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Final report

Overview of hazardous substances potentially emitted from offshore industries to the marine environment

Part 4: Emissions from offshore energy industry and other sea-based activities

by:

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On behalf of the German Environment Agency

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Abstract: Overview of hazardous substances potentially emitted from offshore industries to the marine environment

Within the RESOW project (Reduction of impacts of hazardous substances during installation and operation of offshore windfarms) potential emissions of hazardous substances from the offshore wind and oil as well as gas industries into the North Sea and Baltic Sea are investigated. This report of work package 4 provides an overview of substances potentially emitted from sea-based activities to the marine environment and which therefore may be relevant as additional contaminants according to Commission Decision (EU) 2017/848 (European Commission, 2017) for Descriptor 8 criteria D8C1. The aim is to support identification of relevant contaminants from offshore sources and if possible, to estimate the pollutant discharges to the environment from the respective offshore sources into the marine environment. The results can support the work of regional sea conventions to figure out relevant substances for their marine regions which are emitted offshore. In this report contaminants emitted from three types of sea-based sources into the marine environment were studied, next to the offshore industry which was studied in previous work packages from the RESOW project, including mariculture, maritime transport and (historically) dumped munition. The sources of mariculture and maritime transport were investigated in-depth, however, the source of dumped munition was only investigated to a limited extent.

Kurzbeschreibung: Potenzielle Schadstoffemissionen der Offshore Öl- und Gasindustrie in die

Meeresumwelt

Im Rahmen des RESOW-Projekts (Reduzierung von Schadstoffwirkungen beim Bau und Betrieb von Offshore-Windenergieanlagen, Umspann- und Konverterplattformen und Seekabeln) werden potenzielle Einträge aus Offshore-Industriequellen in die Meeresumwelt von Nord- und Ostsee untersucht. Der vorliegende Bericht des Arbeitspakets 4 gibt einen Überblick über Stoffe, die potenziell aus Offshore Quellen in die Meeresumwelt freigesetzt werden und die als zusätzliche Schadstoffe gemäß des Beschlusses (EU) 2017/848 der Kommission (Europäische Kommission, 2017) für Deskriptor 8, Kriterium D8C1 relevant sein können. Hiermit soll die Arbeit der regionalen Meeresschutzkonventionen unterstützt werden, um relevante Schadstoffe aus verschiedenen Offshore-Quellen zu identifizieren und, wenn möglich, die Menge der Schadstoffeinträge in die Meeresumwelt aus den individuellen Offshore-Quellen abzuschätzen. Neben den potenziellen Schadstoffen aus der Offshore-Wind- und Offshore-Öl- und Gasindustrie, die in den Arbeitspaketen 1 und 2 des RESOW Projektes identifiziert wurden, werden im Rahmen dieses Arbeitspakets drei weitere Offshore-Quellen betrachtet: Aquakultur, Seeverkehr und (historisch) versenkte Munition. Während die Einflüsse der Aquakultur und des Seeverkehrs eingehend untersucht wurden, konnte der Einfluss der versenkten Munition nur begrenzt untersucht werden.

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List of abbreviations

AFFF	Aqueous Film Forming Foam
APP	Antifouling Paint Particles
BAT	Best Available Technique
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
DCOIT	Dichloro-octylisothiazolinone
DDT	Dichloro-diphenyl-trichloroethane
ECHA	European Chemicals Agency
EEA	European Environmental Agency
EEZ	Exclusive Economic Zone
EGCS	Exhaust Gas Cleaning Systems
EMERGE	Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions
FDA	Food and Drug Administration
HELCOM	HELsinki COMmission
ICAF	Impressed Current Antifouling Systems
IMO	International Maritime Organization
MSFD	Marine Strategy Framework Directive
MTBE	Methyl Tertiary-Butyl Ether
OCP	Offshore Converter Platform
OSPAR	OSlo and PARis Conventions
OSS	Offshore Sub Station
OWT	Offshore Wind Turbine
PAH	Polycyclic Aromatic Hydrocarbons
PBT	Persistant, Bioaccumulative and Toxic
PCB	PolyChlorinated Biphenyls
PRTR	Pollutant Release and Transfer Register
SIN	Substitute It Now
TCMS	2,3,5,6-TetraChloro-4-(MethylSulfonyl)pyridine
TCMTB	2-(ThioCyanoMethylThio)Benzothiazole
VOC	Volatile Organic Compound
WFD	Water Framework Directive

Summary

The RESOW project and aim of the current study

This report presents the results of work package (WP) 4 of the RESOW project (Reduction of impacts of hazardous substances during installation and operation of offshore windfarms). In previous work packages hazardous substances from the offshore wind industry (WP1) and offshore oil and gas industry (WP2) were identified. In this study additionally further substances emitted to the marine environment from other sea-based activities are identified. The main research objectives of this work package are:

1. To provide an overview of substances potentially emitted from sea-based activities to the marine environment which may be relevant as additional contaminants according to Commission Decision (EU) 2017/848 (European Commission, 2017) for Descriptor 8 criteria D8C1 and to support regional cooperation to identify relevant contaminants from offshore sources and,
2. if possible, to estimate the amount of pollutant discharges to the environment from the respective offshore sources into the marine environment.

Sea-based emission sources of contaminants into the marine environment

In this report contaminants emitted from three additional types of sea-based sources into the marine environment were studied next to the offshore industry, including mariculture, maritime transport and (historically) dumped munitions. The sources of mariculture and maritime transport were investigated in-depth, however, the source of dumped munition was only investigated to a limited extent. Contaminants from mariculture include medicinal products used to treat fish against e.g. bacteria, parasites and stress (anaesthetics), feed additives and antifouling biocides used for protection of nets and submerged structures used in mariculture. In maritime transport various products are used which may lead to contaminant discharged into the marine environment. These are e.g. antifouling coatings, galvanic anodes, additionally operational discharges, scrubbers and spills may lead as well to emission of contaminants into the marine environment. Whether or not the emissions pose a risk to the environment depends on the hazardous properties of the emitted substances and the load that is emitted into the marine environment. If the additionally identified substances from mariculture, maritime transport and (historically) dumped munition are hazardous, was not assessed in this study.

Estimating emissions of chemical substances from sea-based source into the marine environment is difficult

It is often difficult to determine substance specific emission loads. Substance loads from maritime shipping and/or mariculture were estimated only if the substances of concern had been identified as hazardous within the two reports (WP1 and WP2) on sources from the offshore wind industry or offshore oil and gas industry. Emission loads from the offshore industry were compared with the emissions from other sea-based sources. Total emission loads from the offshore wind industry could not be estimated. Total emission loads from the offshore oil and gas industry could only be estimated based on produced water and sacrificial anodes. Total loads of substances emitted via maritime transport were estimated specifically for the Baltic Sea. For the North Sea only the total load of substances emitted from scrubbers was estimated. As there is only limited offshore oil and gas industry in the Baltic Sea only a comparison between emissions from maritime transport and the offshore oil and gas industry from the North Sea was done. For most substances the emitted load from the offshore oil and gas industry is much higher than the emitted load from maritime transport. Copper/copper oxide is being the exception, as the highest emission originates from maritime transport.

