OSPAR COMMISSION

# Modelling of discharges to the marine environment from open circuit flue gas scrubbers on ships in the OSPAR Maritime Area

OSPAR

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# Modelling of discharges to the marine environment from open circuit flue gas scrubbers on ships in the OSPAR Maritime Area

## Acknowledgments

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**OSPAR Convention**

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the “OSPAR Convention”) was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. The Contracting Parties are Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

**Convention OSPAR**

La Convention pour la protection du milieu marin de l´Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d´Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. Les Parties contractantes sont l´Allemagne, la Belgique, le Danemark, l´Espagne, la Finlande, la France, l´Irlande, l´Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d´Irlande du Nord, la Suède, la Suisse et l´Union européenne

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# Executive summary


- The total effluent release volume from Exhaust Gas Cleaning Systems (EGCS) in all OSPAR Regions was about 622 million tonnes in 2020.
- Of this, 99.9% was from open loop EGCS systems.
- OSPAR Region II has the highest discharge volumes of all studies areas, about 47% of the EGCS discharge water is released in the North Sea and the English Channel.
- Most contributing ship types are containerships, Roll-On/Roll-Off cargo ships (RoRo), bulk cargo carriers and crude oil tankers.
- About 47% of the effluent is released from vessels carrying an EU flag.
- Most of the EGCS in the OSPAR Maritime Area are of open loop type, but the share of hybrid systems is larger in the fleet operating in this area than what is observed for the global fleet.
- About 84% of the EGCS effluent in the OSPAR Maritime Area is released inside the 200 nautical mile zones.
- Discharges inside the 12 nautical mile zones are roughly 130 million tonnes, which is about 21% of the total effluent volume.
- Contaminant loads from EGCS in the OSPAR Maritime Area are dominated by open loop discharges, where vanadium (106 tonnes), zinc (87 tonnes) and nickel (35 tonnes) may originate from heavy fuel oil. Chromium (66) may also originate from piping material in the scrubber, which, together with marine growth protection systems, is the hypothesized primary source of zinc copper (22 tonnes) in EGCS open loop discharge water.
- The estimated open loop contaminant loads are in the order of 1000-10,000 times higher than the closed loop loads. Also in closed loop discharge, vanadium constitutes the largest calculated load (1213 kg), almost four times the load of Nickel (312 kg). Chromium and zinc from closed loop was 66 kg and 30 kg respectively, while the estimated load of copper was somewhat lower, 5.2 kg.
- The estimated PAH loads in OSPAR Regions I-V are dominated by naphtalene (2.3 tonnes), followed by phenanthrene (1.2 tonnes) and fluorene, acenaphthene, and pyrene in the range 160-390 kg, and fluoranthene and chrysene in the range 70-90 kg (Table 6 and 7). The remaining nine of the EPA 16 PAH:s were estimated to be in the range 5-47 kg respectively. The estimated total load of PAH:s is close to 2.5 times higher than the mass of EPA 16 PAH, suggesting that e.g. alkylated PAHs should also be considered
- Comparing modelled loads of cadmium, copper, lead, mercury and zinc from EGCS discharge to available monitoring data on riverine input in the OSPAR Region shows that the relative contribution from scrubbers is mainly in the order of permilles, but up to 5.2% (copper), 5.8% (cadmium) and 7.4% (mercury) compared to loads from riverine input in Sweden. #

# Récapitulatif

- Le volume total des rejets d'effluents provenant des systèmes d'épuration des gaz d'échappement (EGCS) dans toutes les Régions OSPAR était d'environ 622 millions de tonnes en 2020.
- Sur ce total, 99,9% provenaient de systèmes EGCS en boucle ouverte.
- La Région II d'OSPAR a les volumes de rejets les plus élevés de toutes les zones étudiées, environ 47 % des eaux de lavage EGCS sont rejetées dans la mer du Nord et la Manche.
- Les types de navires qui y contribuent le plus sont les porte-conteneurs, les navires de charge RoRo (Roll-On/Roll-Off), les vraquiers et les pétroliers.
- Environ 47 % des effluents sont rejetés par des navires battant pavillon européen.
- La plupart des EGCS de la zone maritime OSPAR sont de type boucle ouverte, mais la part des systèmes hybrides est plus importante dans la flotte opérant dans cette zone que ce qui est observé pour la flotte mondiale.
- Environ 84% des effluents des EGCS de la zone maritime OSPAR sont rejetés à l'intérieur des limites de 200 milles nautiques.
- Les rejets à l'intérieur des zones de 12 milles nautiques représentent environ 130 millions de tonnes, soit environ 21 % du volume total des effluents.
- Les charges de contaminants provenant des EGCS dans la zone maritime OSPAR sont dominées par les rejets en boucle ouverte, où le vanadium (106 tonnes), le zinc (87 tonnes) et le nickel (35 tonnes) peuvent provenir du fioul lourd. Le chrome (66) peut également provenir du matériel de tuyauterie dans l'épurateur, qui, avec les systèmes de protection de la croissance marine, est la source principale supposée du cuivre-zinc (22 tonnes) dans les eaux de rejet en boucle ouverte de l'EGCS.
- Les charges estimées de contaminants en boucle ouverte sont de l'ordre de 1000 à 10 000 fois plus élevées que celles en boucle fermée. Toujours dans les rejets en circuit fermé, le vanadium constitue la plus grande charge calculée (1 213 kg), soit près de quatre fois la charge du nickel (312 kg). Le chrome et le zinc provenant de la boucle fermée étaient respectivement de 66 kg et 30 kg, tandis que la charge estimée du cuivre était un peu plus faible, 5,2 kg.
- Les charges estimées des hydrocarbures aromatiques polycycliques (HAP) dans les Régions I-V d'OSPAR sont dominées par le naphtalène (2,3 tonnes), suivi du phénanthrène (1,2 tonne) et du fluorène, de l'acénaphtène et du pyrène dans la fourchette 160-390 kg, et du fluoranthène et du chrysène dans la fourchette 70-90 kg (Tableaux 6 et 7). Les neuf autres des 16 HAP de l'EPA ont été estimés dans une fourchette de 5 à 47 kg respectivement. La charge totale estimée des HAP est près de 2,5 fois supérieure à la masse des HAP de l'EPA 16, ce qui suggère que les HAP alkylés, par exemple, doivent également être pris en compte.
- La comparaison des charges modélisées de cadmium, cuivre, plomb, mercure et zinc provenant des rejets des EGCS avec les données de surveillance disponibles sur les apports fluviaux dans la région OSPAR montre que la contribution relative des épurateurs est principalement de l'ordre de 1000-quantiles, mais jusqu'à 5,2% (cuivre), 5,8% (cadmium) et 7,4% (mercure) par rapport aux charges provenant des apports fluviaux en Suède.

# 1 Introduction

Exhaust Gas Cleaning Systems (EGCS), also known as scrubbers, are used onboard ships as an alternative way to comply with current limits regarding sulphur oxide ($SO_X$) emissions to the atmosphere (Lunde Hermansson et al. 2021). However, beside $SO_X$, other contaminants, e.g. metals and polycyclic aromatic hydrocarbons, are washed out from the exhausts and discharged to the sea. There is growing concern that discharges from wide-scale use of EGCS pose a threat for the marine environment (ICES 2020, Hassellöv et al., 2020 and references therein, Teuchies et al., 2020, Thor et al. 2021). In some ports, regions and countries restrictions apply with respect to discharge from EGCS, but there is no general harmonization of current restrictions[1].

## 1.1 EGCS installation statistics

The introduction of global sulfur cap of 0.5% for marine fuels on Jan 1st, 2020, was predicted to increase the number of EGCS significantly. According to the International Maritime Organization (IMO) Fuel Availability Report (Faber et al., 2016), the predicted uptake of EGCS in the global fleet would reach 3800 vessels by January 2020. According to IMO Global Integrated Shipping Information System (GISIS) notifications, over 1200 EGCS systems were installed by that time, but since then the number of EGCS systems has

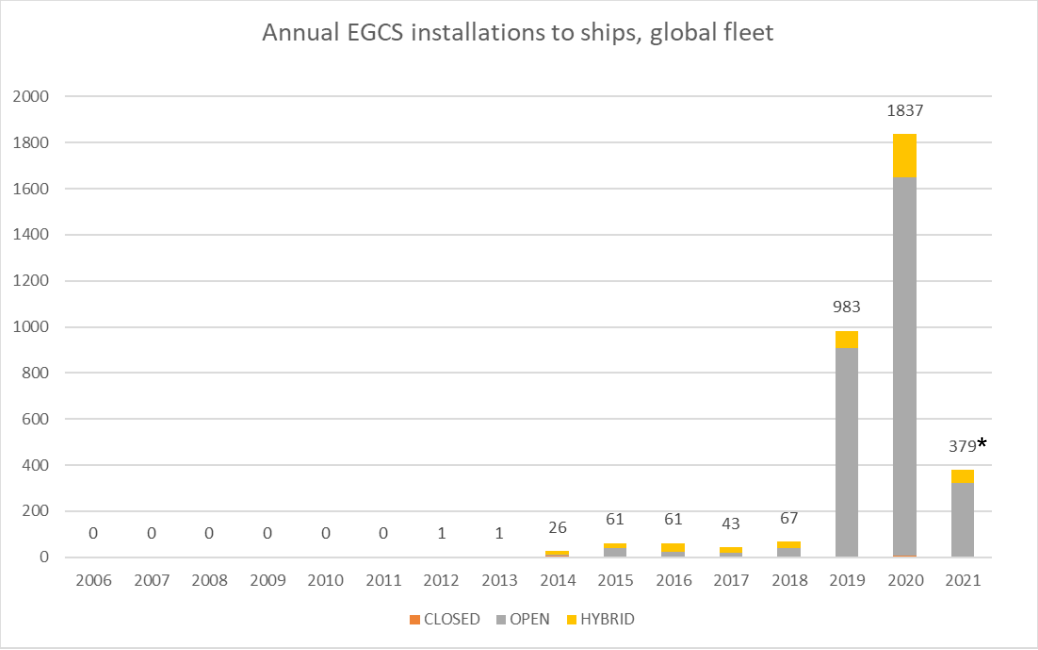


*Figure 1. Installations of EGCS systems onboard ships each year. This data was collected from IMO GISIS notifications on Aug 8th 2021 and it only includes data for the first seven months of 2021.*

increased rapidly. By the end of 2020, almost 3100 vessels were reported to be equipped with these systems and over 3400 units were reported by August 2021. As can be seen from Figure 1, installations increased more than ten-fold during 2019 compared to 2018, and more than 1800

[1] Industry News: No Scrubs: Countries and Ports where Restrictions on EGCS Discharges Apply (nepia.com)

systems were installed on ships during 2020. The period 2014-2018 involved 260 vessels in total, mostly operating on $SO_X$ Emission Control Areas (SECA), where strict 0.1% sulfur limits have been in place since 2015. In 2021, the EGCS installations seem to have decreased despite Figure 1 containing data for a partial year, because during the first seven months only 379 units were installed. Regardless, the cumulative installations already exceeded 3450 units by that time (Figure 2).

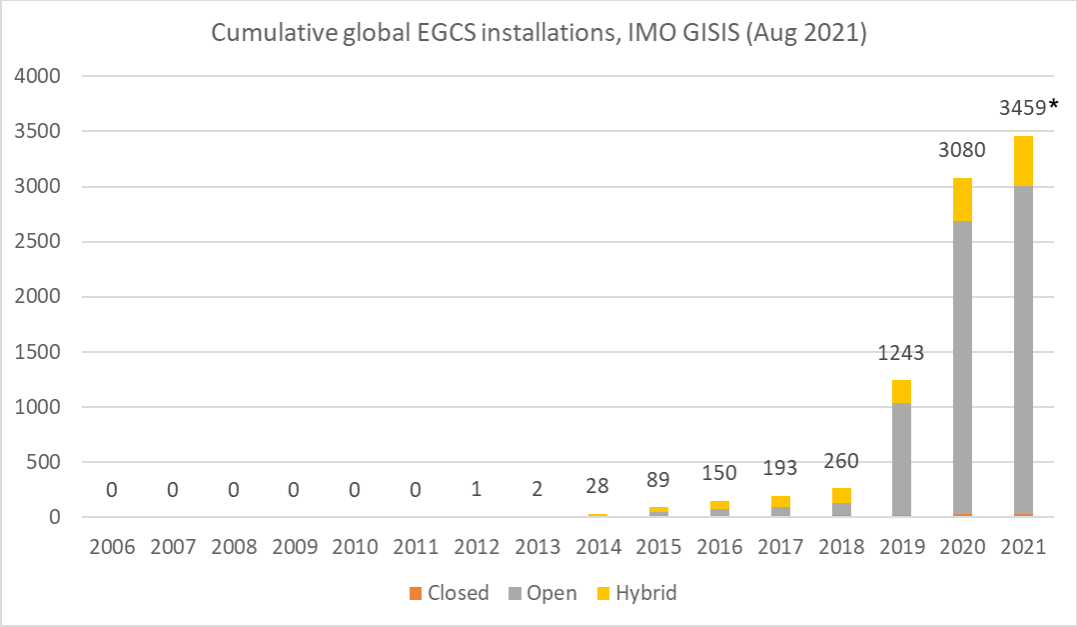


*Figure 2. Number of ships in the global fleet with EGCS by Aug 8th 2021 according to IMO GISIS.*

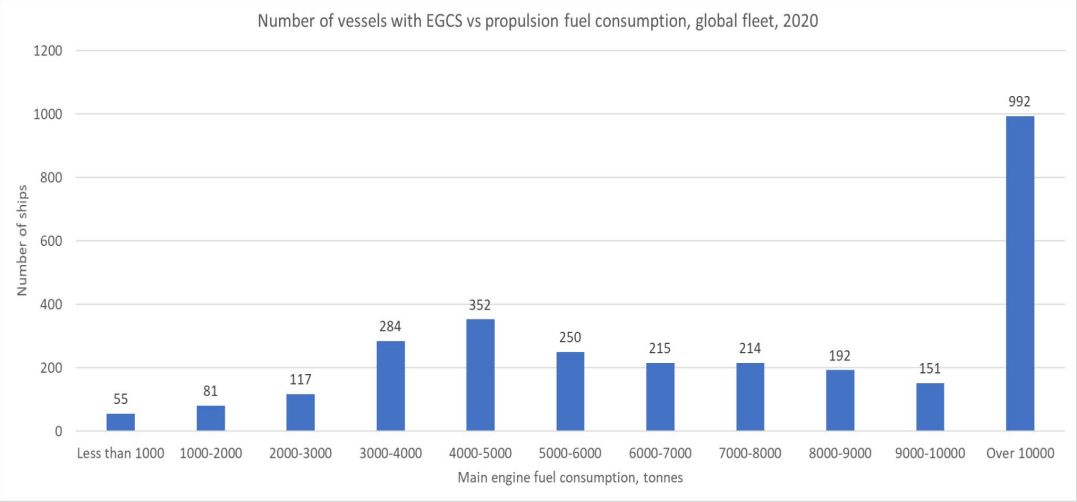


*Figure 3. Estimated propulsion fuel consumption of the global active scrubber fleet (2903 vessels) in 2020. This graph is based on global scrubber modeling done with the STEAM model.*

Both economic and environmental aspects will have an impact on EGCS installations. National rules banning open loop discharge in various ports could make EGCS problematic in these areas, depending on the EGCS type. However, it is probable that large annual fuel consumption and significant price difference between high and low sulfur fuel grades make EGCS attractive (Reynolds and Caughlan, 2011). Indeed, based on global modeling of ship emissions, it seems that a larger propulsion fuel consumption than 3000 - 4000 tonnes per year (Figure 3) makes EGCS an attractive option.

## 1.2 Global pattern of EGCS discharge

Discharges of the global EGCS fleet (Figure 4) are concentrated around main shipping lanes, making East Asian Sea regions a global hot spot for these discharges. In Figure 4, these areas are marked with blue color and main shipping lanes are clearly visible. Figure 5 depicts volumes of EGCS discharges by sea regions defined by the International Hydrographic Organization (IHO). In this Figure, the size of the circle is proportional to EGCS discharge volume.

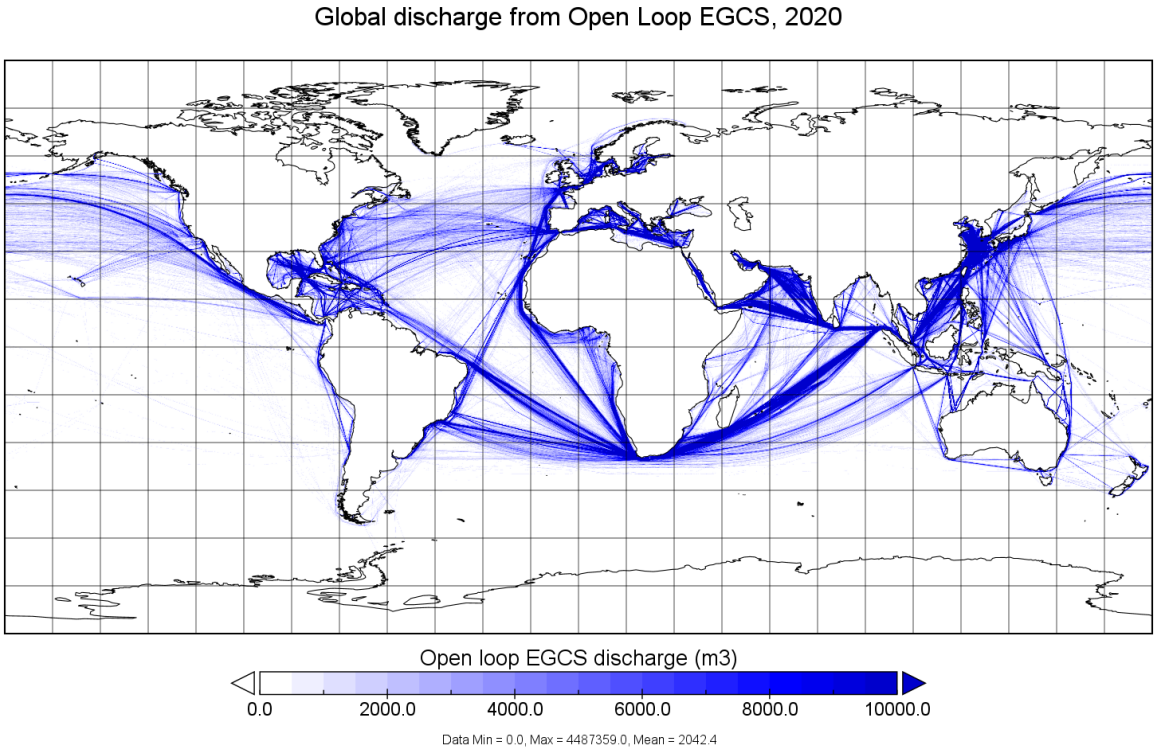


*Figure 4. Global distribution of estimated Open Loop EGCS discharge in 2020. These data are based on global STEAM modeling.*

Global EGCS hotspots are concentrated along the main shipping lanes from China through the Malacca Strait towards both the Persian Gulf and Europe. Globally, over 9,5 billion tonnes of Open Loop EGCS effluent were discharged to the sea during the year 2020.

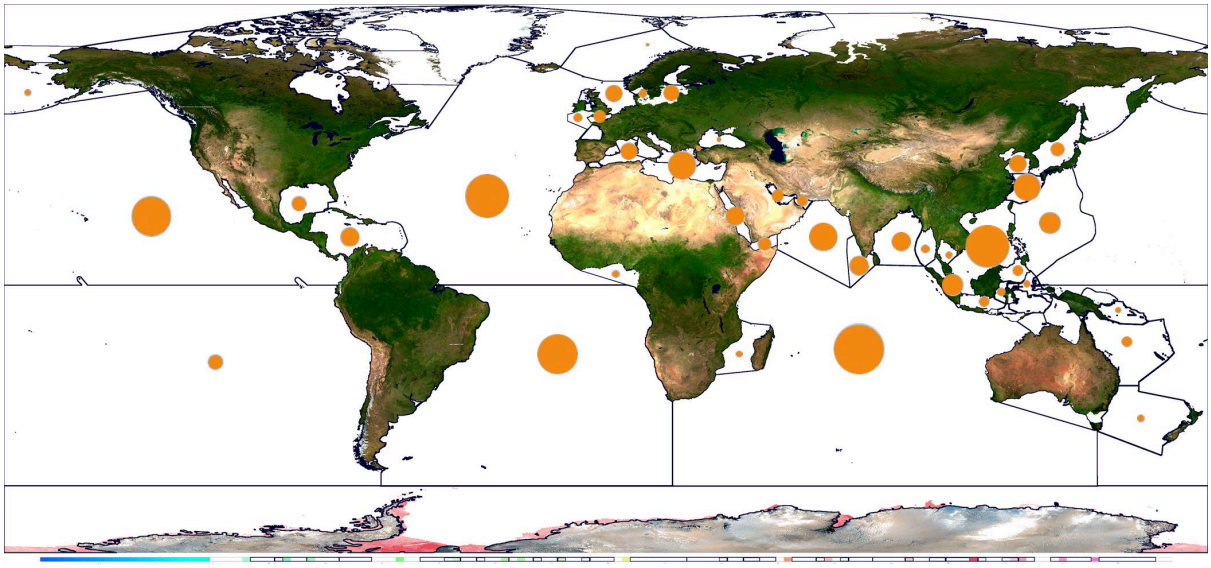

*Figure 5. Global EGCS Open loop discharge on various sea regions during 2020. Size of the circle is relative to the discharge volume. Sea region definitions follow those from IHO.*

## 1.3 Contaminants in EGCS discharge water

EGCS discharge water is a complex chemical mixture, where metals and PAHs are the most frequently reported (Ytreberg et al., 2020). Open loop discharge water is also acidic, typically pH<3, while pH in closed loop process water is adjusted (to maintain sulphur removal capacity) by addition of base, most often NaOH. In addition to contaminants, washout of eutrophying nitrogen oxides ($NO_X$) has also been reported (Ytreberg et al. 2021). The reported contaminant concentrations are highly variable and governed by a number of factors such as the fuel used, type of engine and EGCS, engine speed and operation, the water/exhaust gas ratio, and leaking from the piping material, yet the detailed chemistry is not fully understood (Linders et al., 2019). Previous reports (Linders et al. 2019, and Hassellöv et al. 2020) have raised concerns regarding the lack of monitoring of metals in the discharge water guidelines. In the revised IMO guidelines for EGCS (MEPC 2015, 2018 and 2021) metal concentrations are still not directly targeted, but only indirectly assessed using turbidity as a proxy. Concerns have also been raised regarding the optical method used for onboard monitoring of $PAH_{PHE}$ as proxy for PAH-concentrations (Linders et al., 2019, Schmolke et al., 2020). With respect to discrete sampling and chemical characterization of scrubber discharge water in lab, a recent study by Du et al. (2022) concludes that reported data on EPA 16 PAHs, not including alkylated PAHs, may lead to significant underestimations (between 5-15 times lower) of PAH concentrations in scrubber discharge water. An analogous relation has previously been reported from analysis of crude oils, where the PAH content were (up to 30 times lower), when alkylated PAHs were omitted from the analysis (Yim et al. 2011).

To put the contaminant load to the environment from scrubbers in context to other sources, Ytreberg et al., (2022 preprint, pending revision), made a comparison for the Baltic Sea. Following the use of copper based antifouling paints (509 tonnes Cu/yr), operation of scrubbers in open loop mode (7 tonnes Cu/yr) made shipping the single most dominant identified sources of hazardous substances to the Baltic Sea. Discharge from open loop scrubbers was identified as a major source of vanadium and anthracene to the Baltic Sea. It should be noted though that the comparison made by

Ytreberg et al (2022 preprint) was based on 2018 data, implying that the loads from scrubbers may be up to three times higher today. Beyond the uncertainties in the scrubber load estimations, data on riverine, atmospheric, and point sources, should be considered as crude estimates, yet the conclusion that scrubbers are a substantial source of contaminants to the Baltic Sea is indisputable. Ytreberg et al. (2022, preprint pending revision) conclude that switching to operation in closed loop mode, could reduce the loads of most PAHs and metals with up to 90%.

# 2 Task description

This study includes modeled estimates of EGCS effluent release from open and closed loop systems in the OSPAR Regions (I-V), but some results in the global domain are also given to provide a global perspective to ship emission modeling. The modeled EGCS effluent releases were subdivided to OSPAR regions I-V, Exclusive Economic Zone (EEZ) and territorial water (12 nautical miles from the coastline) contributions. The modeling approach used in this work was the Ship Traffic Emission Assessment Model (STEAMv3.5) of the Finnish Meteorological Institute.

# 3 Description of OSPAR Regions

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the ‘OSPAR Convention') includes five (I-V) regions depicted in Figure 6. Area I extends from the southernmost tip of Greenland to Franz-Josef land, and includes the Faroe Islands in the south. OSPAR Region II includes the North Sea and the English Channel; area III includes the Celtic and Irish sea, extending to Outer Hebrides in the north. Area IV covers the Bay of Biscay and the Iberian Peninsula coastline extending south to Gibraltar along the 11W meridian. Finally, Area V is limited to OSPAR Regions III and IV in the east, and 42W meridian and latitudes 36N and 62N in south and north.

