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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OSPAR's Quality Status Report 2023

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

Acknowledgments

Jukka-Pekka Jalkanen[1], Tiia Grönholm[1], Ida-Maja Hassellöv[2]

[1]Atmospheric Composition, Finnish Meteorological Institute, Erik Palmen's Square 1, 00560 Helsinki, Finland
[2]Chalmers University of Technology, Mechanics and Maritime Sciences, Campus Lindholmen, 412 96 Gothenburg, Sweden

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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

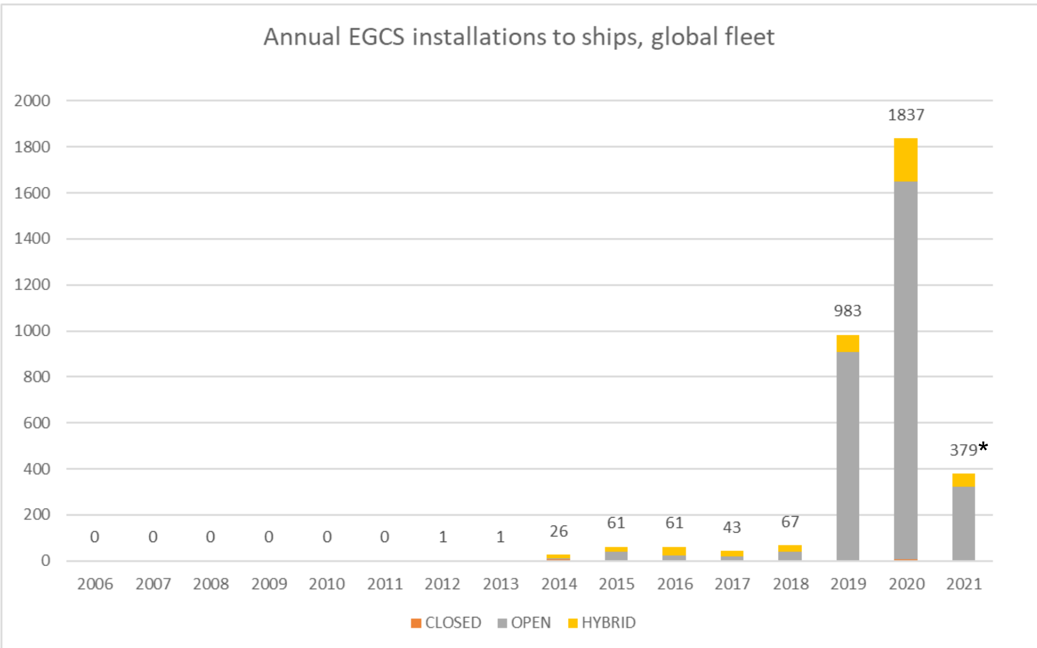


Figure 1. Installations of EGCS systems onboard ships each year. This data was collected from IMO GISIS notifications on Aug 8th 2021 and it only includes data for the first seven months of 2021.

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).

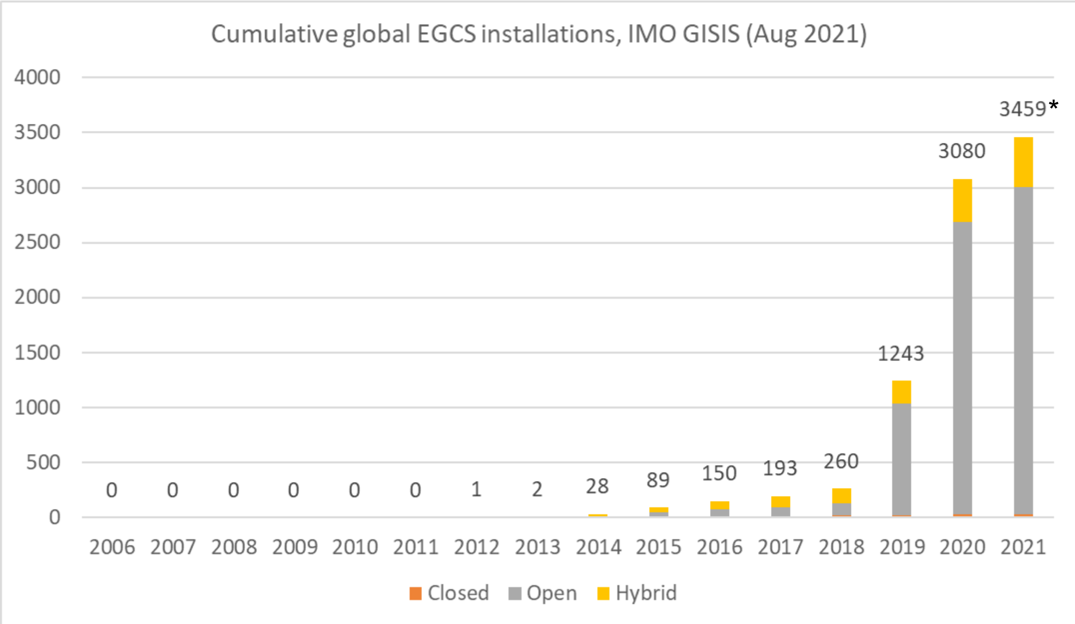


Figure 2. Number of ships in the global fleet with EGCS by Aug 8th 2021 according to IMO GISIS.

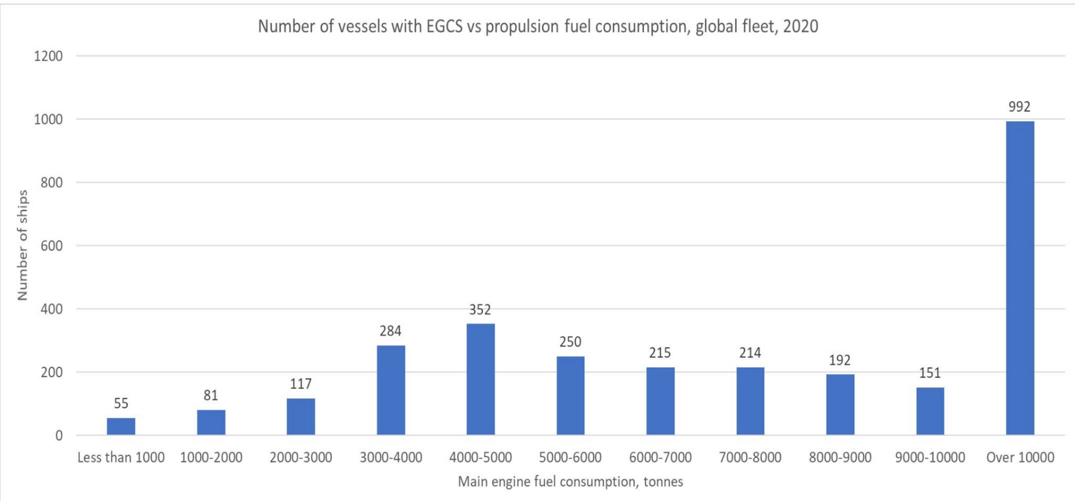


Figure 3. Estimated propulsion fuel consumption of the global active scrubber fleet (2903 vessels) in 2020. This graph is based on global scrubber modeling done with the STEAM model.

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.

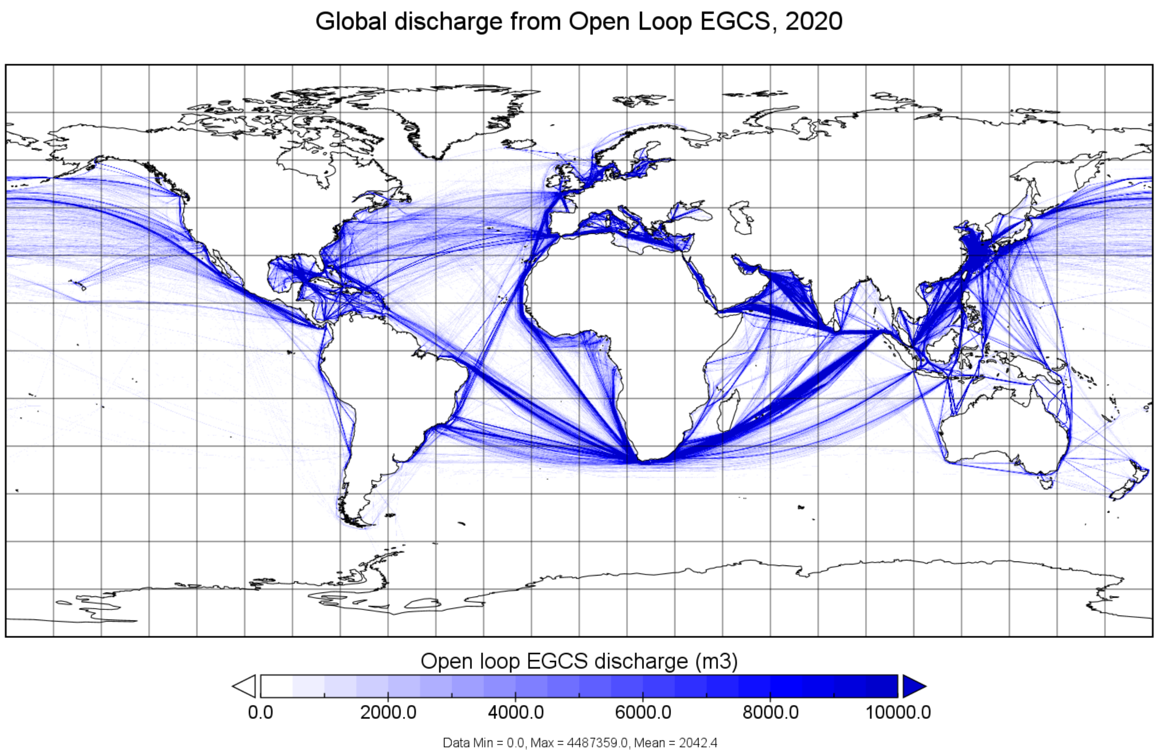


Figure 4. Global distribution of estimated Open Loop EGCS discharge in 2020. These data are based on global STEAM modeling.