Zusammenfassung

RESOW-Projekt und das Ziel der aktuellen Studie

Dieser Bericht stellt die Ergebnisse des Arbeitspakets (AP) 4 des RESOW-Projekts (Reduzierung von Schadstoffwirkungen bei Bau und Betrieb von Offshore-Windenergieanlagen, Umspann,- und Konverterplattformen und Seekabeln) vor. In früheren Arbeitspaketen wurden gefährliche Stoffe aus der Offshore-Windindustrie (AP1) und der Offshore-Öl- und Gasindustrie (AP2) ermittelt. In dieser Studie werden weitere Stoffe identifiziert, die aus anderen offshore Aktivitäten in die Meeresumwelt freigesetzt werden. Die wichtigsten Ziele dieses Arbeitspakets sind:

1. Übersicht über chemische Stoffe, die potenziell bei maritimen Aktivitäten in die Meeresumwelt gelangen und als zusätzliche Schadstoffe gemäß dem Beschluss (EU) 2017/848 der Kommission (Europäische Kommission, 2017) für Deskriptor 8, Kriterium D8C1 relevant sein können, um somit relevante Schadstoffe aus Offshore-Quellen zu identifizieren und den regionalen Zusammenhang zwischen Kontaminanten und offshore Quellen zu erkennen, und,
2. wenn möglich, die Menge der Schadstoffeinträge aus den jeweiligen Offshore-Quellen in die Meeresumwelt abzuschätzen.

Offshore Quellen von Schadstoffemissionen in die Meeresumwelt

In diesem Bericht wurden Schadstoffe untersucht, die neben der Offshore-Wind und Offshore-Öl-und-Gas-Industrie von drei weiteren Offshore Quellen in die Meeresumwelt gelangen können; darunter Aquakultur, der Seeverkehr und (in der Vergangenheit) versenkte Munition. Die Quellen Aquakultur und Seeverkehr wurden eingehend untersucht, während die Quelle der versenkten Munition nur begrenzt untersucht wurde. Zu den gefährlichen Stoffen, die aus der Aquakultur eingetragen werden, gehören Arzneimittel, die zur Behandlung der Fische gegen z.B. Bakterien, Parasiten und Stress eingesetzt werden (Anästhetika), Futtermittelzusätze und Antifouling-Mittel, die zum Schutz von Netzen und Unterwasserstrukturen in der Aquakultur verwendet werden. Im Seeverkehr werden verschiedene Produkte verwendet, die zu Schadstoffeinträgen in die Meeresumwelt führen können, wie z. B. Antifouling-Anstriche. Darüber hinaus können auch Korrosionsschutz Anoden, betriebliche Abwässer, Schiffsabgasreinigungsanlagen und Leckagen zu einer Emission von Stoffen in die Meeresumwelt führen. Ob diese Emissionen ein Risiko für die Umwelt darstellen, hängt von den Eigenschaften der emittierten Stoffe und von der Menge, in der die Stoffe in die Meeresumwelt abgegeben werden, ab. Ob die zusätzlich identifizierten Stoffe aus der Marikultur, dem Seeverkehr und (historisch) versenkter Munition gefährlich sind oder nicht, wurde in dieser Studie nicht bewertet.

Die Abschätzung von Emissionen aus Offshore-Quellen in die Meeresumwelt ist schwierig

Es ist oft schwierig, stoffspezifische Emissionsmengen zu bestimmen. Die Mengen der Stoffeinträge aus der Seeschifffahrt und/oder Aquakultur wurden nur dann abgeschätzt, wenn die betreffenden Stoffe in den Berichten zur Offshore-Windindustrie oder der Offshore-Öl- und Gasindustrie als gefährlich eingestuft waren. Die Emissionsmengen aus der Offshore-Industrie wurden mit den Emissionen aus anderen maritimen Quellen verglichen. Die gesamte Emissionsmenge aus der Offshore-Windindustrie konnte nicht geschätzt werden. Die gesamten Emissionsmengen aus der Offshore-Öl- und Gasindustrie konnten nur auf der Grundlage von Produktionswasser und Opferanoden geschätzt werden. Die Gesamtfracht von Stoffen, die über den Seeverkehr emittiert werden, wurde nur für die Ostsee geschätzt. Die Gesamtfracht von Stoffen, die von Schiffsabgasreinigungsanlagen emittiert werden, wurde auf der Grundlage der

Studie nur für die Nordsee geschätzt. Da es in der Ostsee kaum Offshore-Öl- und -Gasindustrie gibt, wurde ein Vergleich nur zwischen den Emissionen aus dem Seeverkehr und der Offshore-Öl- und -Gasindustrie in der Nordsee durchgeführt. Bei den meisten Stoffen ist die Emission durch die Offshore-Öl- und -Gasindustrie wesentlich höher als die Emission durch den Seeverkehr. Kupfer/Kupferoxid bildet die Ausnahme, da hier die meisten Emissionen aus dem Seeverkehr stammen.

1 Introduction

1.1 Background information

Contaminants may reach the marine environment via land-based sources or via sea-based sources as well as via atmospheric transport. Contaminants from land-based sources are mostly emitted to the marine environment via rivers, while examples of sources in the marine environment itself include mariculture (marine aquaculture), maritime transport (shipping) and the offshore energy industry.

In 2016 Tornero and Hanke compiled a list of contaminants potentially released from sea-based anthropogenic sources containing 276 substances (Tornero & Hanke, 2016a), of which most are linked to offshore oil and gas activities, shipping or mariculture. Please note that in some cases substances are associated with multiple sea-based sources. The full list of substances is included in the study from Tornero & Hanke (2016a).

1.2 The RESOW project

This report presents the results of workpackage (WP) 4 of the RESOW project. The overall goal of the RESOW project is to create an overview of the most relevant hazardous substances emitted from offshore sources to the North Sea and the Baltic Sea.