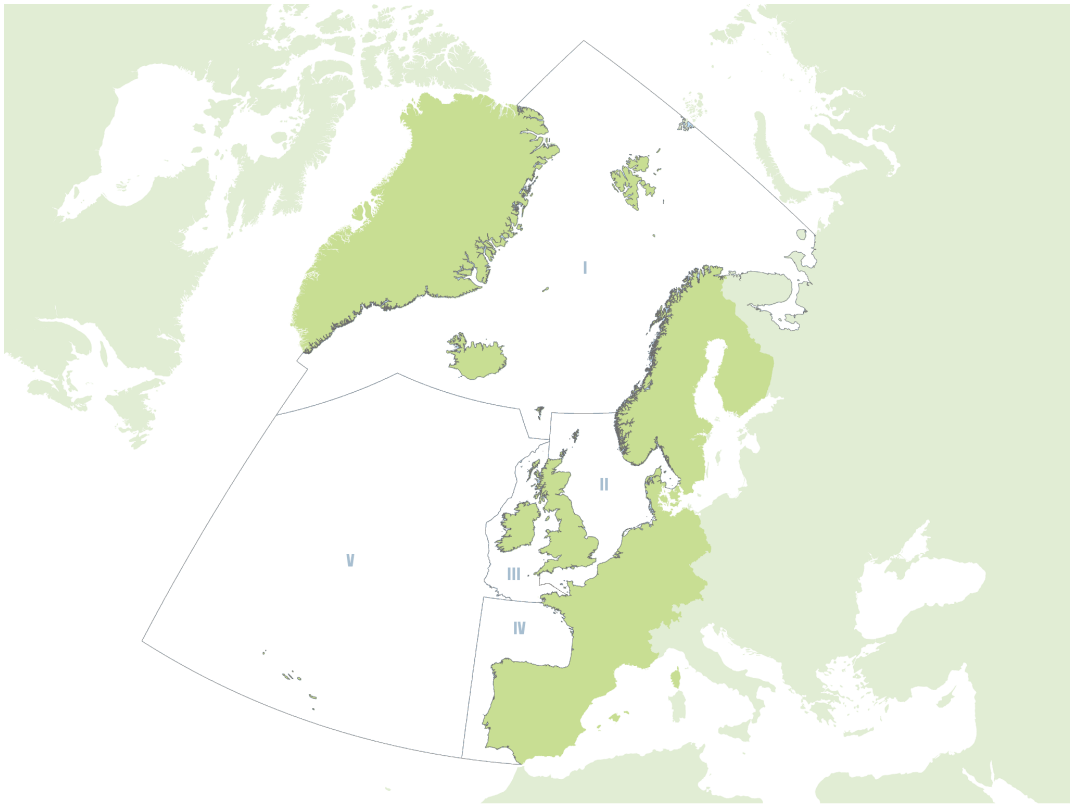


*Figure 6. OSPAR Regions I-V.*

The polygons describing the Exclusive Economic Zones (EEZ) and the territorial (12 nautical miles) waters of each country were obtained from the Flanders Marine Institute (Flanders Marine Institute, 2019a, 2019b). In case of disputed sea areas, no statements are made concerning the alternative polygons defining these regions. The EEZ polygons used in this work are indicated by Figure 7 and territorial waters are described in Figure 8. Results of EGCS effluent discharges for these three levels of area allocations are collected in Chapter 6.

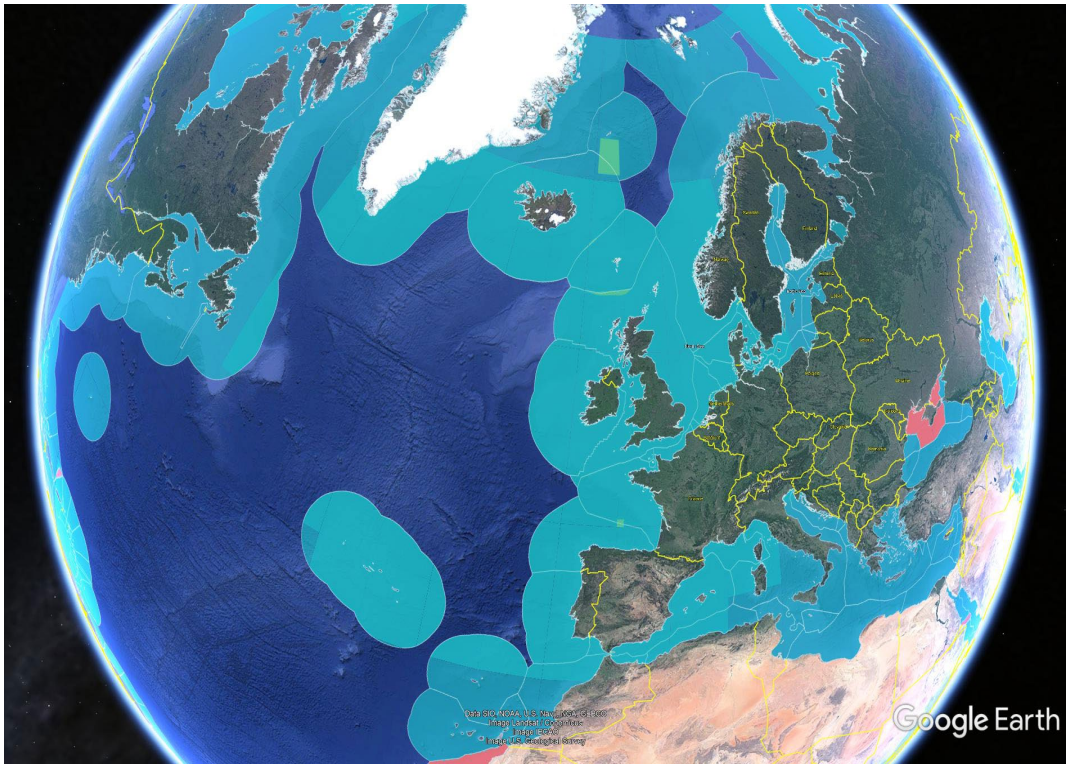


*Figure 7. Exclusive Economic Zones in the OSPAR domain, from Flanders Marine Institute (2019a).*


*Figure 8. Description of territorial waters (12 NM) were made according to the Flanders Marine Institute (2019b).*

# 4 Modeling approach

In this work, the Ship Traffic Emissions Assessment Model (STEAMv3.5) was used (Jalkanen et al., 2009, 2012, 2021; Johansson et al., 2017, 2013) to predict vessel power use and EGCS effluent

discharge, considering open/closed/hybrid EGCS equipment and their installation dates. The model takes as input the global vessel activity included in Automatic Identification System (AIS) position reports. Both terrestrial and satellite AIS were used to describe vessel activity during the year 2020, with over 5.2 billion position reports. These data were obtained from the commercial provider Orbcomm Ltd. To model each vessel also the technical description of the global fleet is needed, which was provided by IHS Markit. This allows for the consideration of propulsion and machinery details in the modeling.

In this work, all ambient (wind, wave, sea ice and sea currents) contributions were turned off and theoretical relation of speed to power was used. STEAM evaluates the instantaneous power need of each vessel based on vessel properties and speed indicated by AIS position reports. Air emissions are modeled considering vessel operation area and relevant emission regulation.

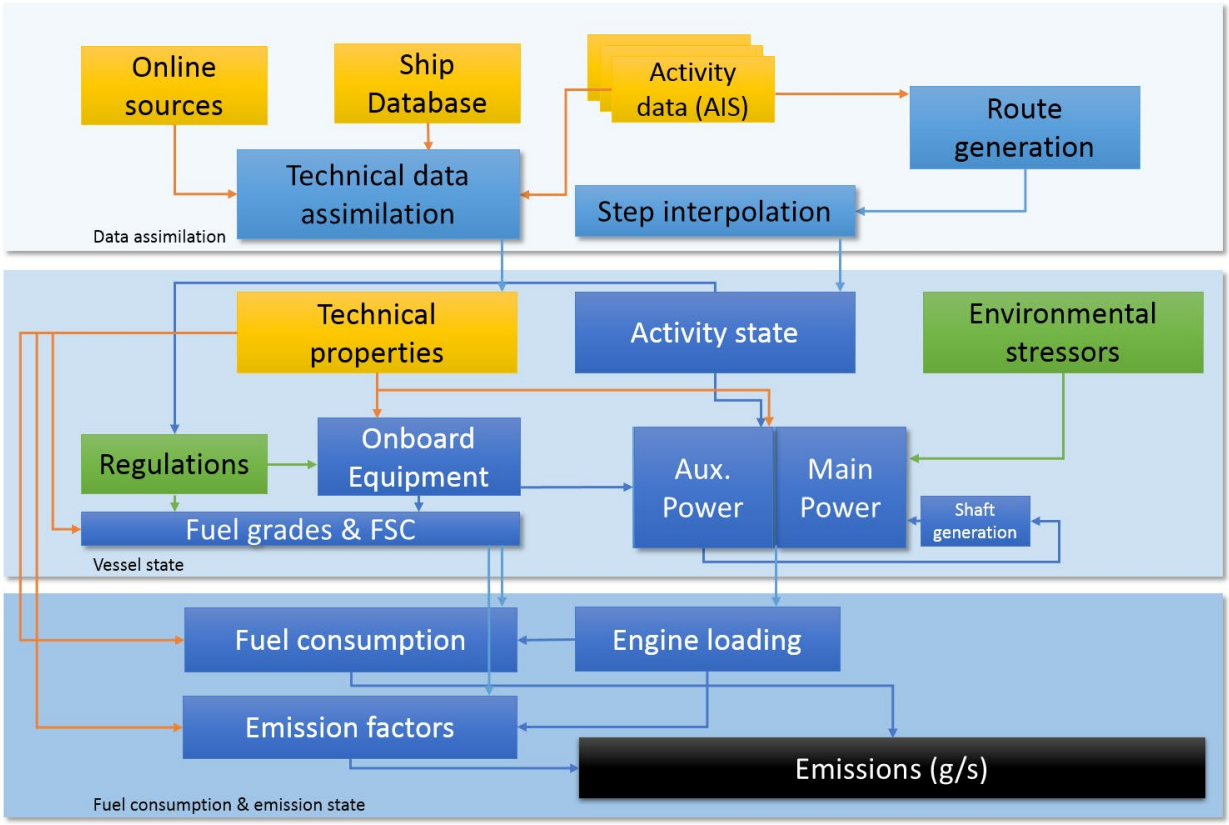


*Figure 9. Schematic summary of various modeling steps involved in STEAM work. Image from Johansson et al (2017).*

## 4.1 Discharge modeling

For the purpose of discharge modeling, required effluent volume was determined based on instantaneous power need (kW in use) and applying 90 $m^3$ $MWh^{-1}$ discharge rate for open loop and 0.45 $m^3$ $MWh^{-1}$ for closed loop EGCS. Note, that these are not normalized values (45 $m^3$ $MWh^{-1}$), but represent volumes observed from normal EGCS operation during voyages (Teuchies et al., 2020, Ytreberg et al., 2020) and similar rates have been also in two recent studies (Schmolke, et al., 2020; Tronczynski et al., 2022). Additional power needed to operate scrubber pumps is modeled by adding 2% to estimated instantaneous main engine power. Further details of the methodology can be found

in (Jalkanen et al., 2021). Note, that STEAM provides estimates for EGCS discharges in volume units ($m^3$) which need to be combined with water sampling and laboratory analysis to yield mass flux of various pollutants to the sea. The motivation for volumetric description of discharges is the complex chemical composition of EGCS effluents which would require tracking of potentially dozens of compounds.

The modeling approach applied in this study has been used previously e.g in HELCOM and EMTER reporting (EMSA and EEA, 2021; Jalkanen et al., 2021b, 2021a). For ecotoxicological analysis and environmental impact assessments, this work needs to be combined with complementary laboratory analysis of effluent composition and dispersion modeling to determine where the sea currents carry the discharge. This work will be carried out in the ongoing H2020/EMERGE project 2020-2024 (https://emerge-h2020.eu/), which includes updates to the modeling tools used in environmental impact assessments, STEAM included. In STEAM, emissions and discharges are modeled considering relevant regulation. For the EU this necessitates the use of IMO MARPOL Annex 1, 4, 5 and 6 rules, EU Sulphur directive requirements as well as the Ballast Water Management Convention (BWMC) and Antifouling Convention (AFC) regulations in the modeling.

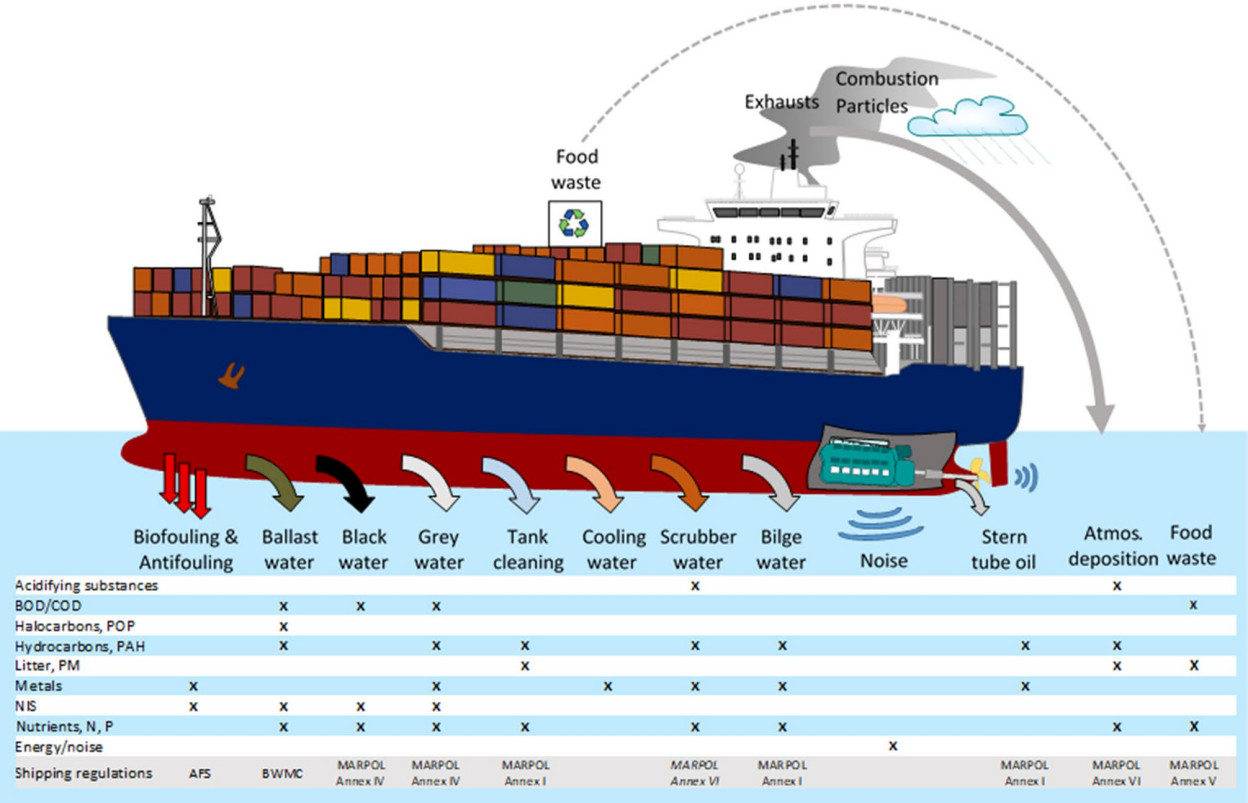


*Figure 10. Discharge streams from ships and regulatory instruments used in controlling the various discharges. Note, that STEAM includes all these discharge streams with the exception of Tank cleaning and Cooling water, which are not yet included. Image by I.-M. Hassellöv (Jalkanen et al., 2021).*

Air emissions and discharges from ships were modeled using a 0.05 by 0.1 deg daily lat-lon grid with the World Geological Survey 84 coordinate system. The STEAM runs were made excluding the inland waterway traffic in AIS data. This excludes some inland harbor emission contributions, but it should not have any major impact on EGCS effluent releases.

## 4.2 Post processing of results

Global STEAM-data was imported as netcdf-raster file in QGIS version 3.22.3. OSPAR region polygons were imported as vector shapefiles from OSPAR secretariat and territorial seas (12NM) and exclusive economic zones (200 NM) polygons from Flanders Marine Institute(Flanders Marine Institute, 2019a, 2019b). Using the polygons as a mask layer, the raster data from STEAM was segmented in OSPAR I – V areas, and EEZ and territorial areas per country. Then, the sum of discharge water over the selected areas was calculated for open and closed loop scrubbers.

## 4.3 Calculations of contaminant loads

The STEAM output volumes of open and closed loop scrubber discharge water, for the selected areas were combined (Eq 1), where V is the volume of open or closed loop respectively, and c the concentration of the individual contaminants in the respective open or closed loop discharge water.

Eq 1 $$V_{discharge\ water} \times c_{contaminant\ in\ discharge\ water} = m_{contaminant}$$

The concentrations of contaminants compiled from all publicly available data (Ytreberg et al., 2020), applying the selection used by Lunde Hermansson et al. (2021) where 31 open loop samples fulfilled the criteria of reporting the discharge flow rate (68±9 $m^3MWh^{-1}$) and operating at engine loads ≥ 50% of MCR (Table 1). The sample set for EGCS in closed loop operation was smaller, only 6 samples fulfilled the criteria on reporting the discharge flow rate (0.35 ± 0.3 $m^3MWh^{-1}$) and operated at engine loads ≥ 50% of MCR (Table 1). All samples did not contain data for all contaminants, why the final number of analyzed samples are included in the table.

The reported contaminant concentrations are highly variable, and average values together with ±95% confidence intervals (with respect to the reported concentrations), were used to provide an indication of the variability. Loads were calculated separately for Open and Closed loop scrubbers, within the respective OSPAR I – V areas, and EEZ and territorial areas per country, with respect to Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Vanadium, Zinc, Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene , Fluoranthene, Pyrene, Benz(a)anthrancene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene, Indeno(1,2,3-c,d)pyrene, Sum EPA 16 PAH, Sum total PAH..

The detailed data for the respective countries, are provided in Appendix 1 – Contaminant loads. To put the contaminant loads from EGCS in perspective, a comparison was made to riverine load data (from year 2019) as reported to the OSPAR Riverine Inputs and Direct Discharges Monitoring Programme (RID), extracted February 2022[2].

[2] https://www.ospar.org/work-areas/hasec/hazardous-substances/rid Results

*Table 1. Average concentrations, and ±95% confidence interval, of contaminants in Open loop and Closed loop EGCS discharge water. The total number of different samples are 31, but no single sample contained data on all contaminants, why the number of analyzed samples are also provided. The available data on contaminant concentrations in closed loop discharge water is even sparser than the open loop data.*

| | OL Average (µg/L) | OL ±95%CI (µg/L) | # analyzed samples | CL Average (µg/L) | CL ±95%CI (µg/L) | # analyzed sampels |
|---|---|---|---|---|---|---|
| **Arsenic** | 3.80 | 0.666 | 27 | 19.0 | 10.1 | 6 |
| **Cadmium** | 0.585 | 0.187 | 27 | 0.852 | 0.362 | 6 |
| **Chromium** | 10.2 | 6.50 | 20 | 932 | 2340 | 5 |
| **Copper** | 35.4 | 22.6 | 27 | 73.4 | 72.0 | 6 |
| **Lead** | 4.93 | 1.99 | 27 | 3.94 | 1.78 | 6 |
| **Mercury** | 0.0928 | 0.0128 | 9 | 0.100 | N/A | 2 |
| **Nickel** | 55.6 | 18.3 | 27 | 4391 | 2591 | 6 |
| **Vanadium** | 169 | 57.1 | 27 | 17078 | 8974 | 6 |
| **Zinc** | 141 | 154 | 27 | 428 | 359 | 6 |
| **Naphthalene** | 3.68 | 1.41 | 28 | 0.96 | 1.06 | 6 |
| **Acenaphthylene** | 0.109 | 0.0589 | 26 | 0.0459 | 0.0619 | 6 |
| **Acenaphthene** | 0.262 | 0.104 | 26 | 0.244 | 0.272 | 6 |
| **Fluorene** | 0.623 | 0.158 | 26 | 0.788 | 0.788 | 6 |
| **Phenanthrene** | 1.86 | 0.504 | 26 | 3.98 | 5.30 | 6 |
| **Anthracene** | 0.0537 | 0.0296 | 26 | 2.09 | 5.28 | 6 |
| **Fluoranthene** | 0.138 | 0.063 | 26 | 0.522 | 0.984 | 6 |
| **Pyrene** | 0.253 | 0.156 | 26 | 0.750 | 1.57 | 6 |
| **Benz(a)anthrancene** | 0.0749 | 0.0731 | 26 | 0.263 | 0.625 | 6 |
| **Chrysene** | 0.119 | 0.0698 | 26 | 0.299 | 0.697 | 6 |
| **Benzo(b)fluoranthene** | 0.0301 | 0.0205 | 26 | 0.123 | 0.290 | 6 |
| **Benzo(k)fluoranthene** | 0.00933 | 0.00746 | 21 | 0.00500 | N/A | 5 |
| **Benzo(a)pyrene** | 0.0226 | 0.0163 | 26 | 0.0429 | 0.0974 | 6 |
| **Dibenzo(a,h)anthracene** | 0.00869 | 0.00370 | 26 | 0.0202 | 0.0391 | 6 |
| **Benzo(g,h,i)perylene** | 0.0142 | 0.00876 | 26 | 0.0781 | 0.185 | 6 |
| **Indeno(1,2,3-c,d)pyrene** | 0.0220 | 0.0269 | 26 | 0.0399 | 0.0896 | 6 |
| **Sum EPA 16 PAH** | 1.04 | 0.836 | 4 | N/D | | 0 |
| **Sum total PAH** | 7.46 | 2.37 | 22 | 3.63 | 3.85 | 5 |

# 5 Results

An overall view of ship traffic in the overall OSPAR region is provided by a $CO_2$ map, which is indicative of the amount of fuel used in the area (Figure 11). Heavily trafficked shipping lanes from Gibraltar via the English Channel to the Baltic Sea area are clearly visible with their traffic separation schemes. Some of the northernmost ship tracks are probably because of the MOSAiC ice drifting expedition (2019-2020) and its support vessels. Most of the traffic in Arctic areas are tankers to Polyarny-Murmansk and Kara Sea, cargo traffic to Svalbard and fishing.

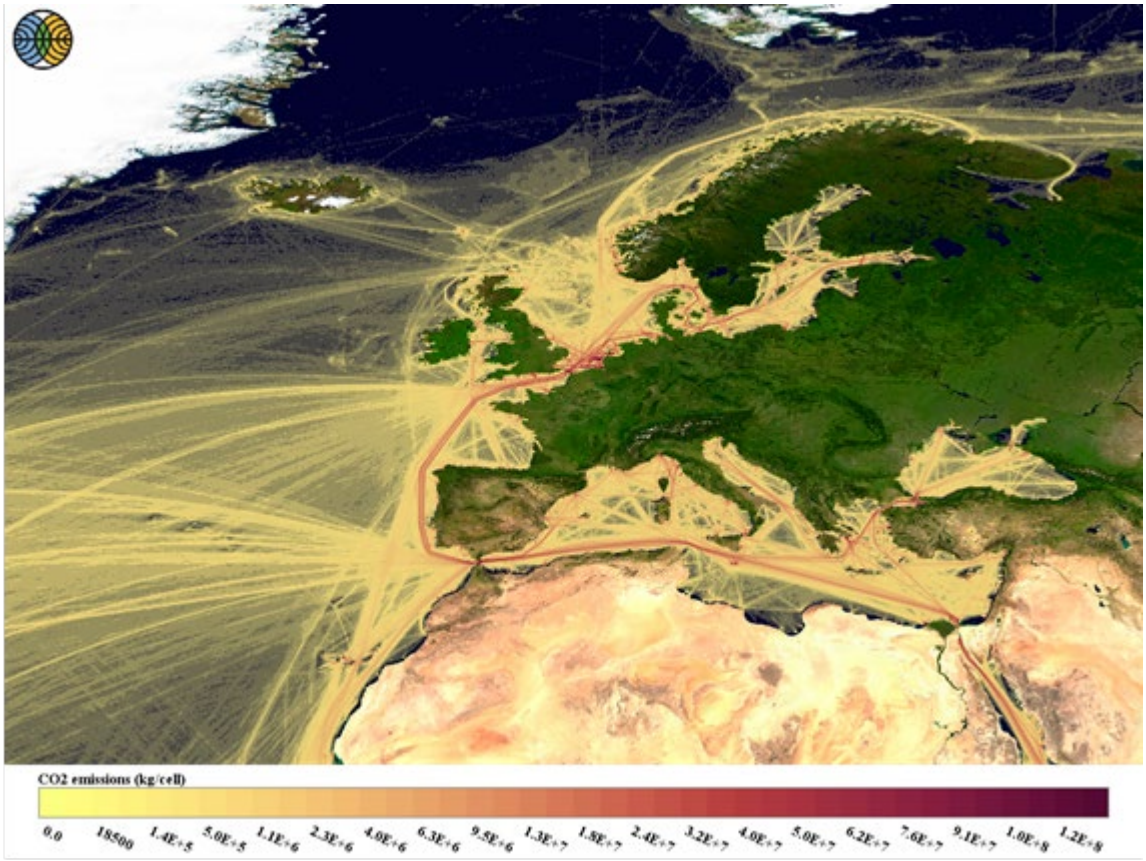


*Figure 11. Ship emitted CO2 in the EU domain during the year 2020. This image depicts emissions of CO2 from ships sailing all the sea areas, not just OSPAR domains.*

## 5.1 Emission inside the overall OSPAR Region

The shipping in the five OSPAR domains together emitted about nine percent of global shipping $CO_2$ in 2020. Largest fuel consumption was estimated for containerships, oil tankers and dry cargo ships. These vessels emitted approximately 60% of $CO_2$ in the area. The 1900 largest vessels were responsible for 18% of the $CO_2$ emitted, whereas almost 115000 active AIS transceivers were observed in the area. Of these, about 21900 were transmitting both the IMO registry number and the MMSI code. However, these vessels were responsible for 83% of the $CO_2$ emitted. About 60000 vessels transmitting only MMSI code could not be identified from the existing ship database of IHS Markit. These were treated as small vessels, so as not to overestimate their contribution to emission totals. Table 1 reports the emission totals for the combined OSPAR domain.

*Table 2. Emission and discharge totals for the combined OSPAR regions (I-V). The values in parentheses indicate the share of emissions in relation to global 2020 modeling results.*

| Species | Total (% from global) |
|---|---|
| $NO_x$[thousand tonnes] | 1 281 (7.9%) |
| $SO_x$[thousand tonnes] | 129 (6.1%) |
| $PM_{2.5}$[thousand tones] | 33 (9.6%) |
| CO[thousand tonnes] | 127 (9.8%) |
| $CO_2$[thousand tonnes] | 74 080 (8.6%) |
| $CH_4$[thousand tonnes] | 26 (15.3%) |
| NMVOC[thousand tonnes] | 14 (8.9%) |
| Open loop EGCS (million $m^3$) | 622 (6.5%) |
| Closed loop EGCS (million $m^3$) | 0.1 (24.8%) |

It is noteworthy that the combined OSPAR domain has a relatively large share of methane emissions, when compared to the share of $CO_2$. This reflects the increased use of Liquid Natural Gas (LNG) as ship fuel in the area. It should also be noted that the share of closed loop EGCS discharge has a larger share than the discharge from open loop systems. Most of the closed or hybrid loop vessels in the global fleet operate in the Baltic - North Sea area, which reflects the early adoption of these systems in existing $SO_X$ Emission Control Areas.