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.

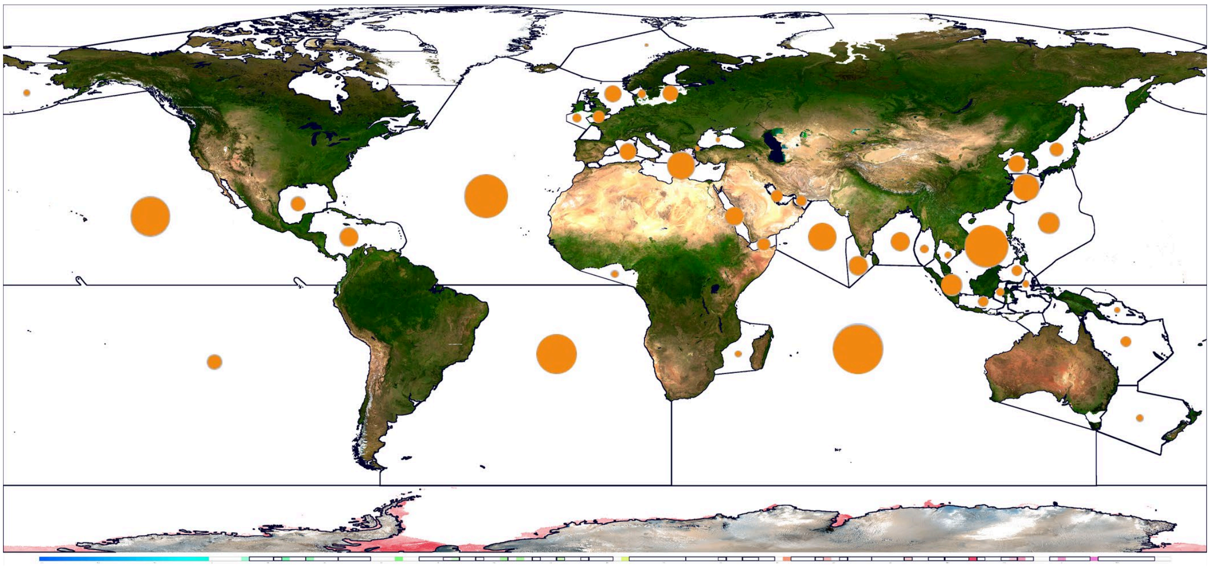


Figure 5. Global EGCS Open loop discharge on various sea regions during 2020. Size of the circle is relative to the discharge volume. Sea region definitions follow those from IHO.

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.

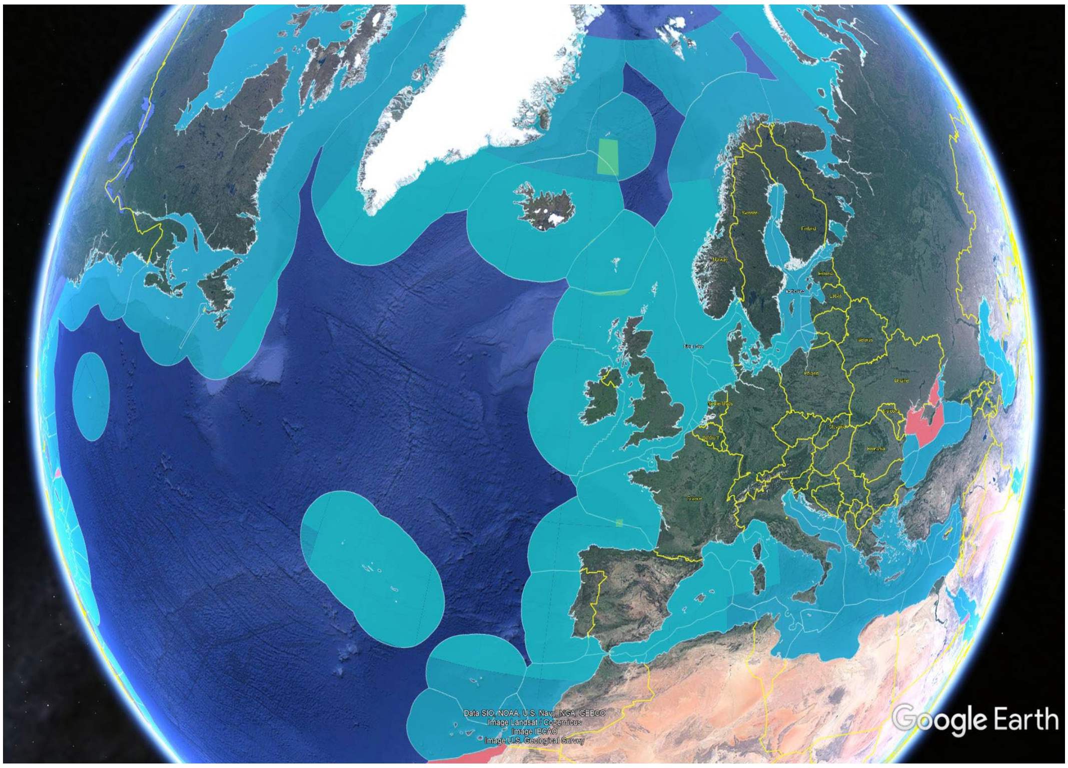


Figure 7. Exclusive Economic Zones in the OSPAR domain, from Flanders Marine Institute (2019a).

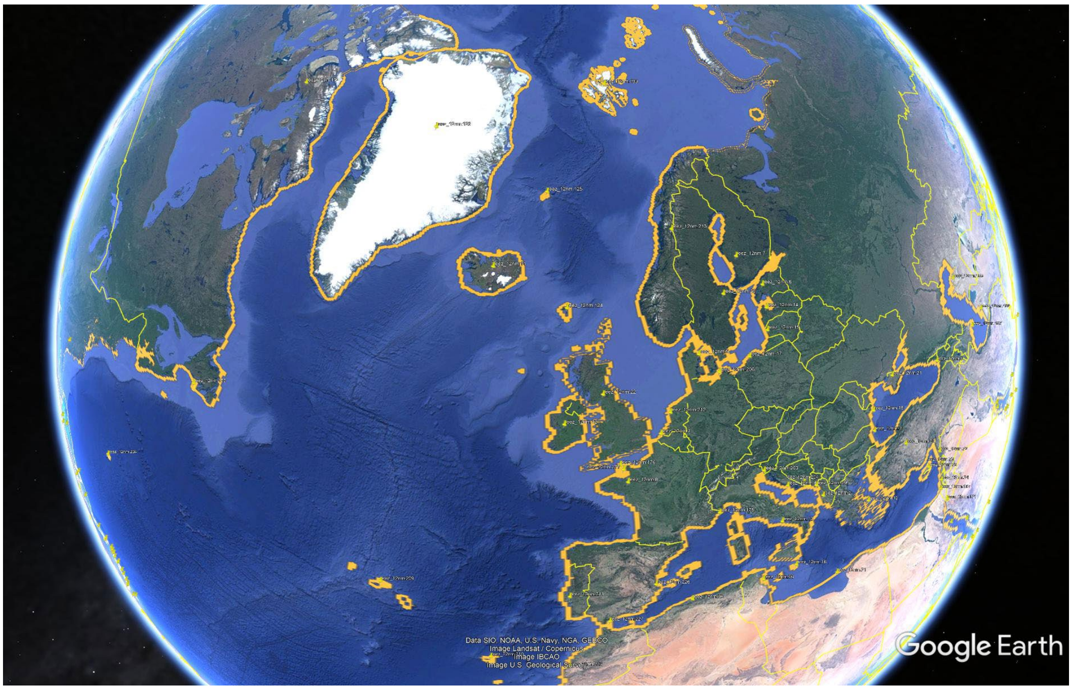


Figure 8. Description of territorial waters (12 NM) were made according to the Flanders Marine Institute (2019b).

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.