In WP1 an overview of substances emitted from various activities related to offshore wind farming is presented (UBA, in press a). In WP2 an overview of substances emitted from various activities related to offshore oil and gas exploration and production is presented (UBA, 2023). In WP1 and 2 the lists of emitted substances were assessed to identify those substances that may pose a risk to the marine environment. These hazardous substances are identified by assessing their hazardous potential based on PBT criteria (persistant, bioaccumulative and toxic). Additionally various substance lists were consulted, such as SIN-list (Substitute It Now), OSPAR list of substances of possible concern, OSPAR list of chemicals for priority action, the ECHA endocrine disruptor assessment list and the priority substances under the European Water Framework Directive (WFD) (more precisely: river basin specific pollutants and priority substances respectively listed in annex 6 and 8 of the German Ordinance on the Protection of Surface Waters, which represents the national implementation of the Water Framework Directive). For more information on the selection of hazardous substances, please have a look at the reports of WP1 and 2.

In WP3, recommendations are proposed to reduce emission from offshore wind farming, using Best Available Technique (BAT).

In WP4 the lists of hazardous substances as determined in WP1 and 2 are complemented by adding substances emitted to the marine environment from other sea-based activities. In this report the results of WP4 are presented.

1.3 Research Objectives

As in the previous three workpackages, the area under investigation includes the scope of the Marine Strategy Framework Directive (MSFD), EU Directive 2008/56/EC5. The MSFD applies to marine waters from the seaward side of the baseline to the end of the Exclusive Economic Zone (EEZ). In Commission Decision (EU) 2017/848 (European Commission, 2017) criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment are layed down. According to this Commission Decision relevant pollutants from offshore sources that can cause pollution effects are to be considered in addition to the priority substances of the WFD, if relevant. The priority substances under the WFD (Annex 8 of the Surface Water Ordinance of 20 June 2016 (OGewV, 2016) are therefore not considered in this study, but the river basin-specific pollutants (substances in Annex 6, OGewV, 2016) are. Hazardous substances in the marine environment should be assessed by EU member states, as defined under MSFD Descriptor 8 (European Commission, 2017).

The main research objectives of this WP are:

1. To provide an overview of substances potentially emitted from sea-based activities to the marine environment which may be relevant as additional contaminants according to Commission Decision (EU) 2017/848 (European Commission, 2017) for Descriptor 8 criteria D8C1 and to support regional cooperation to identify relevant contaminants from offshore sources.
2. and, if possible, to estimate the pollutant discharges to the environment from the respective offshore sources into the marine environment.

1.4 Methodology

In WP1 and 2 extensive literature research was done to identify those substances emitted from the offshore wind industry and oil and gas industry with hazardous properties for the marine environment. In WP4 substances from other sea-based sources are added to the list of potentially hazardous substances from the previous workpackages. These substances are identified by a limited literature review, confined to publicly available information from OSPAR[1], HELCOM[2], the EMERGE project[3] and the Dutch Pollutant Release and Transfer Register (PRTR)[4]. Additionally, a limited number of selected papers and reports were reviewed as well, see the full list of references in chapter 5.

[1] https://www.ospar.org/

[2] https://helcom.fi/

[3] https://emerge-h2020.eu/

[4] https://www.emissieregistratie.nl/

2 Identification of substances emitted to the marine environment from sea-based sources

In this chapter potential emissions from sea-based sources are described in more detail. The following sea-based sources are described: offshore wind industry, oil and gas industry, mariculture and maritime transport (shipping).

2.1 Offshore wind industry

In WP1 of the RESOW project an overview on possible emissions from the offshore wind industry is presented (UBA, in press. a). Emissions from the offshore wind industry can be associated to the different life phases of offshore wind structures such as installation, operation and decommissioning. The analysis shows that the highest emissions into the marine environment are caused by materials applied in open systems, such as the release of metals from galvanic corrosion protection measures. Furthermore, aqueous film forming foams (AFFF), fuels and outdoor applied hydraulic oils are found to be a possible emission source, since they have a higher risk to be spilled into the marine environment due to accidents. Only substances that are potentially emitted via open systems and closed systems with a higher risk of accidents are identified as hazardous substances, the overview of those substances can be found in Table 4 and

Table 5 in Appendix A. Substances potentially emitted via closed systems with a low risk of accidents are not included. In WP4 only those substances that are not regulated under the WFD priority list of substances are of interest and are shown in Appendix A.1.

2.2 Offshore oil and gas industry

In WP2, an overview on potential emissions of hazardous substances from the oil and gas industry is presented (UBA, 2023). Emission sources from the offshore oil and gas industry can be associated to the different activities on the offshore platforms and include emissions from drilling fluids, cuttings piles, accidental spills, produced water and corrosion protection materials. Most emissions originating from offshore oil and gas platforms consist of a mixture of both naturally occurring chemicals and man-made chemicals added to these materials to facilitate various offshore processes. For example, naturally occurring chemicals, such as hydrocarbons, may end up in the environment via various oil and gas activities, such as drilling oil production. The composition of the natural materials can be very variable and mostly depends on environmental circumstances and the age of the well. Only for the natural composition of produced water enough information seemed to be available about the quantitative composition (UBA, 2023). The quantitative composition of the manmade chemicals added to produced water and drilling fluids is not available and could therefore not be determined. In WP2 only the qualitative composition of produced water and of corrosion protection could be analysed in depth for presence of hazardous substances. Many of the substances emitted via produced water, such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals, and corrosion protection are expected to be hazardous to the marine environment. In Table 6 in Appendix A an overview of the selected hazardous substances from the oil and gas industry, as determined in WP2, is presented. In this report only those substances that are not regulated under the WFD priority list of substances are of interest and are shown in Appendix A.2.

2.3 Mariculture

A broad range of substances is used in marine aquaculture, also called mariculture, to increase productivity and efficiency. All substances from mariculture, as identified in the paper by Tornero and Hanke (Tornero & Hanke, 2016b), are included in Table 7 in Appendix B, only excluding those substances that are regulated under the WFD list of priority substances. In the following sections more information on emissions from the various activities related to mariculture is presented.

2.3.1 Veterinary medicinal products

Medicinal products are used in aquaculture for various purposes which are mainly related to protection, as explained in more detail in the following:

2.3.1.1 Antibiotics

Antibiotics are used to fight bacterial infections. Antibiotics are usually administered to organisms together with their feed, but other methods, such as injection of antibiotics, are sometimes used as well. Both injection and feeding of antibiotics results in high levels of antibiotics and their breakdown products being emitted into the marine environment (Ferreira et al., 2007). For example, in intensive fisheries approximately 70-80% of antibiotics administered to the fish end up in the environment (Ferreira et al., 2007).

2.3.1.2 Parasiticides

Parasiticides are mainly used against parasitic diseases. Examples of parasiticides include various pyrethroids, organophosphates and avermectins. Some parasiticides, such as cypermethrin, are listed as priority substances under the WFD (Tornero & Hanke, 2016b).