The total EGCS effluent release in the OSPAR Region was estimated to be 622 million cubic meters, which is about three times the corresponding release in the Baltic Sea area (198 million $m^3$) (Jalkanen et al., 2021a). About 38% of the 622 million $m^3$ EGCS discharge occurs in the sea areas around the UK, in the North Sea, Celtic Sea and the English Channel. Even if the volumetric discharge in the Northern Atlantic is larger than in these sea areas, a large discharge in more confined waters of English Channel and the North Sea is significant (Figure 12).

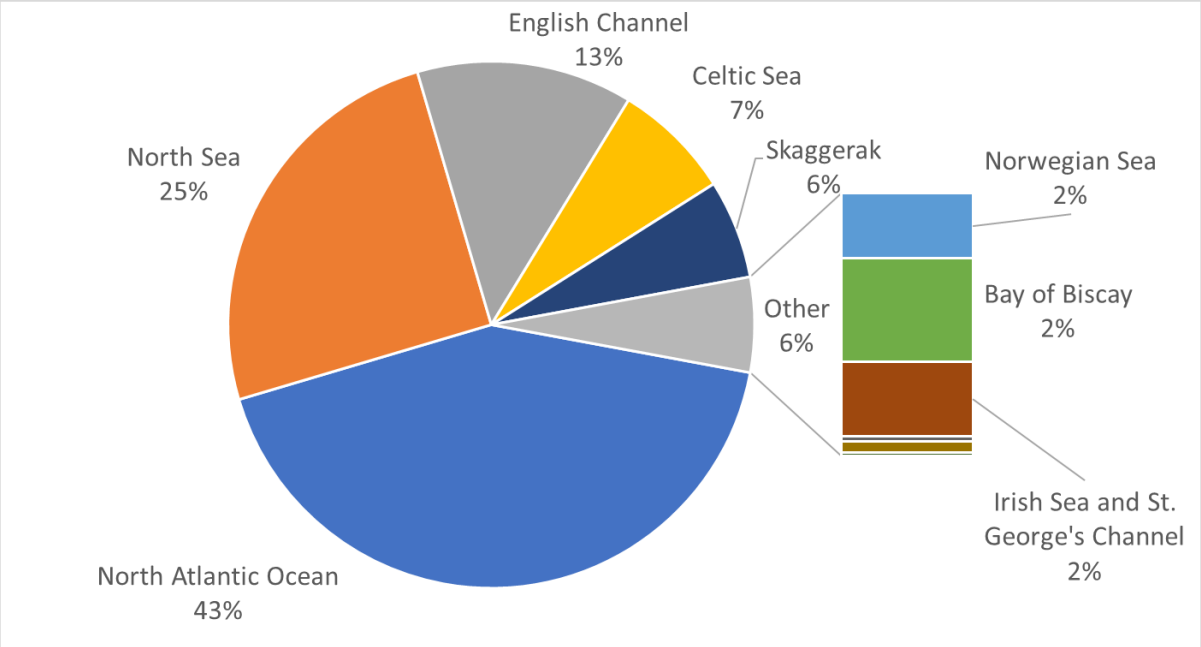


*Figure 12. Combined discharge from both open and closed loop EGCS in various sea regions. These sea regions are defined by the International Hydrographic Organization (IHO) and they are not directly comparable to OSPAR Regions.*

The bleed off from closed loop systems is significantly smaller in volume than the total discharge from open loop EGCS by a factor of ~5000. From the studied OSPAR domains, the largest discharge occurs in the English Channel, especially near the Rotterdam area. The main shipping lane from Gibraltar to the Baltic Sea is clearly visible from Figure 13.

In the OSPAR domain (areas I-V), high EGCS discharge volumes were predicted at least for the following locations and shipping routes:

- Rotterdam area has the highest regional EGCS discharge total
- Dublin-Holyhead
- Portsmouth-Caen/Le Havre
- Rotterdam-Harwich
- Bruges/Vlissingen area
- Hirtshals-Larvik
- Hirtshals-Kristiansand
- Ferries from Oslo towards Fredrikshavn, Copenhagen and Kiel
- Main shipping lane from Gibraltar to English Channel

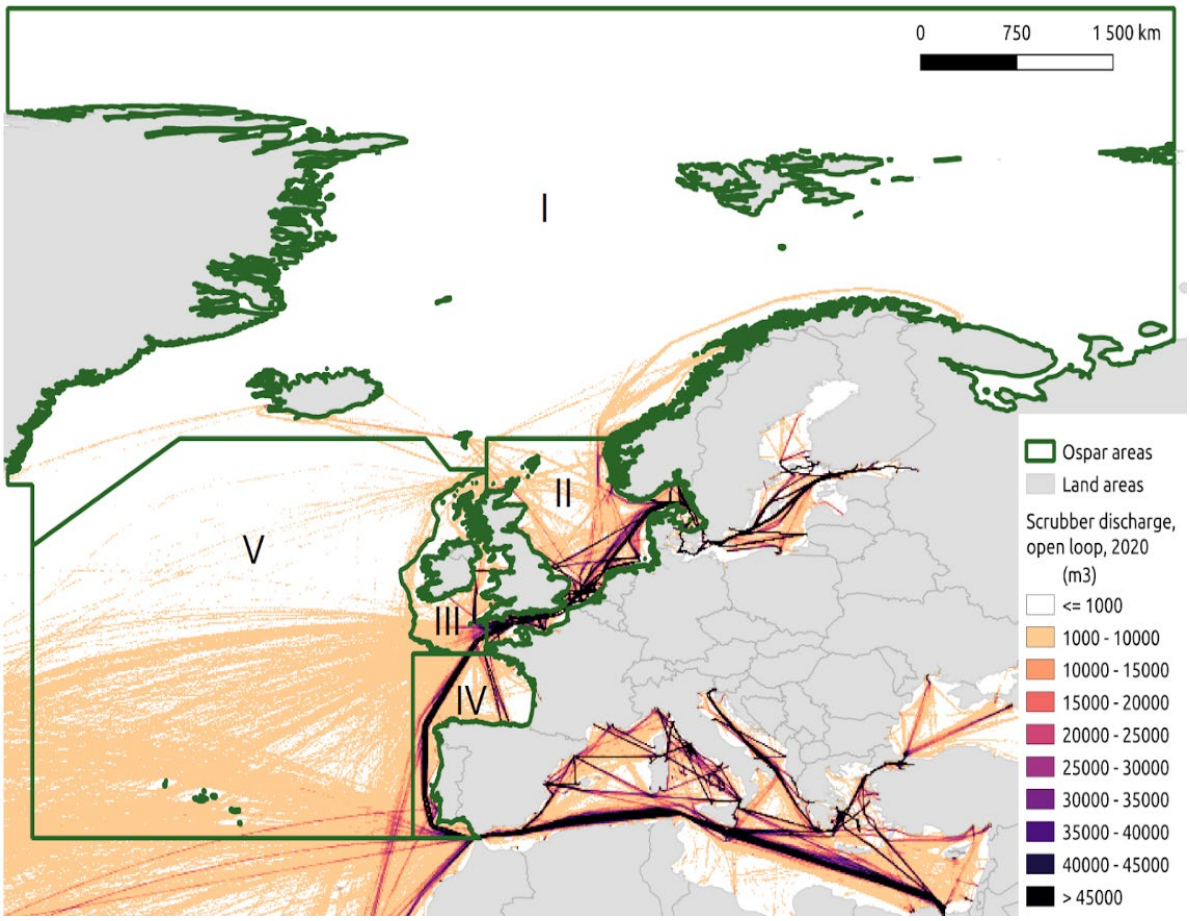


*Figure 13. Open loop discharge from EGCS in Europe.*

Effluent releases from closed loop systems are concentrated along the shipping lanes towards Bremerhaven and Hamburg, but to lesser extent also on the Hoek van Holland – Harwich shipping lane Figure 14. The modeling of discharges is done at ship level, which allows various classifications of the discharges. One example is given in Figure 15, which lists open loop discharge by ship type. This comparison reveals that the containerships are the largest contributors with 38% (236 million $m^3$) of the total discharge of 622 million cubic meters. The next three ship types, ropax, oil tanker and bulk cargo carriers contribute almost equally (10-11%). These ship types represent over 60% of the total discharges.

Another classification of these results is given in Figure 16, which depicts the installed EGCS by ship type. About 30% of the containerships are equipped with hybrid EGCS, which are predicted to be run in open loop mode, because there is no compelling regulation or other reasons to operate these systems in closed loop mode. The alkalinity of seawater in the OSPAR Region is suitable for open loop operation, which may not be possible in brackish water areas like the Bothnian Bay in the Baltic Sea. Most of the closed loop systems are installed in ropax vessels.

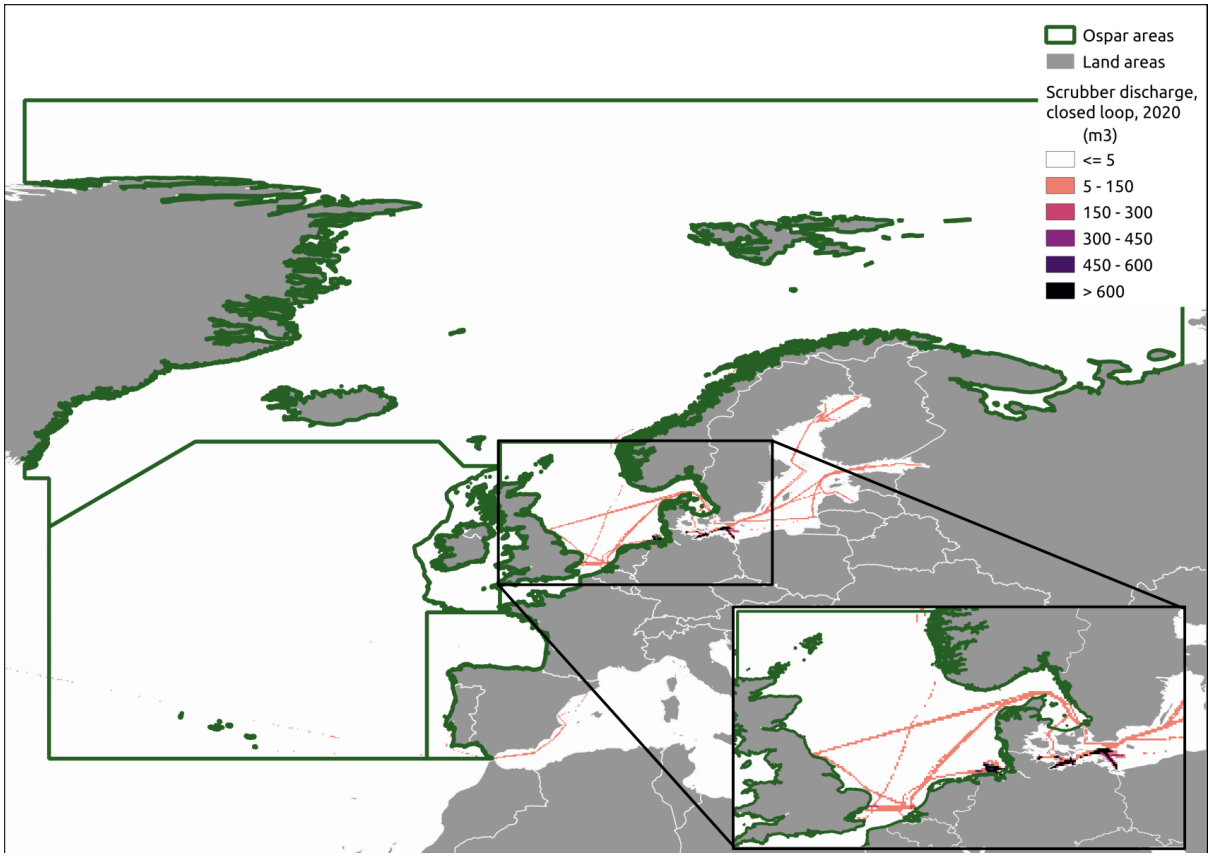


*Figure 14. Closed loop discharges are probably from hybrid scrubbers entering German EEZ and switching the mode of operation from open to closed loop. There is a faintly visible closed loop discharge between Hoek van Holland-Harwich, which can be associated with the RoPax route between these two ports.*

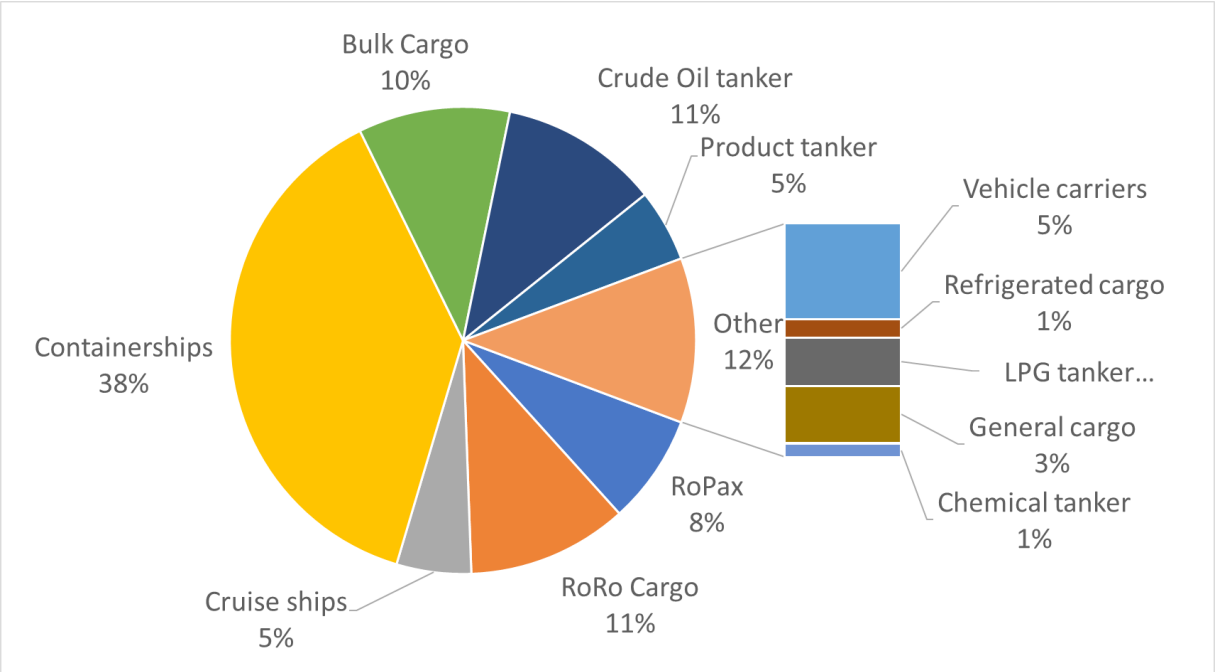


*Figure 15. Open loop EGCS discharge by ship type for the OSPAR Region during 2020.*

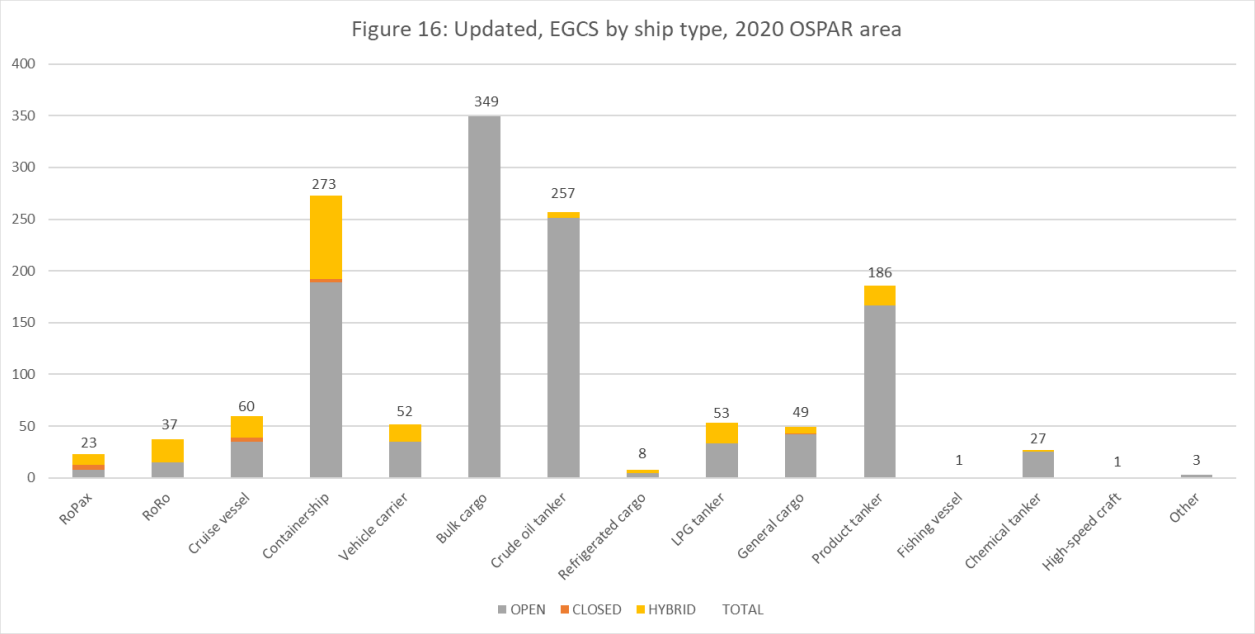


*Figure 16. Installation of EGCS by ship type in the OSPAR Region. This allocation is based on vessels which were active during 2020 in the OSPAR domain.*

Flag state allocation of EGCS discharges (Figure 17) reveals that Danish vessels have the largest contribution to discharges. Almost half of the discharge in the OSPAR Region comes from vessels registered to an EU member state. Panama, Liberia, and Marshall Island flagged vessels are responsible for 30% of the total EGCS discharge.

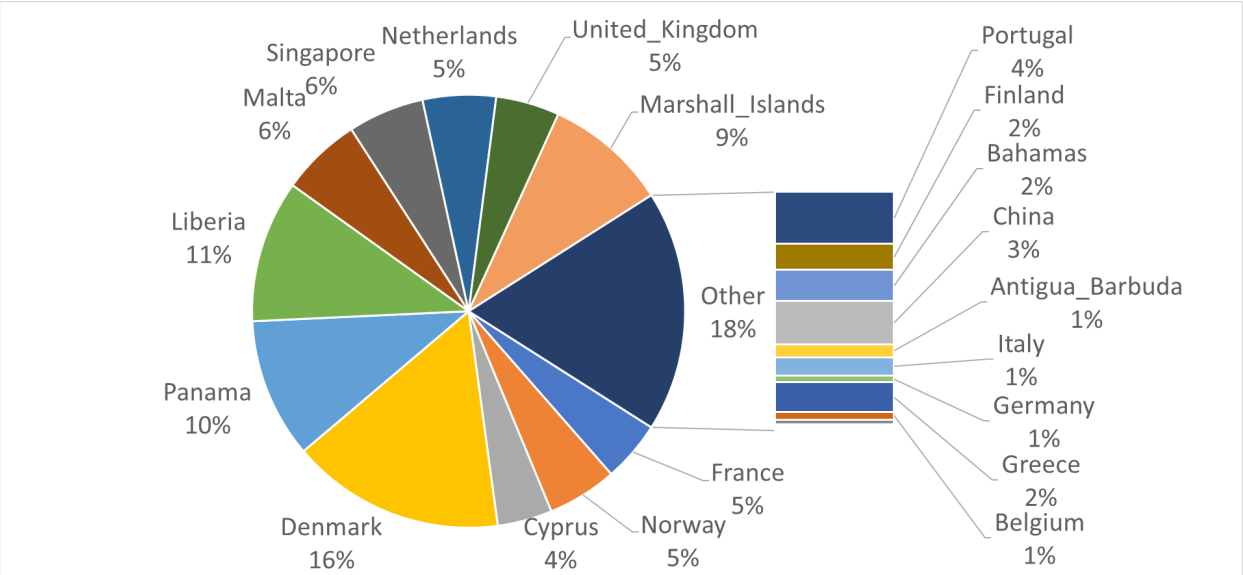


*Figure 17. EGCS Open loop discharge by vessel flag state in 2020.*

The Baltic Sea fleet has a slightly higher share of hybrid loop systems compared to the fleet operating in the OSPAR domain (Figure 18). However, in this modeling work, all hybrid systems are assumed to operate in open loop mode if regulations and sea water alkalinity allow it. Currently, German EEZ and Bothnian Bay are defined as areas where open loop operation is not possible.

Closed loop mode is only applied in regions where open loop operation of EGCS is prohibited. It should be noted that in the German EEZ use of open loop EGCS is allowed, in contrast to the modeling done in this work which incorrectly allows only closed loop operation inside the German EEZ. This shortcoming will be addressed in the next STEAM update.

It should be noted that the ongoing modeling work done in the H2020/EMERGE project will introduce several new areas where open loop EGCS is not allowed. This requires that both the polygons and date of entry to force are properly defined for these areas. This work is in progress, but it was not completed in time of writing this report.

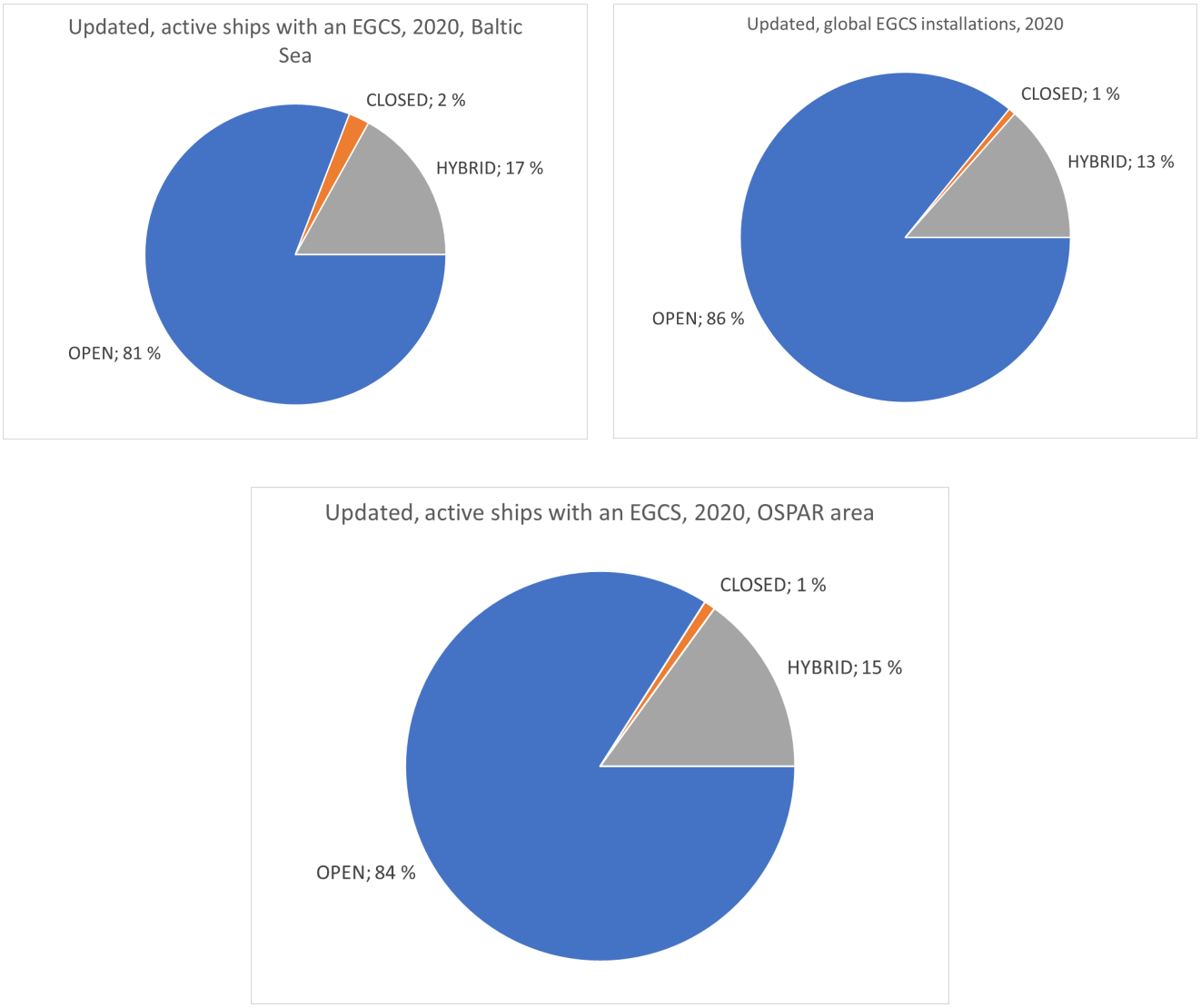


*Figure 18. EGCS installations by equipment type, global fleet. Based on data collected from IMO GISIS on Aug 8th 2021*

Most of the global EGCS installations are of open loop type. Globally, over 86% of EGCS are of this type, whereas closed and hybrid systems share the remaining 14%. However, the part of the global fleet which operates on Baltic Sea area has a significantly higher share of hybrid systems (Figure 18).

## 5.2 Results by OSPAR Region

Most of the EGCS effluent is released in the North Sea area (OSPAR II), but also OSPAR IV has high discharge volume, because it includes the main shipping lane from the Gibraltar towards Rotterdam.

*Table 3. Summary of EGCS effluent discharge in the OSPAR Regions I-V. Discharges are given in units of thousand cubic meters. Numbers in parenthesis indicate the share of EGCS discharge in relation to the OSPAR domain (I-V) totals. With this, the EGCS discharge in OSPAR I area is about 2% of the total discharge of 622 million tonnes in the whole OSPAR domain (I-V).*

| OSPAR Area | Area (1000 km$^2$) | EGCS discharge (open) (1000 m$^3$) | | EGCS discharge (closed) (1000 m$^3$) | Proportion Closed/Open (‰) |
|---|---|---|---|---|---|
| **I** | 5 480 | 14 484 | (2 %) | 1.8 | 1.3 |
| **II** | 770 | 282 076 | (45 %) | 64.2 | 2.3 |
| **III** | 370 | 47 856 | (8%) | 0.3 | 0.3 |
| **IV** | 530 | 156 497 | (25%) | 0.8 | 0.8 |
| **V** | 6 360 | 121 227 | (19%) | 3.8 | 3.8 |
| **Total** | 13 510 | 622 140 | (100%) | 71 | 1.1 |

### 5.2.1 OSPAR Region I

The first OSPAR Region includes Arctic waters of the whole domain. The release of EGCS is the smallest of all the OSPAR domains and is concentrated mostly in shipping lanes off the Norwegian coastline to Narvik and Polyarny-Murmansk area (Figure 19).

