TEXTE

61/2024

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Part 3: Best available techniques avoiding emissions into the marine environment from the offshore wind industry

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On behalf of the German Environment Agency

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Abstract: Best available techniques to avoid emissions into the marine environment from the offshore wind industry

Within the RESOW project (Reduction of impacts of hazardous substances during installation and operation of offshore windfarms) potential emission from the offshore industry into the North- and Baltic Seas are investigated. This report of work package 3 provides an overview on best available techniques to avoid emissions into the marine environment from the offshore wind industry during installation, operation and decommissioning. The document is based on the high priority substances identified in work package (WP) 1 (UBA, in press.).

Besides risk management as overall practice to reduce potential emission with a focus on recommended procedures, timely inspection and knowledgeable/experienced personnel, this document zooms in onto the technical measures and techniques that are currently available, tested and economically feasible. For each technical area the current legislative background is given followed by a description of available techniques. The areas covered are technical installation, storage, bunkering, fire protection, corrosion protection, discharges in open systems, antifouling & cleaning and substitution of substances.

It is noted that the areas covered are not exhaustive, but in line with the key hazardous substances defined in WP1 and with a clear focus on open systems (in direct contact with marine environment).

Kurzbeschreibung: Beste verfügbare Techniken zur Vermeidung von Emissionen der Offshore-Windindustrie in die Meeresumwelt

Im Rahmen des RESOW-Projekts (Reduktion der Auswirkungen gefährlicher Stoffe während der Installation und des Betriebs von Offshore-Windparks) werden mögliche Emissionen der Offshore-Industrie in die Nord- und Ostsee untersucht. Dieser Bericht des Arbeitspakets 3 bietet einen Überblick über die besten verfügbaren Techniken zur Vermeidung von Emissionen der Offshore-Windindustrie in die Meeresumwelt während der Installation, des Betriebs und der Stilllegung. Das Dokument ist auf den im Arbeitspaket (WP) 1 (UBA, im Druck) identifizierten Stoffen mit hoher Priorität basiert.

Neben Risikomanagement als Schlüsselfaktor zur Reduzierung potenzieller Emissionen durch Einsatz von richtigen Verfahren, pünktlicher Inspektion und sachkundigem/erfahrenem Personal geht dieses Dokument auf die technischen Maßnahmen und Techniken ein, die derzeit verfügbar, getestet und wirtschaftlich machbar sind. Für jeden technischen Bereich wird der aktuelle gesetzgeberische Hintergrund angegeben, gefolgt von einer Beschreibung der verfügbaren Techniken. Die abgedeckten Bereiche sind technische Installation, Lagerung, Bunkern, Brandschutz, Korrosionsschutz, Einleitungen in offene Systeme, Antifouling & Reinigung und Substitution von Stoffen.

Es wird darauf hingewiesen, dass die abgedeckten Bereiche nicht erschöpfend sind, sondern im Einklang mit den in WP1 definierten Schlüsselschadstoffen stehen mit einem klaren Fokus auf offenen Systeme, die in direktem Kontakt mit der Meeresumwelt stehen.

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AFFF	Aqueous Film Forming Foam
ALARP	As Low As Reasonable Practicable
AwSV	Ordinance on Facilities Handling Substances that are Hazardous to Water (Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen)
BAT	Best available technique
BATNEEC	Best available techniques not entailing excessive costs
BREF	Best Available Techniques Reference
BSH	German Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie)
CAS	Chemical Abstracts Service
ECHA	European Chemicals Agency
EEZ	Exclusive economic zone
EIA	Environmental Impact Assessment
FEP	Site development plan (Flächenentwicklungsplan)
FFF	Fluorine Free Foams
GACP	Galvanic cathodic protection
ICAF	Impressed Current Antifouling Protection System
ICCP	Impressed current cathodic protection
IMO	International maritime organisation
MARPOL	International Convention for the Prevention of Marine Pollution from Ships
MNOC	Minimum Number Of Coats
MPGS	Marine Growth Prevention System
MSDS	Material safety data sheets
n.d.	no date
NDFT	Nominal Dry Film Thickness
OCP	Offshore converter platform
OSPAR	Oslo and Paris Conventions
OSS	Offshore substation
OWF	Offshore wind-farm
OWT	Offshore wind-turbine
PBT	Persistent, bioaccumulative and toxic
PFAS	Per- and polyfluoroalkyl substances
PFHxS	Perfluorohexane sulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
PLONOR	(Substances, which) Pose little or no risk to the environment
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals

AFFF	Aqueous Film Forming Foam
RESOW	Reduction of impacts of hazardous substances during installation and operation of offshore windfarms
SCADA	Supervisory Control And Data Acquisition systems
SIN	Substitute it now
SVHC	Substance of very high concern
TSA	Thermal Sprayed Aluminium
TSS	Total Suspended Solids
UBA	German Environment Agency (Umweltbundesamt)

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We are also very grateful to Dr. Anita Künitzer and Hans-Peter Damian from the Umweltbundesamt (UBA) for their continuous guidance during the implementation of this analysis, the numerous discussions, meetings and checks of chapters and drafts of this report, as well as the advice by further experts from the Umweltbundesamt.

Summary

The offshore wind industry is a relatively young industry, but the market has been growing significantly in the last years. This trend is expected to be ongoing to fulfil the EU strategy purpose to increase Europe's offshore wind capacity to at least 60 GW in 2030 and 300 GW in 2050. Knowing about this trend, it is important to get aware about the impact of the fast-growing wind energy industry on the environment. Until today the environmental impact of the offshore wind industry regarding chemical emissions into the aquatic environment has not been assessed comprehensively. The aim of this research project named "Reduction of impacts of hazardous substances during installation and operation of offshore windfarms" (RESOW) is to provide an overview on the substance emissions from the offshore industry. Thereby, possible substance emission sources shall be associated to certain functional units of offshore structures during the lifecycles of the structures such as installation, operation, and decommissioning. Furthermore, the emission sources should be quantified to give an overview of the possible emission from the offshore industries.

This Work Package 3 Report provides an overview of measures and technologies that are suitable to avoid or at least reduce the risk that substances identified as priority substances (WP1) are entering the marine environment. The aim is that this document helps the permitting authority BSH as well as applying industry, to identify appropriate technologies and procedures to reduce emissions of priority substances. This will focus both on avoidance of emissions due to procedures and maintenance as well as actual technologies, construction requirements or materials used to limit emissions as much as possible.

Currently, no specific technical guideline applies in the German exclusive economic zone (EEZ) regarding the application and use of substances which are hazardous to the aquatic environment other than the site development plan FEP2023 (Flächenentwicklungsplan). The German Ordinance on Facilities Handling Substances that are Hazardous to Water (AwSV, 2017) on the application and use of substances which are hazardous to the aquatic environment for the application onshore is only applicable by law for coastal waters (12 nautical miles) and not in the EEZ where most offshore wind installations are being built. However, the site development plan (BSH, 2020 and 2023) gives general technical requirements to minimise emissions as much as possible.

Guidelines including measures and best practice for handling of hazardous substances specifically for the application on offshore wind structures – as regularly submitted by the windfarm operators - limit the risk of accidents or spillage due to structural measures. The risk of emissions of materials applied in a principally closed system with a higher risk for accidents is mostly associated to human failure. This emphasizes the importance of strict routines, safety protocols and experienced personnel for the maintenance procedure on offshore structures. This is addressed in detail in the Chapter on risk management.

The report focuses on the identified key hazardous substances (in WP1) in open systems that are in direct contact with the marine environment (such as corrosion protection) and substances that have a high volume or high risk of exposure. Therefore, the report is divided in several technical areas with respective recommendation on the prevention and reduction of marine emissions:

- Technical Installation: ensure regular visual inspection for leakage or use of supervisory control and data acquisition (SCADA) systems to detect leaks or other short comings timely.