2.3.1.3 Anesthetics

In aquaculture anesthetics are sometimes used to sedate fish during egg and spawn stripping and during transportation in order to reduce stress for fish. The use of anesthetics is irregular and in low doses, therefore limiting the emission to the marine environment (Burridge et al., 2010). There are two types of anesthetics, natural and synthetic. Currently the only synthetic anesthetic approved by the Food and Drug Administration (FDA) is tricaine methanesulfonate (MS-222) (FDA, 2022). The most commonly used natural anesthetic is clove oil (Aydin et al., 2020).

2.3.2 Disinfectants

In Europe, only biocidal products of product type 3 (disinfections for veterinary hygiene) that are registered or authorized according to the Biocidal Products Regulation (Regulation (EU) No 528/2012) in the respective country for the intended use should be used. Generally, disinfectants are more re levant in land-based aquaculture.

2.3.3 Feed additives

Fish feed formulations supplemented with a variety of trace elements and metals to fulfil mineral requirements of fish are the main source of metal contamination in sediment under fish cages (Grigorakis and Rigos, 2011; Simpson et al., 2013). Feed formulas mainly contain copper, zinc, iron, manganese, and sometimes other trace elements like cobalt, arsenic, magnesium and selenium (CIESM, 2007; Burridge et al., 2010).

2.3.4 Antifouling biocides

Antifouling measures are commonly used in aquaculture equipment, especially in mariculture. Antifouling biocides are applied as a coating on the submerged structures and net-cages used in mariculture to prevent the occurrence of biofouling. After the use of tributyltin (TBT) was prohibited by the International Maritime Organization (IMO) in 2008 (IMO, 2002) nowadays most antifouling paints are based on copper, mainly as copper oxide (Tornero & Hanke, 2016b).

2.4 Maritime transport (shipping)

In the following sections more information on emissions related to the various aspects of maritime transport is presented.

2.4.1 Antifouling coatings

The underwater surfaces of ships are prone to fouling, which means growth of microorganisms, plants, algae and animals. Fouling can have a detrimental effect on these surfaces, increasing the operational cost of maritime transport due to higher fuel needs. In order to prevent the growth and accumulation of organisms on ships and vessels, the hulls are often coated with antifouling paints containing biocides. Antifouling coatings can end up in the marine environment via leaching, but also via antifouling paint particles (APP) generated during activities such as maintenance and by collisions. Increased levels of zinc, copper and cybutryne were found in a study of active substances and metabolites from antifouling coatings (Daehne et al., 2017). The IMO has prohibited the use of cybutryne in antifouling systems from 1 January 2023 (IMO, 2021). As described in 2.3.4 the use of tributyltin (TBT) in antifouling paints was prohibited by the IMO in 2008 (IMO, 2002). All contaminants from maritime transport as identified in the paper by Tornero and Hanke (2016b) are included in Table 7 in Appendix B, only excluding those substances that are regulated under the WFD priority list of substances.

2.4.2 Anodes

Ships are coated in order to prevent corrosion, however, as the coating alone is not sufficient to protect from corrosion additionally cathodic protection is used. Cathodic protection is done using anodes, which are more electrochemically negative then the coating and therefore corrode first. The two main metals being used as anodes in maritime transport are zinc and aluminium (Dutch PRTR, 2015). As described in previous workpackages from the RESOW project metallic anodes are alloys which can contain other metals as well. Aluminium anodes may for example contain zinc and indium, which support the functionality of the anode and e.g. cadmium as impurity (WP1 report, UBA in press a).

2.4.3 Operational discharges

Operational discharges, such as wastewater, are related to any ship-based pollution that is not restricted to accidents. If and where operational discharges take place depends on regulations and the location of the ships. For example, ships may only discharge untreated black wastewater outside the 12-mile zone (MARPOL, 2012).

In a study on the operational discharges from fishing vessels and other non-recreational vessels it was found that the greatest environmental concern due to operational discharges was represented by copper and arsenic (US EPA, 2010). Source of these discharges were not specified.

In 2020 59% of detected spills from ships on the Baltic Sea consisted of greywater, garbage, litter and other unknown materials (HELCOM, 2022).

2.4.4 Scrubbers

In order to reduce atmospheric sulphur emissions Exhaust Gas Cleaning Systems (EGCS), or so-called scrubbers, can be used to clean exhaust gases from ships. Open-loop scrubbers use sea-water to clean exhaust gases, the scrubber discharge water is discharged directly back to the sea mostly without treatment (ICCT, 2020). Closed-loop scrubbers use seawater or freshwater to clean exhaust gases. The exhaust gas cleaning water is filtered on board after which most of the water is recirculated and used again. Only a small amount of water is discharged at sea after being treated respective it is stored on board (ICTT, 2020). Hybrid systems exist as well. In the scrubber SO_x is converted to sulphuric acid, which is then discharged as acidic discharge water. Contaminants occurring in exhaust gasses are trapped in the discharge water and discharged along with the converted sulphuric acid.

In 2022 OSPAR modelled estimates of the marine environment from EGCS on ships in the OSPAR Maritime Area (OSPAR, 2022a). According to this study the main contaminants entering the marine environment via EGCS discharges are metals and PAHs as well as oil residues, for more information on substance loads see Chapter 3. Contaminant loads from those discharges are dominated by discharges from open loop systems as they discharge higher volumes of discharge water and furthermore dominate the scrubber market. OSPAR estimated that metal loads from closed-loop systems are about 1,000-10,000 times lower than in open-loop systems. PAH loads from closed-loop systems are about 100,000-1,000,000 times lower than from open-loop systems, since most of the EGCS are open-loop systems and closed-loop systems are usually more efficient in the removal of PAHs than metals (OSPAR, 2022a). In the study by OSPAR (2022a) it was estimated that 622 million m^3 EGCS effluent is discharged in the North East Atlantic Ocean (of this, 99.9% was from open loop EGCS systems), compared to an estimated amount of 198 million m^3 discharge water in the Baltic Sea (Jalkanen et al., 2021). In total an estimated volume of 17.1 million m^3 EGCS effluent from open-loop systems is discharged in the EEZ of Germany, compared to 0.17 million m^3 effluent from closed-loop systems (OSPAR, 2022a). Only a small volume of EGCS effluent is discharged from hybrid systems (OSPAR, 2022a).

2.4.5 Spills

Shipping is a common method to transport materials and goods but also both chemicals and oil from one place to another. Purnell (2009) estimated that about 2,000 different chemicals were regularly transported via sea in 2009 and that by 2015 the chemical transport via sea would be up to 215 million tonnes. Therefore, many different chemicals may end up in the marine environment due to accidental spills of chemicals (Purnell, 2009).

