulation") is considering a number of policy options, some of which are related to an expanded scope of pollutants informed by the ICF review[1].

2.2 This report

This report assesses the contribution of the refining sector to emissions to air of the 17 pollutants identified by ICF (2020), together with hydrogen sulphide (H_2S), in the context of a potential expansion of the E-PRTR pollutant scope in the course of the ongoing revision of the E-PRTR regulation. Hydrogen sulphide was included alongside the 17 pollutants identified by ICF as it is known to be commonly present in the refining process, but was not on the indicative lists for sectors 1(a) and 1(c) proposed in ICF (2020).

In the report, these 18 air pollutants are referred to as "candidate" pollutants.

2.3 Assessment approach

The assessment examined each air pollutant according to the following two criteria:

- **Relevance**: are the environmental issues and associated parameters relevant for the activity or process concerned?
- **Significance**: is the industrial process and its emissions a significant part of industrial pollution in the EU, currently or trending?

Assessment of pollutants as relevant to the refining sector was based on a desk-based literature review building on previous screening analysis conducted by Concawe. In assessing pollutants in terms of emissions significance, a review of a range of emissions data sources was completed to understand the potential scale of emissions of each pollutant deemed relevant.

[1] Proposals for a revised E-PRTR Regulation were published in April 2022 and include a proposed mechanism for the updating of the pollutant lists via implementing acts.

3 Air pollutant relevance to the refining sector

Previous analysis by Concawe looked into air emissions of the 18 air pollutants of interest associated with refining activities. This identified emissions factors (EFs) for each pollutant and estimated emissions associated with two base case refineries, one having a crude refining capacity being about the 80th percentile of European oil refinery population and the other greater than the 95th percentile. These emissions were compared against proposed E-PRTR reporting thresholds for each pollutant set out in the ICF review. This analysis was supplemented with a further literature review to define each pollutant as relevant or not as well as expert judgement.

As EFs could be identified for all pollutants but one, a conservative approach was adopted assuming that all pollutants are of relevance to the refining sector. The exception to this is acrylonitrile for which no EFs were identified and which is primarily released by petrochemical plants which produce or handle the chemical. No evidence was found to suggest that acrylonitrile emissions are relevant to the refining sector, with acrylonitrile production and end-product manufacture being the dominant source of emissions (WHO, 2000). On this basis, acrylonitrile was screened out from further assessment. Additionally, thallium was also judged ‘not relevant’ on the basis that EFs published for thallium emissions are based on measurements below the limits of detection of monitoring equipment. As such, conclusive evidence of emissions from the refining sector are lacking (see Table 3-1).

A summary of the relevance of the 18 assessed air pollutants is presented in Table 3-1. Pollutants screened in as relevant were subsequently assessed for significance (Chapter 4).

Table 3-1 Relevance of air pollutants to refining sector

Pollutant	Pollutant group	Relevance to refining sector	Relevant?
Black carbon (BC)	Particulates	Formed by the incomplete combustion of fossil fuels and biomass feedstocks. Emitted from refineries, with documented emission factors (EFs) for refining activities (EMEP/EEA, 2019a).	Relevant
$PM_{2.5}$	Particulates	Formed by the incomplete combustion of fossil fuels and biomass feedstocks. Emitted from refineries, EFs for refining activities have been documented (EMEP/EEA, 2019a).	Relevant
Total suspended particulate (TSP)	Particulates	Formed by the incomplete combustion of fossil fuels and biomass feedstocks. Emitted from refineries, EFs for refining activities have been documented (EMEP/EEA, 2019a).	Relevant
Chromium (VI) compounds (as Cr)	Metals	Refineries are an emission source. EFs for refining activities have been documented, including stationary combustion, catalytic cracking, and coking units (US EPA, 2015).	Relevant
Selenium and compounds (as Se)	Metals	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
Cobalt and compounds (as Co)	Metals	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
Manganese and compounds (as Mn)	Metals	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
Vanadium and compounds (as V)	Metals	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
Beryllium and compounds (as Be)	Metals	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
Antimony and compounds (as Sb)	Metals	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant

Pollutant	Pollutant group	Relevance to refining sector	Relevant?
Thallium and compounds (as Tl)	Metals	EFs for refining activities have been documented (US EPA, 2015). However, the supporting data indicate that these EFs are based solely on measurements below the limits of detection of measurement equipment, thus there is no evidence that thallium is emitted.	Not relevant
Acetaldehyde	Volatile organic compounds (VOCs)	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
n-Hexane	VOCs	n-Hexane is primarily released by industries handling it. Virtually all of it is obtained from refinery-based processes (ATSDR, n.d.). EFs for refining activities have been documented (US EPA, 2015).	Relevant
Formaldehyde	VOCs	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
Acrolein	VOCs	Emitted from refineries, EFs for refining activities have been documented (US EPA, 2015).	Relevant
Acrylonitrile	VOCs	Primarily released from petrochemical plants where it is produced and end-product manufacture (WHO, 2000), not relevant to mineral oil and gas refineries.	Not relevant
Carbon disulphide (CS_2)	Sulphur-containing compounds	Released from refineries, mainly from energy production required for other refinery processes (Environment Agency, 2009). EFs for refining activities have been documented (US EPA, 2015).	Relevant
Hydrogen sulphide (H_2S)	Sulphur-containing compounds	Noted as a by-product of the refining of some crude oils (Public Health England, 2016). EFs for refining activities have been documented (US EPA, 2015).	Relevant