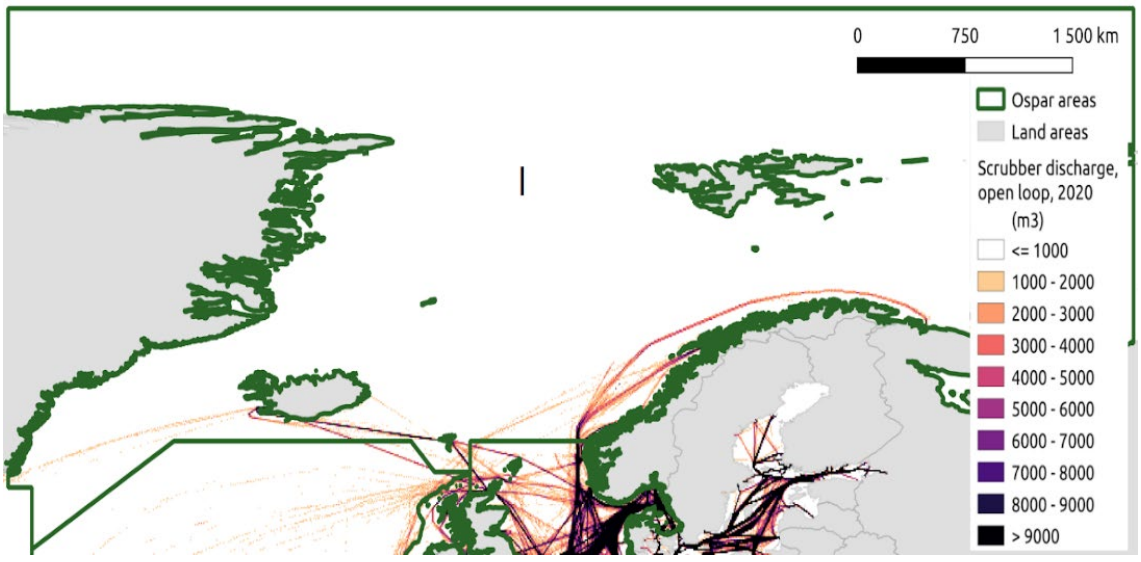


*Figure 19. EGCS discharge from open loop systems in the OSPAR I area. Please note the scale in color is the same as in OSPAR V area, but different than in II, III, and IV areas.*

### 5.2.2 OSPAR Region II and OSPAR Region III

The North Sea and the English Channel are included in the OSPAR II domain. Effluent releases from EGCS are the highest of all OSPAR Regions and represent almost half of the discharge in the whole OSPAR domain (areas I-V). Considering the limited water area of the English Channel, and that about one third of the effluent discharges of the OSPAR II area occur there, the English Channel is probably the most heavily impacted sea area in Europe regarding the EGCS discharge.

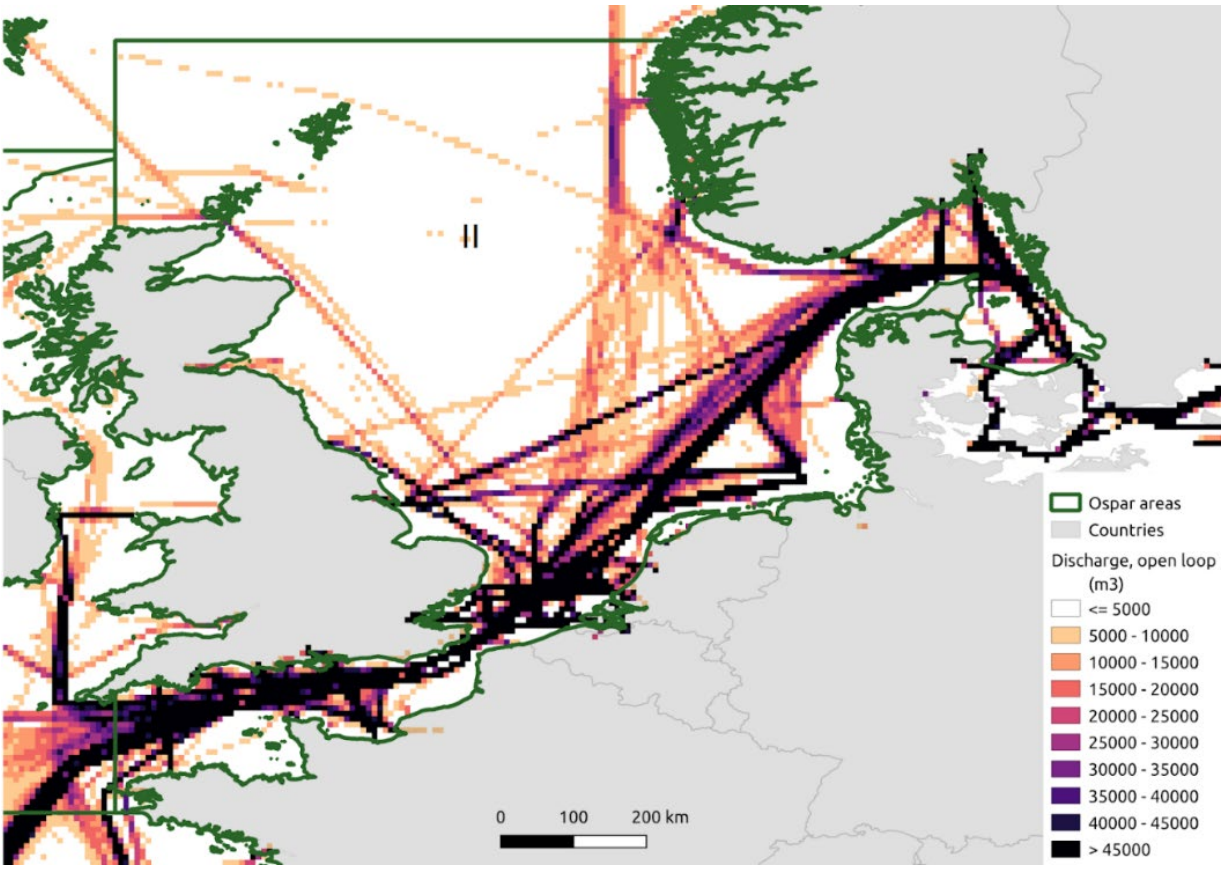


*Figure 20. Open loop discharge in OSPAR Region II. Please note the scale in color is the same as in OSPAR III and IV areas, but different than in I and V areas.*

In the OSPAR III area, discharges for the Celtic Sea, Irish Sea northwards towards the Outer Hebrides include a busy ship route between Dublin and Liverpool. This is very visible in Figure 21 and total EGCS effluent discharge in OSPAR III area is almost 48 million tonnes (7.7% of the OSPAR I-V total).

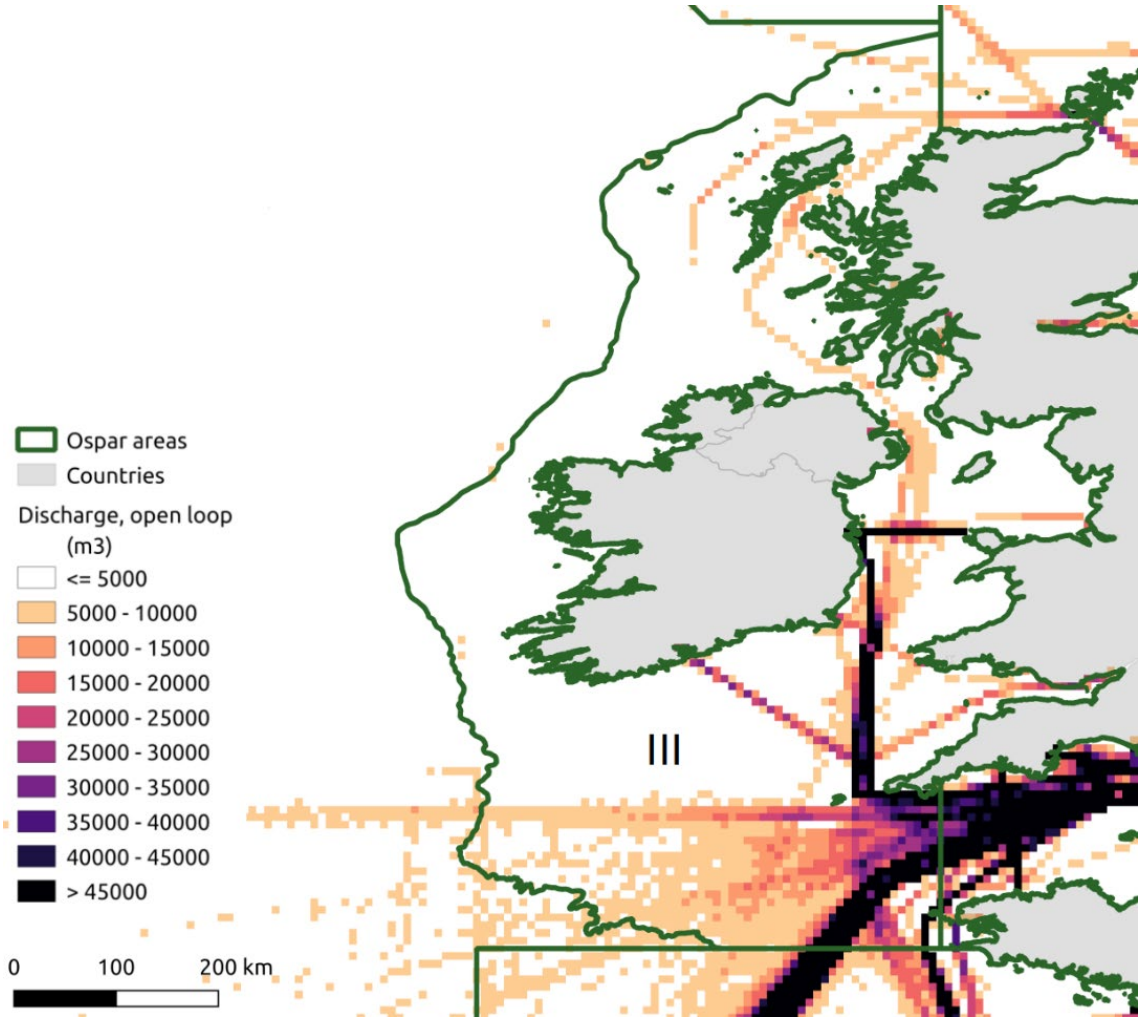


*Figure 21. Open loop discharge in OSPAR Region III. Please note the scale in color is the same as in OSPAR II and IV areas, but different than in I and V areas.*

### 5.2.3 OSPAR Region IV

The shipping lanes from the English Channel towards the ports of Bilbao and Santander are visible in effluent release map (Figure 22). However, most of the discharges are concentrated on the main shipping lane between Gibraltar and the English Channel, where the intercontinental traffic from Africa, North and South America converge towards the shipping routes in European sea regions.

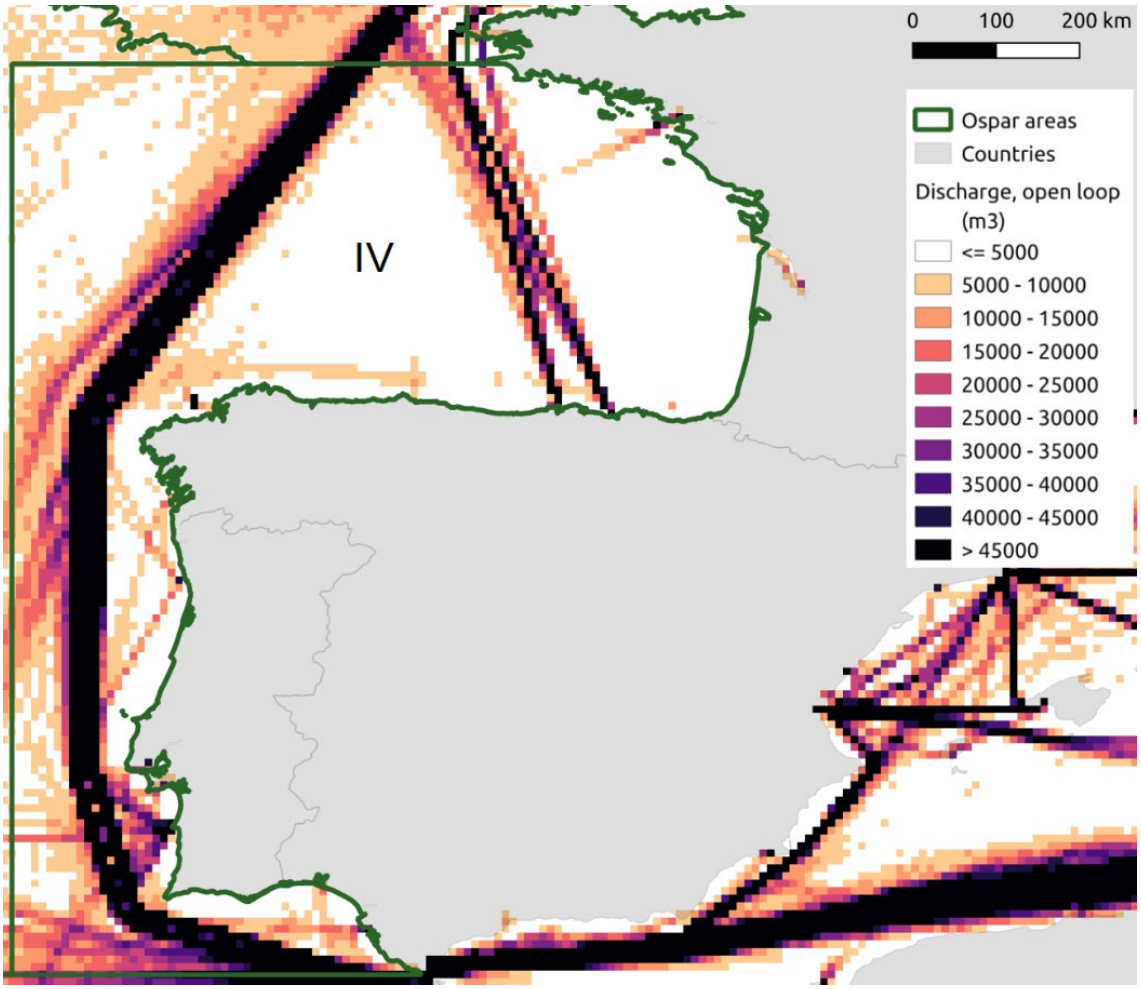


*Figure 22. Open loop discharge in OSPAR Region IV. Please note the scale in colors which is the same as in OSPAR Regions II and III but different than in areas I and V.*

### 5.2.4 OSPAR Region V

The main shipping routes between North and South America travel through OSPAR Region V. Despite the relatively large discharge total of 121 million cubic meters (19% of total discharge), these are dispersed over a large sea area (Figure 23).

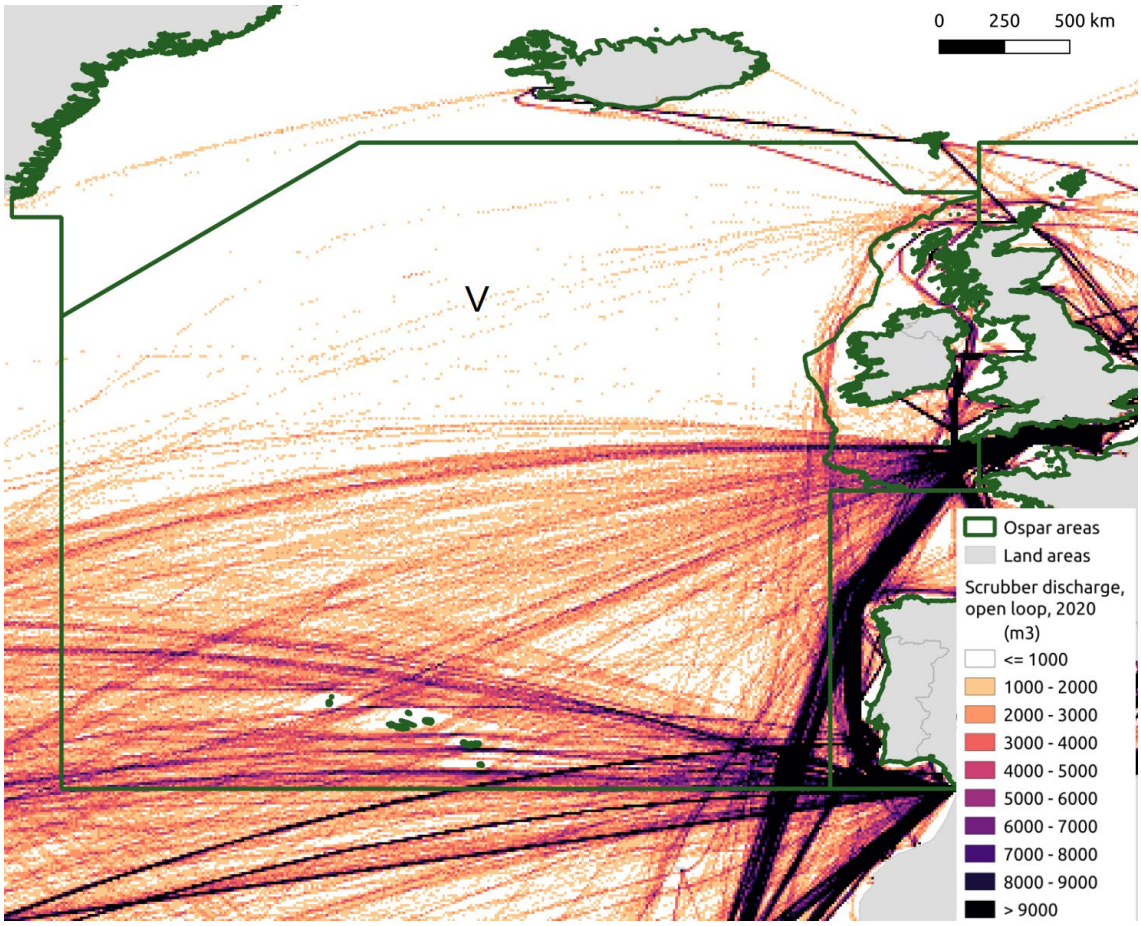


*Figure 23. Open loop discharge in OSPAR Region IV. Please note the scale in color is the same as in OSPAR I area, but different than in II, III, and IV areas.*

## 5.3 Results by EEZ

To determine how much of EGCS effluents were released within each EEZ, the 200 nautical mile polygons from Flanders Maritime Institute (Flanders Marine Institute, 2019a) were used to cut out the discharge totals for each OSPAR country (Figure 24). It should be noted that in Table 3, all OSPAR countries are included but only those which have coastline in any of the OSPAR Regions have non-zero contributions. Further, in case of countries which have coastline both in and outside the OSPAR Regions are split into separate contributions. Discharges from EGCS inside an EEZ, which is also inside some OSPAR region, are indicated with an asterisk (*) in Table 3. Around 84% of open loop scrubber discharge waters in OSPAR Region is coming from these EEZ 200 NM regions.

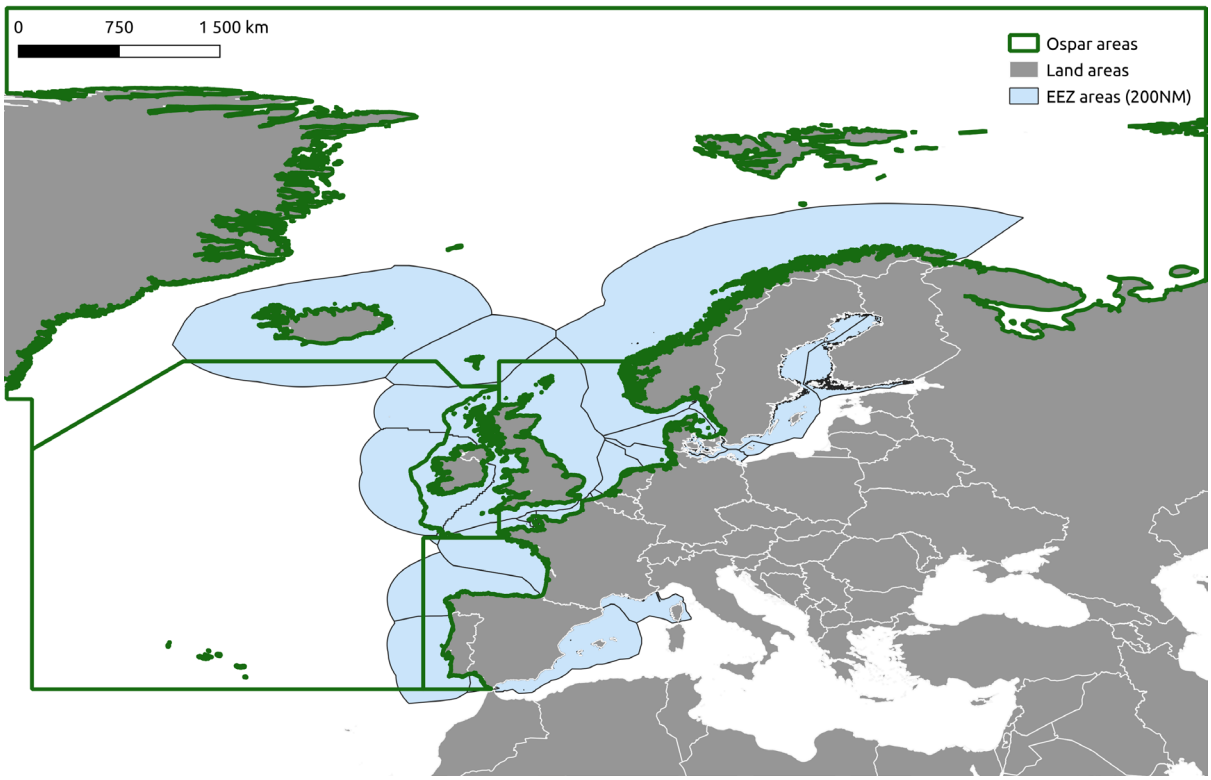


*Figure 24. Blue color indicates EEZ (200 NM) areas of OSPAR countries. The green line shows the borders of OSPAR Region.*

*Table 4. Open and closed loop EGCS discharges in each EEZ (200 NM) for OSPAR countries. For countries having areas inside and outside of the OSPAR region, both contributions are given. Asterisk (*) indicates the contribution from EEZ inside the OSPAR domain.*

| OSPAR countries EEZ region (200 NM) | EGCS discharge (open, 1000 $m^3$) | EGCS discharge (closed, 1000 $m^3$) | Closed/Open (‰) |
|---|---|---|---|
| Belgium | 5 700 | 0.01 | 0.0 |
| Denmark | 87 900 / *53 600 | 20.59 / *3.15 | 2.3 / *0.6 |
| Faroe Islands | 2 800 | 0 | 0 |
| Finland | 29 900 / *n/a | 2.44 / *n/a | 0.8 / *n/a |
| France | 89 600 / *75 000 | 0.40 / *0.15 | 0.1 / *0.0 |
| Germany | 17 100 / *13 800 | 168.78 / *47.88 | 98.4 / *34.7 |
| Iceland | 3 800 | 0 | 0 |
| Ireland | 14 300 | 0.02 | 0.0 |
| The Netherlands | 56 200 | 5.93 | 1.1 |
| Norway | 32 300 | 2.79 | 0.9 |
| Portugal | 83 800 / *76 500 | 1.04 / *0.71 | 0.1 / *0.1 |
| Spain | 146800 / *57 100 | 2.45 / *0.22 | 0.2 / *0.0 |
| Sweden | 79 600 / *12 100 | 7.83 / *0.44 | 1.0 / *0.4 |
| Switzerland | n/a | n/a | n/a |
| UK | 118 000 | 6.01 | 0.5 |

* Inside OSPAR Region

## 5.4 Results by 12 NM zones

Discharges inside the 12 nautical mile zones were also investigated, to determine the share of EGCS effluent release which occurs close to the coastlines (Figure 25). According to STEAM predictions, about 21% of the effluent is released inside the 12 NM polygons. Totals for each country are given in Table 4, and as with Table 3, the contributions in and outside the OSPAR Regions are marked with an asterisk (*).

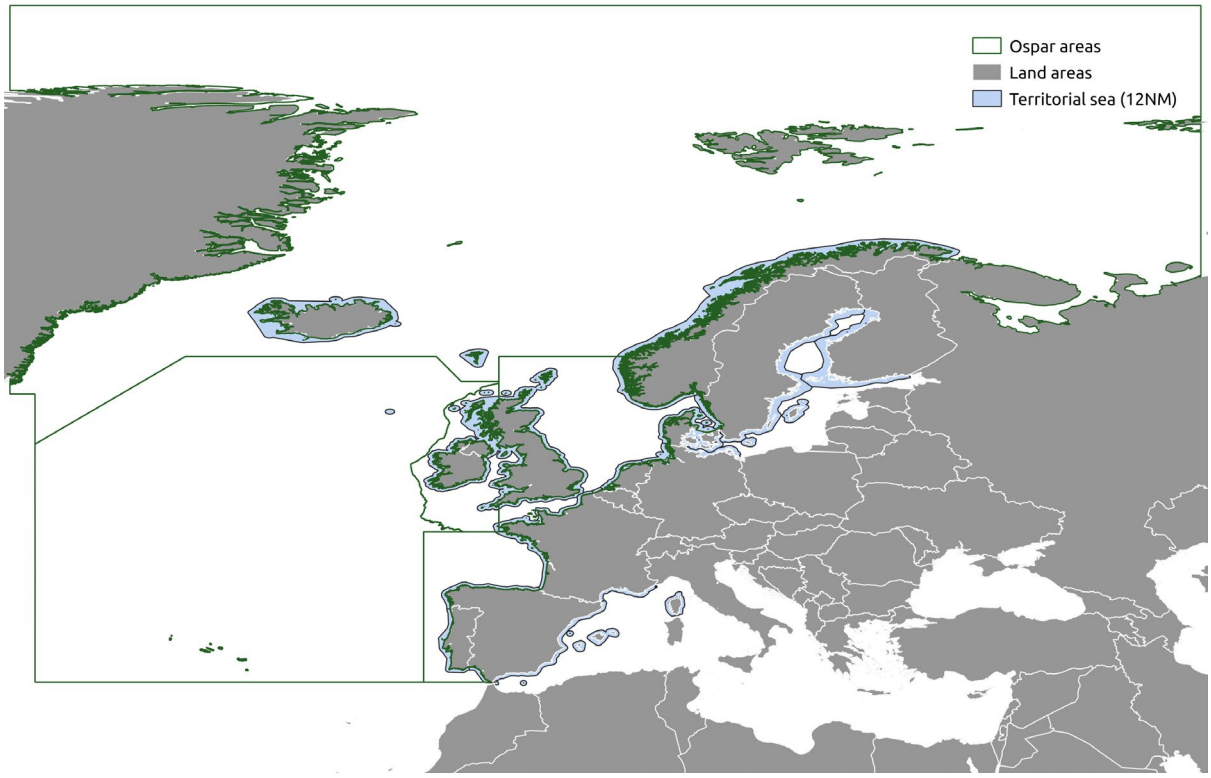


*Figure 25. Territorial water areas (12 NM) of OSPAR countries. The green lines show the borders of OSPAR Regions.*

Table 4 includes a comparison to the recent work of the ICCT, a study which includes global EGCS effluent modeling. This can be used to compare the ICCT results(Osipova et al., 2021) to our work. There are some differences between the ICCT study setup and this one, which need to be considered, however.