In 2020 41% of detected spills from ships on the Baltic Sea were verified as mineral oil or other substances (HELCOM, 2022). Oil tanker accidents account for 10-15% of the oil ending up in the marine environment every year (European Environmental Agency, 2008). Oil spills are an important source of PAHs, volatile organic compounds (VOCs) and Benzene, Toluene, Ethylbenzene and Xylene (BTEX) (Sammarco et al., 2013).

2.5 Dumped chemical munition sites

After the second World War chemical munition was dumped in both the Baltic Sea and the North East Atlantic (HELCOM, 2022; OSPAR, 2022b). HELCOM (2022) estimated that a total load of

40,000 tonnes of chemical munition was dumped into the Baltic Sea. The main concern arises from chemical weapons containing organo-arsenic agents. Arsenic may partition with the marine sediment, however there are no signs that arsenic also ends up in the water column (HELCOM, 2022; OSPAR, 2022b). The source of dumped chemical munition is not studied in the rest of this report.

2.6 Overview

In Table 7 in Appendix B all identified hazardous substances from the maritime transport, aquaculture and offshore energy are combined in one table. Priority substances regulated under the WFD are not included in this table as these substances are already covered with regard to descriptor 8 MSFD.

In Table 1, a selection of substances from Table 6 is made, based on the substances identified in WP1 and 2 of the RESOW project as relevant for the offshore energy industry. If these selected substances are also emitted from mariculture and/or maritime transport the substance is shown in bold. Please note that there is only limited oil and gas industry in the Baltic Sea (HELCOM, 2018).

From Table 6 it can be observed that ten different substances which are identified as being hazardous substances from either the offshore wind industry and/or offshore oil and gas industry are also emitted from other sea-based sources. These substances will be investigated more thoroughly in the next chapter.

Table 1: Overview of selected hazardous substances from offshore wind industry and offshore oil and gas industry, complemented with additional sources from mariculture and maritime transport. Substances that are both emitted from offshore industry and mariculture and/or maritime transport are shown in bold.

Substance	Maritime transport	Mariculture	Offshore wind industry	Offshore oil and gas industry
1,2-benzisothiazol-3(2H)-one			X	
2-methyl-2H-isothiazol-3-one			X	
4-tert-butylphenol				X
4-tert-octylphenol				X
4-tert-pentylphenol				X
Acenaphthene	X			X
Arsenic	X	X		X
Benz[a]anthracene	X			X
Bisphenol A			X	
Chrysene	X			X

Substance	Maritime transport	Mariculture	Offshore wind industry	Offshore oil and gas industry
Copper oxide/Copper	X	X	X	
Dibenzo[a,h] anthracene	X			X
Fluorene	X			X
Fluorosurfactant/ component			X	
Indium			X	
Naphthenic acids, zinc salts			X	
Orange oil, sweet, ext.			X	
Phenanthrene	X			X
Pyrene	X			X
Sodium decyl sulphate			X	
Sodium hypochlorite			X	
Stoddard solvent[5]			X	
Toluene				X
Zinc	X	X	X	X

[5] Stoddard solvent is a synthetically made organic solvent that comes from the refining of crude oil.

3 Emissions of identified substances from sea-based sources

In the previous chapter several substances were identified to be investigated more thoroughly in this chapter, namely acenaphthene, arsenic, benz[a]anthracene, chrysene, copper/copper oxide (as sum of total copper), dibenzo[a,h] anthracene, fluorene, toluene, phenanthrene, pyrene and zinc. These substances are all identified as being hazardous in WP1 and 2 and are all emitted from offshore wind industry or offshore oil and gas industry. Additionally, in chapter 2 these substances were also identified to be emitted from other sea-based sources. In this chapter the emissions from the identified substances emitted from other sea-based sources are estimated when possible, in order to compare the emissions from the offshore industry with other sea-based sources.

3.1 Emission estimations

This section includes estimated emissions from WP1 and 2, complemented with estimated emissions from other sea-based sources.

3.1.1 Acenaphthene

Acenaphthene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of acenaphthene via produced water was estimated to be 970 kg/per year (UBA, 2023).

Acenaphthene is emitted from the maritime transport via the discharge of EGCS discharge water. In 2022 OSPAR estimated the average emission of acenapthene to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 73.9 kg/year and the discharge of closed loop EGCS to be 0.0157kg/year (OSPAR, 2022a), adding up to a total of 73.9157 kg/year (https://www.ospar.org/convention/the-north-east-atlantic). Ytreberg et al. (2022) estimated the total emission of acenaphthene from ships in the Baltic Sea to be 37 kg/year (Ytreberg et al., 2022).

3.1.2 Arsenic

Arsenic is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of arsenic via produced water was estimated to be 12,970 kg/year (UBA, 2023).

Arsenic is emitted from maritime transport via operational discharges and discharges of EGCS discharge water. No estimated emissions are available for emissions of operational discharges, however, the Dutch PRTR describes a method to estimate emissions of wastewater from various types of ships. Emission factors may be used to roughly estimate the emission from wastewater from ships. In 2022 OSPAR estimated the average emission of arsenic to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 1,072 kg/year and the discharge of closed loop EGCS to be 1.22 kg/year (OSPAR, 2022a), adding up to a total of 1,073.22 kg/year. Ytreberg et al. (2022) estimated the total emission of arsenic from ships in the Baltic Sea to be 1,400 kg/year (Ytreberg et al., 2022).

Arsenic is emitted from mariculture via feed additives. No estimated emissions are available and no method for calculating estimated emissions is described by the Dutch PRTR.

3.1.3 Benz[a]anthracene

Benz[a]anthracene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of benz[a]anthracene via produced water was estimated to be 0.08 kg/year (UBA, 2023).

Benz[a]anthracene is emitted from the maritime transport via the discharge of EGCS discharge water. In 2022 OSPAR estimated the average emission of benz[a]anthracene to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 21.1 kg/year and the discharge of closed loop EGCS to be 0.0169 kg/year (OSPAR, 2022a), adding up to a total of 21.1169 kg/year. Ytreberg et al. (2022) estimated the total emission of benz[a]anthracene from ships in the Baltic Sea to be 23 kg/year (Ytreberg et al., 2022).

3.1.4 Chrysene

Chrysene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of chrysene via produced water was estimated to be 300 kg/year (UBA, 2023).

Chrysene is emitted from the maritime transport via the discharge of EGCS discharge water. In 2022 OSPAR estimated the average emission of chrysene to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 33.5 kg/year and the discharge of closed loop EGCS to be 0.0192 kg/year (OSPAR, 2022a), adding up to a total of 33.5192 kg/year. Ytreberg et al. (2022) estimated the total emission of chrysene from ships in the Baltic Sea to be 36 kg/year (Ytreberg et al., 2022).