4 Assessment of significance of air emissions from the refining sector

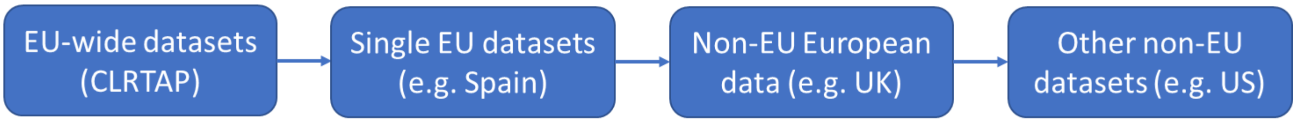
4.1 Assessment approach

The assessment of emissions significance for each air pollutant was based on a comparison of emissions from the refining sector against emissions from all industrial activities and/or total national emissions. A range of data sources were examined to inform the assessment, including national level inventories from a variety of geographies, and scientific and non-academic institutional literature. Sources, upon which the assessment of significance were based, were prioritised for review on the basis of the certainty in the data and their representativeness of the EU context. Broadly, this prioritisation was as follows:

- EU-wide emissions datasets: these were considered the most robust basis for the assessment of significance across the entire EU. These include reporting under the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP) (Umweltbundesamt, 2022).
- Single-state (or limited number of countries) datasets from EU-27: national datasets, including emissions inventories and pollutant release and transfer registers were investigated across the EU Member States. Specifically, the Spanish PRTR was examined for useful data due to its expanded pollutant coverage compared to other EU Member States and the fact that it does not apply emission reporting thresholds so should be more complete (see Section 4.2.2).
- Datasets from non-EU European countries. Specifically, data were obtained from the UK National Atmospheric Emissions Inventory.
- Datasets from non-EU geographies (e.g. the US EPA Toxics Release Inventory) and/or limited-scope scientific studies.

This hierarchy of data sources upon which the analysis of pollutants was based is also visualised in Figure 4-1.

Figure 4-1 Prioritisation of data sources consulted in the review



The specific data sources used as the basis for assessment of significance are presented in Chapter 4.2 along with a discussion of their associated uncertainties.

It is important to highlight that there are no established guidelines or thresholds for identifying sectoral emissions as significant or not. Consequently, a series of indicative significance thresholds were devised by Logika based on expert judgement; these are displayed in Table 4-1. Where emissions from refining account are less than one percent (<1%) of total industrial emissions, they were considered a negligible contributor overall and therefore not significant. Emissions exceeding 5% of total industrial emissions were judged as significant, while emissions falling between these two thresholds (1% - 3%) were identified as ‘potentially not significant’, and emissions between 3% - 5% were classed as ‘potentially significant’. Pollutant emissions from refineries are also expressed as a percentage of total jurisdictional emissions (including sectors beyond just industry e.g. total emissions for all sources for EU or national) in Section 4.3 where these data are available. However, this is included for context only, and the overall judgement of significance was conducted based solely on the contribution of refining emissions to total emissions from industry.

Table 4-1 Significance thresholds for analysing pollutant emissions

Refining sector emissions as a percentage of total industrial emissions (%)	Significance class
<1	Not significant
1 - 3	Potentially not significant
3 - 5	Potentially significant
>5	Significant

As discussed above, there are no established thresholds for determining significance of emissions so the thresholds adopted in Table 4-1 are indicative and based on expert judgement. It is important to note that adopting different significance thresholds would alter the outcome of the assessment, at least for some pollutants. As such, the findings of the assessment should be treated as indicative rather than conclusive.

4.2 Data sources

A number of data sources were explored in order to inform the assessment of significance of the pollutants identified as relevant. The key data sources that were subsequently used for the assessment are detailed below, along with a discussion on the uncertainties associated with each of them and the implications of basing the assessment of significance on them. The latest data available from each data source consulted were used in the assessment of significance; different sources have data available for different years.

Different sources make use of different methodologies to quantify sector emissions. These include 'Tier 1' methodologies based on applying emission factors (EFs) to activity data. With any sector, there are uncertainties associated with the application of broad, all-encompassing EFs at national level as they may not accurately represent differences in installations; in the case of the refining sector, they would fail to account for differences in refining processes, fuel composition, and application of emissions control techniques. However, there is scope for application of technology-specific approaches ('Tier 2') and even facility-specific approaches ('Tier 3') where the required activity data are available.

4.2.1 EU reporting under UNECE Convention on Long-Range Transboundary Air Pollution

The UNECE CLRTAP entered into force in 1983, and includes all EU Member States among its signatories as well as the UK. The CLRTAP establishes national emissions reduction targets for a range of pollutants; these are transposed into EU legislation by the National Emissions reduction Commitments (NEC) Directive (2016/2284/EU). The Convention is implemented by the European Monitoring and Evaluation Programme (EMEP), which collates annual national emissions data submitted by Member States as part of their reporting obligations, and makes them available via the Centre on Emission Inventories and Projections (CEIP) online WebDab portal (Umweltbundesamt, 2022). With the exception of some exempted sectors, the overall scope of reported data are total national emissions which are disaggregated by industrial activity based on nomenclature for reporting (NFR) codes, including '1A1b Petroleum refining' and '1B2aiv Fugitive emissions oil: Refining / storage'.

EMEP and the European Environment Agency (EEA) have produced technical guidance (EMEP/EEA, 2019a) for Member States setting out procedures for compiling emissions for different sectors. The default approach for quantifying emissions from both petroleum refining (1A1b) (EMEP/EEA, 2019b) and fugitive emissions from refining (1B2aiv) (EMEP/EEA, 2019c) is a 'Tier 1' methodology using generic EFs. In the case of refining (1A1b), the activity data used in the Tier 1 method are national level fuel consumption figures, while for fugitive emissions (1B2aiv) EFs are applied to refined oil production volumes at national level. In the context of EU reporting, refineries are typically considered key emissions sources, and it is expected that Member States use a site-specific approach to quantifying emissions. Emissions factors for PM for emissions from refineries in the EMEP guidebook represent filterable emissions only, whereas for some other sources, such as automotive combustion, emissions factors encapsulate both filterable and condensable fractions. This is a result of the technical difficulties of measuring condensable fractions from stack emissions, and introduces a level of uncertainty in comparing emissions from mineral oil and gas refining with total industrial and national emissions. However, the refining contribution to condensable PM (CPM) is minor compared to other sources (Concawe, 2021), and so this is not likely to be a source of high uncertainty.