- **First**, the ICCT includes discharges from all areas which belong to an EEZ of a country. This includes overseas territories, like those on the Caribbean seas which belong to the EEZ of the UK. Since a regional domain used for OSPAR Regions does not extend to all these areas, overseas territories are not considered in this study. This will increase the ICCT discharge totals because remote overseas territories outside the OSPAR Regions are not included in the current study.

- **Second**, the ship activity data used in the ICCT study is from the year 2019, which is different from the 2020 data used in our study. It should be noted that extrapolation of 2019 shipping activity to 2020 does not consider the Covid19 pandemic effects and is likely to lead to an overestimation of shipping activity, especially the passenger traffic which suffered from travel restrictions.
- **Third**, ICCT study lists EGCS installations at the end of 2020, which includes 3600 vessels with EGCS installed. Our report includes scrubber installations reported in IMO GISIS, whereas ICCT uses Clarksons data. According to the global run for 2020 made for this report, 3080 vessels with an EGCS were identified based on GISIS entries in 2020. By August 8$^{th}$ 2021, 3459 entries for EGCS could be identified, but this is still somewhat less than the total reported in the ICCT report. Since the number of EGCS installations is larger in the ICCT report, it will increase their total discharge volumes compared to our estimates.
- **Fourth**, ICCT uses normalized discharge rates which are consistent with earlier IMO reports, i.e 45 $m^3$ $MWh^{-1}$ and 0.1 $m^3$ $MWh^{-1}$ for open and closed loop systems, respectively. The STEAM modeling was done using a higher effluent discharge rate (90 for open and 0.45 $m^3$ $MWh^{-1}$ for closed loop) which are in accordance with the latest literature (Teuchies et al., 2020). This will double the STEAM totals in comparison to ICCT totals.
- **Fifth**, discharges from vessels traveling inland waterways were not considered in STEAM work, whereas the ICCT study clearly includes some contributions from this traffic. The global coastline resolved in STEAM work uses a 1 km water mask, which may contribute small uncertainty to EGCS releases very close to the coast. This will increase ICCT totals in comparison to this work.

- **Sixth**, the ICCT study reports EGCS effluent discharge totals without distinguishing open and closed loop systems, which are provided separately in STEAM predictions.

Noting these differences, the results for STEAM predictions for EGCS discharges are given in Table 4.

*Table 5. EGCS discharge from open and closed loop scrubbers from Territorial regions (12 NM) to the coastline. The values are presented for each country as total and separately for areas intersecting the OSPAR Region (*). Corresponding values from the ICCT work are also included in this table. However, it should be noted that these are based on 2019 activity data.*

| OSPAR countries Territorial regions (12 NM), 2020 | EGCS discharge (open, 1000 $m^3$) Total / in OSPAR Region* | EGCS discharge (closed, 1000 $m^3$) Total / in OSPAR Region* | ICCT (all, 1000 $m^3$), 2019 |
|---|---|---|---|
| Belgium | 1 900 | 0.0 | 3 078 |
| Denmark | 51 800 / *22 100 | 14.0 / *1.0 | 62 040 |
| Faroe Islands | 600 | 0 | Incl. in DK totals |
| Finland | 26 800 / *n/a | 1.7 / *n/a | 16 614 |
| France | 13 000 / *8 100 | 0.1 / *0.0 | 31 652 |
| Germany*** | 2 800 / *200 | 140 / *50 | 38 111 |
| Iceland | 1 700 | 0 | 1 241 |
| Ireland | 4 500 | 0 | 5 431 |
| The Netherlands | 21 000 | 1.9 | 19 227 |
| Norway | 14 800 | 2.8 | 10 142 |
| Portugal | 2 000 | 0.1 | 3 304 |
| Spain | 24 200 / *1 800 | 1.2 / *0.0 | 35 637 |
| Sweden | 47 900 / *10 100 | 4.5 / *0.4 | 46 635 |
| Switzerland | n/a | n/a | 0 |

| | | | |
|---|---|---|---|
| UK | 40 800 | 3.2 | 99 901** |

* Part of the EEZ which is inside the OSPAR domain.

** Including the UK overseas territories

***German EEZ was assumed to be an open loop ban area. Multiplying closed loop totals with a factor 90/0.45 will yield about 30 million $m^3$, which of similar magnitude as the ICCT estimate.

The STEAM totals for Germany include a restriction of open loop scrubbing inside the EEZ, which deviates from currently known requirements which only necessitate the use of closed loop mode in German harbors and inland waterways (excluding harbor areas along the Rhine). This assumption makes open loop EGCS discharge of STEAM for Germany very small because, in the model, closed loop operation is required for all the German EEZ. This issue will be addressed in the ongoing H2020/EMERGE work, which will revise the global open loop restriction areas and their adoption dates.

Effluent discharges inside the 12 nautical mile zones are about 21% of all the EGCS effluent discharge inside the five OSPAR Regions. This share increases to 22% if the closed loop discharges inside the German 12 NM zone are converted to open loop.

Four of the five listed differences between this and the ICCT study increase the ICCT discharge estimate in relation to this study. Inclusion of overseas territories probably has a minor effect, because small island states in e.g Caribbean mostly include cruise ship traffic in addition to some cargo routes. The discrepancy in installed EGCS units probably increases the ICCT estimates by approximately 20%, assuming that discharges from EGCS are relative to the number of units (3600 vs 3080). The contribution from inland waterway traffic has probably a relatively minor influence on the discharge totals. According to our previous work, fuel consumption from inland waterway shipping visible in AIS is in the order of few percent from global totals. The use of 2020 global data will include the effect of the Covid19 pandemic, which is not present in the 2019 data ICCT used. It is likely that this effect alone will increase the ICCT estimates for 2020 by 10-20%.

These four contributions all make ICCT estimates larger than what the corresponding STEAM totals would be. However, there is a significant balancing effect, which comes from the use of larger effluent discharge rate of STEAM. Based on recent studies (Teuchies et al., 2020, and Ytreberg et al., 2020), discharge rates of 90 and 0.45 $m^3$ $MWh^{-1}$ were adopted for open and closed loop systems in STEAM, which doubles the discharge when compared to ICCT modeling approach.

## 5.5 Contaminant loads in OSPAR Regions

Contaminant loads of metals and PAHs were calculated for OSPAR regions (Table 5 and Table 6) and a comparison with riverine input data (year 2019) from OSPAR RID were made with respect to cadmium, copper, lead, mercury and zinc, within OSPAR regions I-IV that were available in the RID-data (Table 7 and Table 8). Data from the following countries were available in the RID database: Belgium, France, Germany, Iceland, Ireland, The Netherlands, Norway, Portugal, Spain, Sweden and the UK. The comparison at OSPAR regional level, may therefore be biased, as riverine data are missing from some countries. A comparison was also made between RID riverine contaminant input within individual countries coastal area, compared to EGCS discharge within the countries' 12NM zones within OSPAR Region (Table 9 to Table 13). It should be noted that the comparison should be regarded as an indication of order of magnitude, as there are large uncertainties both in the EGCS

volume discharge calculations, as well as in the OSAPR RID-data. Detailed numbers for all OSPAR member states (EEZ, 12 NM, and EEZ OSPAR share) estimated contaminant loads can be found in Appendix

*Table 6. Contaminant loads (kg/yr) from open loop EGCS in OSPAR Regions. All figures are calculated from the volumes originating from the STEAM-output in this study, in combination with the contaminant average concentrations and ±95% confidence interval (±95%CI) originating from Ytreberg et al. (2020) and Lunde Hermansson et al. (2021).*

| | OSPAR I | | OSPAR II | | OSPAR III | | OSPAR IV | | OSPAR V | | OSPAR I-V | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 55.0 | 9.65 | 1072 | 188 | 182 | 31.9 | 595 | 104 | 461 | 80.8 | 2364 | 414 |
| **Cadmium** | 8.47 | 2.71 | 165 | 52.8 | 28.0 | 8.96 | 91.5 | 29.3 | 70.9 | 22.7 | 364 | 117 |
| **Chromium** | 148 | 94.1 | 2888 | 1832 | 490 | 311 | 1602 | 1017 | 1241 | 787 | 6369 | 4041 |
| **Copper** | 513 | 328 | 9999 | 6384 | 1696 | 1083 | 5547 | 3542 | 4297 | 2743 | 22052 | 14080 |
| **Lead** | 71.5 | 28.8 | 1392 | 562 | 236 | 95 | 772 | 312 | 598 | 241 | 3069 | 1239 |
| **Mercury** | 1.34 | 0.186 | 26.2 | 3.62 | 4.44 | 0.614 | 14.5 | 2.01 | 11.2 | 1.55 | 57.7 | 7.98 |
| **Nickel** | 806 | 265 | 15696 | 5167 | 2663 | 877 | 8708 | 2867 | 6746 | 2221 | 34619 | 11397 |
| **Vanadium** | 2445 | 826 | 47611 | 16093 | 8077 | 2730 | 26415 | 8928 | 20461 | 6916 | 105009 | 35493 |
| **Zinc** | 2036 | 2229 | 39658 | 43418 | 6728 | 7366 | 22003 | 24088 | 17044 | 18659 | 87469 | 95761 |
| **Naphthalene** | 53.4 | 20.4 | 1039 | 398 | 176 | 67.5 | 577 | 221 | 447 | 171 | 2292 | 878 |
| **Acenaphthylene** | 1.58 | 0.853 | 30.7 | 16.6 | 5.22 | 2.82 | 17.1 | 9.21 | 13.2 | 7.14 | 67.8 | 36.6 |
| **Acenaphthene** | 3.80 | 1.51 | 73.9 | 29.5 | 12.5 | 5.00 | 41.0 | 16.3 | 31.8 | 12.7 | 163 | 65 |
| **Fluorene** | 9.03 | 2.28 | 176 | 44.5 | 29.8 | 7.54 | 97.6 | 24.7 | 75.6 | 19.1 | 388 | 98 |
| **Phenanthrene** | 27.0 | 7.31 | 526 | 142 | 89.2 | 24.1 | 292 | 78.9 | 226 | 61.1 | 1159 | 314 |
| **Anthracene** | 0.777 | 0.428 | 15.140 | 8.34 | 2.57 | 1.42 | 8.40 | 4.63 | 6.51 | 3.59 | 33.4 | 18.4 |
| **Fluoranthene** | 1.99 | 0.91 | 38.8 | 17.8 | 6.59 | 3.02 | 21.5 | 9.9 | 16.7 | 7.65 | 85.6 | 39.2 |
| **Pyrene** | 3.66 | 2.26 | 71.3 | 44.0 | 12.1 | 7.46 | 39.5 | 24.4 | 30.6 | 18.9 | 157 | 97.0 |
| **Benz(a)anthrancene** | 1.08 | 1.06 | 21.1 | 20.6 | 3.58 | 3.50 | 11.7 | 11.4 | 9.08 | 8.86 | 46.6 | 45.5 |
| **Chrysene** | 1.72 | 1.01 | 33.5 | 19.7 | 5.68 | 3.34 | 18.6 | 10.9 | 14.4 | 8.46 | 73.8 | 43.4 |
| **Benzo(b)fluoranthene** | 0.436 | 0.297 | 8.48 | 5.79 | 1.44 | 0.982 | 4.71 | 3.21 | 3.65 | 2.49 | 18.7 | 12.8 |
| **Benzo(k)fluoranthene** | 0.135 | 0.108 | 2.63 | 2.11 | 0.447 | 0.357 | 1.46 | 1.17 | 1.13 | 0.905 | 5.81 | 4.64 |
| **Benzo(a)pyrene** | 0.327 | 0.236 | 6.37 | 4.61 | 1.08 | 0.781 | 3.53 | 2.55 | 2.74 | 1.98 | 14.1 | 10.2 |
| **Dibenzo(a,h)anthracene** | 0.126 | 0.0536 | 2.45 | 1.04 | 0.416 | 0.177 | 1.36 | 0.580 | 1.05 | 0.449 | 5.41 | 2.30 |
| **Benzo(g,h,i)perylene** | 0.205 | 0.127 | 4.00 | 2.47 | 0.679 | 0.419 | 2.22 | 1.37 | 1.72 | 1.06 | 8.82 | 5.45 |
| **Indeno(1,2,3-c,d)pyrene** | 0.319 | 0.390 | 6.22 | 7.60 | 1.05 | 1.29 | 3.45 | 4.22 | 2.67 | 3.27 | 13.7 | 17 |
| **Sum EPA 16 PAH** | 15.1 | 12.1 | 293 | 236 | 49.8 | 40.0 | 163 | 131 | 126 | 101 | 647 | 520 |
| **Sum total PAH** | 108 | 34 | 2106 | 670 | 357 | 114 | 1168 | 372 | 905 | 288 | 4644 | 1477 |

*Table 7 Contaminant loads (kg/yr) from closed loop EGCS in OSPAR Regions. All figures are calculated from the volumes originating from the STEAM-output in this study, in combination with the contaminant average concentrations and ±95% confidence interval (±95%CI) originating from (Ytreberg et al., 2020 and Lunde Hermansson et al. 2021). N/D in an Average column indicates that the substance has not been detected in the available reported data on concentrations, and therefore the ±95% CI is left empty. N/A in an ±95% CI column indicates that the concentration is based on only one reported value, why ±95% CI cannot be calculated. Numbers less than 1g are reported as <0.001kg and the associated ±95%CI is left empty.*

| | OSPAR I | | OSPAR II | | OSPAR III | | OSPAR IV | | OSPAR V | | OSPAR I-V | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 0.034 | 0.0182 | 1.22 | 0.650 | 0.00569 | 0.00304 | 0.0152 | 0.00810 | 0.0720 | 0.0385 | 1.35 | 0.718 |
| **Cadmium** | 0.00153 | 0.000651 | 0.0547 | 0.0232 | <0.001 | | <0.001 | | 0.00324 | 0.00137 | 0.0605 | 0.0257 |
| **Chromium** | 1.68 | 4.21 | 59.8 | 150 | 0.280 | 0.702 | 0.746 | 1.87 | 3.54 | 8.89 | 66.2 | 166 |
| **Copper** | 0.132 | 0.130 | 4.71 | 4.62 | 0.022 | 0.0216 | 0.059 | 0.058 | 0.279 | 0.274 | 5.21 | 5.11 |
| **Lead** | 0.00709 | 0.00321 | 0.253 | 0.114 | <0.001 | | 0.00315 | 0.00143 | 0.0150 | 0.00677 | 0.280 | 0.127 |
| **Mercury** | <0.001 | N/A | 0.006 | N/A | <0.001 | N/A | <0.001 | N/A | <0.001 | N/A | 0.007 | N/A |
| **Nickel** | 7.903 | 4.663 | 281.877 | 166.312 | 1.317 | 0.777 | 3.51 | 2.07 | 16.7 | 9.84 | 312 | 184 |
| **Vanadium** | 30.7 | 16.2 | 1096 | 576 | 5.12 | 2.69 | 13.7 | 7.18 | 64.9 | 34.1 | 1213 | 637 |
| **Zinc** | 0.770 | 0.646 | 27.451 | 23.034 | 0.128 | 0.108 | 0.342 | 0.287 | 1.62 | 1.36 | 30.4 | 25.5 |
| **Naphthalene** | 0.00172 | 0.00192 | 0.0615 | 0.0684 | <0.001 | | <0.001 | | 0.00364 | 0.00405 | 0.0680 | 0.0756 |
| **Acenaphthylene** | <0.001 | | 0.00295 | 0.00398 | <0.001 | | <0.001 | | <0.001 | | 0.00326 | 0.00440 |
| **Acenaphthene** | <0.001 | | 0.0157 | 0.0175 | <0.001 | | <0.001 | | <0.001 | | 0.0173 | 0.0193 |
| **Fluorene** | 0.00142 | 0.00142 | 0.0506 | 0.0506 | <0.001 | | <0.001 | | 0.00299 | 0.00300 | 0.0559 | 0.0560 |
| **Phenanthrene** | 0.00716 | 0.0095 | 0.255 | 0.341 | 0.001 | 0.002 | 0.003 | 0.004 | 0.0151 | 0.0202 | 0.282 | 0.377 |
| **Anthracene** | 0.004 | 0.0095 | 0.134 | 0.339 | <0.001 | | 0.002 | 0.004 | 0.00794 | 0.02008 | 0.148 | 0.375 |
| **Fluoranthene** | <0.001 | | 0.0335 | 0.0631 | <0.001 | | <0.001 | | 0.00198 | 0.00374 | 0.0371 | 0.070 |
| **Pyrene** | 0.00135 | 0.00283 | 0.0482 | 0.101 | <0.001 | | <0.001 | | 0.00285 | 0.00598 | 0.0533 | 0.112 |
| **Benz(a)anthrancene** | <0.001 | | 0.0169 | 0.0401 | <0.001 | | <0.001 | | 0.00100 | 0.00237 | 0.0187 | 0.0443 |
| **Chrysene** | <0.001 | | 0.0192 | 0.0447 | <0.001 | | <0.001 | | 0.00114 | 0.00265 | 0.0212 | 0.0495 |
| **Benzo(b)fluoranthene** | <0.001 | | 0.00791 | 0.0186 | <0.001 | | <0.001 | | 0.000468 | 0.00110 | 0.00874 | 0.0206 |
| **Benzo(k)fluoranthene** | <0.001 | N/A | <0.001 | N/A | <0.001 | N/A | <0.001 | N/A | <0.001 | N/A | <0.001 | N/A |
| **Benzo(a)pyrene** | <0.001 | | 0.00275 | 0.00625 | <0.001 | | <0.001 | | <0.001 | | 0.003 | 0.00691 |
| **Dibenzo(a,h)anthracene** | <0.001 | | 0.00130 | 0.00251 | <0.001 | | <0.001 | | <0.001 | | 0.001 | 0.00278 |
| **Benzo(g,h,i)perylene** | <0.001 | | 0.00502 | 0.0119 | <0.001 | | <0.001 | | <0.001 | | 0.006 | 0.0131 |
| **Indeno(1,2,3-c,d)pyrene** | <0.001 | | 0.00256 | 0.00575 | <0.001 | | <0.001 | | <0.001 | | 0.00283 | 0.00636 |
| **Sum EPA 16 PAH** | N/D | | N/D | | N/D | | N/D | | N/D | | N/D | |
| **Sum total PAH** | 0.007 | 0.007 | 0.233 | 0.247 | 0.001 | 0.001 | 0.003 | 0.003 | 0.014 | 0.015 | 0.258 | 0.274 |

### 5.5.1 Metal and PAH loads in OSPAR Regions

Vanadium constitutes the largest calculated load (106 tonnes) of individual metals in the OSPAR I-V region followed by zinc (87 tonnes), nickel (35tonnes) and copper (22 tonnes) (Table 6 and 7). Both vanadium and nickel are known to be present in heavy fuel oil, while e.g. copper and zinc are hypothezised to primarily originate from marine growth protection systems and piping (Hassellöv et al. 2020, Lunde Hermansson et al., 2021). The calculated loads of chromium, lead and arsenic are in the range of 6.4 to 2.4 tonnes, while cadmium and mercury were 0.36 and 0.06 tonnes respectively.

The estimated open loop contaminant loads are in the order of 1000-10,000 times higher than the closed loop loads (Table 6 and 7), except for vanadium, chromium, nickel and anthracene that were 86-225 times higher from the open loop. Also in the contaminant load from closed loop discharge, vanadium constitutes the largest calculated load (1213 kg), almost four times the load of Nickel (312 kg). Chromium and zinc from closed loop was 66 kg and 30 kg respectively, while the estimated load of copper was somewhat lower, 5.2 kg. The estimated PAH loads in OSPAR I-V region are dominated by naphtalene (2.3 tonnes), followed by phenanthrene (1.2 tonnes) and fluorene, acenaphthene, and pyrene in the range 160-390 kg, and fluoranthene and chrysene in the range 70-90 kg (Table 6 and 7). The remaining nine of the EPA 16 PAH:s were estimated to be in the range 5-47 kg respectively. The estimated total load of PAH:s is close to 2.5 times higher than the mass of EPA 16 PAH, suggesting that e.g. alkylated PAHs should also be considered (Du et al. 2022).

### 5.5.2 Comparison of loads from other sources

The comparison is limited to OSPAR I-IV regions, as the RID database does not include OSPAR V. The total share of contaminant load from open loop discharge, relative OSPAR-reported riverine load, in the entire OSPAR I-IV area, ranges between 0.5% (lead) to 1.9% (zinc) (Table 8 and 9). Looking at the respective OSPAR regions, OSPAR III is the only region where the open loop discharge for all five contaminants is below 0.6%, while OSPAR I, II and IV, show a relative cadmium contribution around 1.8%, and in OSPAR II the relative load of copper is in the same order of magnitude (1.9%), while copper in OSPAR I, III and IV are in the range of 0.3-0.6% relative riverine input. The highest relative contribution is noted for lead in OSPAR IV (2.1%).

For future studies it would be interesting to also compare the loads from scrubber discharge to OSPAR HASEC monitoring data from point sources. Even though the relative load from scrubbers in the current study appeared to be low, it is important to remember that scrubber discharge is a pressure that is possible to regulate, and in the case for Sweden for example, regulating scrubber discharge could imply reduction of e.g., cadmium, copper and mercury in the order of 5.2-7.4% compared to riverine input. Further, the general decreasing trend in the loads of e.g. mercury, cadmium and lead, from riverine input since the 1990s (OSPAR Intermediate Assessment 2017[3]), in combination with an increasing number of vessels operating with scrubbers may increase the relative contribution of contaminants from scrubbers over time.

[3] Intermediate Assessment 2017 - OSPAR-OAP (Prod)

*Table 8. Estimated metal loads (t/yr) from EGCS open loop discharge, vs riverine input from OSPAR RID.*

| | OSPAR I | | OSPAR II | | OSPAR III | | OSPAR IV | | OSPAR I-IV | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RID | OL | RID | OL | RID | OL | RID | OL | RID | OL |
| **Cadmium** | 0.46 | 0.008 | 9.37 | 0.16 | 5.49 | 0.03 | 4.98 | 0.09 | 20.3 | 0.29 |
| **Copper** | 97.8 | 0.51 | 535 | 10.00 | 300 | 1.70 | 1887 | 5.55 | 1826 | 17.8 |
| **Lead** | 4.41 | 0.07 | 300 | 1.39 | 187 | 0.24 | 37.0 | 0.77 | 528 | 2.47 |
| **Mercury** | 0.11 | 0.001 | 1.75 | 0.03 | 0.94 | 0.00 | 5.54 | 0.01 | 8.34 | 0.05 |
| **Zinc** | 163 | 2.04 | 2424 | 39.7 | 1574 | 6.73 | 1348 | 22.0 | 3813 | 70.4 |

*Table 9. Estimated metal loads (t/yr) from EGCS closed loop discharge, vs riverine input from OSPAR RID.*

| | OSPAR I | | OSPAR II | | OSPAR III | | OSPAR IV | | OSPAR I-IV | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RID | CL | RID | CL | RID | CL | RID | CL | RID | CL |
| **Cadmium** | 0.46 | 0.000001 | 9.37 | 0.000037 | 5.49 | 0.000000 | 4.98 | 0.000001 | 20.3 | 0.0000571 |
| **Copper** | 97.8 | 0.000935 | 535 | 0.0333 | 300 | 0.000156 | 1887 | 0.000416 | 1826 | 0.00492 |
| **Mercury** | 4.41 | 0.000015 | 300 | 0.000529 | 187 | 0.000003 | 37.0 | 0.000007 | 528 | 0.000264 |
| **Lead** | 0.11 | 0.000000 | 1.75 | 0.000000 | 0.94 | 0.000000 | 5.54 | 0.000000 | 8.34 | 0.00000671 |
| **Zinc** | 163 | 0.000698 | 2424 | 0.0249 | 1574 | 0.000116 | 1348 | 0.000310 | 3813 | 0.0287 |

The relative contribution of contaminants from closed loop EGCS is less than 0.6‰ (copper in OSPAR II) both in the entire OSPAR I-IV region, as well as in the individual regions. The total share of EGCS, i.e., contaminant load from open loop and closed loop discharge is completely dominated by open loop discharge (Table 8 and Table 9). The relative contribution of cadmium from EGCS ranges from less than 1‰ in Germany, to 1% in Icelandic water, and 5.8% in Swedish water. The contribution of copper from EGCS versus riverine input is lower than 5‰ for all countries but Sweden (5.2%) and Iceland (1.4%). Regarding lead, the EGCS input is lower than 11‰ for all countries but Sweden (2.3%) and Iceland (1.7%). Also for mercury, all countries but two show lower EGCS contribution than 7‰, but higher numbers for Sweden 7.4% and Spain 2.8%. For all five contaminants, closed loop contribution was always lower than 3‰ and only 10% of the values (five values) indicated the closed loop contribution to be higher than 0.1‰. Still, the individual shares of the five contaminants from closed loop scrubbers are the highest in German waters (Table 10-14), in line with the larger closed loop discharge volumes for Germany calculated in Table 4.