3.1.5 Copper oxide/copper

Copper and copper oxide are taken together as a copper sum here. In 2020 HELCOM estimated the amount of copper input to the Baltic Sea to be 8,000 kg/year (HELCOM, 2020).

Copper is emitted from the offshore oil and gas industry via produced water. In workpackage WP2 the emission of copper via produced water was estimated to be 3,010 kg/year (UBA, 2023).

Copper oxide is emitted from the offshore wind industry via the use of copper anodes in so called Impressed Current Antifouling Systems (ICAF). No emission is estimated in WP1.

Copper oxide is emitted from mariculture via antifouling measures. No estimated emissions are available and no method for calculating estimated emissions is described by the Dutch PRTR.

Copper is emitted from maritime transport via anodes, from antifouling coatings and from discharges of EGCS discharge water. No estimated emissions are available for copper from anodes. The Dutch PRTR describes a method to estimate emissions from anodes. Emission factors may be used to roughly estimate the emission from anodes. HELCOM estimated the amount of copper emitted from antifouling paints of maritime transport to be 366,000 kg/year (HELCOM, 2020). In 2022 OSPAR estimated the average emission of copper to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 9,999 kg/year and the discharge of closed loop EGCS to be 4.71 kg/year (OSPAR, 2022a), adding up to a total of 10,003.71 kg/year. Ytreberg et al. (2022) estimated the total emission of copper from ships in the Baltic Sea to be 518,000 kg/year (Ytreberg et al., 2022). The estimates for the North Sea are relatively low compared to the estimate for the Baltic Sea since they only show the contribution of EGCS and do not included emissions from anodes and antifouling coatings.

3.1.6 Dibenzo[a,h]anthracene

Dibenzo[a,h]anthracene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of dibenzo[a,h]anthracene via produced water was estimated to be 10 kg/year (UBA, 2023).

Dibenzo[a,h]anthracene is emitted from the maritime transport via the discharge of EGCS effluent. In 2022 OSPAR estimated the average emission of dibenzo[a,h]anthracene to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 2.45 kg/year and the discharge of closed loop EGCS to be 0.00130 kg/year (OSPAR, 2022a), adding up to a total of 2.4513 kg/year. Ytreberg et al. (2022) estimated the total emission of dibenzo[a,h] anthracene from ships in the Baltic Sea to be 5 kg/year (Ytreberg et al., 2022).

3.1.7 Fluorene

Fluorene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of fluorene via produced water was estimated to be 4,490 kg/year (UBA, 2023).

Fluorene is emitted from the maritime transport via the discharge of EGCS discharge water. In 2022 OSPAR estimated the average emission of fluorene to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 176 kg/year and the discharge of closed loop EGCS to be 0.0506 kg/year (OSPAR, 2022a), adding up to a total of 176.0506 kg/year. Ytreberg et al. (2022) estimated the total emission of fluorene from ships in the Baltic Sea to be 90 kg/year (Ytreberg et al., 2022).

3.1.8 Toluene

Toluene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of toluene from produced water was estimated to be 3,310 kg/ year (UBA, 2023).

Toluene is emitted from ships via oil spills. No estimated emissions are available. Emission factors can be used to determine the emission from oil spills based on the estimated volume of oil spills. Emission factors are described in the Dutch PRTR for various PAHs, however these emission factors are not available for toluene (Dutch PRTR, 2016). Therefore, the emission of toluene from oil spills cannot be estimated.

3.1.9 Phenanthrene

Phenanthrene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of phenanthrene via produced water was estimated to be 9.32 kg/year (UBA, 2023). Please note that this number only reflects the emission of phenanthrene alone as identified in WP2, not of mixtures of phenanthrene and other substances or the C1-, C2- or C3-congeners which have also been identified.

Phenanthrene is emitted from the maritime transport via the discharge of EGCS discharge water. In 2022 OSPAR estimated the average emission of phenanthrene to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 526 kg/year and the discharge of closed loop EGCS to be 0.255kg/year (OSPAR, 2022a), adding up to a total of 526.255 kg/year. Ytreberg et al. (2022) estimated the total emission of phenanthrene from ships in the Baltic Sea to be 290 kg/year (Ytreberg et al., 2022).

3.1.10 Pyrene

Pyrene is emitted from the offshore oil and gas industry via produced water. In WP2 the emission of pyrene via produced water was estimated to be 0.25 kg/year (UBA, 2023).

Pyrene is emitted from the maritime transport via the discharge of EGCS discharge water. In 2022 OSPAR estimated the average emission of pyrene to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 71.3 kg/year and the discharge of closed loop EGCS to be 0.0482 kg/year (OSPAR, 2022a), adding up to a total of 71.3482 kg/year. Ytreberg et al. (2022) estimated the total emission of pyrene from ships in the Baltic Sea to be 60 kg/year (Ytreberg et al., 2022).

3.1.11 Zinc

Zinc is emitted from the offshore wind industry via leaching of sacrificial anodes. In WP1 the emission of zinc from offshore wind industry was calculated for a number of windfarms, however, no total emission into the marine environment was calculated. Zinc is emitted from the offshore oil and gas industry via produced water and from sacrificial anodes. In WP2 the emission of zinc from produced water was estimated to be 2,173 tonnes per year and the emission of zinc from sacrificial anodes was estimated to be 1,869 tonnes per year, together this adds up to 4,042 tonnes zinc per year (UBA, 2023).

Zinc is emitted from mariculture via feed additives. No estimated emissions are available and no method for calculating estimated emissions is described by the Dutch PRTR.

Zinc is emitted from maritime shipping via anodes, operational discharges and releases of EGCS discharge water. No estimations are available for zinc emissions from anodes. No estimated emissions are available. However, in the Dutch PRTR a method to estimate the emission of zinc from anodes is described (Dutch PRTR, 2015). No estimated emissions are available for zinc emissions via operational discharges and no method for calculating estimated emissions is described by the Dutch PRTR. In 2022 OSPAR estimated the average emission of zinc to the North Sea (OSPAR region II) from the discharge from open loop EGCS to be 39,658 kg/year and the discharge of closed loop EGCS to be 27.451kg/year (OSPAR, 2022a), adding up to a total of 39,685.451 kg/year. Ytreberg et al. (2022) estimated the total emission of zinc from ships in the Baltic Sea to be 117,000 kg/year (Ytreberg et al., 2022).

3.2 Emission comparison

In Table 2 and

Table 3 an overview of the estimated emissions of identified substances to the Baltic Sea and North Sea from sea-based sources as determined in the previous section are shown respectively. As there is only limited offshore oil and gas in the Baltic Sea this source is not included in Table 2. In the tables NA means there is no information available to estimate the emission and - means the substance is not identified as originating from this source.