Overall, considering their EU-wide and sector-wide scope, these data are considered the most representative picture of the EU emissions context and the most robust basis for assessment of significance. As with any sector, it is necessary, to acknowledge the methodological uncertainties if a Member State applies a simple 'Tier 1' emission factor approach as this will not capture efforts made by the refining sector to control emissions e.g. in response to the BAT Conclusions. However, this is not expected to be the case in most, if not all, Member States as they would typically apply a site specific approach. Additionally, there may be inconsistencies in how some emissions from refineries are reported by some Member States under sector code 1A1b (petroleum refining) and/or other industrial combustion sectors but it is not feasible to further refine such estimates.

4.2.2 Spanish national Pollutant Release and Transfer Register

All 27 EU Member States are signatories to the Kyiv Protocol on Pollutant Release and Transfer Registers (PRTRs) under the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters. This places a requirement on them to establish and maintain a publicly accessible, facility-specific national PRTR (UNECE, 2022). This requirement is also implemented at the EU level through the European PRTR (E-PRTR), which collates emissions from industrial facilities operating above set activity thresholds, which are defined in Annex I of the E-PRTR Regulation (EC No 166/2006) (European Commission, 2006).

In contrast to most other EU Member States, Spain operates its national PRTR with an expanded suite of 115 pollutants compared with the 91 reported in the E-PRTR (PRTR España, n.d.)[2], and without pollutant reporting thresholds meaning that, in theory, the PRTR captures all industrial emissions (in scope). Emissions are reported at facility level, and are calculated based on guidance (PRTR España, n.d.) produced by the Spanish government (for example, the guidance specifies that metals emissions are to be determined in line with EN 14385:2004, which establishes a procedure based on periodic measurements).

Data from the Spanish PRTR are publicly accessible online (PRTR España, n.d.), and are available at industrial sector level. It is important to note, however, that the Spanish PRTR includes only point source emissions, and does not factor fugitive emissions. As only data on metals emissions, which are principally associated with point source emissions, were obtained from the Spanish PRTR, this is not considered a significant source of uncertainty. However, basing an assessment of emissions significance in the EU on data from a single member State presents some uncertainties, although the industrial emissions profile of Spain is considered broadly representative of the EU as a whole. Data from the Spanish PRTR formed part of the basis for the ICF analysis (2020).

[2] Additional substances reported for emissions to air under the Spanish PRTR include total suspended particulates (TSP), thallium, antimony, cobalt, manganese, vanadium, TOC.

4.2.3 UK National Atmospheric Emissions Inventory

The UK National Atmospheric Emissions Inventory (NAEI) includes estimated annual emissions to air of pollutants including greenhouse gases (GHGs), heavy metals, and particulates (Department for Business, Energy & Industrial Strategy, 2022). Unlike the PRTRs mentioned in previous sections, the NAEI is not compiled just from reporting by individual installations. Instead, the inventory is based on a variety of sources including national energy statistics (which are combined with emission factors to estimate emissions) as well as facility-level data (where available e.g. using the national PRTR reporting). The NAEI accompanies the UK's submission under the CLRTAP, and therefore seeks to represent total national emissions. Data are available broken down by sector and activity. Given its close economic and industrial links with the EU, as well as its participation in EU regulatory frameworks until recently, UK data are considered a suitable approximation of EU emissions. As with the use of data from the Spanish PRTR (chapter 4.2.2), there are uncertainties in basing the assessment on data from a single jurisdiction and efforts have been made to inform the assessment on multiple sources of data where possible.

4.2.4 US Environmental Protection Agency Toxics Release Inventory

The US Environmental Protection Agency (EPA) maintains the Toxics Release Inventory (TRI), a PRTR covering chemicals with carcinogenic or chronic human health effects, significant adverse acute human health effects, or significant adverse environmental effects. Currently, 770 different chemicals are listed in the TRI, and facilities that manufacture or process them in quantities above set thresholds must report annually to the EPA (US EPA, 2022b). Not all industrial sectors are within the scope of the TRI, and facilities beneath set reporting thresholds within included sectors are not required to report.

To allow appropriate comparison to data from the TRI in a European context, it is necessary to consider the differences in typical crude slates and refining processes in the United States. This is particularly important for pollutants groups such as metals and the reduced sulphur species that are present in crude oil. This comparison is presented in Appendix A1.1. Overall, whilst there are some differences between the US and EU in terms of the refining sector the TRI does provide a useful reference point for considering significance of emissions, particularly in the absence of any European data.

4.3 Results

4.3.1 Particulates

Data on emissions of BC, $PM_{2.5}$ and TSP are available at EU-level from reporting under UNECE CLRTAP. Emissions associated with mineral oil and gas refining are displayed in Table 4-2, and are expressed as a percentage of industrial emissions and total emissions. The data indicate that mineral oil and gas refineries contribute <2% of industrial emissions and <1% of total emissions for each pollutant. On the basis of this contribution, emissions of $PM_{2.5}$ from the refining sector are considered ***potentially not significant***, while TSP and BC emissions are considered ***not significant***. It should be noted that TSP and dust emissions can broadly be considered to be equivalent.