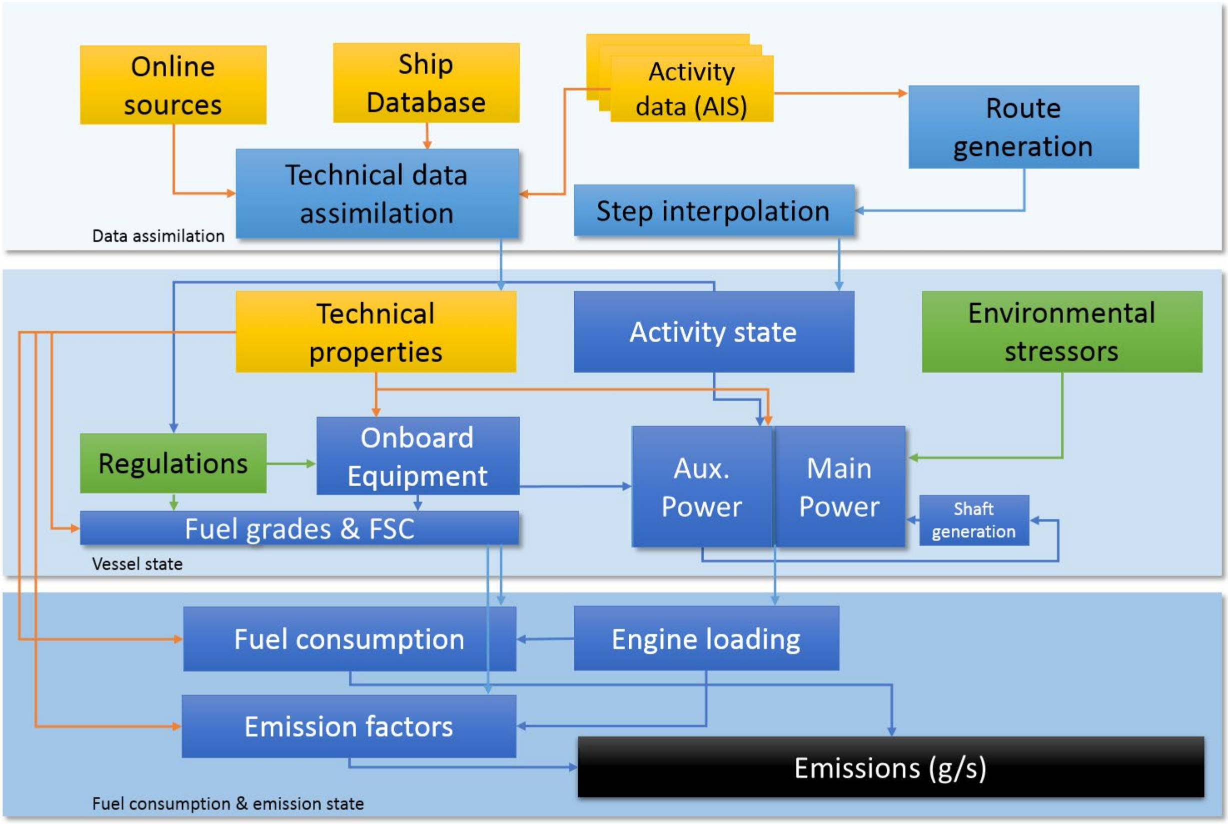
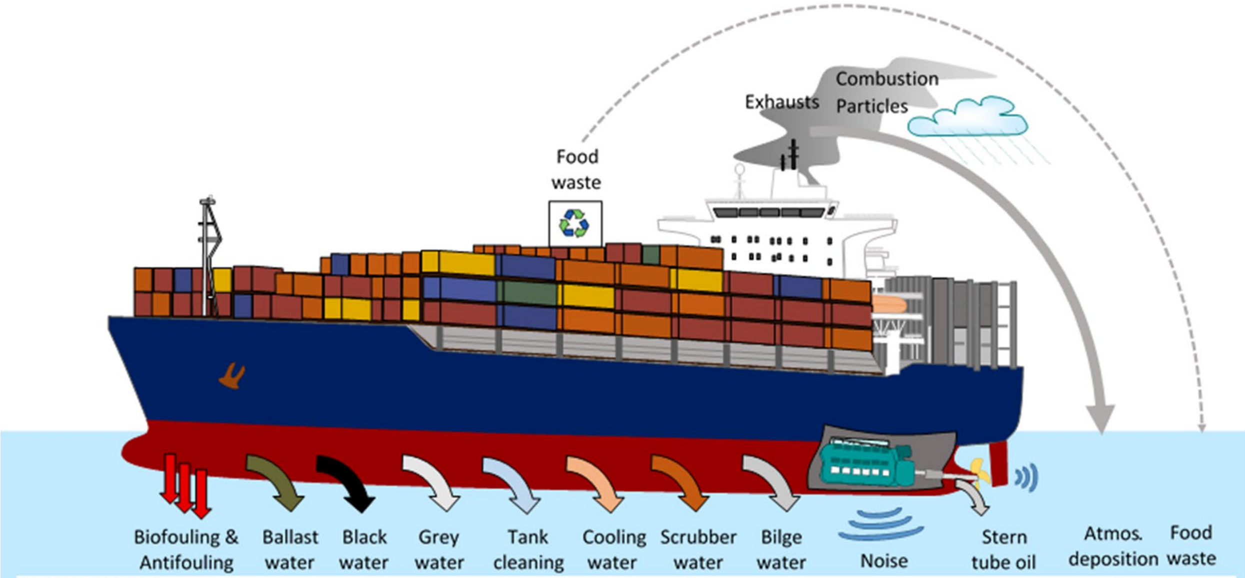


Figure 9. Schematic summary of various modeling steps involved in STEAM work. Image from Johansson et al (2017).

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.



	Biofouling & Antifouling	Ballast water	Black water	Grey water	Tank cleaning	Cooling water	Scrubber water	Bilge water	Noise	Stern tube oil	Atmos. deposition	Food waste
Acidifying substances							x				x	
BOD/COD		x	x	x								x
Halocarbons, POP		x										
Hydrocarbons, PAH		x		x	x		x	x		x	x	
Litter, PM					x						x	x
Metals	x			x		x	x	x		x		
NIS	x	x	x	x								
Nutrients, N, P		x	x	x	x		x	x			x	x
Energy/noise									x			
Shipping regulations	AFS	BWMC	MARPOL Annex IV	MARPOL Annex IV	MARPOL Annex I		MARPOL Annex VI	MARPOL Annex I		MARPOL Annex I	MARPOL Annex VI	MARPOL Annex V

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.

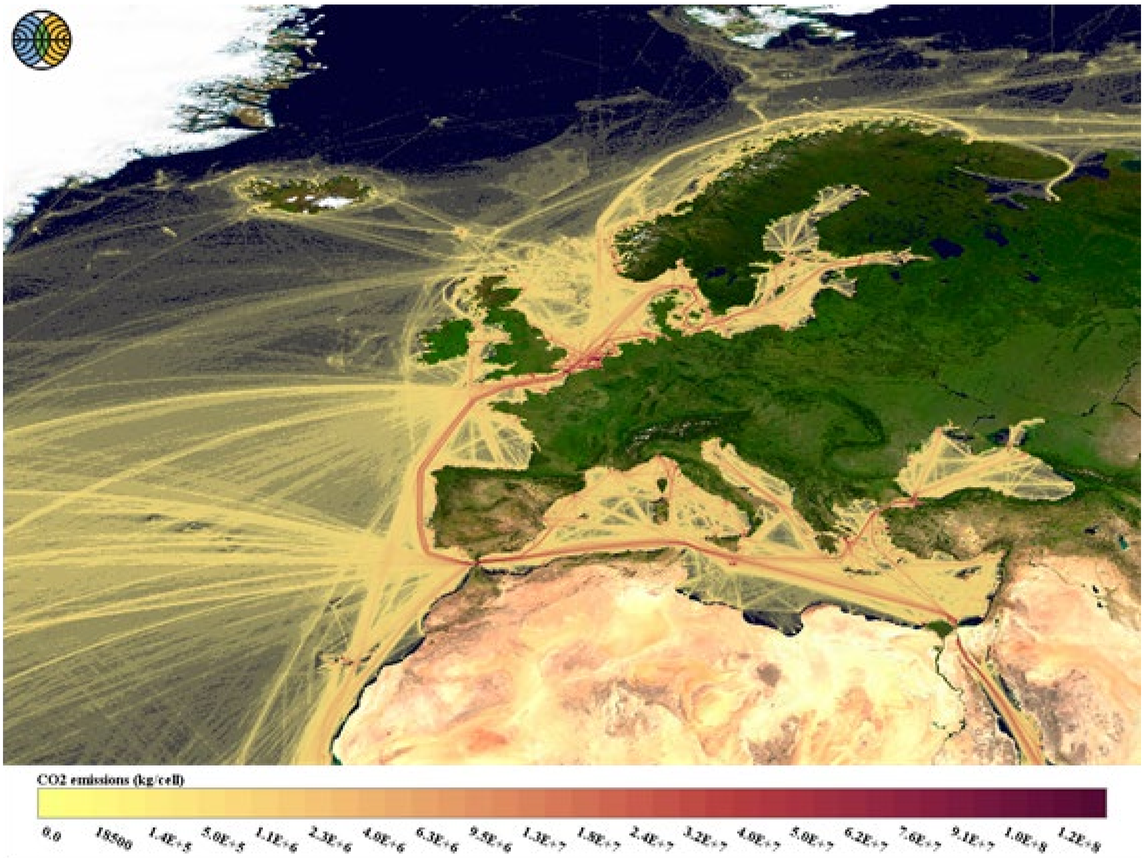


Figure 11. Ship emitted CO2 in the EU domain during the year 2020. This image depicts emissions of CO2 from ships sailing all the sea areas, not just OSPAR domains.