- Storage: besides following appropriate design as indicated in legislation, two items are highlighted for consideration during permitting the design of the actual storage facilities and the actual substances stored.
- Bunkering: the documented procedure with respect to bunkering seem to be sufficient to minimise accidents if procedures and protocols are followed and emergency procedures are in place.
- Fire protection: it is important to closely follow the development of firefighting foams in the future to make good permitting decisions balancing the ban of PFAS containing fire foams and alternatives that are equally reliable and effective. Where possible early warning systems and reductions of false alarms should be implemented.
- Corrosion Protection: ICCP systems for corrosion protection are cost efficient and result in very low emission to the marine environment and are recommended for use in new platforms (if operation conditions allow). Ongoing research such as "Chemical emissions from offshore wind turbines: possible influences on the marine environment and their assessment" ((OffChEm II, 2022) Hereon and BSH) should be followed.
- Discharge in open system: It is important that the design takes into account that most offshore structures are unmanned most of the time. A SCADA system can help to detect failure or dysfunction by designing accessible sampling points that can be monitored.
- Antifouling and cleaning: The German Site development plan (BSH, 2023) gives clear guidance that open cooling systems and with that the need for anti-fouling is highly undesired. This means that the insistence of the developer on an open system needs to be well documented and supported.
- Substitution of substances: Procedures to ensure that the newest available technologies are used in the design phase of wind farm developments should be integrated in the permitting process by challenging the developers on the avoidance of using hazardous substances identified in WP1.

Zusammenfassung

Die Offshore-Windindustrie ist eine relativ junge Branche, der Markt ist jedoch in den letzten Jahren erheblich gewachsen. Es wird erwartet, dass dieser Trend anhält, um das Ziel der EU-Strategie zu erfüllen, Europas Offshore-Windkapazität auf mindestens 60 GW im Jahr 2030 und 300 GW im Jahr 2050 zu erhöhen. Angesichts dieses Trends ist es wichtig, sich über die Auswirkungen der schnell wachsende Windenergiebranche auf die Umwelt im Klaren zu sein. Bis heute wurden die Umweltauswirkungen der Offshore-Windindustrie in Bezug auf Emissionen in die aquatische Umwelt nicht umfassend bewertet. Ziel des Forschungsprojekts „Reduktion der Auswirkungen gefährlicher Stoffe bei der Installation und dem Betrieb von Offshore-Windparks" (RESOW) ist es, einen Überblick über die Emissionen der Offshore Wind - Industrie zu geben. Dabei sollen mögliche Emissionsquellen bestimmten funktionalen Bereichen von Offshore-Bauwerken während der Lebenszyklen der Bauwerke wie Installation, Betrieb und Stilllegung zugeordnet werden. Darüber hinaus sollten die Emissionsquellen quantifiziert werden, um einen Überblick über die möglichen Emissionen der Offshore-Industrien zu erhalten.

Der Arbeitspaket 3 Bericht gibt einen Überblick über Maßnahmen und Technologien, die geeignet sind, die Risiken, dass als prioritär identifizierte Stoffe (AP1) in die Meeresumwelt

gelangen, zu vermeiden oder zumindest zu reduzieren. Ziel ist, dass dies Dokument der Genehmigungsbehörde BSH sowie der beantragenden Industrie hilft, geeignete Technologien und Verfahren zur Reduzierung der Emissionen prioritärer Stoffe zu identifizieren. Dabei geht es sowohl um die Vermeidung von Emissionen aufgrund von Verfahren und Wartung als auch um tatsächliche Technologien, Bauanforderungen oder verwendete Materialien, um die Emissionen so weit wie möglich zu begrenzen.

Derzeit gibt es in der deutschen ausschließlichen Wirtschaftszone (AWZ) außer dem Flächenentwicklungsplan FEP2023 keine spezifische technische Richtlinie für den Einsatz und die Verwendung gewässergefährdender Stoffe. Die Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen (AwSV) über den Einsatz und die Verwendung gewässergefährdender Stoffe für den Einsatz an Land gilt gesetzlich nur für Küstengewässer (ìnnerhalb der 12 Meilenzone) und nicht für die AWZ, in der die meisten Offshore-Windanlagen gebaut werden. Allerdings werden im Flächenentwicklungsplan (BSH, 2020 und 2023) allgemeine technische Vorgaben gemacht, um die Emissionen möglichst gering zu halten.

Richtlinien mit Maßnahmen und Best Practices für den Umgang mit umweltgefährlichen Stoffen speziell für die Anwendung auf Offshore-Windkraftanlagen – wie sie regelmäßig von den Windparkbetreibern vorgelegt werden – begrenzen das Risiko von Unfällen oder unbeabsichtigte Austritte aufgrund baulicher Maßnahmen. Das unbeabsichtigte Austreten von Stoffen, die in geschlossenen Systemen eingesetzt werden, sind häufig auf menschliche Fehler zurückzuführen. Dies unterstreicht die Bedeutung strenger Routinen, Sicherheitsprotokolle und erfahrenen Personals für die Wartungsverfahren an Offshore-Strukturen. Darauf wird im Kapitel Risikomanagement ausführlich eingegangen.