Table 2: Estimated emissions of selected substances to the Baltic Sea from sea-based sources in kg/year.

Substance	Maritime transport	Mariculture	Offshore wind
Acenaphthene	37	-	-
Arsenic	1,400	NA	-
Benz[a]anthracene	23		
Chrysene	36	-	-
Copper oxide/ copper	518,000	NA	NA
Dibenzo[a,h] anthracene	5	-	-
Fluorene	90	-	-
Toluene	-	-	-
Phenanthrene	290	-	-
Pyrene	60	-	-
Zinc	117,000	NA	NA

Table 3: Estimated emissions of selected substances to the North Sea from sea-based sources in kg/year.

Substance	Maritime transport	Mariculture	Offshore wind	Offshore oil and gas
Acenaphthene	74	-	-	970
Arsenic	1,100	NA	-	12,970
Benz[a]anthracene	21		-	0.08
Chrysene	34	-	-	300
Copper oxide/ copper	10,000	NA	NA	3,010
Dibenzo[a,h] anthracene	2	-	-	10
Fluorene	180	-	-	4,490
Toluene	-	-	-	3,310
Phenanthrene	530			9.32

Substance	Maritime transport	Mariculture	Offshore wind	Offshore oil and gas
Pyrene	71			0.25
Zinc	40,000	NA	NA	4,042,000

4 Conclusion

This study shows that there are many different substances potentially emitted into the marine environment via various sea-based sources. Whether or not these emissions may be a risk to the environment depends on the hazardous properties of the emitted substances and the concentration or amount that is emitted into the marine environment. In previous workpackages from the RESOW project potentially hazardous substances were identified from the offshore wind industry and the offshore oil and gas industry. In this study all substances from additional sea-based sources namely maritime transport, mariculture and dumped munition were identified, although dumped munition was only studied limited. Those substances that were identified as hazardous should be studied more closely to determine whether they should be added as additional contaminants according to Commission Decision (EU) 2017/848 (European Commission, 2017) for Descriptor 8 criteria D8C1.

Substance loads from maritime shipping and/or mariculture were estimated if the concerning substances were identified as hazardous from the offshore wind industry or offshore oil and gas industry. This was done in order to compare the emission loads from the offshore industry with the emissions from other sea-based sources. It was difficult to determine substance specific emission loads, as these numbers are not often calculated or measured in other studies and no calculations and experimental work were performed in this study. Total emission loads from the offshore wind industry could not be estimated (WP1 report, UBA in press a). Total emission loads from the offshore oil and gas industry could only be estimated based on produced water and sacrificial anodes (WP2 report, UBA, 2023). Total loads of substances emitted via maritime transport into the Baltic Sea were estimated by Ytreberg et al. (2022). OSPAR (2022a) estimated only the total load of substances emitted from scrubbers into the North Sea. As there is only limited offshore oil and gas industry in the Baltic Sea only a comparison between emissions from maritime transport and the offshore oil and gas industry from the North Sea was done. For most substances the emitted load from the offshore oil and gas industry is much higher than the emitted load from maritime transport, copper/copper oxide being the exception.

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A Overview of hazardous substances from previous workpackages

A.1 Overview of selected hazardous substances from offshore wind industry as determined in workpackage 1 of the RESOW project

Table 4: Selected substances from open sources in the offshore wind industry in the North east Atlantic Sea and Baltic Sea.

Substance	Material	Location*	WFD priority substance
Bisphenol A	Coatings	OWT, OSS, OCP	
Cadmium	Sacrificial anodes	OWT, OSS, OCP	Yes
Copper	Sacrificial anodes	OWT, OSS, OCP	
Indium	Sacrificial anodes	OWT, OSS, OCP	
Mercury	Sacrificial anodes	OWT, OSS, OCP	Yes
Zinc	Sacrificial anodes	OWT, OSS, OCP	
Copper oxide	ICAF Antifouling	OCP	
Sodium hypochlorite	Antifouling	OCP	
Stoddard solvent	Building Mastic	OWT	
Orange oil, sweet, ext.	Floor cleaner	OCP	

* Locations from the offshore wind industry include Offshore Wind Turbines (OWT), Offshore Sub Stations (OSS) and Offshore Converter Platforms (OCP).

Table 5: Selected substances from closed systems with a higher risk of accidents in the wind industry in the North Sea and Baltic Sea.

Substance	Material	Location	WFD priority substance
Fluorosurfactants	Fire protection	helicopter deck OSS, OCP	PFOS and it's derivatives: yes
Naphthenic acids, zinc salts	Gear oil, Grease	crane on OWT	
Sodium decyl sulphate	Fire protection	OSS, OCP	
1,2-benzisothiazol-3(2H)-one	Fire protection	OSS	
2-methyl-2H-isothiazol-3-one	Fire protection	OSS	
Naphthalene	Fuel	OSS, OCP	Yes

A.2 Overview of selected hazardous substances from offshore oil and gas industry as determined in workpackage 2 of the RESOW project

Table 6: Selected substances from the offshore oil and gas industry in the North Sea.

Substance	Source	WFD priority substance
Polycyclic Aromatic Hydrocarbons		
Acenaphthene	Produced water	
Anthracene	Produced water	Yes
Benz[a]anthracene	Produced water	
Benzo[a]pyrene	Produced water	Yes
Benzo[b]fluoranthene	Produced water	Yes
Benzo[ghi]perylene	Produced water	Yes
Chrysene	Produced water	
Dibenzo[a,h] anthracene	Produced water	
Fluoranthene	Produced water	Yes
Fluorene	Produced water	
Napthalene	Produced water	Yes
Phenanthrene	Produced water	
Pyrene	Produced water	
Phenols		
4-tert-butylphenol	Produced water	
4-tert-octylphenol	Produced water	
4-tert-pentylphenol	Produced water	
Nonylphenol (C9 alkyl phenols representative)	Produced water	Yes
Other industrial chemicals		
Benzene	Produced water	Yes
Toluene	Produced water	
Metals and elements		
Arsenic	Produced water	
Cadmium	Produced water	Yes
Lead	Produced water	Yes
Mercury	Produced water	Yes
Nickel	Produced water	Yes

Substance	Source	WFD priority substance
Zinc	Corrosion protection	

B Overview of potentially emitted substances from sea-based sources

Table 7: Overview of potentially emitted substances from sea-based sources in the North Sea and Baltic Sea.