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).

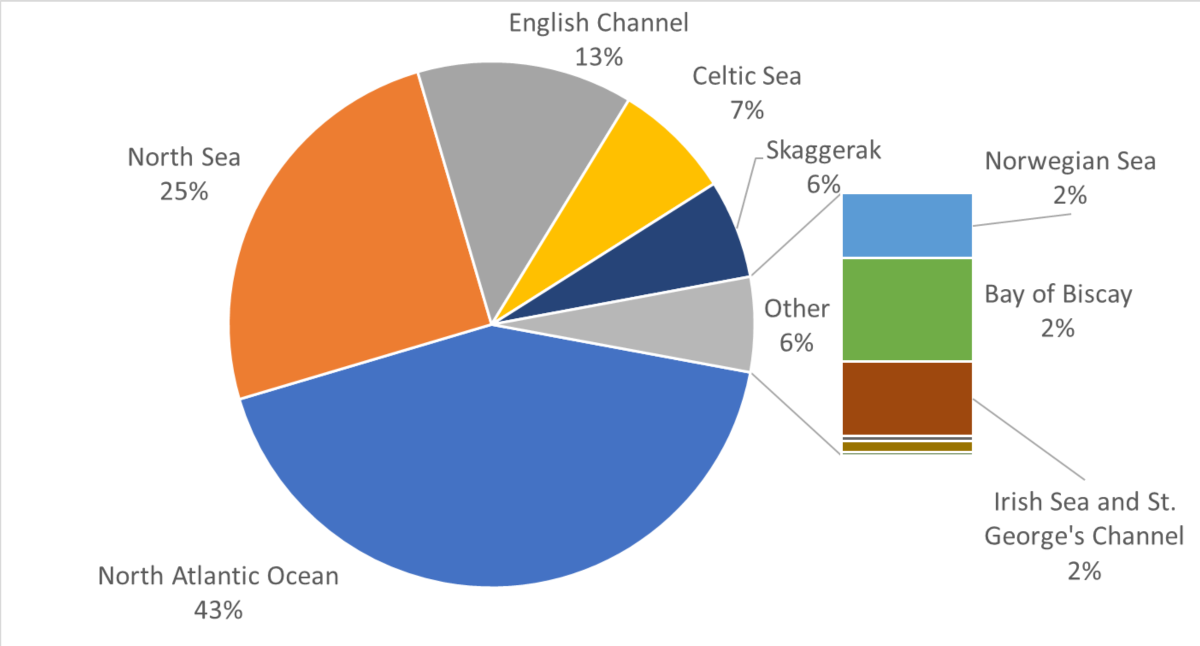


Figure 12. Combined discharge from both open and closed loop EGCS in various sea regions. These sea regions are defined by the International Hydrographic Organization (IHO) and they are not directly comparable to OSPAR Regions.

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

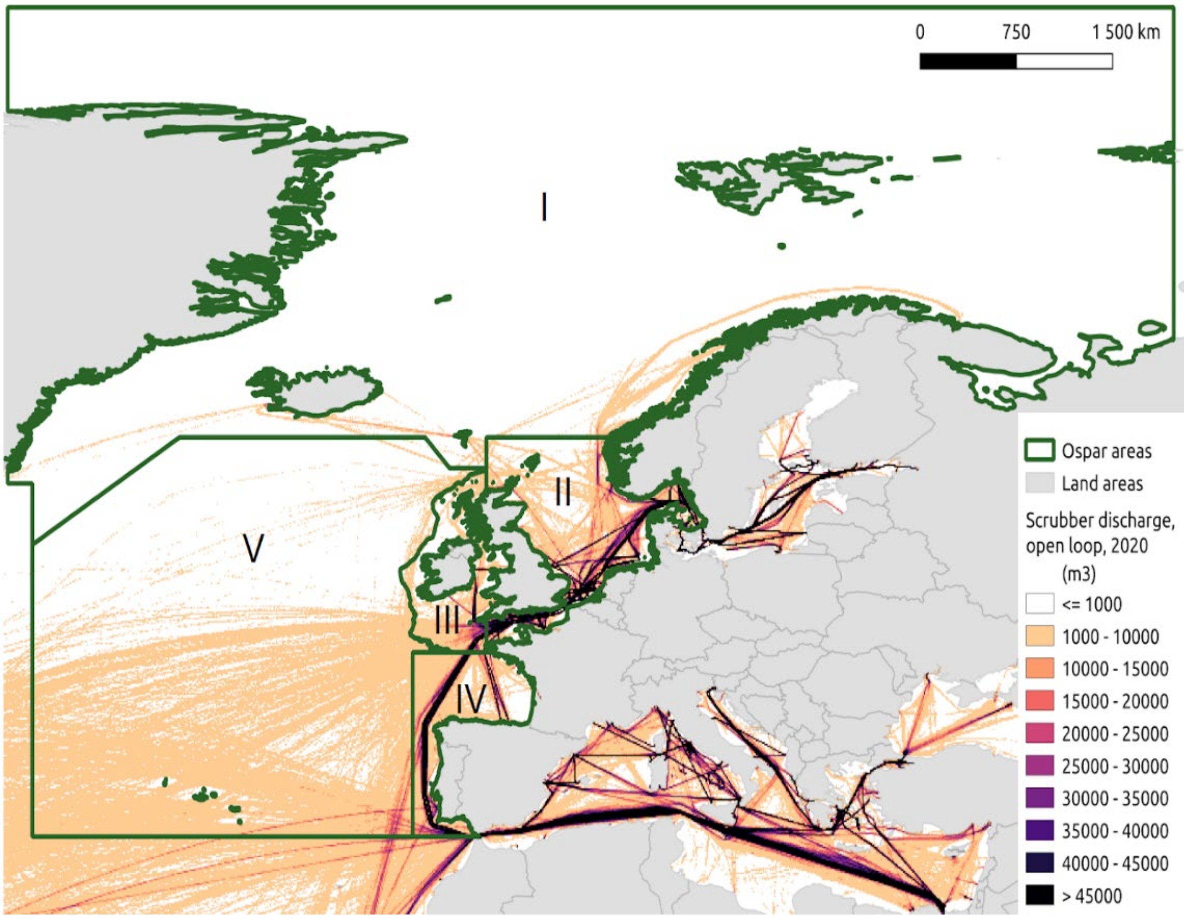


Figure 13. Open loop discharge from EGCS in Europe.

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. Most 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.

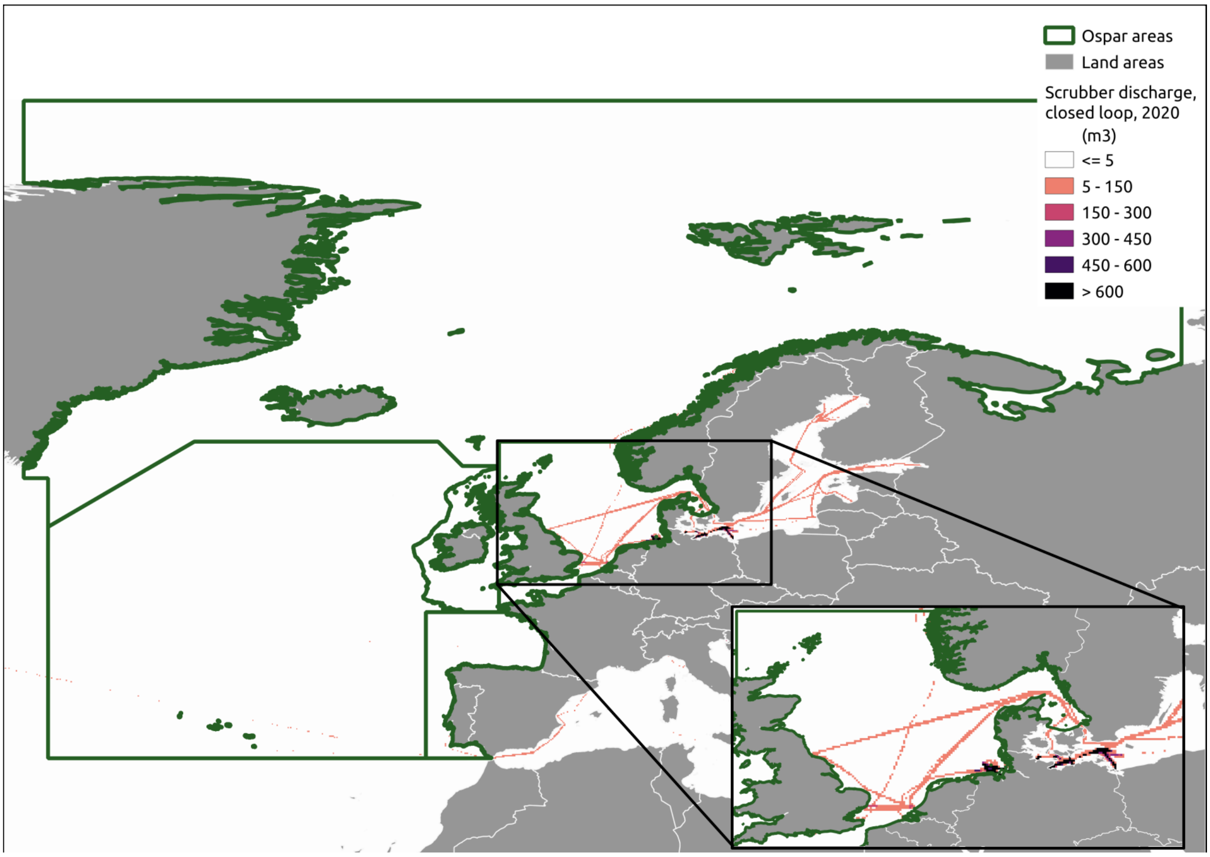


Figure 14. Closed loop discharges are probably from hybrid scrubbers entering German EEZ and switching the mode of operation from open to closed loop. There is a faintly visible closed loop discharge between Hoek van Holland-Harwich, which can be associated with the RoPax route between these two ports.