Der Bericht konzentriert sich auf die in WP1 identifizierten Schadstoffen, die in offenen Systemen in direktem Kontakt mit der Meeresumwelt stehen (z. B. Korrosionsschutz), und auf Schadstoffe, die ein hohes Volumen oder ein hohes Expositionsrisiko aufweisen. Daher ist der Bericht in mehrere technische Bereiche mit entsprechenden Empfehlungen zur Vermeidung und Reduzierung von Meeresemissionen unterteilt:

- Technische Installation: Regelmäßige Sichtprüfung auf Lecks oder Verwendung von SCADA-Systemen (Supervisory Control and Data Acquisition), um Lecks oder andere Mängel rechtzeitig zu erkennen.
- Lagerung: Befolgung von relevanter Gesetzgebung und Regeln im Entwurf und Bau der Anlagen (Lagereinrichtungen und tatsächlich gelagerte Stoffe)
- Bunkern: Ausreichende Regeln und Gesetzgebung in Bezug auf das Bunkern. Um Unfälle zu minimieren ist es wichtig, dass festgelegte Verfahren und Protokolle befolgt werden und Notfallpläne vorhanden sind.
- Brandschutz: Es ist wichtig, die Entwicklung von Feuerlöschschäumen in der Zukunft genau zu verfolgen, um gute Genehmigungsentscheidungen zu treffen, die das Verbot von PFAS-haltigen Feuerlöschschäumen und Alternativen, die gleichermaßen zuverlässig und wirksam sind, abwägen. Wo möglich sollten Frühwarnsysteme und eine Reduzierung von Fehlalarmen implementiert werden.
- Korrosionsschutz: ICCP-Systeme zum Korrosionsschutz sind kosteneffizient und führen zu sehr geringen Emissionen in die Meeresumwelt. Sie werden für den Einsatz in neuen Plattformen empfohlen (sofern die Betriebsbedingungen dies zulassen). Laufende Forschungsarbeiten wie zum Beispiel „Chemische Emissionen aus Offshore-

Windkraftanlagen: Mögliche Einflüsse auf die Meeresumwelt und ihre Bewertung“ (OffChEm II) (Hereon und BSH) sollten verfolgt werden.

- Abwasser: Es ist wichtig, dass bei der Planung berücksichtigt wird, dass die meisten Offshore-Strukturen die meiste Zeit unbemannt sind. Ein SCADA-System kann dabei helfen, Ausfälle oder Funktionsstörungen zu erkennen. Hierzu sind zugängliche und überwachbare Probenahmepunkte wichtig.
- Antifouling und Reinigung: Der deutsche Flächenentwicklungsplan (BSH, 2023) macht deutlich, dass offene Kühlsysteme und damit die Notwendigkeit von Antifouling nicht erwünscht sind. Das bedeutet, dass Anlagenbauer, die auf einem offenen System bestehen, diese Wahl sehr gut begründen müssen.
- Substitution von Stoffen: Das Genehmigungsverfahren sollte sicherstellen, dass die neuesten (kommerziell) verfügbaren Technologien für den Entwurf von Windparkentwicklungen verwendet werden.

1. Introduction

1.1 Introduction of the RESOW research project

1.1.1 Motivation

The offshore wind industry is a relatively young industry, but the market has been growing significantly in the last years. This trend is expected to be ongoing to fulfil the EU strategy proposed to increase Europe's offshore wind capacity to at least 60 GW in 2030 and 300 GW in 2050 (European Union, 2020). Also, Germany formulated the goal to increase the offshore wind energy capacity in the Wind Energy at Sea Act (Windenergie-auf-See-Gesetz, WindSeeG) to a capacity of 20 GW till 2030 and 40 GW till 2040 (WindSeeG, 2016). Recent developments led to an even more ambitious aim of the German government of 20 GW till 2030 and even 70GW by 2045 for the offshore wind energy capacity as an amendment to the Wind Energy at Sea Act (Press and Information Office of the Federal Government, 2022).