Although there are limited data on vanadium toxicity, there are an increasing number of studies (e.g. Shiffer and Liber 2017a and b; Watt et al. 2018), suggesting that water quality guidelines with respect to vanadium should be developed. Such development would also call for inclusion of vanadium in marine monitoring programs. Other elements that could be interesting to monitor are nickel and chromium, which together with copper have been suggested to increase toxicity of diesel fuel to marine nematodes (Hefdi et al. 2013). In addition to increased monitoring efforts, there is a need for improved fuel characterization standards. Current standards are developed from an engine/operational perspective, were e.g. trace elements such as vanadium that may increase wear are analyzed, but there is a lack of inclusion of other elements that may pose an increased pressure on the (marine) environment or human health, as highlighted in 2011 by CE Delft (de Buck, 2011). Beside importance for improved fuel characterization standards for HFO used in scrubbers, there is also an immediate need for more extensive characterization of different types of low sulphur fuel oils, such as VLSFO (very low sulphur fuel oil, 0.5% S) and ULSFO (ultra low sulphur fuel oil, 0.1%). To

enable improved comparison between the environmental impact following use of scrubbers versus low sulphur fuel oils, in line with the work by Lunde Hermansson et al. (2021), there is a need for better understanding of the possible environmental impact resulting from all available fuel alternatives. In the ongoing PAME EPPR project "New Low Sulphur Fuels, Fate, and Behavior in Cold Water Conditions"[4], this type of effort is initiated.

*Table 10. Cadmium loads (t/yr) from EGCS open and closed loop discharge in OSPAR member states territorial waters 12 NM, compared with available data on riverine input extracted from OSPAR RID.*

| | Other sources | 12NM | | | 12NM EGCS/Other sources (‰) | | |
|---|---|---|---|---|---|---|---|
| | RID | Open loop | Closed loop | Tot EGCS | Open loop | Closed loop | Tot EGCS |
| **Belgium** | 0.55 | 0.0011 | 0.0000 | 0.0011 | 2.06 | 0.0000 | 2.06 |
| **France** | 1.32 | 0.0076 | 0.0000 | 0.0076 | 5.75 | 0.0000 | 5.75 |
| **Germany** | 2.45 | 0.0016 | 0.0001 | 0.0018 | 0.67 | 0.0501 | 0.72 |
| **Iceland** | 0.1 | 0.0010 | 0.0000 | 0.0010 | 10.09 | 0.0000 | 10.1 |
| **Ireland** | 1 | 0.0026 | 0.0000 | 0.0026 | 2.63 | 0.0016 | 2.63 |
| **The Netherlands** | 2.64 | 0.0123 | 0.0000 | 0.0123 | 4.65 | 0.0006 | 4.65 |
| **Norway** | 1.58 | 0.0087 | 0.0000 | 0.0087 | 5.49 | 0.0015 | 5.50 |
| **Portugal** | 0.33 | 0.0012 | 0.0000 | 0.0012 | 3.52 | 0.0001 | 3.52 |
| **Spain** | 3.77 | 0.0142 | 0.0000 | 0.0142 | 3.75 | 0.0003 | 3.75 |
| **Sweden** | 0.48 | 0.0280 | 0.0000 | 0.0280 | 58.36 | 0.0081 | 58.4 |
| **UK** | 6.08 | 0.0238 | 0.0000 | 0.0238 | 3.92 | 0.0004 | 3.92 |

*Table 11. Copper loads (t/yr) from EGCS open and closed loop discharge in OSPAR member states territorial waters 12 NM, compared with available data on riverine input extracted from OSPAR RID.*

| | Other sources | 12NM | | | 12NM EGCS/Other sources (‰) | | |
|---|---|---|---|---|---|---|---|
| | RID | Open loop | Closed loop | Tot EGCS | Open loop | Closed loop | Tot EGCS |
| **Belgium** | 24.85 | 0.0687 | 0.0000 | 0.0687 | 2.76 | 0.0000 | 2.76 |
| **France** | 374.39 | 0.4597 | 0.0000 | 0.4597 | 1.23 | 0.0000 | 1.23 |
| **Germany** | 101.13 | 0.0997 | 0.0106 | 0.1103 | 0.99 | 0.105 | 1.09 |
| **Iceland** | 4.38 | 0.0611 | 0.0000 | 0.0611 | 13.96 | 0.0000 | 14.0 |
| **Ireland** | 72.46 | 0.1593 | 0.0001 | 0.1594 | 2.20 | 0.0019 | 2.20 |
| **The Netherlands** | 178.47 | 0.7444 | 0.0001 | 0.7445 | 4.17 | 0.0008 | 4.17 |
| **Norway** | 176.1 | 0.5260 | 0.0002 | 0.5263 | 2.99 | 0.0012 | 2.99 |
| **Portugal** | 16.27 | 0.0703 | 0.0000 | 0.0703 | 4.32 | 0.0003 | 4.32 |
| **Spain** | 533.46 | 0.8575 | 0.0001 | 0.8576 | 1.61 | 0.0002 | 1.61 |
| **Sweden** | 32.74 | 1.6975 | 0.0003 | 1.6979 | 51.85 | 0.0102 | 51.9 |
| **UK** | 311.4 | 1.4447 | 0.0002 | 1.4449 | 4.64 | 0.0007 | 4.64 |

[4] PAME - New Low Sulphur Fuels, Fate, and Behavior in Cold Water Conditions

*Table 12. Lead loads (t/yr) from EGCS open and closed loop discharge in OSPAR member states territorial waters 12 NM, compared with available data on riverine input extracted from OSPAR RID.*

| | Other sources | 12NM | | | 12NM EGCS/Other sources | | |
|---|---|---|---|---|---|---|---|
| | RID | Open loop | Closed loop | Tot EGCS | Open loop | Closed loop | Tot EGCS |
| **Belgium** | 12.38 | 0.0096 | 0.0000 | 0.0096 | 0.77 | 0.0000 | 0.77 |
| **France** | 28.77 | 0.0640 | 0.0000 | 0.0640 | 2.22 | 0.0000 | 2.22 |
| **Germany** | 89.15 | 0.0139 | 0.0006 | 0.0144 | 0.16 | 0.0064 | 0.16 |
| **Iceland** | 0.51 | 0.0085 | 0.0000 | 0.0085 | 16.69 | 0.0000 | 16.69 |
| **Ireland** | 15.74 | 0.0222 | 0.0000 | 0.0222 | 1.41 | 0.0005 | 1.41 |
| **The Netherlands** | 78.19 | 0.1036 | 0.0000 | 0.1036 | 1.33 | 0.0001 | 1.33 |
| **Norway** | 22.64 | 0.0732 | 0.0000 | 0.0732 | 3.23 | 0.0005 | 3.23 |
| **Portugal** | 4.07 | 0.0098 | 0.0000 | 0.0098 | 2.40 | 0.0001 | 2.40 |
| **Spain** | 11.53 | 0.1193 | 0.0000 | 0.1194 | 10.35 | 0.0004 | 10.35 |
| **Sweden** | 10.37 | 0.2363 | 0.0000 | 0.2363 | 22.78 | 0.0017 | 22.78 |
| **UK** | 254.6 | 0.2011 | 0.0000 | 0.2011 | 0.79 | 0.0000 | 0.79 |

*Table 13. Mercury loads (t/yr) from EGCS open and closed loop discharge in OSPAR member states territorial waters 12 NM, compared with available data on riverine input extracted from OSPAR RID.*

| | Other sources | 12NM | | | 12NM EGCS/Other sources | | |
|---|---|---|---|---|---|---|---|
| | RID | Open loop | Closed loop | Tot EGCS | Open loop | Closed loop | Tot EGCS |
| **Belgium** | 0.09 | 0.0002 | 0.0000 | 0.0002 | 2.00 | 0.0000 | 2.00 |
| **France** | 5.51 | 0.0012 | 0.0000 | 0.0012 | 0.22 | 0.0000 | 0.22 |
| **Germany** | 0.52 | 0.0003 | 0.0000 | 0.0003 | 0.50 | 0.0277 | 0.53 |
| **Iceland** | 0.06 | 0.0002 | 0.0000 | 0.0002 | 2.67 | 0.0000 | 2.67 |
| **Ireland** | 0.42 | 0.0004 | 0.0000 | 0.0004 | 0.99 | 0.0005 | 0.99 |
| **The Netherlands** | 0.6 | 0.0019 | 0.0000 | 0.0019 | 3.25 | 0.0003 | 3.25 |
| **Norway** | 0.2 | 0.0014 | 0.0000 | 0.0014 | 6.88 | 0.0014 | 6.89 |
| **Portugal** | 0 | 0.0002 | 0.0000 | 0.0002 | - | - | - |
| **Spain** | 0.08 | 0.0022 | 0.0000 | 0.0022 | 28.06 | 0.0015 | 28.06 |
| **Sweden** | 0.06 | 0.0044 | 0.0000 | 0.0044 | 74.05 | 0.0076 | 74.1 |
| **UK** | 0.8 | 0.0038 | 0.0000 | 0.0038 | 4.73 | 0.0004 | 4.73 |

*Table 14. Zinc loads (t/yr) from EGCS open and closed loop discharge in OSPAR member states territorial waters 12 NM, compared with available data on riverine input extracted from OSPAR RID.*

| | Other sources | 12NM | | | 12NM EGCS/Other sources | | |
|---|---|---|---|---|---|---|---|
| | RID | Open loop | Closed loop | Tot EGCS | Open loop | Closed loop | Tot EGCS |
| **Belgium** | 109.44 | 0.2725 | 0.0000 | 0.2725 | 2.49 | 0.0000 | 2.49 |
| **France** | 369.11 | 1.8235 | 0.0000 | 1.8235 | 4.94 | 0.0001 | 4.94 |
| **Germany** | 704.8 | 0.3955 | 0.0617 | 0.4572 | 0.56 | 0.0875 | 0.65 |
| **Iceland** | 21.25 | 0.2425 | 0.0000 | 0.2425 | 11.41 | 0.0000 | 11.41 |
| **Ireland** | 363.5 | 0.6318 | 0.0008 | 0.6326 | 1.74 | 0.0022 | 1.74 |
| **The Netherlands** | 560.63 | 2.9525 | 0.0008 | 2.9534 | 5.27 | 0.0014 | 5.27 |
| **Norway** | 478.8 | 2.0865 | 0.0012 | 2.0877 | 4.36 | 0.0025 | 4.36 |
| **Portugal** | 8.14 | 0.2788 | 0.0000 | 0.2788 | 34.25 | 0.0030 | 34.26 |
| **Spain** | 1081.57 | 3.4013 | 0.0005 | 3.4018 | 3.14 | 0.0005 | 3.15 |
| **Sweden** | 115.8 | 6.7331 | 0.0019 | 6.7350 | 58.14 | 0.0168 | 58.16 |
| **UK** | 1696.85 | 5.7303 | 0.0014 | 5.7316 | 3.38 | 0.0008 | 3.38 |

# 6 Uncertainties

There are several contributions to the overall uncertainty of modeled EGCS discharge totals. These arise from overall power prediction (kilowatts) used by ships, discharge rates from open/closed loop systems, geospatial variation of discharges and completeness of ship fleet data.

In our previous work comparisons of modeled fuel consumption have been compared with fuel reports required by the EU MRV mechanism (European Union, 2016). Although these comparisons do not directly provide information of air emissions or discharges, they provide a benchmark for assessing the accuracy of predicted fuel consumption and vessel power use. The most recent MRV comparison can be found in the latest HELCOM Maritime emission report (Jalkanen et al., 2021b). In short, the average absolute deviation involved in predicted STEAM fuel consumption for any vessel was 20%, which covers all sources of uncertainty concerning gaps in vessel technical data, incomplete AIS coverage, uncertainties in modeling specific fuel oil consumption and ambient conditions. On inventory level, for 1604 ships, a deviation of 7.8% (over prediction) was observed. Full analysis of model performance can be found elsewhere (Jalkanen et al., 2021b).

The effluent discharge rate used in the OSPAR study has about 50% uncertainty, which was given by Teuchies et al (Teuchies et al., 2020) in their study of 51 vessels equipped with an EGCS. This, and the overall uncertainty of the instantaneous power prediction together, will probably lead to total uncertainty of ±60% at inventory level. This is also the uncertainty of the total loads, which are calculated as a product of discharge volume and pollutant concentration of the effluent water samples. Most of the uncertainty comes from the determination of the EGCS discharge rate, which is connected to fuel sulfur content used by ships equipped with EGCS and the properties of sea water used in SOx scrubbing. Future research should include these features to reduce especially the discharge rate uncertainty.

The information of EGCS installations come from IMO GISIS database which may have significant delay between EGCS installation, flag state notification and data availability through the GISIS database. In some cases, this delay can be several months. This feature should be acknowledged, especially if EGCS modeling is required for periods close to real time. This study is less likely to be impacted, because EGCS data were obtained over seven months after the end of the year 2020.

There are also large variations and uncertainties in the reported concentrations of contaminants in scrubber discharge water; originating both from sampling procedures (including time from sampling to analysis, particle removal etc) and the expected natural variations of the scrubber water due to fuel and system operation specific features. The conservative approach used in this study, only including concentrations where data was also available on the discharge flow rates, and the engine load (≥ 50% of MCR), reduces the number of possible samples to include in the analysis. The data presented are average numbers, i.e., if a worst-case scenario should be produced one could consider using the upper 95% confidence interval instead. Linders et al. (2019) have also suggested that the low molecular PAHs dissolved in scrubber water are more easily extracted and analyzed, while the heavier PAHs, originating from the combustion process) are not as easily extracted during total analysis, of non-filtered discharge water.

The work carried out in the H2020/EMERGE project will include an update of areas where open loop usage is not allowed. This requires determination of relevant area definitions as well as starting dates. This work is in progress, but has not been completed yet, especially for local rules for specific port areas which have been introduced since January 2020.

# 7 Summary

Discharges from open loop systems are over 99.9% from the total EGCS discharge, which were estimated to be 622 million cubic meters in 2020 inside the OSPAR overall domain (I-V). Of this discharge, almost half occurs in the English Channel and the North Sea areas (OSPAR II). The second largest contribution (25%) comes from ships operating in the OSPAR IV area, along the main shipping lane from Gibraltar to the English Channel. Arctic areas (OSPAR I) have the smallest EGCS discharges from the studied areas.

Containerships are the largest source of EGCS release, and they are responsible for 38% of the total discharge. The next three ship types contribute 10-11% shares of the total discharge: roro cargo ships, bulk cargo and crude oil tankers. The effluent released by these vessels together is almost 70% of all EGCS discharges.

Flag state analysis of EGCS discharges indicate that the largest contribution comes from vessels carrying the Danish flag (16%), with Liberia (11%), Panama (10%) and Marshall Islands (9%) with the next largest shares. The EU flagged vessels together release almost half (47%) of the EGCS discharges.

At the global fleet level, hybrid or closed loop EGCS is installed in 14% of the vessels, but in the OSPAR domain this share is larger (29%). Similar observation was done for the Baltic Sea fleet, where over 90% of the EGCSs were of hybrid or closed loop type.

From the 622 million tonnes of EGCS effluent released to the sea in OSPAR Regions (I-V), about 84% is released closer than 200 nautical miles from the shoreline. Further, the effluent release inside the 12 nautical mile limit was estimated as 130 million tonnes, which is about 21% of the OSPAR total.

Vanadium, known to be present in heavy fuel oil, constitutes the largest calculated load (106 tonnes) of individual metals in the OSPAR I-V region. Zinc (87 tonnes) and copper (22 tonnes) are hypothesized to primarily originate from marine growth protection systems and piping. Nickel (34 tonnes) may also originate from the fuel or from piping material in the scrubber.

The estimated open loop contaminant loads are in the order of 1000-10,000 times higher than the open loop loads. Similar as for the open loop, the largest calculated load from closed loop systems is vanadium (1213 kg), almost four times the load of nickel (312 kg) , and 18 times the load of chromium (66kg.

The estimated PAH loads in OSPAR I-V region are dominated by napthalene (2.3 tonnes) and phenanthrene (1.2 tonnes), followed by fluorene, acenaphthene, pyrene, fluoranthene and chrysene , in the range 390-73- kg respectively. The remaining nine of the EPA 16 PAH:s were estimated to be

in the range 5-47 kg respectively). The estimated total load of PAH:s is close to 7 times higher than the mass of EPA 16 PAH, suggesting that e.g. alkylated PAHs should also be considered.

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# Disclaimer

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# Appendix 1 – Contaminant loads per country

Loads are provided in the following categories, all values in kg for the year 2020:

| | |
|---|---|
| $OL_{EEZ\ Tot}$ | Contaminant mass from Open Loop scrubber discharge within a member state's total EEZ |
| $OL_{12NM\ Tot}$ | Contaminant mass from Open Loop scrubber discharge within a member state's territorial water, 12 NM |
| $OL_{EEZ\ OSPAR\ share}$ | Contaminant mass from Open Loop scrubber discharge within a member state's EEZ within the OSPAR region |
| $CL_{EEZ\ Tot}$ | Contaminant mass from Closed Loop scrubber discharge within a member state's total EEZ |
| $CL_{12NM\ Tot}$ | Contaminant mass from Closed Loop scrubber discharge within a member state's territorial water, 12 NM |
| $CL_{EEZ\ OSPAR\ share}$ | Contaminant mass from Closed Loop scrubber discharge within a member state's EEZ within the OSPAR region |

All figures are calculated from the volumes originating from the STEAM-output in this study, in combination with the contaminant average concentrations and ±95% confidence interval (±95%CI) originating from (Ytreberg et al., 2020, and Lunde Hermansson et al. 2021). N/D in an Average column indicates that the substance has not been detected in the available reported data on concentrations, and therefore the ±95% CI is left empty. N/A in an ±95% CI column indicates that the concentration is based on only one reported value, why ±95% CI cannot be calculated. Numbers less than 0.1g are reported as <0.001kg and the associated ±95%CI is left empty.

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Reference:

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# Belgium

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** |
| **Arsenic** | 21.8 | 3.81 | 7.36 | 1.29 | *Entire EEZ inside* | | 0.000169 | 0.000090 | <0.0001 | | *Entire EEZ inside* | |
| **Cadmium** | 3.35 | 1.07 | 1.13 | 0.363 | *= $OL_{EEZ\ Tot}$* | | <0.0001 | | <0.0001 | | *= $CL_{EEZ\ Tot}$* | |
| **Chromium** | 58.6 | 37.2 | 19.8 | 12.6 | | | 0.0112 | 0.0183 | 0.00169 | 0.00276 | | |
| **Copper** | 203 | 130 | 68.7 | 43.9 | | | 0.000656 | 0.00064 | <0.0001 | | | |
| **Lead** | 28.2 | 11.4 | 9.56 | 3.86 | | | <0.0001 | | <0.0001 | | | |
| **Mercury** | 0.531 | 0.0734 | 0.180 | 0.0249 | | | <0.0001 | N/A | <0.0001 | N/A | | |
| **Nickel** | 319 | 105 | 108 | 35.5 | | | 0.0392 | 0.0232 | 0.00593 | 0.00350 | | |
| **Vanadium** | 966 | 327 | 327 | 111 | | | 0.153 | 0.0802 | 0.0231 | 0.0121 | | |
| **Zinc** | 805 | 881 | 272 | 298 | | | 0.00382 | 0.00321 | 0.00058 | 0.00048 | | |
| **Naphthalene** | 21.1 | 8.08 | 7.14 | 2.73 | | | <0.0001 | | <0.0001 | | | |
| **Acenaphthylene** | 0.624 | 0.337 | 0.211 | 0.114 | | | <0.0001 | | <0.0001 | | | |
| **Acenaphthene** | 1.50 | 0.598 | 0.508 | 0.202 | | | <0.0001 | | <0.0001 | | | |
| **Fluorene** | 3.57 | 0.903 | 1.21 | 0.305 | | | <0.0001 | | <0.0001 | | | |
| **Phenanthrene** | 10.7 | 2.89 | 3.61 | 0.977 | | | <0.0001 | | <0.0001 | | | |
| **Anthracene** | 0.307 | 0.169 | 0.104 | 0.0573 | | | <0.0001 | | <0.0001 | | | |
| **Fluoranthene** | 0.788 | 0.361 | 0.267 | 0.122 | | | <0.0001 | | <0.0001 | | | |
| **Pyrene** | 1.45 | 0.892 | 0.490 | 0.302 | | | <0.0001 | | <0.0001 | | | |
| **Benz(a)anthrancene** | 0.429 | 0.418 | 0.145 | 0.142 | | | <0.0001 | | <0.0001 | | | |
| **Chrysene** | 0.679 | 0.400 | 0.230 | 0.135 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(b)fluoranthene** | 0.172 | 0.118 | 0.0583 | 0.0398 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(k)fluoranthene** | 0.0534 | 0.0427 | 0.0181 | 0.0145 | | | <0.0001 | N/A | <0.0001 | N/A | | |
| **Benzo(a)pyrene** | 0.129 | 0.0935 | 0.0438 | 0.0316 | | | <0.0001 | | <0.0001 | | | |
| **Dibenzo(a,h)anthracene** | 0.0498 | 0.0212 | 0.0168 | 0.00718 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(g,h,i)perylene** | 0.0812 | 0.0502 | 0.0275 | 0.0170 | | | <0.0001 | | <0.0001 | | | |
| **Indeno(1,2,3-c,d)pyrene** | 0.126 | 0.154 | 0.0427 | 0.0522 | | | <0.0001 | | <0.0001 | | | |
| **Sum EPA 16 PAH** | 5.95 | 4.79 | 2.02 | 1.62 | | | N/D | | N/D | | | |
| **Sum total PAH** | 42.7 | 13.6 | 14.5 | 4.60 | | | <0.0001 | | <0.0001 | | | |

# Denmark

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 334 | 58.6 | 197 | 34.5 | 204 | 35.7 | 0.390 | 0.208 | 0.266 | 0.142 | 0.0596 | 0.0318 |
| **Cadmium** | 51.4 | 16.5 | 30.3 | 9.71 | 31.4 | 10.0 | 0.0175 | 0.00744 | 0.0119 | 0.00506 | 0.00268 | 0.00114 |
| **Chromium** | 900 | 571 | 531 | 337 | 549 | 348 | 19.2 | 48.2 | 13.1 | 32.8 | 2.93 | 7.36 |
| **Copper** | 3116 | 1989 | 1837 | 1173 | 1901 | 1214 | 1.51 | 1.48 | 1.03 | 1.01 | 0.231 | 0.227 |
| **Lead** | 434 | 175 | 256 | 103 | 265 | 107 | 0.0811 | 0.0367 | 0.0552 | 0.0250 | 0.0124 | 0.00561 |
| **Mercury** | 8.15 | 1.13 | 4.81 | 0.665 | 4.98 | 0.688 | 0.00206 | N/A | 0.00140 | | 0.0 | N/A |
| **Nickel** | 4891 | 1610 | 2884 | 950 | 2985 | 983 | 90.4 | 53.3 | 61.5 | 36.3 | 13.8 | 8.15 |
| **Vanadium** | 14836 | 5015 | 8749 | 2957 | 9054 | 3060 | 352 | 185 | 239 | 126 | 53.7 | 28.2 |
| **Zinc** | 12358 | 13529 | 7288 | 7979 | 7542 | 8257 | 8.80 | 7.39 | 5.99 | 5.03 | 1.35 | 1.13 |
| **Naphthalene** | 324 | 124 | 191 | 73.1 | 198 | 75.7 | 0.0197 | 0.0219 | 0.0134 | 0.0149 | 0.00301 | 0.00335 |
| **Acenaphthylene** | 9.58 | 5.18 | 5.65 | 3.05 | 5.85 | 3.16 | 0.000946 | 0.00128 | 0.000643 | 0.000868 | 0.0 | 0.0 |
| **Acenaphthene** | 23.0 | 9.18 | 13.6 | 5.41 | 14.1 | 5.60 | 0.00503 | 0.00561 | 0.00342 | 0.00382 | 0.0 | 0.0 |
| **Fluorene** | 54.8 | 13.9 | 32.3 | 8.17 | 33.4 | 8.46 | 0.0162 | 0.0162 | 0.0110 | 0.0110 | 0.00248 | 0.00248 |
| **Phenanthrene** | 164 | 44.3 | 96.6 | 26.1 | 100.0 | 27.1 | 0.0819 | 0.109 | 0.0557 | 0.0743 | 0.0125 | 0.0167 |
| **Anthracene** | 4.72 | 2.60 | 2.78 | 1.53 | 2.88 | 1.59 | 0.0430 | 0.109 | 0.0293 | 0.0740 | 0.00657 | 0.0166 |
| **Fluoranthene** | 12.1 | 5.54 | 7.14 | 3.27 | 7.38 | 3.38 | 0.0107 | 0.0203 | 0.00731 | 0.0138 | 0.00164 | 0.00309 |
| **Pyrene** | 22.2 | 13.7 | 13.1 | 8.08 | 13.6 | 8.36 | 0.0155 | 0.0324 | 0.0105 | 0.0220 | 0.00236 | 0.00495 |
| **Benz(a)anthrancene** | 6.58 | 6.42 | 3.88 | 3.79 | 4.02 | 3.92 | 0.00542 | 0.0129 | 0.00368 | 0.00875 | 0.0 | 0.00196 |
| **Chrysene** | 10.4 | 6.14 | 6.15 | 3.62 | 6.37 | 3.74 | 0.00616 | 0.0143 | 0.00419 | 0.00976 | 0.0 | 0.00219 |
| **Benzo(b)fluoranthene** | 2.64 | 1.80 | 1.56 | 1.06 | 1.61 | 1.10 | 0.00254 | 0.00598 | 0.00173 | 0.00407 | 0.0 | 0.0 |
| **Benzo(k)fluoranthene** | 0.820 | 0.656 | 0.484 | 0.387 | 0.501 | 0.400 | 0.000103 | N/A | <0.0001 | | <0.0001 | N/A |
| **Benzo(a)pyrene** | 1.99 | 1.43 | 1.17 | 0.846 | 1.21 | 0.876 | 0.000883 | 0.00200 | 0.000601 | 0.00136 | 0.0 | 0.0 |
| **Dibenzo(a,h)anthracene** | 0.764 | 0.326 | 0.451 | 0.192 | 0.466 | 0.199 | 0.000416 | 0.000806 | 0.000283 | 0.000548 | <0.0001 | 0.0 |
| **Benzo(g,h,i)perylene** | 1.25 | 0.770 | 0.735 | 0.454 | 0.761 | 0.470 | 0.00161 | 0.00381 | 0.00109 | 0.00259 | 0.0 | 0.0 |
| **Indeno(1,2,3-c,d)pyrene** | 1.94 | 2.37 | 1.14 | 1.40 | 1.18 | 1.45 | 0.000821 | 0.00185 | 0.000558 | 0.00126 | 0.0 | 0.0 |
| **Sum EPA 16 PAH** | 91.4 | 73.5 | 53.9 | 43.3 | 55.8 | 44.8 | N/D | | N/D | | N/D | |
| **Sum total PAH** | 656 | 209 | 387 | 123 | 400 | 127 | 0.0747 | 0.0793 | 0.0508 | 0.0540 | 0.0114 | 0.0121 |