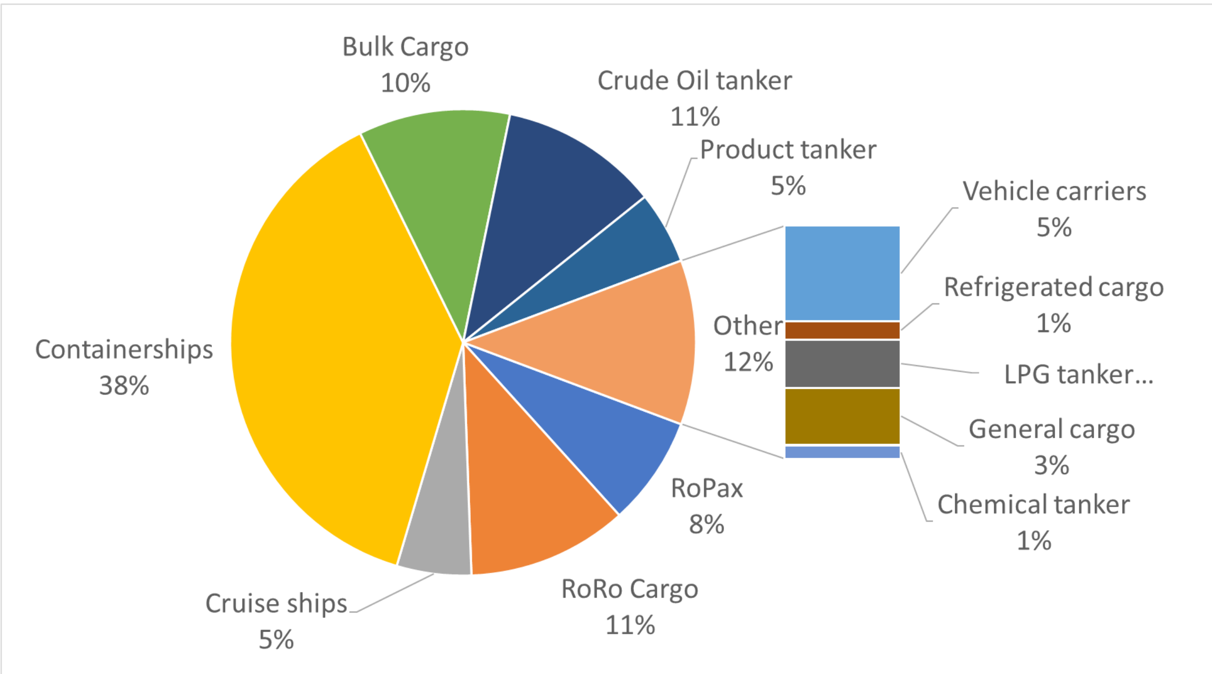


Figure 15. Open loop EGCS discharge by ship type for the OSPAR Region during 2020.

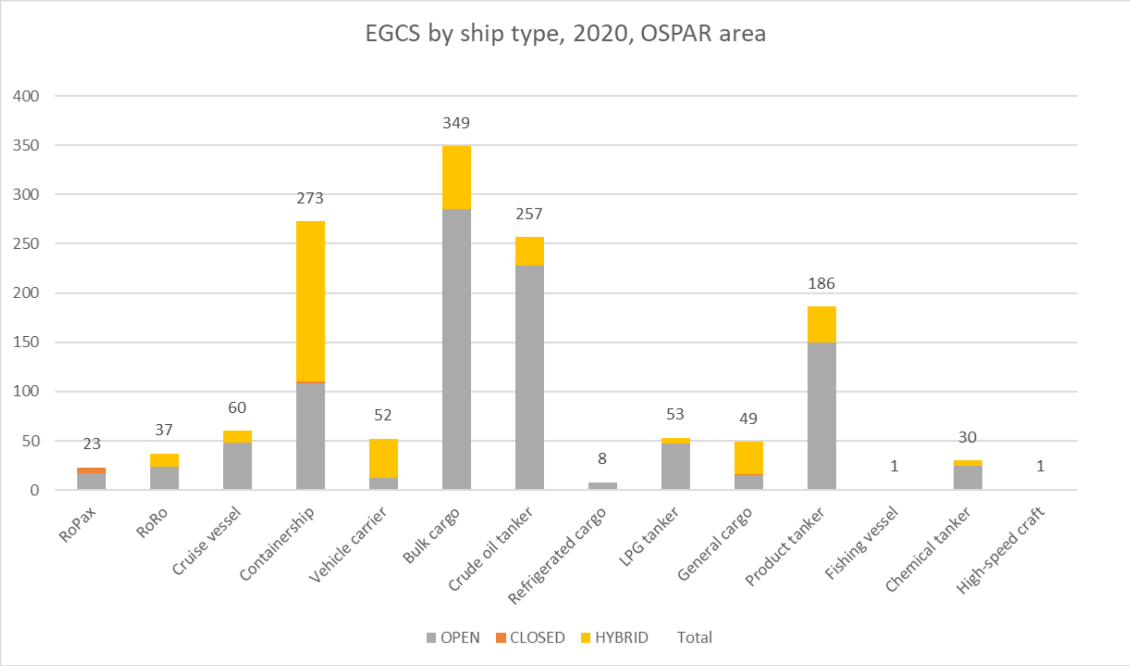


Figure 16. Installation of EGCS by ship type in the OSPAR Region. This allocation is based on vessels which were active during 2020 in the OSPAR domain.

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.

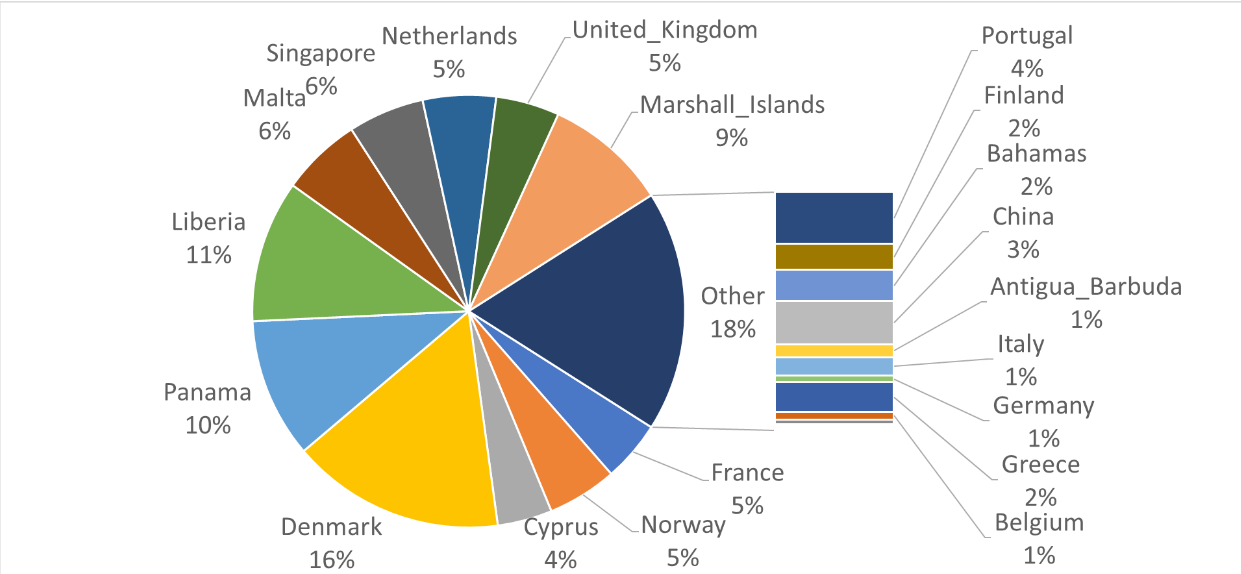


Figure 17. EGCS Open loop discharge by vessel flag state in 2020.