Table 4-2 EU-27+UK particulate emissions from mineral oil and gas refining

Pollutant	EU-27+UK emissions from refining (t, 2019) [A]	As % of EU-27+UK industrial emissions [B]	As % of total EU-27+UK emissions
BC[3]	216	0.9	0.1
$PM_{2.5}$	4,164	1.7	0.3
TSP	8,656	0.9	0.2

Source: (Umweltbundesamt, 2022).

[A] Includes emissions from sectors 1A1b (petroleum refining) and 1B2aiv (fugitive emissions oil: refining/storage).

[B] Includes emissions from energy supply, and manufacturing and extractive industries.

As this judgement is based on UNECE CLRTAP data which is EU-wide in its scope (plus the UK), there is a ***high degree of certainty*** in this judgement. The minor methodological and emissions classifications uncertainties associated with these data must, however, be recognised (chapter 4.2.1).

4.3.2 Heavy metals

Chromium (VI) (as Cr) and selenium (as Se)

None of the data sources consulted include emissions of Cr(VI), although Cr(VI) emissions are included within the chromium emissions reported in sources including the CLRTAP. Sources from the US indicate that approximately a third of chromium released into the atmosphere from anthropogenic sources is in hexavalent form (ATSDR, 2012). In the UK, a comparable fraction of less than 20% has been reported (Defra, 2008), although in both cases there is no indication of differences in the fraction of total Cr emissions which are Cr(VI) between industrial sectors. Assuming that the fraction of chromium emitted as Cr(VI) is uniform across different industries, it is possible to determine the significance of Cr(VI) emissions from the refining sector based on the reported total chromium emissions. This assumption, however, introduces a degree of uncertainty.

Reporting under the CLRTAP incorporates data on chromium (Cr) and selenium (Se) emissions, shown in Table 4-3. At just below 5% of industrial emissions, mineral oil and gas refining is a ***potentially significant*** contributor to Cr releases, also accounting for around 3% of total emissions of the metal. By comparison, industrial emissions of Cr are also reported in the European Pollutant Release and Transfer Register (E-PRTR) based on EU Member State reporting under the Industrial Emissions Directive. The E-PRTR data (EEA, 2022) indicate that mineral oil and gas refineries account for 15 t of Cr emissions, accounting for 24% of total industrial emissions. Based on these findings, emissions would be classed as ***significant***. Considering that the CLRTAP data indicate that Cr emissions are close to the adopted threshold for significance, and the E-PRTR data suggest emissions are well over the 5% threshold, Cr(VI) emissions from refineries are judged to be ***significant*** overall. Given the EU-wide scope of these datasets, they are directly representative of the EU context. However, the large difference in the percentage of total industrial emissions attributable to refining

[3] BC emissions reported under the UNECE CLRTAP are calculated in line with the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2019a). It is not known which countries reporting in line with the guidebook use Tier 1, Tier 2, or Tier 3 methodologies. It is also unclear whether the Tier 1 and Tier 2 emission factors in the guidebook are representative of flaring incidents, although it is considered unlikely. Similarly, Tier 3 methodologies are likely to be representative of normal operating conditions, thus not factoring in flaring incidents. As such, it is considered that BC reporting is unlikely to account for flaring incidents, and the uncertainties associated in calculating emissions from these.

in the two datasets presents ***uncertainty*** in the overall findings. Reporting on emissions under the E-PRTR is subject to capacity thresholds for some activities, but not mineral oil and gas refineries, which partly explains the larger share of total industrial emissions attributable to refining in this dataset.

Se emissions from refining are smaller and judged ***potentially not significant***, corresponding to approximately 2% of industrial and total emissions. As with particulate emissions, this assessment is considered ***representative*** of the overall EU context based on the data reviewed.

Table 4-3 EU-27+UK Chromium (Cr) and Selenium (Se) emissions from mineral oil and gas refining

Pollutant	EU-27+UK emissions from refining (t, 2019) [A]	As % of EU-27+UK industrial emissions [B]	As % of total EU-27+UK emissions
Cr	10	5.0	2.8
	15 [C]	23.6 [C]	-
Se	2	2.1	1.9

Source: (Umweltbundesamt, 2022).

[A] Includes emissions from sectors 1A1b (petroleum refining) and 1B2aiv (fugitive emissions oil: refining/storage).

[B] Includes emissions from energy supply, and manufacturing and extractive industries.

[C] Based on data from the E-PRTR (EEA, 2022).

Cobalt (as Co)

Information on emissions of cobalt (Co) were obtained from the Spanish PRTR and the US EPA TRI. The collated data are presented in Table 4-4. Data from the Spanish dataset indicate that mineral oil and gas refineries are a negligible contributor to total industrial Co emissions, while in the US refining accounts for a larger portion. Overall, based on the Spanish dataset, the refining sector is a ***not significant*** source of Co emissions, although it is ***uncertain*** how representative data from one EU Member State are of overall EU emission trends, especially when considering the higher proportional emissions observed in the US data.

Table 4-4 Cobalt (Co) emissions from mineral oil and gas refining

Data source	Emissions from refining (t, 2020)	Total industrial emissions (t, 2020)	Refining emissions as % of total industrial emissions
Spanish PRTR	0.0006	1.8	<0.1
US EPA TRI	0.2	10.6	2.2

Manganese (as Mn)

Emissions data for manganese (Mn) are available from the Spanish PRTR and the UK NAEI. Table 4-5 shows that emissions from mineral oil and gas refining account for 3.5% of total industrial emissions for Spain. In the UK, refinery emissions are a negligible contributor to industrial and total national emissions. On this basis, refining is considered to contribute a ***potentially significant fraction*** of Mn emissions in the EU, although there are ***uncertainties*** in basing this judgement on limited datasets.