# Faroe Islands

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** |
| **Arsenic** | 10.7 | 1.87 | 2.18 | 0.382 | *Entire EEZ inside* | | 0.0 | 0.0 | 0.0 | 0.0 | *Entire EEZ inside* | |
| **Cadmium** | 1.64 | 0.525 | 0.336 | 0.107 | *= $OL_{EEZ\ Tot}$* | | 0.0 | 0.0 | 0.0 | 0.0 | *= $CL_{EEZ\ Tot}$* | |
| **Chromium** | 28.7 | 18.2 | 5.87 | 3.73 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Copper** | 99.4 | 63.4 | 20.3 | 13.0 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Lead** | 13.8 | 5.58 | 2.83 | 1.14 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Mercury** | 0.260 | 0.0360 | 0.0532 | 0.00736 | | | 0.0 | N/A | 0.0 | N/A | | |
| **Nickel** | 156 | 51.4 | 31.9 | 10.5 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Vanadium** | 473 | 160 | 96.8 | 32.7 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Zinc** | 394 | 432 | 80.6 | 88.3 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Naphthalene** | 10.3 | 3.96 | 2.11 | 0.809 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Acenaphthylene** | 0.306 | 0.165 | 0.0625 | 0.0338 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Acenaphthene** | 0.735 | 0.293 | 0.150 | 0.0599 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Fluorene** | 1.75 | 0.442 | 0.358 | 0.0904 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Phenanthrene** | 5.22 | 1.41 | 1.07 | 0.289 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Anthracene** | 0.150 | 0.0829 | 0.0308 | 0.0170 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Fluoranthene** | 0.386 | 0.177 | 0.0790 | 0.0362 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Pyrene** | 0.708 | 0.437 | 0.145 | 0.0894 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benz(a)anthrancene** | 0.210 | 0.205 | 0.0430 | 0.0419 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Chrysene** | 0.333 | 0.196 | 0.0681 | 0.0400 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benzo(b)fluoranthene** | 0.0843 | 0.0575 | 0.0173 | 0.0118 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benzo(k)fluoranthene** | 0.0262 | 0.0209 | 0.00535 | 0.00428 | | | 0.0 | N/A | 0.0 | N/A | | |
| **Benzo(a)pyrene** | 0.0633 | 0.0458 | 0.0130 | 0.00937 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Dibenzo(a,h)anthracene** | 0.0244 | 0.0104 | 0.00499 | 0.00212 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benzo(g,h,i)perylene** | 0.0398 | 0.0246 | 0.00814 | 0.00503 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Indeno(1,2,3-c,d)pyrene** | 0.0618 | 0.0755 | 0.0126 | 0.0155 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Sum EPA 16 PAH** | 2.92 | 2.34 | 0.597 | 0.480 | | | N/D | | N/D | | | |
| **Sum total PAH** | 20.9 | 6.66 | 4.28 | 1.36 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |

# Finland

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 114 | 19.9 | 102 | 17.9 | N/A - entire EEZ | | 0.0463 | 0.0247 | 0.0313 | 0.0167 | N/A - entire EEZ | |
| **Cadmium** | 17.5 | 5.60 | 15.7 | 5.03 | area | | 0.00208 | 0.000882 | 0.00141 | 0.000598 | area | |
| **Chromium** | 306 | 194 | 275 | 174 | | | 2.28 | 5.71 | 1.54 | 3.87 | | |
| **Copper** | 1060 | 676 | 951 | 607 | | | 0.179 | 0.176 | 0.121 | 0.119 | | |
| **Lead** | 147 | 59.5 | 132 | 53.4 | | | 0.00961 | 0.00435 | 0.00651 | 0.00295 | | |
| **Mercury** | 2.77 | 0.383 | 2.49 | 0.344 | | | 0.000244 | N/A | 0.000165 | N/A | | |
| **Nickel** | 1663 | 548 | 1494 | 492 | | | 10.7 | 6.32 | 7.26 | 4.28 | | |
| **Vanadium** | 5045 | 1705 | 4531 | 1531 | | | 41.7 | 21.9 | 28.2 | 14.8 | | |
| **Zinc** | 4203 | 4601 | 3774 | 4132 | | | 1.04 | 0.876 | 0.707 | 0.593 | | |
| **Naphthalene** | 110 | 42.2 | 98.9 | 37.9 | | | 0.00234 | 0.00260 | 0.00158 | 0.00176 | | |
| **Acenaphthylene** | 3.26 | 1.76 | 2.93 | 1.58 | | | 0.000112 | 0.000151 | 0.000076 | 0.000102 | | |
| **Acenaphthene** | 7.83 | 3.12 | 7.03 | 2.80 | | | 0.000596 | 0.000665 | 0.000404 | 0.000451 | | |
| **Fluorene** | 18.6 | 4.71 | 16.7 | 4.23 | | | 0.00192 | 0.00192 | 0.00130 | 0.00130 | | |
| **Phenanthrene** | 55.7 | 15.1 | 50.0 | 13.5 | | | 0.00971 | 0.0129 | 0.00658 | 0.00877 | | |
| **Anthracene** | 1.60 | 0.884 | 1.44 | 0.794 | | | 0.00510 | 0.0129 | 0.00345 | 0.00874 | | |
| **Fluoranthene** | 4.11 | 1.89 | 3.69 | 1.69 | | | 0.00127 | 0.00240 | 0.000863 | 0.00163 | | |
| **Pyrene** | 7.55 | 4.66 | 6.78 | 4.18 | | | 0.00183 | 0.00384 | 0.00124 | 0.00260 | | |
| **Benz(a)anthrancene** | 2.24 | 2.18 | 2.01 | 1.96 | | | 0.000642 | 0.00152 | 0.000435 | 0.00103 | | |
| **Chrysene** | 3.55 | 2.09 | 3.18 | 1.87 | | | 0.000730 | 0.00170 | 0.000495 | 0.00115 | | |
| **Benzo(b)fluoranthene** | 0.899 | 0.614 | 0.807 | 0.551 | | | 0.000301 | 0.000709 | 0.000204 | 0.000480 | | |
| **Benzo(k)fluoranthene** | 0.279 | 0.223 | 0.251 | 0.200 | | | <0.0001 | N/A | 0.000008 | N/A | | |
| **Benzo(a)pyrene** | 0.675 | 0.488 | 0.606 | 0.438 | | | 0.000105 | 0.000238 | 0.000071 | 0.000161 | | |
| **Dibenzo(a,h)anthracene** | 0.260 | 0.111 | 0.233 | 0.0994 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(g,h,i)perylene** | 0.424 | 0.262 | 0.381 | 0.235 | | | 0.000191 | 0.000451 | 0.000129 | 0.000306 | | |
| **Indeno(1,2,3-c,d)pyrene** | 0.659 | 0.805 | 0.592 | 0.723 | | | <0.0001 | | 0.000066 | 0.000148 | | |
| **Sum EPA 16 PAH** | 31.1 | 25.0 | 27.9 | 22.4 | | | N/D | | N/D | | | |
| **Sum total PAH** | 223 | 71.0 | 200 | 63.7 | | | 0.00885 | 0.00940 | 0.00600 | 0.00637 | | |

# France

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 340 | 59.7 | 49.3 | 8.64 | 285 | 49.9 | 0.00766 | 0.00409 | 0.00110 | 0.00059 | 0.00293 | 0.00156 |
| **Cadmium** | 52.4 | 16.8 | 7.59 | 2.43 | 43.9 | 14.0 | 0.0 | 0.0 | <0.0001 | | 0.000131 | 0.000056 |
| **Chromium** | 917 | 582 | 133 | 84.2 | 768 | 487 | 0.376 | 0.945 | 0.0542 | 0.136 | 0.144 | 0.361 |
| **Copper** | 3174 | 2027 | 460 | 294 | 2658 | 1697 | 0.0296 | 0.0291 | 0.00426 | 0.00418 | 0.0113 | 0.0111 |
| **Lead** | 442 | 178 | 64.0 | 25.8 | 370 | 149 | 0.00159 | 0.000720 | 0.000229 | 0.000104 | 0.000608 | 0.000275 |
| **Mercury** | 8.31 | 1.15 | 1.20 | 0.166 | 6.96 | 0.962 | <0.0001 | N/A | <0.0001 | N/A | <0.0001 | N/A |
| **Nickel** | 4983 | 1641 | 722 | 238 | 4172 | 1373 | 1.77 | 1.05 | 0.255 | 0.150 | 0.678 | 0.400 |
| **Vanadium** | 15115 | 5109 | 2189 | 740 | 12655 | 4277 | 6.90 | 3.62 | 0.992 | 0.521 | 2.64 | 1.39 |
| **Zinc** | 12590 | 13784 | 1823 | 1996 | 10541 | 11540 | 0.173 | 0.145 | 0.0248 | 0.0208 | 0.0660 | 0.0554 |
| **Naphthalene** | 330 | 126 | 47.8 | 18.3 | 276 | 106 | 0.000387 | 0.000430 | <0.0001 | | 0.000148 | 0.000164 |
| **Acenaphthylene** | 9.76 | 5.27 | 1.41 | 0.764 | 8.17 | 4.41 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Acenaphthene** | 23.5 | 9.35 | 3.40 | 1.35 | 19.6 | 7.83 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Fluorene** | 55.8 | 14.1 | 8.09 | 2.04 | 46.7 | 11.8 | 0.000318 | 0.000318 | <0.0001 | | 0.000122 | 0.000122 |
| **Phenanthrene** | 167 | 45.2 | 24.2 | 6.54 | 140 | 37.8 | 0.00161 | 0.00214 | 0.000231 | 0.000308 | 0.000614 | 0.000819 |
| **Anthracene** | 4.81 | 2.65 | 0.696 | 0.384 | 4.02 | 2.22 | 0.000844 | 0.00213 | 0.000121 | 0.000307 | 0.000323 | 0.000816 |
| **Fluoranthene** | 12.3 | 5.65 | 1.79 | 0.818 | 10.3 | 4.73 | 0.000211 | 0.000397 | <0.0001 | | <0.0001 | |
| **Pyrene** | 22.6 | 14.0 | 3.28 | 2.02 | 18.9 | 11.7 | 0.000303 | 0.000635 | <0.0001 | | 0.000116 | 0.000243 |
| **Benz(a)anthrancene** | 6.71 | 6.54 | 0.971 | 0.948 | 5.61 | 5.48 | 0.000106 | 0.000252 | <0.0001 | | <0.0001 | |
| **Chrysene** | 10.6 | 6.25 | 1.54 | 0.905 | 8.90 | 5.23 | 0.000121 | 0.000281 | <0.0001 | | <0.0001 | |
| **Benzo(b)fluoranthene** | 2.69 | 1.84 | 0.390 | 0.266 | 2.25 | 1.54 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Benzo(k)fluoranthene** | 0.836 | 0.668 | 0.121 | 0.0968 | 0.700 | 0.560 | <0.0001 | N/A | <0.0001 | N/A | <0.0001 | N/A |
| **Benzo(a)pyrene** | 2.02 | 1.46 | 0.293 | 0.212 | 1.69 | 1.22 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Dibenzo(a,h)anthracene** | 0.778 | 0.332 | 0.113 | 0.0480 | 0.652 | 0.278 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Benzo(g,h,i)perylene** | 1.27 | 0.785 | 0.184 | 0.114 | 1.06 | 0.657 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Indeno(1,2,3-c,d)pyrene** | 1.97 | 2.41 | 0.286 | 0.349 | 1.65 | 2.02 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Sum EPA 16 PAH** | 93.1 | 74.9 | 13.5 | 10.8 | 78.0 | 62.7 | N/D | | N/D | | N/D | |
| **Sum total PAH** | 668 | 213 | 96.8 | 30.8 | 560 | 178 | 0.00147 | 0.00156 | 0.00021 | 0.000224 | 0.000560 | 0.000595 |

# Germany

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 65.1 | 11.4 | 10.7 | 1.87 | 52.4 | 9.19 | 3.20 | 1.71 | 2.73 | 1.46 | 0.908 | 0.484 |
| **Cadmium** | 10.0 | 3.21 | 1.65 | 0.527 | 8.07 | 2.58 | 0.144 | 0.0610 | 0.123 | 0.0521 | 0.0408 | 0.0173 |
| **Chromium** | 176 | 111 | 28.8 | 18.3 | 141 | 89.6 | 157 | 395 | 134 | 337 | 44.6 | 112 |
| **Copper** | 608 | 388 | 99.7 | 63.7 | 489 | 312 | 12.4 | 12.2 | 10.6 | 10.4 | 3.51 | 3.45 |
| **Lead** | 84.6 | 34.1 | 13.9 | 5.60 | 68.1 | 27.5 | 0.665 | 0.301 | 0.568 | 0.257 | 0.189 | 0.0853 |
| **Mercury** | 1.59 | 0.220 | 0.261 | 0.0361 | 1.28 | 0.177 | 0.0169 | N/A | 0.0144 | N/A | 0.00479 | N/A |
| **Nickel** | 954 | 314 | 157 | 51.5 | 768 | 253 | 741 | 437 | 633 | 374 | 210 | 124 |
| **Vanadium** | 2894 | 978 | 475 | 160 | 2329 | 787 | 2882 | 1515 | 2463 | 1294 | 818 | 430 |
| **Zinc** | 2410 | 2639 | 396 | 433 | 1940 | 2124 | 72.2 | 60.6 | 61.7 | 51.7 | 20.5 | 17.2 |
| **Naphthalene** | 63.2 | 24.2 | 10.4 | 3.97 | 50.8 | 19.5 | 0.162 | 0.180 | 0.138 | 0.154 | 0.0459 | 0.0510 |
| **Acenaphthylene** | 1.87 | 1.01 | 0.307 | 0.166 | 1.50 | 0.812 | 0.00775 | 0.0105 | 0.00663 | 0.00893 | 0.00220 | 0.00297 |
| **Acenaphthene** | 4.49 | 1.79 | 0.737 | 0.294 | 3.62 | 1.44 | 0.0412 | 0.0460 | 0.0352 | 0.0393 | 0.0117 | 0.0130 |
| **Fluorene** | 10.7 | 2.70 | 1.75 | 0.443 | 8.60 | 2.17 | 0.133 | 0.133 | 0.114 | 0.114 | 0.0377 | 0.0377 |
| **Phenanthrene** | 31.9 | 8.65 | 5.24 | 1.42 | 25.7 | 6.96 | 0.671 | 0.895 | 0.574 | 0.765 | 0.190 | 0.254 |
| **Anthracene** | 0.920 | 0.507 | 0.151 | 0.0832 | 0.741 | 0.408 | 0.353 | 0.892 | 0.301 | 0.762 | 0.100 | 0.253 |
| **Fluoranthene** | 2.36 | 1.08 | 0.387 | 0.177 | 1.90 | 0.870 | 0.0881 | 0.166 | 0.0753 | 0.142 | 0.0250 | 0.0471 |
| **Pyrene** | 4.33 | 2.67 | 0.711 | 0.438 | 3.49 | 2.15 | 0.127 | 0.265 | 0.108 | 0.227 | 0.0359 | 0.0753 |
| **Benz(a)anthrancene** | 1.28 | 1.25 | 0.211 | 0.206 | 1.03 | 1.01 | 0.0444 | 0.105 | 0.0379 | 0.0901 | 0.0126 | 0.0299 |
| **Chrysene** | 2.03 | 1.20 | 0.334 | 0.196 | 1.64 | 0.963 | 0.0505 | 0.118 | 0.0431 | 0.101 | 0.0143 | 0.0334 |
| **Benzo(b)fluoranthene** | 0.516 | 0.352 | 0.0846 | 0.0577 | 0.415 | 0.283 | 0.0208 | 0.0490 | 0.0178 | 0.0419 | 0.00590 | 0.0139 |
| **Benzo(k)fluoranthene** | 0.160 | 0.128 | 0.0263 | 0.0210 | 0.129 | 0.103 | 0.0 | N/A | 0.0 | N/A | 0.0 | N/A |
| **Benzo(a)pyrene** | 0.387 | 0.280 | 0.0635 | 0.0459 | 0.312 | 0.225 | 0.00724 | 0.0164 | 0.00618 | 0.0140 | 0.00205 | 0.00466 |
| **Dibenzo(a,h)anthracene** | 0.149 | 0.0635 | 0.0245 | 0.0104 | 0.120 | 0.0511 | 0.00341 | 0.00661 | 0.00292 | 0.00564 | 0.0 | 0.00187 |
| **Benzo(g,h,i)perylene** | 0.243 | 0.150 | 0.0399 | 0.0247 | 0.196 | 0.121 | 0.0132 | 0.0312 | 0.0113 | 0.0267 | 0.00374 | 0.00885 |
| **Indeno(1,2,3-c,d)pyrene** | 0.378 | 0.462 | 0.0620 | 0.0758 | 0.304 | 0.372 | 0.00673 | 0.0151 | 0.00575 | 0.0129 | 0.00191 | 0.00429 |
| **Sum EPA 16 PAH** | 17.8 | 14.3 | 2.93 | 2.35 | 14.3 | 11.5 | N/D | | N/D | | N/D | |
| **Sum total PAH** | 128 | 40.7 | 21.0 | 6.68 | 103 | 32.8 | 0.612 | 0.650 | 0.523 | 0.556 | 0.174 | 0.184 |

# Iceland

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 14.3 | 2.50 | 6.55 | 1.15 | *Entire EEZ inside* | | 0.0 | 0.0 | 0.0 | 0.0 | *Entire EEZ inside* | |
| **Cadmium** | 2.19 | 0.703 | 1.01 | 0.323 | *= $OL_{EEZ\ Tot}$* | | 0.0 | 0.0 | 0.0 | 0.0 | *= $CL_{EEZ\ Tot}$* | |
| **Chromium** | 38.4 | 24.4 | 17.7 | 11.2 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Copper** | 133 | 84.9 | 61.1 | 39.0 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Lead** | 18.5 | 7.47 | 8.51 | 3.43 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Mercury** | 0.348 | 0.0481 | 0.160 | 0.0221 | | | 0.0 | N/A | 0.0 | N/A | | |
| **Nickel** | 209 | 68.7 | 96.0 | 31.6 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Vanadium** | 633 | 214 | 291 | 98.4 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Zinc** | 527 | 577 | 243 | 265 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Naphthalene** | 13.8 | 5.29 | 6.35 | 2.43 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Acenaphthylene** | 0.409 | 0.221 | 0.188 | 0.102 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Acenaphthene** | 0.983 | 0.392 | 0.452 | 0.180 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Fluorene** | 2.34 | 0.591 | 1.08 | 0.272 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Phenanthrene** | 6.99 | 1.89 | 3.21 | 0.870 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Anthracene** | 0.201 | 0.111 | 0.0926 | 0.0510 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Fluoranthene** | 0.516 | 0.237 | 0.237 | 0.109 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Pyrene** | 0.948 | 0.585 | 0.436 | 0.269 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benz(a)anthrancene** | 0.281 | 0.274 | 0.129 | 0.126 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Chrysene** | 0.445 | 0.262 | 0.205 | 0.120 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benzo(b)fluoranthene** | 0.113 | 0.0770 | 0.0519 | 0.0354 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benzo(k)fluoranthene** | 0.0350 | 0.0280 | 0.0161 | 0.0129 | | | 0.0 | N/A | 0.0 | N/A | | |
| **Benzo(a)pyrene** | 0.0847 | 0.0612 | 0.0390 | 0.0282 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Dibenzo(a,h)anthracene** | 0.0326 | 0.0139 | 0.0150 | 0.00639 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Benzo(g,h,i)perylene** | 0.0532 | 0.0329 | 0.0245 | 0.0151 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Indeno(1,2,3-c,d)pyrene** | 0.0827 | 0.101 | 0.0380 | 0.0465 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |
| **Sum EPA 16 PAH** | 3.90 | 3.14 | 1.79 | 1.44 | | | N/D | | N/D | | | |
| **Sum total PAH** | 28.0 | 8.91 | 12.9 | 4.10 | | | 0.0 | 0.0 | 0.0 | 0.0 | | |

# Ireland

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** |
| **Arsenic** | 54.5 | 9.55 | 17.1 | 2.99 | *Entire EEZ inside* | | 0.000363 | 0.000194 | <0.0001 | | *Entire EEZ inside* | |
| **Cadmium** | 8.39 | 2.69 | 2.63 | 0.842 | *= $OL_{EEZ\ Tot}$* | | <0.0001 | | <0.0001 | | *= $CL_{EEZ\ Tot}$* | |
| **Chromium** | 147 | 93.1 | 46.0 | 29.2 | | | 0.0179 | 0.0448 | <0.0001 | | | |
| **Copper** | 508 | 324 | 159 | 102 | | | 0.00141 | 0.00138 | <0.0001 | | | |
| **Lead** | 70.7 | 28.5 | 22.2 | 8.95 | | | <0.0001 | | <0.0001 | | | |
| **Mercury** | 1.33 | 0.184 | 0.417 | 0.0576 | | | <0.0001 | N/A | <0.0001 | N/A | | |
| **Nickel** | 798 | 263 | 250 | 82.3 | | | 0.0841 | 0.0496 | <0.0001 | | | |
| **Vanadium** | 2420 | 818 | 758 | 256 | | | 0.327 | 0.172 | <0.0001 | | | |
| **Zinc** | 2016 | 2207 | 632 | 692 | | | 0.00819 | 0.00687 | <0.0001 | | | |
| **Naphthalene** | 52.8 | 20.2 | 16.6 | 6.34 | | | <0.0001 | | <0.0001 | | | |
| **Acenaphthylene** | 1.56 | 0.844 | 0.490 | 0.265 | | | <0.0001 | | <0.0001 | | | |
| **Acenaphthene** | 3.76 | 1.50 | 1.18 | 0.469 | | | <0.0001 | | <0.0001 | | | |
| **Fluorene** | 8.94 | 2.26 | 2.80 | 0.708 | | | <0.0001 | | <0.0001 | | | |
| **Phenanthrene** | 26.7 | 7.23 | 8.37 | 2.27 | | | <0.0001 | | <0.0001 | | | |
| **Anthracene** | 0.769 | 0.424 | 0.241 | 0.133 | | | <0.0001 | | <0.0001 | | | |
| **Fluoranthene** | 1.97 | 0.904 | 0.619 | 0.283 | | | <0.0001 | | <0.0001 | | | |
| **Pyrene** | 3.62 | 2.23 | 1.14 | 0.700 | | | <0.0001 | | <0.0001 | | | |
| **Benz(a)anthrancene** | 1.07 | 1.05 | 0.336 | 0.328 | | | <0.0001 | | <0.0001 | | | |
| **Chrysene** | 1.70 | 1.00 | 0.533 | 0.314 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(b)fluoranthene** | 0.431 | 0.294 | 0.135 | 0.0922 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(k)fluoranthene** | 0.134 | 0.107 | 0.0419 | 0.0335 | | | <0.0001 | N/A | <0.0001 | N/A | | |
| **Benzo(a)pyrene** | 0.324 | 0.234 | 0.101 | 0.0734 | | | <0.0001 | | <0.0001 | | | |
| **Dibenzo(a,h)anthracene** | 0.125 | 0.0531 | 0.0391 | 0.0166 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(g,h,i)perylene** | 0.203 | 0.126 | 0.0637 | 0.0394 | | | <0.0001 | | <0.0001 | | | |
| **Indeno(1,2,3-c,d)pyrene** | 0.316 | 0.386 | 0.0990 | 0.121 | | | <0.0001 | | <0.0001 | | | |
| **Sum EPA 16 PAH** | 14.9 | 12.0 | 4.67 | 3.76 | | | N/D | | N/D | | | |
| **Sum total PAH** | 107 | 34.0 | 33.5 | 10.7 | | | <0.0001 | | <0.0001 | | | |

# The Netherlands

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 214 | 37.5 | 79.8 | 14.0 | *Entire EEZ inside* | | 0.112 | 0.0600 | 0.0358 | 0.0191 | *Entire EEZ inside* | |
| **Cadmium** | 32.9 | 10.5 | 12.3 | 3.93 | *= $OL_{EEZ\ Tot}$* | | 0.00505 | 0.00214 | 0.00161 | 0.000684 | *= $CL_{EEZ\ Tot}$* | |
| **Chromium** | 576 | 365 | 215 | 136 | | | 5.53 | 13.9 | 1.76 | 4.42 | | |
| **Copper** | 1993 | 1273 | 744 | 475 | | | 0.435 | 0.427 | 0.139 | 0.136 | | |
| **Lead** | 277 | 112 | 104 | 41.8 | | | 0.0234 | 0.0106 | 0.00745 | 0.00337 | | |
| **Mercury** | 5.22 | 0.721 | 1.95 | 0.269 | | | 0.000593 | N/A | 0.000189 | N/A | | |
| **Nickel** | 3129 | 1030 | 1169 | 385 | | | 26.0 | 15.4 | 8.30 | 4.90 | | |
| **Vanadium** | 9492 | 3208 | 3545 | 1198 | | | 101 | 53.2 | 32.3 | 17.0 | | |
| **Zinc** | 7906 | 8656 | 2953 | 3232 | | | 2.54 | 2.13 | 0.808 | 0.678 | | |
| **Naphthalene** | 207 | 79.3 | 77.4 | 29.6 | | | 0.00568 | 0.00632 | 0.00181 | 0.00201 | | |
| **Acenaphthylene** | 6.13 | 3.31 | 2.29 | 1.24 | | | 0.000273 | 0.000367 | <0.0001 | | | |
| **Acenaphthene** | 14.7 | 5.87 | 5.50 | 2.19 | | | 0.00145 | 0.00162 | 0.000462 | 0.000515 | | |
| **Fluorene** | 35.1 | 8.86 | 13.1 | 3.31 | | | 0.00467 | 0.00468 | 0.00149 | 0.00149 | | |
| **Phenanthrene** | 105 | 28.4 | 39.1 | 10.6 | | | 0.0236 | 0.0315 | 0.00752 | 0.0100 | | |
| **Anthracene** | 3.02 | 1.66 | 1.13 | 0.621 | | | 0.0124 | 0.0313 | 0.00395 | 0.00999 | | |
| **Fluoranthene** | 7.74 | 3.55 | 2.89 | 1.32 | | | 0.00310 | 0.00583 | 0.000987 | 0.00186 | | |
| **Pyrene** | 14.2 | 8.76 | 5.31 | 3.27 | | | 0.00445 | 0.00933 | 0.00142 | 0.00297 | | |
| **Benz(a)anthrancene** | 4.21 | 4.11 | 1.57 | 1.53 | | | 0.00156 | 0.00371 | 0.000497 | 0.00118 | | |
| **Chrysene** | 6.67 | 3.93 | 2.49 | 1.47 | | | 0.00177 | 0.00413 | 0.000566 | 0.00132 | | |
| **Benzo(b)fluoranthene** | 1.69 | 1.15 | 0.632 | 0.431 | | | 0.000731 | 0.00172 | 0.000233 | 0.000549 | | |
| **Benzo(k)fluoranthene** | 0.525 | 0.420 | 0.196 | 0.157 | | | <0.0001 | N/A | <0.0001 | N/A | | |
| **Benzo(a)pyrene** | 1.27 | 0.918 | 0.474 | 0.343 | | | 0.000254 | 0.000578 | <0.0001 | | | |
| **Dibenzo(a,h)anthracene** | 0.489 | 0.208 | 0.183 | 0.0778 | | | 0.000120 | 0.000232 | <0.0001 | | | |
| **Benzo(g,h,i)perylene** | 0.798 | 0.493 | 0.298 | 0.184 | | | 0.000464 | 0.00110 | 0.000148 | 0.000350 | | |
| **Indeno(1,2,3-c,d)pyrene** | 1.24 | 1.52 | 0.463 | 0.566 | | | 0.000237 | 0.000532 | <0.0001 | | | |
| **Sum EPA 16 PAH** | 58.5 | 47.0 | 21.8 | 17.6 | | | N/D | | N/D | | | |
| **Sum total PAH** | 420 | 134 | 157 | 49.9 | | | 0.0215 | 0.0229 | 0.00686 | 0.00728 | | |