The Baltic Sea fleet has a very high 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.

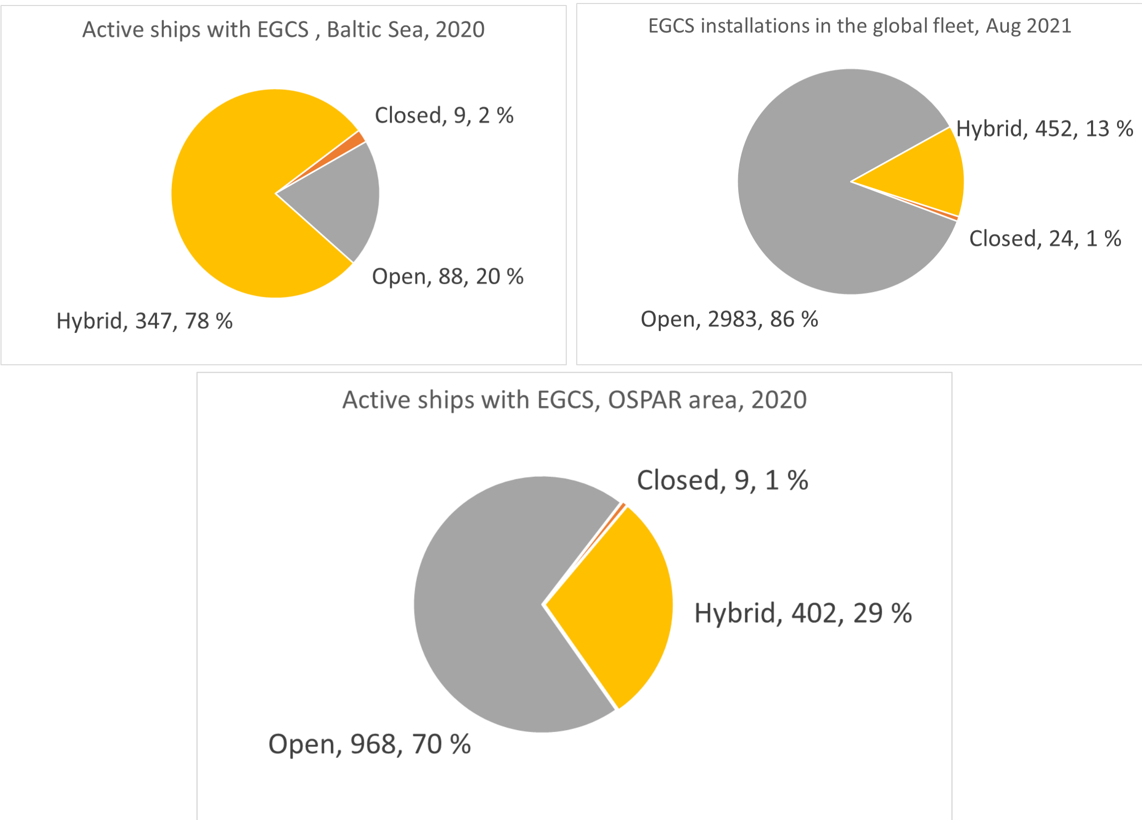


Figure 18. EGCS installations by equipment type, global fleet. Based on data collected from IMO GISIS on Aug 8th 2021.

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). Most of the vessels with a hybrid EGCS operate in the Baltic Sea area, which is very different from the global situation (Jalkanen et al., 2021a).

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).

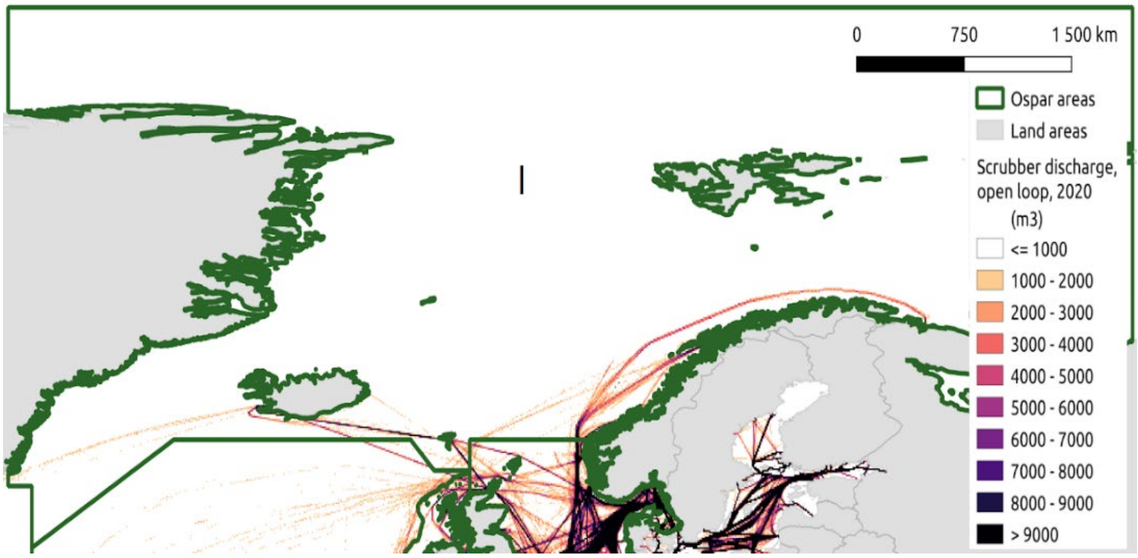


Figure 19. EGCS discharge from open loop systems in the OSPAR I area. Please note the scale in color is the same as in OSPAR V area, but different than in II, III, and IV areas.

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.

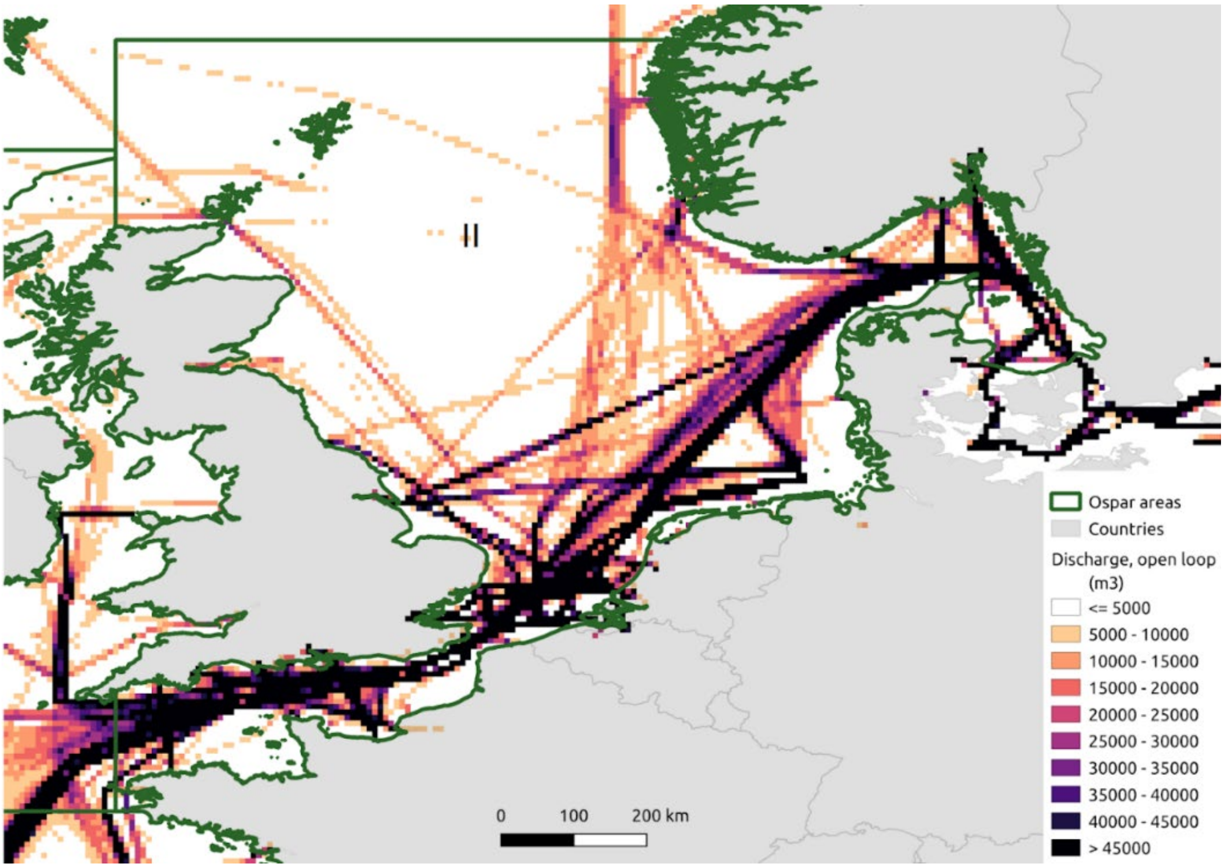


Figure 20. Open loop discharge in OSPAR Region II. Please note the scale in color is the same as in OSPAR III and IV areas, but different than in I and V areas.