Table 4-5 Manganese (Mn) emissions from mineral oil and gas refining

Data source	Emissions from refining (t, 2020)	As % of industrial emissions	As % of total national emissions
Spanish PRTR	0.3	3.5	- [A]
UK NAEI	0.03	<0.1 [B]	<0.1

[A] The Spanish PRTR reports only industrial emissions, not total national emissions including non-industrial sources (e.g. transport).

[B] Includes emissions from energy supply, and manufacturing and extractive industries.

Vanadium (as V)

Data on vanadium (V) emissions were obtained from the Spanish PRTR and the UK NAEI. Spanish refinery emissions of vanadium are ***not a significant*** fraction of emissions from the industrial sector, and in the UK refinery emissions are a ***potentially not significant*** contributor to industrial and total emissions. Data from the US indicate that refining is the dominant industrial source of vanadium emissions to air. However, the Spanish and UK datasets are considered more representative of the European context; Appendix A1.1. presents a comparison of refining in the US and Europe.

Table 4-6 Vanadium (V) emissions from mineral oil and gas refining

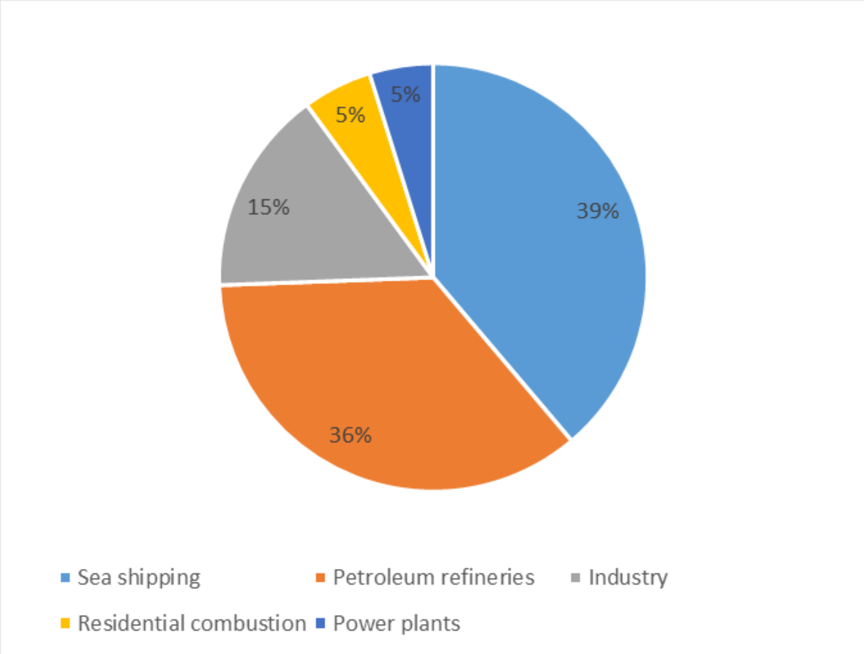
Data source	Emissions from refining (t, 2020)	As % of industrial emissions	As % of total national emissions
Spanish PRTR	0.02	0.1	- [A]
UK NAEI	0.9	1.7 [B]	0.2
US EPA TRI	55.2	64.5	- [A]

[A] The Spanish PRTR and US EPA TRI reports only industrial emissions, not total national emissions including non-industrial sources (e.g. transport).

[B] Includes emissions from energy supply, and manufacturing and extractive industries.

By contrast, a study (Visschedijk et al., 2013) into V emissions in North West Europe in 2005 indicated that mineral oil and gas refineries accounted for a ***significantly higher*** 36% of total emissions in the area (Figure 4-2), which covered Belgium, Germany, Denmark, France, the UK, Luxembourg, the Netherlands, and the North Sea OSPAR region. The reason for the discrepancy between the North West Europe data and the Spanish and UK figures is unclear, but may be linked to changes in fuel type and/or refining processes and emissions control between 2005 and 2020. It is likely that the 2020 datasets are more representative of the current EU context, although the discrepancies in the literature and age of some sources reviewed cast ***significant uncertainty*** over the assessment of emissions significance.

Figure 4-2 Vanadium (V) emissions in North West Europe, 2005



Beryllium (as Be)

Emissions data for beryllium (Be) were only available from the UK NAEI (Table 4-7). The data indicate that the UK refining sector contributes a minor fraction to total emissions, but a greater fraction of emissions from industry, suggesting that the refining sector could be considered a ***significant*** Be emissions source. Due to the limited scope of the available data, there are ***uncertainties*** over the representativeness of this judgement of the EU.

Table 4-7 Beryllium (Be) emissions from mineral oil and gas refining

Data source	Emissions from refining (t, 2020)	As % of industrial emissions	As % of total national emissions
UK NAEI	0.05	10.1 [A]	1.0

[A] Includes emissions from energy supply, and manufacturing and extractive industries.

Antimony (as Sb)

The US EPA TRI contains data on antimony (Sb) emissions from industrial sources, including refineries. Emissions data (Table 4-8) indicate that the refining sector is a ***significant*** contributor to total industrial emissions. In the absence of other data, this is considered to also be the case for the EU although there are ***questions over the applicability*** of US data in forming a judgement on EU emissions significance.

Table 4-8 Antimony (Sb) emissions from mineral oil and gas refining

Data source	Emissions from refining (t, 2020)	Total industrial emissions to air (t, 2020)	As % of total industrial emissions
US EPA TRI	0.5	8.0	6.0

4.3.3 Volatile Organic Compounds (VOCs)

Acetaldehyde, n-Hexane and formaldehyde

Acetaldehyde, n-Hexane and formaldehyde emissions data are reported in the US EPA TRI – these are displayed in Table 4-9. Based on these figures, the refining sector is considered a ***not significant*** contributor to industrial emissions of acetaldehyde, a ***potentially not significant*** source of formaldehyde emissions, and a ***significant*** source of n-Hexane emissions. The applicability of these data, from a single, non-EU jurisdiction, for the assessment of the EU emissions context is, however, of ***high uncertainty***.