Substance/solvent	Shipping	Mariculture	Offshore wind industry	Offshore oil and gas industry*
Metals/metalloids				
Aluminum	X[1]			
Arsenic	X[1, 2]	X[1]		X[4]
Chromium	X[1, 2]			
Copper	X[1, 2]	X[1]		
Indium			X[3]	
Iron	X[1]	X[1]		
Magnesium		X[1]		
Manganese	X[1]	X[1]		
Molybdenum	X[2]			
Selenium		X[1]		
Vanadium	X[1, 2]			
Zinc	X[1, 2]	X[1]	X[3]	X[4]
Organometallic compounds				
Copper pyrithione	X[1]	X[1]		
Dibutyltin (DBT)	X[1]			
Monobutyltin (MBT)	X[1]			
Tributyltin (TBT)	X[1]			
TPBP (KH101) (triphenylborane pyridine)	X[1]			
Zinc pyrithione	X[1]	X[1]		
Zineb	X[1]	X[1]		
Ziram	X[1]			
Inorganic compounds				
Ammonia	X[1]			
Chromium trioxide	X[1]			
Copper oxide		X[1]	X[3]	
Copper thiocyanate	X[1]			

Substance/solvent	Shipping	Mariculture	Offshore wind industry	Offshore oil and gas industry*
Hydrogen peroxide		X[1]		
Iodophoros		X[1]		
Phosphoric acid	X[1]			
Sodium hydroxide	X[1]			
Sodium hypochlorite			X[3]	
Sulfuric acid	X[1]			
Organic compounds				
1-dodecanol	X[1]			
1-nonanol	X[1]			
1,2-benzisothiazol-3(2H)-one			X[3]	
2-butoxyethanol	X[1]			
2,6-ditert-butyl-4-methylphenol		X[1]		
2-methyl-2H-isothiazol-3-one			X[3]	
4-tert-butylphenol				X[4]
4-tert-pentylphenol				X[4]
Acenaphthene	X[2]			X[4]
Acenaphthylene	X[2]			
Acetic acid	X[1]			
Acrylonitrile	X[1]			
Alkyl (C5-C8, C9) benzenes	X[1]			
Amoxicillin		X[1]		
Aniline	X[1]			
Astaxanthin		X[1]		
Azamethiphos		X[1]		
Benz[a]anthracene	X[2]			X[4]
Benzocaine		X[1]		
Bisphenol A			X[3]	
Bis(2-ethylhexyl)adipate	X[1]			
Bronopol		X[1]		

Substance/solvent	Shipping	Mariculture	Offshore wind industry	Offshore oil and gas industry*
Butyl Acrylate	X[1]			
Butylated hydroxyanisole		X[1]		
Canola oil	X[1]			
Canthaxanthin		X[1]		
Capsaicin	X[1]			
Chloramphenicol		X[1]		
Chlorothalonil	X[1]	X[1]		
Chrysene	X[2]			X[4]
Corn oil	X[1]			
Cyclohexane	X[1]			
Cyclopentadiene	X[1]			
DCOIT (sea-Nine 21)	X[1]	X[1]		
DDTs		X[1]		
Decanoic acid	X[1]			
Deltamethrin		X[1]		
Dibenzo[a,h] anthracene	X[2]			X[4]
Dichlofluanid	X[1]	X[1]		
Diflubenzuron		X[1]		
Dioxins		X[1]		
Di-propylene glycol butyl ether	X[1]			
Di-propylene glycol monomethyl ether	X[1]			
Distillates (petroleum), hydrotreated light (SP 250)	X[1]			
Emamectin benzoate		X[1]		
Enrofloxacin		X[1]		
Erythromycin		X[1]		
Ethoxyquin		X[1]		
Ethylbenzene	X[1]			
Ethylene glycol	X[1]			
Fatty acids, fish oil, ethoxylated	X[1]			

Substance/solvent	Shipping	Mariculture	Offshore wind industry	Offshore oil and gas industry*
Florfenicol		X[1]		
Flumequine		X[1]		
Fluorene	X[2]			X[4]
Fluorsurfactants			X[3]	
Folpet	X[1]			
Formalin		X[1]		
Heptane	X[1]			
Hexane	X[1]			
Isononanol	X[1]			
Ivermectin		X[1]		
Malachite green		X[1]		
Maneb	X[1]			
Medetomidine	X[1]			
Metacaine		X[1]		
Methanol	X[1]			
Methyl tert-butyl ether (MTBE)	X[1]			
Methylphenols (cresols)	X[1]			
Nalidixic acid		X[1]		
Naphthenic acids, zinc salts			X[3]	
Nitrobenzene	X[1]			
Nonane	X[1]			
Octane	X[1]			
Orange oil			X[3]	
Oxyolinic acid		X[1]		
Oxytetracycline		X[1]		
Palm oil	X[1]			
Phenol	X[1]			
Phenoxyethanol		X[1]		
Piromidic acid		X[1]		
Polyaromatic hydrocarbons (PAH)	X[1]	X[1]		

Substance/solvent	Shipping	Mariculture	Offshore wind industry	Offshore oil and gas industry*
Polychlorinated biphenyls (PCB)		X[1]		
Propyleneglycol (1,2-propanediol)	X[1]			
Propylene oxide	X[1]			
Pyrene	X[2]			X[4]
Quinaldine		X[1]		
Sarafloxacin		X[1]		
Sodium decyl sulphate			X[3]	
Sodium di-iso-octyl sulphosuccinate	X[1]			
Sorbitan, mono-(9Z)-9-octodecenoate	X[1]			
Sorbitan, mono-(9Z)-9-octodecenoate, poly(oxy-1,2-ethanediyl)derivatives	X[1]			
Soybean oil	X[1]			
Stoddard solvent			X[3]	
Styrene monomer	X[1]			
Sulfadiazine		X[1]		
Sulfamethoxazole		X[1]		
Sulfathiazole		X[1]		
Sunflower oil	X[1]			
TCMS pyridine (Densil 100)	X[1]	X[1]		
TCMTB (Busan)	X[1]			
Teflubenzuron		X[1]		
Thiram	X[1]			
Toluene	X[1]			X[4]
Tolylfluanid	X[1]			
Tralopyril (Econea)	X[1]			
Tricaine methane sulphonate (MS-222)		X[1]		
Trichlorfon		X[1]		
Trimethoprim		X[1]		

Substance/solvent	Shipping	Mariculture	Offshore wind industry	Offshore oil and gas industry*
Vitamin C		X[1]		
Vitamin E		X[1]		
Xylene	X[1]			

* Please note that there is limited oil and gas industry located in the Baltic Sea, so the column about substances from this industry is only for the North Sea East Atlantic.

[1] Tornero & Hanke (2016b)

[2] OSPAR (2022a&b)

[3] (WP1 report, UBA in press a)

[4] (WP2 report, UBA 2023)