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).

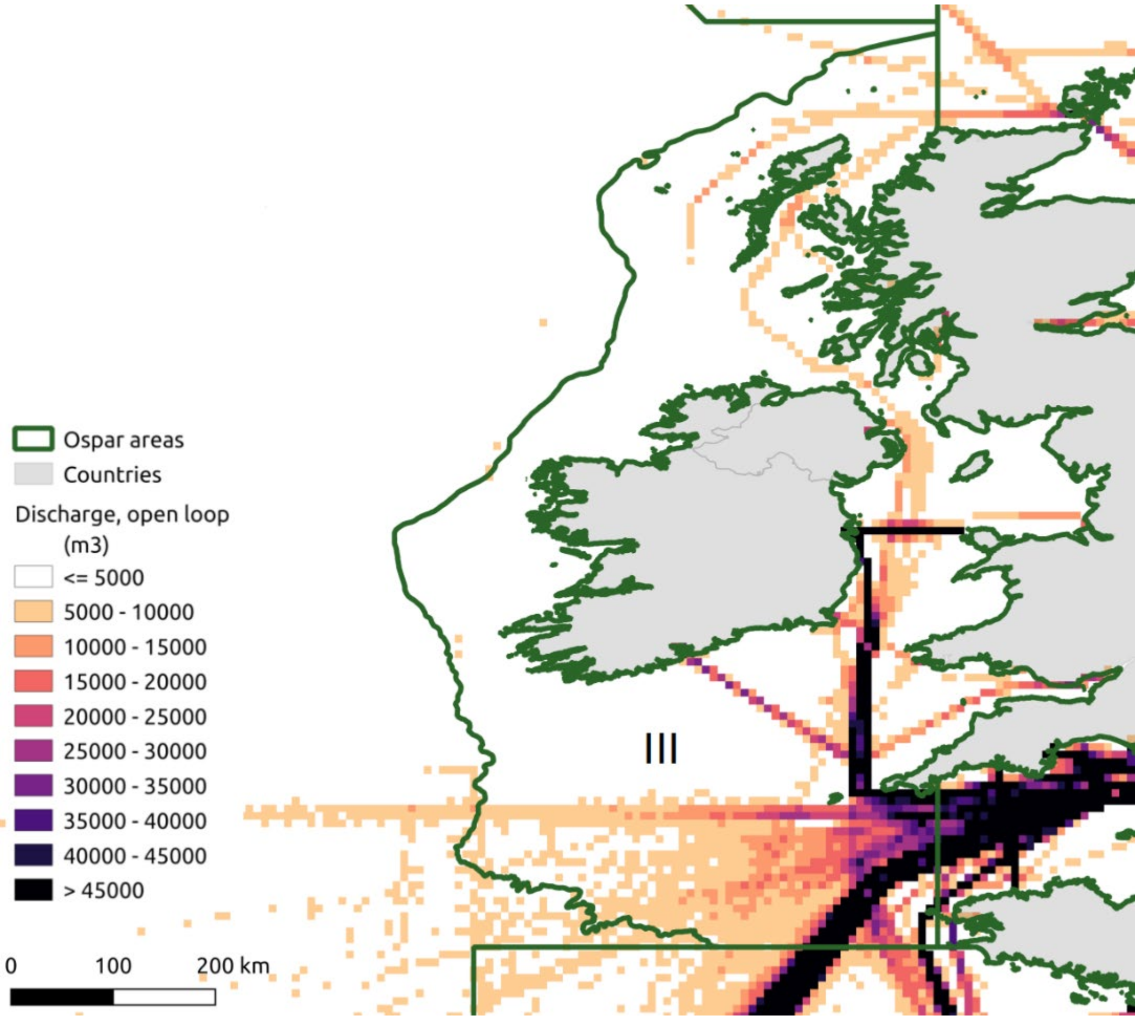


Figure 21. Open loop discharge in OSPAR Region III. Please note the scale in color is the same as in OSPAR II and IV areas, but different than in I and V areas.

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.

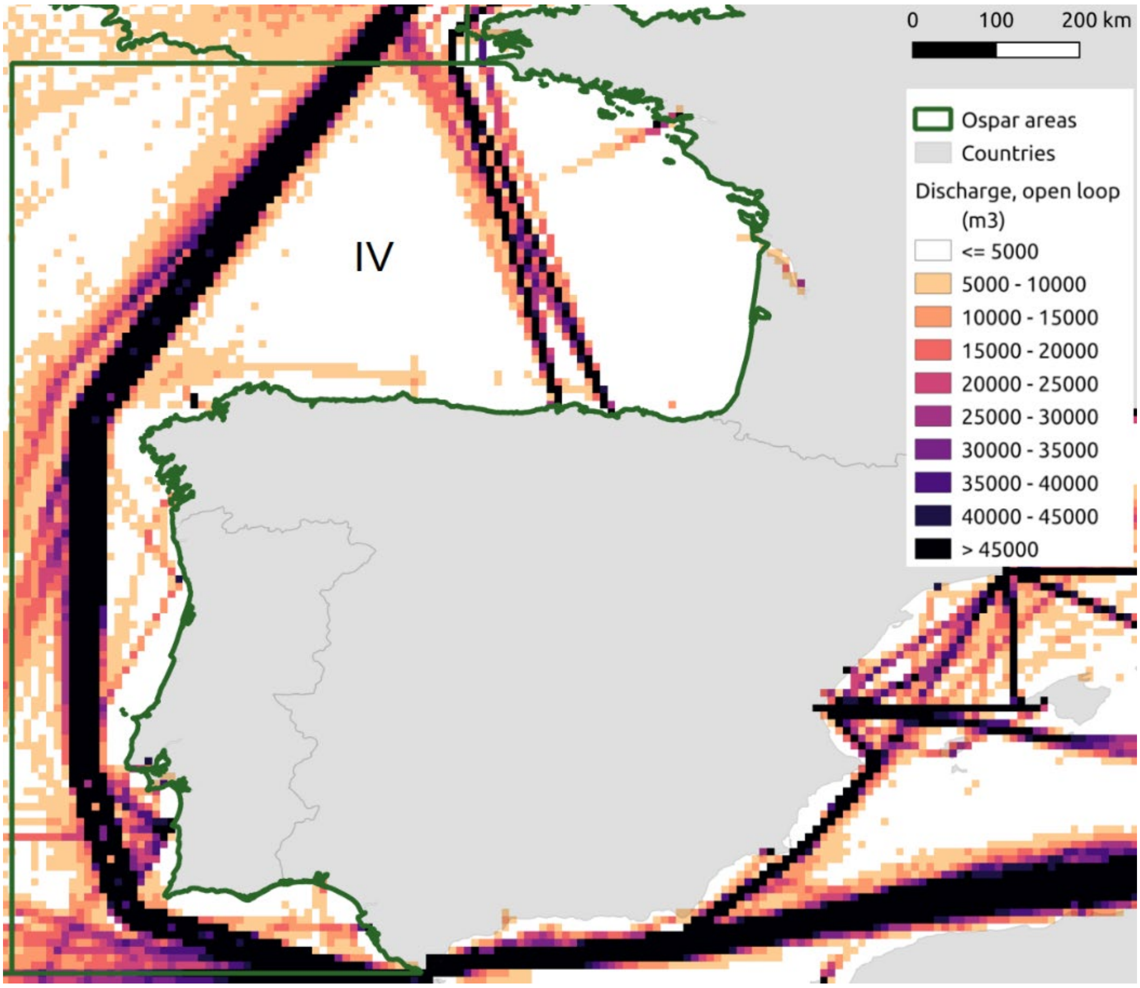


Figure 22. Open loop discharge in OSPAR Region IV. Please note the scale in colors which is the same as in OSPAR Regions II and III but different than in areas I and V.

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).