Table 4-9 Acetaldehyde, n-Hexane and formaldehyde emissions from mineral oil and gas refining (US EPA, 2022a)

Pollutant	Emissions from refining (t, 2020)	Total industrial emissions to air (t, 2020)	As % of total industrial emissions
Acetaldehyde	13	3,332	0.4
n-Hexane	1,112	15,933	7.0
Formaldehyde	31	2,081	1.5

Acrolein

The data review revealed that information on acrolein (C_3H_4O) emissions is very limited. Some data (European Commission Joint Research Centre, 2001) were obtained for the Netherlands and Germany from 1994 showing the main sources of acrolein emissions, displayed in Figure 4-3 and Figure 4-4. Figures specific to mineral oil and gas refining are not available in the datasets, but they indicate that traffic is the overwhelmingly dominant source of acrolein (95% in the Netherlands; 98% in Germany). Emissions from refining fall within the remaining fractions, along with other emissions sources. As such, emissions from refining are considered to be ***not significant***, although it is not possible to determine the scale of emissions in relation to the significance thresholds adopted in the assessment, presenting ***substantial uncertainties***. There are further uncertainties in basing the assessment of significance of acrolein emissions on decades-old data, as the relative acrolein emissions from different sources will have evolved since 1994.

Figure 4-3 Acrolein emissions by sector, Germany, 1994

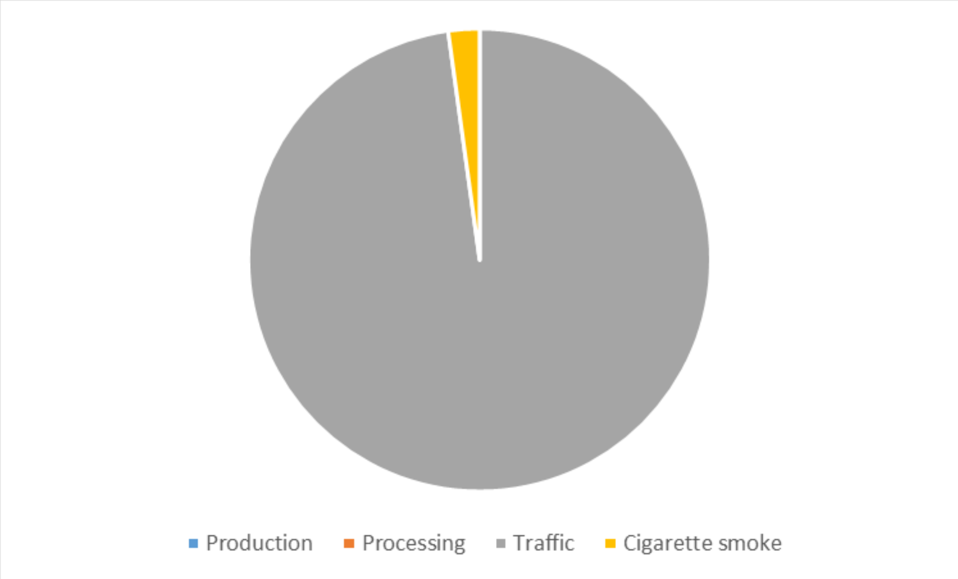
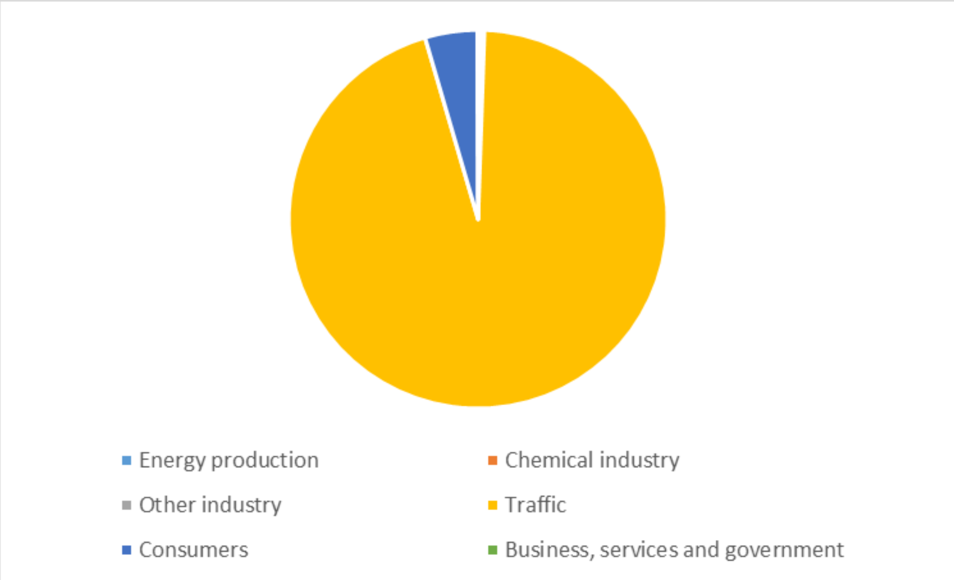


Figure 4-4 Acrolein emissions by sector, Netherlands, 1994



4.3.4 Sulphur-containing compounds

Carbon disulphide (CS_2) and hydrogen sulphide (H_2S) emissions data are available from the US EPA TRI, displayed in Table 4-10. The figures indicate that refinery emissions of CS_2 are ***potentially not significant***, and that the sector is a ***significant*** contributor to H_2S emissions. As discussed above, there are ***significant uncertainties*** in inferring EU emissions trends from one non-EU dataset. The judgements of significance must therefore be interpreted within the context of this uncertainty.