# Norway

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** |
| **Arsenic** | 123 | 21.5 | 56.4 | 9.89 | *Entire EEZ inside* | | 0.0530 | 0.0283 | 0.0532 | 0.0284 | *Entire EEZ inside* | |
| **Cadmium** | 18.9 | 6.04 | 8.68 | 2.78 | *= $OL_{EEZ\ Tot}$* | | 0.00238 | 0.00101 | 0.00239 | 0.00102 | *= $CL_{EEZ\ Tot}$* | |
| **Chromium** | 330 | 210 | 152 | 96.4 | | | 2.60 | 6.54 | 2.62 | 6.57 | | |
| **Copper** | 1144 | 730 | 526 | 336 | | | 0.205 | 0.201 | 0.206 | 0.202 | | |
| **Lead** | 159 | 64.2 | 73.2 | 29.6 | | | 0.0110 | 0.00498 | 0.0111 | 0.00501 | | |
| **Mercury** | 2.99 | 0.414 | 1.38 | 0.190 | | | 0.000279 | N/A | 0.000281 | N/A | | |
| **Nickel** | 1795 | 591 | 826 | 272 | | | 12.3 | 7.24 | 12.3 | 7.28 | | |
| **Vanadium** | 5446 | 1841 | 2505 | 847 | | | 47.7 | 25.1 | 48.0 | 25.2 | | |
| **Zinc** | 4536 | 4966 | 2087 | 2284 | | | 1.19 | 1.00 | 1.20 | 1.01 | | |
| **Naphthalene** | 119 | 45.5 | 54.7 | 20.9 | | | 0.00268 | 0.00297 | 0.00269 | 0.00299 | | |
| **Acenaphthylene** | 3.52 | 1.90 | 1.62 | 0.874 | | | 0.000128 | 0.000173 | 0.000129 | 0.000174 | | |
| **Acenaphthene** | 8.45 | 3.37 | 3.89 | 1.55 | | | 0.000682 | 0.000761 | 0.000686 | 0.000765 | | |
| **Fluorene** | 20.1 | 5.09 | 9.25 | 2.34 | | | 0.00220 | 0.00220 | 0.00221 | 0.00221 | | |
| **Phenanthrene** | 60.1 | 16.3 | 27.7 | 7.49 | | | 0.0111 | 0.0148 | 0.0112 | 0.0149 | | |
| **Anthracene** | 1.73 | 0.954 | 0.797 | 0.439 | | | 0.00584 | 0.0148 | 0.00587 | 0.0148 | | |
| **Fluoranthene** | 4.44 | 2.03 | 2.04 | 0.936 | | | 0.00146 | 0.00275 | 0.00147 | 0.00276 | | |
| **Pyrene** | 8.15 | 5.03 | 3.75 | 2.31 | | | 0.00210 | 0.00439 | 0.00211 | 0.00442 | | |
| **Benz(a)anthrancene** | 2.42 | 2.36 | 1.11 | 1.08 | | | 0.000735 | 0.00175 | 0.000739 | 0.00175 | | |
| **Chrysene** | 3.83 | 2.25 | 1.76 | 1.04 | | | 0.000836 | 0.00195 | 0.000840 | 0.00196 | | |
| **Benzo(b)fluoranthene** | 0.970 | 0.662 | 0.446 | 0.305 | | | 0.000344 | 0.000812 | 0.000346 | 0.000816 | | |
| **Benzo(k)fluoranthene** | 0.301 | 0.241 | 0.139 | 0.111 | | | <0.0001 | N/A | <0.0001 | N/A | | |
| **Benzo(a)pyrene** | 0.729 | 0.527 | 0.335 | 0.242 | | | 0.000120 | 0.000272 | 0.000120 | 0.000273 | | |
| **Dibenzo(a,h)anthracene** | 0.280 | 0.120 | 0.129 | 0.0550 | | | <0.0001 | | <0.0001 | | | |
| **Benzo(g,h,i)perylene** | 0.458 | 0.283 | 0.210 | 0.130 | | | 0.000218 | 0.000517 | 0.000219 | 0.000519 | | |
| **Indeno(1,2,3-c,d)pyrene** | 0.711 | 0.869 | 0.327 | 0.400 | | | 0.000111 | 0.000250 | 0.000112 | 0.000252 | | |
| **Sum EPA 16 PAH** | 33.6 | 27.0 | 15.4 | 12.4 | | | N/D | | N/D | | | |
| **Sum total PAH** | 241 | 76.6 | 111 | 35.2 | | | 0.0101 | 0.0108 | 0.0102 | 0.0108 | | |

# Portugal

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 318 | 55.8 | 7.54 | 1.32 | 291 | 51.0 | 0.0198 | 0.0106 | 0.00107 | 0.000569 | 0.0134 | 0.00718 |
| **Cadmium** | 49.0 | 15.7 | 1.16 | 0.371 | 44.7 | 14.3 | 0.000889 | 0.000378 | <0.0001 | | 0.000604 | 0.000256 |
| **Chromium** | 858 | 544 | 20.3 | 12.9 | 783 | 497 | 0.974 | 2.44 | 0.0524 | 0.132 | 0.661 | 1.66 |
| **Copper** | 2970 | 1896 | 70.3 | 44.9 | 2711 | 1731 | 0.0766 | 0.0752 | 0.00413 | 0.00405 | 0.0520 | 0.0511 |
| **Lead** | 413 | 167 | 9.78 | 3.95 | 377 | 152 | 0.00411 | 0.00186 | 0.000222 | 0.000100 | 0.00279 | 0.00126 |
| **Mercury** | 7.77 | 1.07 | 0.184 | 0.0254 | 7.10 | 0.981 | 0.000104 | N/A | <0.0001 | N/A | <0.0001 | N/A |
| **Nickel** | 4662 | 1535 | 110 | 36.3 | 4256 | 1401 | 4.59 | 2.71 | 0.247 | 0.146 | 3.11 | 1.84 |
| **Vanadium** | 14142 | 4780 | 335 | 113 | 12910 | 4364 | 17.8 | 9.37 | 0.960 | 0.505 | 12.1 | 6.37 |
| **Zinc** | 11780 | 12896 | 279 | 305 | 10754 | 11773 | 0.447 | 0.375 | 0.0240 | 0.0202 | 0.303 | 0.255 |
| **Naphthalene** | 309 | 118 | 7.31 | 2.80 | 282 | 108 | 0.00100 | 0.00111 | <0.0001 | | 0.000679 | 0.000755 |
| **Acenaphthylene** | 9.13 | 4.93 | 0.216 | 0.117 | 8.34 | 4.50 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Acenaphthene** | 22.0 | 8.75 | 0.520 | 0.207 | 20.0 | 7.99 | 0.000255 | 0.000285 | <0.0001 | | 0.000173 | 0.000193 |
| **Fluorene** | 52.2 | 13.2 | 1.24 | 0.313 | 47.7 | 12.1 | 0.000823 | 0.000823 | <0.0001 | | 0.000559 | 0.000559 |
| **Phenanthrene** | 156 | 42.3 | 3.70 | 1.00 | 143 | 38.6 | 0.00415 | 0.00554 | 0.000224 | 0.000298 | 0.00282 | 0.00376 |
| **Anthracene** | 4.50 | 2.48 | 0.106 | 0.0587 | 4.11 | 2.26 | 0.00218 | 0.00552 | 0.000117 | 0.000297 | 0.00148 | 0.00375 |
| **Fluoranthene** | 11.5 | 5.28 | 0.273 | 0.125 | 10.5 | 4.82 | 0.000545 | 0.00103 | <0.0001 | | 0.000370 | 0.000698 |
| **Pyrene** | 21.2 | 13.1 | 0.501 | 0.309 | 19.3 | 11.9 | 0.000784 | 0.00164 | <0.0001 | | 0.000532 | 0.00112 |
| **Benz(a)anthrancene** | 6.27 | 6.12 | 0.148 | 0.145 | 5.73 | 5.59 | 0.000275 | 0.000652 | <0.0001 | | 0.000187 | 0.000443 |
| **Chrysene** | 9.94 | 5.85 | 0.235 | 0.138 | 9.08 | 5.34 | 0.000312 | 0.000728 | <0.0001 | | 0.000212 | 0.000494 |
| **Benzo(b)fluoranthene** | 2.52 | 1.72 | 0.0596 | 0.0407 | 2.30 | 1.57 | 0.000129 | 0.000303 | <0.0001 | | <0.0001 | |
| **Benzo(k)fluoranthene** | 0.782 | 0.625 | 0.0185 | 0.0148 | 0.714 | 0.571 | <0.0001 | N/A | <0.0001 | N/A | <0.0001 | N/A |
| **Benzo(a)pyrene** | 1.89 | 1.37 | 0.0448 | 0.0324 | 1.73 | 1.25 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Dibenzo(a,h)anthracene** | 0.728 | 0.310 | 0.0172 | 0.00735 | 0.665 | 0.283 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Benzo(g,h,i)perylene** | 1.19 | 0.734 | 0.0281 | 0.0174 | 1.08 | 0.670 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Indeno(1,2,3-c,d)pyrene** | 1.85 | 2.26 | 0.0437 | 0.0534 | 1.69 | 2.06 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Sum EPA 16 PAH** | 87.1 | 70.0 | 2.06 | 1.66 | 79.5 | 63.9 | N/D | | N/D | | N/D | |
| **Sum total PAH** | 625 | 199 | 14.8 | 4.71 | 571 | 182 | 0.00379 | 0.00402 | 0.000204 | 0.000217 | 0.00257 | 0.00273 |

# Spain

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 558 | 97.8 | 91.9 | 16.1 | 217 | 38.1 | 0.0465 | 0.0248 | 0.0223 | 0.0119 | 0.00417 | 0.00223 |
| **Cadmium** | 85.9 | 27.5 | 14.2 | 4.53 | 33.4 | 10.7 | 0.00209 | 0.000887 | 0.001000 | 0.000425 | 0.000187 | 0.000080 |
| **Chromium** | 1503 | 953 | 248 | 157 | 585 | 371 | 2.29 | 5.74 | 1.09 | 2.75 | 0.205 | 0.515 |
| **Copper** | 5203 | 3322 | 858 | 547 | 2024 | 1293 | 0.180 | 0.177 | 0.0861 | 0.0846 | 0.0161 | 0.0159 |
| **Lead** | 724 | 292 | 119 | 48.2 | 282 | 114 | 0.00966 | 0.00437 | 0.00463 | 0.00209 | 0.0 | 0.0 |
| **Mercury** | 13.6 | 1.88 | 2.24 | 0.310 | 5.30 | 0.733 | 0.000245 | N/A | 0.000117 | N/A | <0.0001 | N/A |
| **Nickel** | 8168 | 2689 | 1346 | 443 | 3178 | 1046 | 10.8 | 6.35 | 5.16 | 3.04 | 0.967 | 0.570 |
| **Vanadium** | 24776 | 8374 | 4083 | 1380 | 9640 | 3258 | 41.9 | 22.0 | 20.1 | 10.5 | 3.76 | 1.98 |
| **Zinc** | 20638 | 22594 | 3401 | 3724 | 8030 | 8791 | 1.05 | 0.880 | 0.502 | 0.421 | 0.0941 | 0.0790 |
| **Naphthalene** | 541 | 207 | 89.1 | 34.1 | 210 | 80.6 | 0.00235 | 0.00261 | 0.00112 | 0.00125 | 0.0 | 0.0 |
| **Acenaphthylene** | 16.0 | 8.64 | 2.64 | 1.42 | 6.23 | 3.36 | 0.0 | 0.000152 | <0.0001 | | <0.0001 | |
| **Acenaphthene** | 38.5 | 15.3 | 6.34 | 2.53 | 15.0 | 5.97 | 0.0 | 0.0 | 0.0 | 0.000320 | <0.0001 | |
| **Fluorene** | 91.5 | 23.1 | 15.1 | 3.81 | 35.6 | 9.00 | 0.00193 | 0.00193 | 0.0 | 0.0 | 0.000173 | 0.000174 |
| **Phenanthrene** | 274 | 74.0 | 45.1 | 12.2 | 106 | 28.8 | 0.00975 | 0.0130 | 0.00467 | 0.00623 | 0.000875 | 0.00117 |
| **Anthracene** | 7.88 | 4.34 | 1.30 | 0.716 | 3.07 | 1.69 | 0.00512 | 0.0130 | 0.00245 | 0.00620 | 0.000460 | 0.00116 |
| **Fluoranthene** | 20.2 | 9.26 | 3.33 | 1.53 | 7.86 | 3.60 | 0.00128 | 0.00241 | 0.000613 | 0.00115 | 0.000115 | 0.000217 |
| **Pyrene** | 37.1 | 22.9 | 6.11 | 3.77 | 14.4 | 8.90 | 0.00184 | 0.00386 | 0.000881 | 0.00185 | 0.000165 | 0.000346 |
| **Benz(a)anthrancene** | 11.0 | 10.7 | 1.81 | 1.77 | 4.28 | 4.17 | 0.000645 | 0.00153 | 0.000309 | 0.000733 | <0.0001 | |
| **Chrysene** | 17.4 | 10.2 | 2.87 | 1.69 | 6.78 | 3.99 | 0.000734 | 0.00171 | 0.000351 | 0.000818 | <0.0001 | |
| **Benzo(b)fluoranthene** | 4.41 | 3.01 | 0.728 | 0.497 | 1.72 | 1.17 | 0.000302 | 0.000712 | 0.000145 | 0.000341 | <0.0001 | |
| **Benzo(k)fluoranthene** | 1.37 | 1.10 | 0.226 | 0.181 | 0.533 | 0.426 | <0.0001 | N/A | <0.0001 | N/A | <0.0001 | N/A |
| **Benzo(a)pyrene** | 3.32 | 2.40 | 0.546 | 0.395 | 1.29 | 0.932 | 0.000105 | 0.000239 | <0.0001 | | <0.0001 | |
| **Dibenzo(a,h)anthracene** | 1.28 | 0.544 | 0.210 | 0.0896 | 0.496 | 0.212 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Benzo(g,h,i)perylene** | 2.08 | 1.29 | 0.343 | 0.212 | 0.810 | 0.501 | 0.000192 | 0.000454 | <0.0001 | | <0.0001 | |
| **Indeno(1,2,3-c,d)pyrene** | 3.24 | 3.95 | 0.533 | 0.652 | 1.26 | 1.54 | <0.0001 | | <0.0001 | | <0.0001 | |
| **Sum EPA 16 PAH** | 153 | 123 | 25.2 | 20.2 | 59.4 | 47.7 | N/D | | N/D | | N/D | |
| **Sum total PAH** | 1096 | 349 | 181 | 57.5 | 426 | 136 | 0.00890 | 0.00945 | 0.00426 | 0.00452 | 0.000799 | 0.000848 |

# Sweden

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI | Average | ±95%CI |
| **Arsenic** | 302 | 53.0 | 182 | 31.9 | 45.9 | 8.05 | 0.148 | 0.0792 | 0.0862 | 0.0460 | 0.00841 | 0.00449 |
| **Cadmium** | 46.6 | 14.9 | 28.0 | 8.97 | 7.06 | 2.26 | 0.00667 | 0.00283 | 0.00387 | 0.00164 | 0.000378 | 0.000160 |
| **Chromium** | 815 | 517 | 490 | 311 | 124 | 78.4 | 7.30 | 18.3 | 4.24 | 10.6 | 0.414 | 1.04 |
| **Copper** | 2821 | 1801 | 1698 | 1084 | 428 | 273 | 0.574 | 0.564 | 0.333 | 0.327 | 0.0326 | 0.0320 |
| **Lead** | 393 | 158 | 236 | 95.4 | 59.6 | 24.0 | 0.0308 | 0.0140 | 0.0179 | 0.00810 | 0.00175 | 0.000791 |
| **Mercury** | 7.38 | 1.02 | 4.44 | 0.614 | 1.12 | 0.155 | 0.000783 | N/A | 0.000455 | N/A | <0.0001 | N/A |
| **Nickel** | 4428 | 1458 | 2665 | 877 | 672 | 221 | 34.4 | 20.3 | 20.0 | 11.8 | 1.95 | 1.15 |
| **Vanadium** | 13432 | 4540 | 8083 | 2732 | 2038 | 689 | 134 | 70.3 | 77.6 | 40.8 | 7.58 | 3.98 |
| **Zinc** | 11189 | 12249 | 6733 | 7371 | 1698 | 1859 | 3.35 | 2.81 | 1.94 | 1.63 | 0.190 | 0.159 |
| **Naphthalene** | 293 | 112 | 176 | 67.6 | 44.5 | 17.0 | 0.00750 | 0.00834 | 0.00435 | 0.00484 | 0.000425 | 0.000472 |
| **Acenaphthylene** | 8.67 | 4.69 | 5.22 | 2.82 | 1.32 | 0.711 | 0.000360 | 0.000485 | 0.000209 | 0.000282 | <0.0001 | |
| **Acenaphthene** | 20.9 | 8.31 | 12.5 | 5.00 | 3.16 | 1.26 | 0.00191 | 0.00213 | 0.00111 | 0.00124 | 0.000108 | 0.000121 |
| **Fluorene** | 49.6 | 12.5 | 29.9 | 7.55 | 7.53 | 1.90 | 0.00617 | 0.00617 | 0.00358 | 0.00358 | 0.000350 | 0.000350 |
| **Phenanthrene** | 148 | 40.1 | 89.2 | 24.2 | 22.5 | 6.09 | 0.0311 | 0.0415 | 0.0181 | 0.0241 | 0.00176 | 0.00235 |
| **Anthracene** | 4.27 | 2.35 | 2.57 | 1.42 | 0.648 | 0.357 | 0.0164 | 0.0414 | 0.00950 | 0.0240 | 0.000927 | 0.00234 |
| **Fluoranthene** | 11.0 | 5.02 | 6.59 | 3.02 | 1.66 | 0.762 | 0.00409 | 0.00770 | 0.00237 | 0.00447 | 0.000232 | 0.000436 |
| **Pyrene** | 20.1 | 12.4 | 12.1 | 7.46 | 3.05 | 1.88 | 0.00588 | 0.0123 | 0.00341 | 0.00715 | 0.000333 | 0.000698 |
| **Benz(a)anthrancene** | 5.96 | 5.82 | 3.59 | 3.50 | 0.904 | 0.883 | 0.00206 | 0.00489 | 0.00120 | 0.00284 | 0.000117 | 0.000277 |
| **Chrysene** | 9.44 | 5.56 | 5.68 | 3.34 | 1.43 | 0.843 | 0.00234 | 0.00546 | 0.00136 | 0.00317 | 0.000133 | 0.000309 |
| **Benzo(b)fluoranthene** | 2.39 | 1.63 | 1.44 | 0.983 | 0.363 | 0.248 | 0.000964 | 0.00227 | 0.000560 | 0.00132 | <0.0001 | |
| **Benzo(k)fluoranthene** | 0.743 | 0.594 | 0.447 | 0.357 | 0.113 | 0.0901 | <0.0001 | N/A | <0.0001 | N/A | <0.0001 | N/A |
| **Benzo(a)pyrene** | 1.80 | 1.30 | 1.08 | 0.782 | 0.273 | 0.197 | 0.000336 | 0.000762 | 0.000195 | 0.000443 | <0.0001 | |
| **Dibenzo(a,h)anthracene** | 0.692 | 0.295 | 0.416 | 0.177 | 0.105 | 0.0447 | 0.000158 | 0.000306 | 0.000092 | 0.000178 | <0.0001 | |
| **Benzo(g,h,i)perylene** | 1.13 | 0.697 | 0.679 | 0.420 | 0.171 | 0.106 | 0.000612 | 0.00145 | <0.0001 | | <0.0001 | |
| **Indeno(1,2,3-c,d)pyrene** | 1.75 | 2.14 | 1.06 | 1.29 | 0.266 | 0.325 | 0.000312 | 0.000702 | 0.000181 | 0.000407 | <0.0001 | |
| **Sum EPA 16 PAH** | 82.8 | 66.5 | 49.8 | 40.0 | 12.6 | 10.1 | N/D | | N/D | | N/D | |
| **Sum total PAH** | 594 | 189 | 357 | 114 | 90.1 | 28.7 | 0.0284 | 0.0302 | 0.0165 | 0.0175 | 0.00161 | 0.00171 |

# UK

| | $OL_{EEZ\ Tot}$ (kg) | | $OL_{12NM\ Tot}$(kg) | | $OL_{EEZ\ Ospar\ share}$ (kg) | | $CL_{EEZ\ Tot}$ (kg) | | $CL_{12NM\ Tot}$(kg) | | $CL_{EEZ\ Ospar\ share}$ (kg) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** | **Average** | **±95%CI** |
| **Arsenic** | 448 | 78.6 | 155 | 27.2 | *Entire EEZ inside* | | 0.114 | 0.0608 | 0.0600 | 0.0320 | *Entire EEZ inside* | |
| **Cadmium** | 69.0 | 22.1 | 23.8 | 7.63 | *= $OL_{EEZ\ Tot}$* | | 0.00512 | 0.00217 | 0.00269 | 0.00114 | *= $CL_{EEZ\ Tot}$* | |
| **Chromium** | 1208 | 767 | 417 | 265 | | | 5.60 | 14.1 | 2.95 | 7.40 | | |
| **Copper** | 4183 | 2671 | 1445 | 922 | | | 0.441 | 0.433 | 0.232 | 0.228 | | |
| **Lead** | 582 | 235 | 201 | 81.2 | | | 0.0237 | 0.0107 | 0.0125 | 0.00564 | | |
| **Mercury** | 10.9 | 1.51 | 3.78 | 0.523 | | | 0.000601 | N/A | 0.000316 | N/A | | |
| **Nickel** | 6567 | 2162 | 2268 | 747 | | | N/D | 15.6 | 13.9 | 8.20 | | |
| **Vanadium** | 19919 | 6733 | 6879 | 2325 | | | 103 | 53.9 | 54.0 | 28.4 | | |
| **Zinc** | 16592 | 18165 | 5730 | 6273 | | | 2.57 | 2.16 | 1.35 | 1.14 | | |
| **Naphthalene** | 435 | 167 | 150 | 57.5 | | | 0.00576 | 0.00640 | 0.00303 | 0.00337 | | |
| **Acenaphthylene** | 12.9 | 6.95 | 4.44 | 2.40 | | | 0.000276 | 0.000372 | 0.000145 | 0.000196 | | |
| **Acenaphthene** | 30.9 | 12.3 | 10.7 | 4.26 | | | 0.00147 | 0.00164 | 0.000772 | 0.000862 | | |
| **Fluorene** | 73.6 | 18.6 | 25.4 | 6.42 | | | 0.00474 | 0.00474 | 0.00249 | 0.00249 | | |
| **Phenanthrene** | 220 | 59.5 | 75.9 | 20.6 | | | 0.0239 | 0.0319 | 0.0126 | 0.0168 | | |
| **Anthracene** | 6.33 | 3.49 | 2.19 | 1.21 | | | 0.0126 | 0.0318 | 0.00661 | 0.0167 | | |
| **Fluoranthene** | 16.2 | 7.44 | 5.61 | 2.57 | | | 0.00314 | 0.00591 | 0.00165 | 0.00311 | | |
| **Pyrene** | 29.8 | 18.4 | 10.3 | 6.35 | | | 0.00451 | 0.00945 | 0.00237 | 0.00497 | | |
| **Benz(a)anthrancene** | 8.84 | 8.62 | 3.05 | 2.98 | | | 0.00158 | 0.00375 | 0.000832 | 0.00198 | | |
| **Chrysene** | 14.0 | 8.24 | 4.84 | 2.85 | | | 0.00180 | 0.00419 | 0.000947 | 0.00221 | | |
| **Benzo(b)fluoranthene** | 3.55 | 2.42 | 1.23 | 0.837 | | | 0.000740 | 0.00175 | 0.000390 | 0.000919 | | |
| **Benzo(k)fluoranthene** | 1.10 | 0.881 | 0.380 | 0.304 | | | <0.0001 | N/A | <0.0001 | N/A | | |
| **Benzo(a)pyrene** | 2.67 | 1.93 | 0.920 | 0.665 | | | 0.000258 | 0.000585 | 0.000136 | 0.000308 | | |
| **Dibenzo(a,h)anthracene** | 1.03 | 0.437 | 0.354 | 0.151 | | | 0.000122 | 0.000235 | <0.0001 | | | |
| **Benzo(g,h,i)perylene** | 1.67 | 1.03 | 0.578 | 0.357 | | | 0.000470 | 0.00111 | 0.000247 | 0.000585 | | |
| **Indeno(1,2,3-c,d)pyrene** | 2.60 | 3.18 | 0.898 | 1.10 | | | 0.000240 | 0.000539 | 0.000126 | 0.000284 | | |
| **Sum EPA 16 PAH** | 123 | 98.7 | 42.4 | 34.1 | | | N/D | | N/D | | | |
| **Sum total PAH** | 881 | 280 | 304 | 96.8 | | | 0.0218 | 0.0232 | 0.0115 | 0.0122 | | |

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**Our vision is a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification.**

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