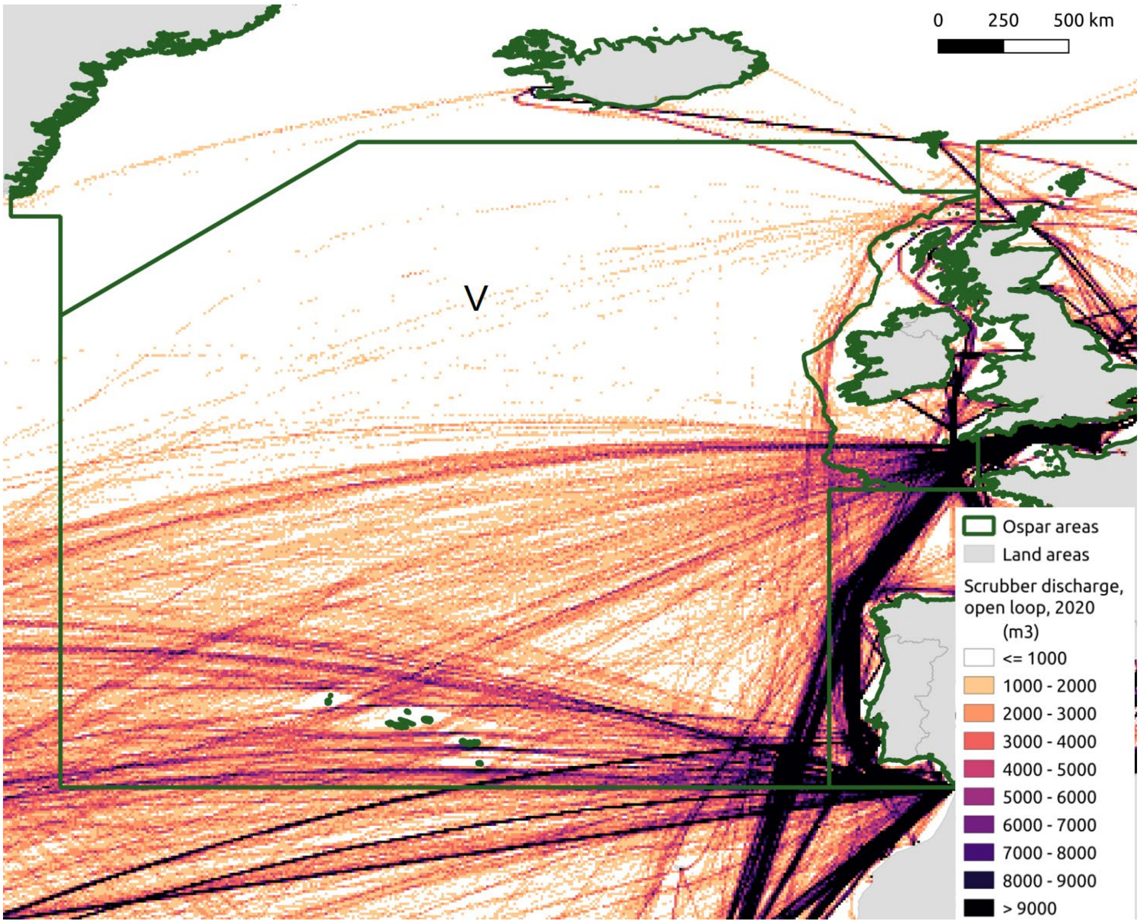


Figure 23. Open loop discharge in OSPAR Region IV. Please note the scale in color is the same as in OSPAR I area, but different than in II, III, and IV areas.

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.

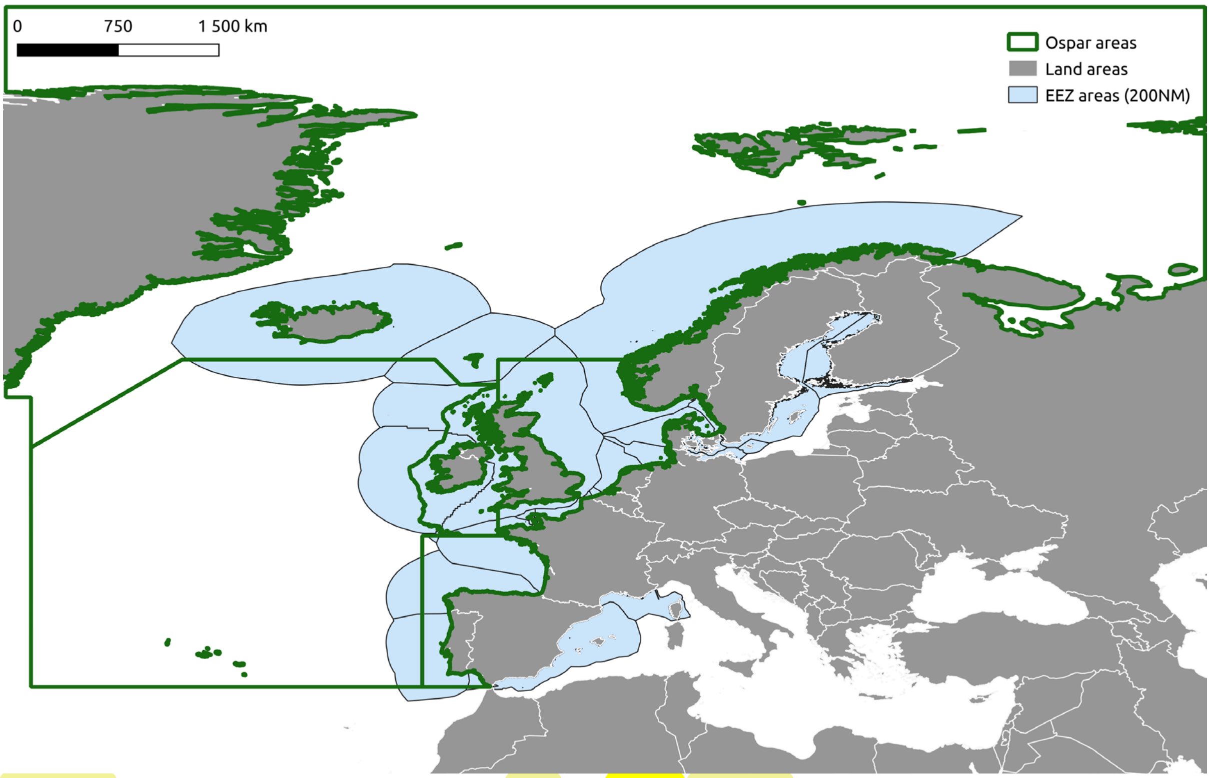


Figure 24. Blue color indicates EEZ (200 NM) areas of OSPAR countries. The green line shows the borders of OSPAR Region.

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 (*).

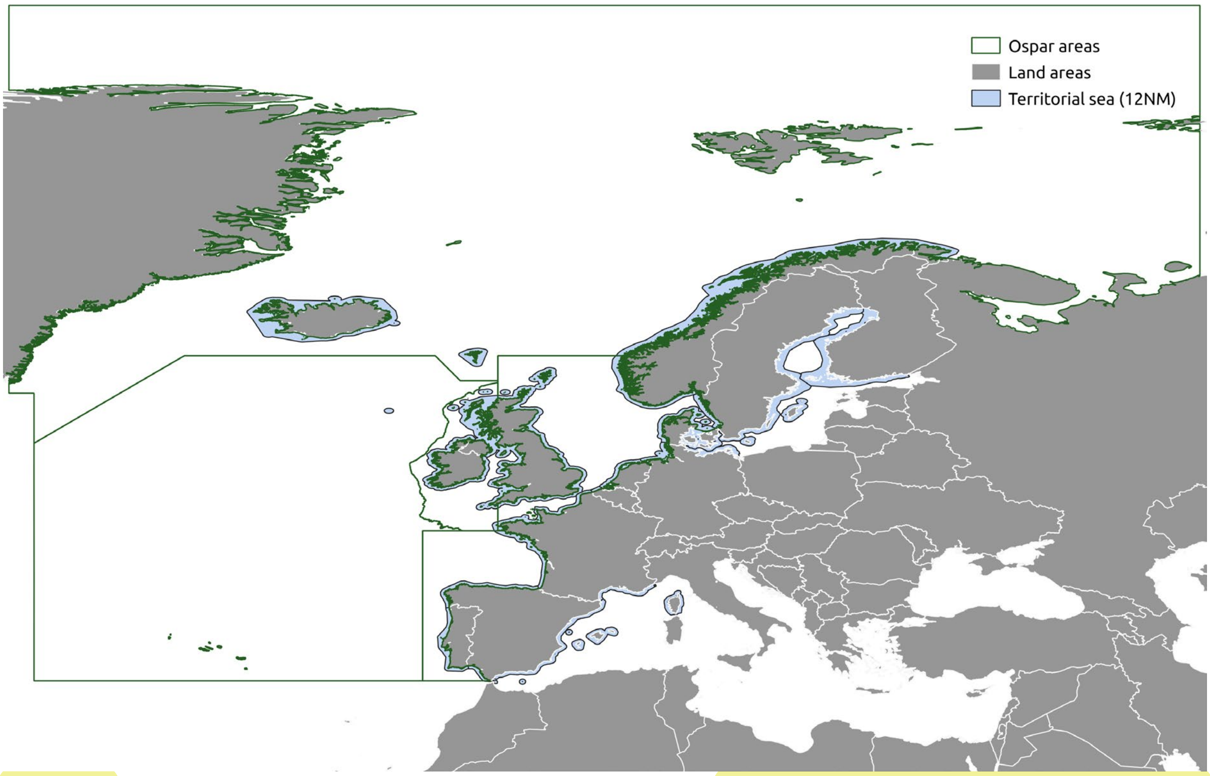


Figure 25. Territorial water areas (12 NM) of OSPAR countries. The green lines show the borders of OSPAR Regions.

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 8th 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.

It should be noted that a large share of the hybrid EGCS systems are installed on ships which operate in the overall OSPAR domain. 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 much larger (29%). Similar observation was done for the Baltic Sea fleet, where over 80% 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.

List of tables:

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		

OSPAR's Quality Status Report 2023

OSPAR Secretariat
The Aspect
12 Finsbury Square
London
EC2A 1AS
United Kingdom

t: +44 (0)20 7430 5200
f: +44 (0)20 7242 3737
e: secretariat@ospar.org
www.ospar.org

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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