Table 4-10 Carbon disulphide (CS_2) and hydrogen sulphide (H_2S) emissions from mineral oil and gas refining (US EPA, 2022a)

Pollutant	Emissions from refining (t, 2020)	Total industrial emissions to air (t, 2020)	As % of total industrial emissions
CS_2	43	3,588	1.2
H_2S	686	7,756	8.9

5 Summary of air emissions significance

Table 5-1 summarises the findings of the assessment of pollutant relevance, and significance of emissions. Overall, all but two (thallium and acrylonitrile) of the 18 air pollutants were considered relevant to the refining sector and therefore screened in for further assessment. For one pollutant (vanadium) the data were highly variable. The refinery sector was judged to be a significant emissions source of five pollutants (Cr(VI), Be, Sb, n-Hexane and H_2S). Emissions of $PM_{2.5}$, Se, V, formaldehyde, and CS_2 were found to be potentially not significant, while Mn emissions were found to be potentially significant. Emissions of all other assessed pollutants from mineral oil and gas refining were judged as not significant.

Table 5-1 Summary of significance of emissions from mineral oil and gas refining

Pollutant	Pollutant group	Relevance	Significance	(Un)Certainty in assessment
Black carbon (BC)	Particulates	Relevant	Not significant	Good quality data
$PM_{2.5}$	Particulates	Relevant	Potentially not significant	Good quality data
Total suspended particulate (TSP)	Particulates	Relevant	Not significant	Good quality data
Chromium (VI) compounds (as Cr)	Metals	Relevant	Significant	Good quality data
Selenium and compounds (as Se)	Metals	Relevant	Potentially not significant	Good quality data
Cobalt and compounds (as Co)	Metals	Relevant	Not significant	Limited EU data
Manganese and compounds (as Mn)	Metals	Relevant	Potentially significant	Limited EU data
Vanadium and compounds (as V)	Metals	Relevant	Potentially not significant	Variable data
Beryllium and compounds (as Be)	Metals	Relevant	Significant	Only non-EU data available
Antimony and compounds (as Sb)	Metals	Relevant	Significant	Only non-EU data available
Thallium and compounds (as Tl)	Metals	Not relevant		
Acetaldehyde	VOCs	Relevant	Not significant	Only non-EU data available
n-Hexane	VOCs	Relevant	Significant	Only non-EU data available

Pollutant	Pollutant group	Relevance	Significance	(Un)Certainty in assessment
Formaldehyde	VOCs	Relevant	Potentially not significant	Only non-EU data available
Acrolein	VOCs	Relevant	Not significant	Limited EU data
Acrylonitrile	VOCs	Not relevant		
Carbon disulphide (CS_2)	Sulphur-containing compounds	Relevant	Potentially not significant	Only non-EU data available
Hydrogen sulphide (H_2S)	Sulphur-containing compounds	Relevant	Significant	Only non-EU data available

6 List of abbreviations

Abbreviation	Explanation
BAT	Best Available Techniques
Be	Beryllium
BC	Black carbon
CEIP	Centre on Emission Inventories and Projections
CLRTAP	Convention on Long-Range Transboundary Air Pollution
Co	Cobalt
CPM	Condensable particulate matter
Cr(VI)	Chromium (VI)
CS_2	Carbon disulphide
EEA	European Environment Agency
EF	Emission factor
EMEP	European Monitoring and Evaluation Programme
E-PRTR	European Pollutant Release and Transfer Register
EU	European Union
GHG	Greenhouse gas
H_2S	Hydrogen sulphide
IED	Industrial Emissions Directive
Mn	Manganese
NAEI	National Atmospheric Emissions Inventory
NECD	National Emissions reduction Commitment Directive
NFR	Nomenclature for reporting
NO_x	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
PM	Particulate matter
PM_{10}	Particulate matter less than 10 micrometres in aerodynamic diameter
$PM_{2.5}$	Particulate matter less than 2.5 micrometres in aerodynamic diameter
PRTR	Pollutant Release and Transfer Register
Sb	Antimony
Se	Selenium
Tl	Thallium
TRI	Toxic Releases Inventory

Abbreviation	Explanation
TSP	Total Suspended Particulates
UNECE	United Nations Economic Commission for Europe
US EPA	United States Environmental Protection Agency
V	Vanadium
WHO	World Health Organisation

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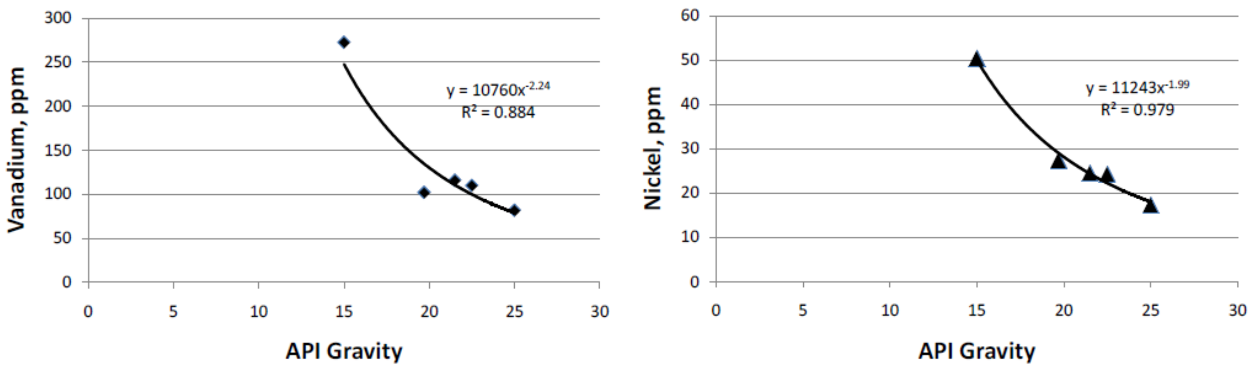
A1.1 Appendix 1: Comparison of US and European refining context

Crude oil composition differs significantly across the globe in terms of constituents, proportions and physical properties. The most common variables describing different crudes include its specific gravity and its sulphur content. In the petroleum industry, it is common to use the American Petroleum Institute (API) gravity scale for defining the specific gravity of crude oil. In this scale, pure water is assigned a value of 10°. Liquids lighter than water, such as oil, are assigned API gravities higher than 10°. Crude oils can be defined as heavy, medium and light using their API gravity (Eni, 2022):

- Heavy – API gravity = 10-25°.
- Medium – API gravity = 26-35°.
- Light – API gravity > 35°.

Crude oil is also categorised as sweet or sour dependent upon the level of sulphur it contains, which occurs in compounds such as hydrogen sulphide, carbon disulphide, carbonyl sulphide and mercaptans, such as ethanethiol. Sweet crudes have sulphur contents less than 0.5% w/w, whilst sour crudes have sulphur contents greater than 1% w/w. Generally, although not exclusively, the heavier the crude oil, the greater its sulphur content. The metal content of crude oil is also inversely proportional to its API gravity; the heavier the crude, the greater concentration of metals (Figure A-1).

Figure A-1 Relationship between API gravity and the content of certain metals in crude oil



Source: Barbooti, M. (2015) 'Evaluation of Analytical Procedures in the Determination of Trace Metals in Heavy Crude Oils by Flame Atomic Absorption Spectrophotometry.' *American Journal of Analytical Chemistry*, 6, 325-333

Table A-1 provides data on the percentage of domestic crude production by sulphur content and API gravity. It indicates that by weight, both regions predominantly produce a sweet and light crude, with the United States producing a higher percentage of sweet crudes but a correspondingly higher percentage of sour crudes than Europe.

Table A-1 Percentage of domestic crude production by sulphur content and gravity

Region	Production by S content			Production by API gravity		
	Sweet	Medium Sour [A]	Sour	Light	Medium	Heavy
Europe [B]	53.4%	42.7%	3.9%	57.9%	33.7%	8.4%
United States	76.4%	6.3%	17.3%	73.5%	22.9%	3.5%

Source: Logika based on data reported in Eni (2022) World Energy Review 2021

[A] Crude oil with a sulphur content between 0.5 – 1% by weight

[B] Includes production in Norway and the UK

However, the properties of domestic crude oil production do not allow the most appropriate analysis of factors which may influence emissions between the two regions, since crude oil is a global product traded on international markets. Indeed, both regions were net importers of oil in 2019, with Europe having a much greater net import ratio compared to the United States (BP, 2020).

In terms of the source of imports, in 2019 Canada accounted for more than 55% of the total imports to the United States, with Mexico (9%) and Saudi Arabia (7%) the other main nations from which crude oil was imported (BP, 2020). All of these nations predominantly produce a heavier, sour crude (Eni, 2022). In the case of Europe, Russia and other CIS nations were the main source of imports (42%), with North and West Africa (24%) the other main region of imports. Whilst crude oil from Russia can be medium but sour, particularly from the Urals region, crude oil produced in Africa is predominantly light and sweet.

Whilst information on the specific crude slate mix at individual refineries is commercially sensitive, inference on the type of crude slate processed can be drawn from the refinery complexity. Since more complex refineries have the additional conversion capability to refine heavier crude slates, it would follow that such refineries would typically have a greater proportion of heavier (and sour) crudes in their crude diet.

The complexity of a refinery is assessed using the Nelson Complexity Index (NCI). The larger the Nelson index of a refinery, the more complex it is. Refinery NCI values range from 1 for a basic topping refinery to ~ 2 for a hydro-skimming refinery, to ~ 5 for cracking refineries and greater than 10 for coking refineries. In 2020, the average NCI value of refineries in North America was 11.6, compared to 9.3 in Europe (Eni, 2022). Both values reflect that, on average, refineries in the United States and in Europe are sophisticated cracking refineries. However, the higher NCI value for the United States reflects the greater proportion of coking refineries which incorporate delayed or fluid coking units to increase the bottom of barrel conversion. This allows the United States, on average, to accept a greater proportion of heavier (and, hence, sour) crudes in their crude diet.

Consequently, in terms of emissions, particularly of metals and reduced sulphur compounds, it could be expected that the estimates from the United States would represent a conservative estimate of emissions from European refineries.

In order to provide a comparison of the relative contribution of the refining sector to industrial emissions in the US and EU27, data for two illustrative pollutants (NOx and PM_{10}) are displayed in Table A-2. The data were obtained from EU reporting under the CLRTAP (Umweltbundesamt, 2022), and from the US EPA's National Point Source Emissions database (US EPA, 2017) for 2017 (the latest year of data in the US dataset). The emissions data indicate that the significance of the refining sectors in the US and EU, relative to total industrial emissions, are very similar for NOx but with a greater difference for PM_{10} emissions.

Table A-2 US and EU27 refinery emissions relative to total industrial emissions

Pollutant	Refinery NOx emissions as percentage of industrial NOx emissions (%)	Refinery PM_{10} emissions as percentage of industrial PM_{10} emissions (%)
US	3.4	5.1
EU27	4.2	0.8