Knowing about this trend, it is important to become aware about the impact of the fast-growing wind energy industry on the environment. Until today the environmental impact of the offshore wind industry regarding chemical emissions into the aquatic environment has not been assessed comprehensively. With regard to the fast growth of this industry, it is important to assess chemical emissions and scout opportunities to reduce or prevent these emissions and their potentially negative effects on the marine environment.

1.1.2 Objectives of the RESOW project

The aim of this research project "Reduction of impacts of hazardous substances during installation and operation of offshore windfarms" (RESOW) is to provide an overview on the emissions of hazardous substance from the offshore industry and to provide guidance for the permitting authorities and the applying industry regarding the best techniques or technologies to avoid such emissions. On structures of the offshore wind industry various operational materials are required for a smooth operation of different technical installations on the structures or long-term structural integrity of the structures. These operational materials can contain substances, which are hazardous to the aquatic environment. In the permitting procedure for offshore windfarms in Germany, it is therefore important to define requirements for the use and handling of materials which may release hazardous substances to the marine environment, and which specify the current requirements of the site development plan (BSH, 2020) in more detail. The aim of this research project is to create an overview of the most relevant hazardous substances, which can be emitted to the marine environment due to offshore activities from offshore wind turbines or platforms (see report of work package 1 "Overview of hazardous substances potentially emitted from offshore industries to the marine environment", Plenker et al. (UBA, in press. a).) and describe how potential emissions of these hazardous substances can be prevented or at least reduced using appropriate best available technology.

The RESOW project contains in total 4 work packages, which have individual objectives. The work packages 1 and 3 focus on the potential emissions of hazardous substances from the offshore wind industry. The work package 1 (WP1) provides an overview on substances hazardous to the marine environment, which are present on offshore wind structures and to estimate the risk that these substances could lead to emission into the marine environment. A brief summary of the relevant findings from the WP1 investigations are provided in Section 1.1.3. The work package 3 (WP3) is built on the findings of the WP1 and identifies technologies to avoid emissions of key hazardous substances from the potential sources. Objectives of WP3 are provided in Section 1.2.

1.1.3 Summary and findings of WP1

The objectives of the WP1 "Overview of hazardous substances potentially emitted from offshore industries to the marine environment: Part 1 The offshore wind industry" were the identification of possible emission sources for hazardous substances associated with the installation, operation and decommissioning of offshore wind energy structures. The focus on offshore wind energy structures included wind turbines, offshore substations, offshore converter stations and cables. In the investigation, emission and waste- and operational materials concepts of various German windfarms in the North- and Baltic Sea have been analysed. Further, experts from UBA, BSH and Deltares as well as external experts have been consulted. In addition, a workshop with internal and external experts has been organised, to discuss the investigation approach as well as the results of the analysis.

The final list of selected hazardous substance of special interest is presented in Table 1: List of selected hazardous substances of special interest and the location of use

More details on the individual substances and their occurrence/volume can be obtained from the report (UBA, in press).

Table 1: List of selected hazardous substances of special interest and the location of use

CAS no.[1]	Substance	Operating material type	Open/closed system	Location of occurrence of substances[1]
10254-57-6	4,4'-methylene bis(dibutyldithiocarbamate)	Gear Oil, Grease	Closed system	Offshore wind-turbine
110-54-3	N-hexane	Grease	Closed system	
113706-15-3	Phosphorodithioic acid, mixed O,O-bis(sec-Bu and isooctyl) esters, zinc salts	Lubricant, Transformer oil, Gear oil	Closed system	OWT, OSS, OCP
12001-85-3	Naphthenic acids, zinc salts	Gear Oil, Grease	Closed Risk Accidents	OWT, OSS, OCP
		Grease, Gear Oil, Lubricant	Closed system	OWT, OSS, OCP
121158-58-5	Phenol, dodecyl-, branched	Lubricant, Gear Oil	Closed system	OWT, OSS, OCP
12179-04-3	Disodium tetraborate, anhydrous	Antifreeze, Coolant	Closed system	OWT
125643-61-0	C7-9-alkyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate	Lubricant, other	Closed system	OWT, OSS, OCP
128-37-0	2,6-di-tert-butyl-p-cresol	Hydraulic oil, Insulating gas/fluid, Lubricant, Transformer Oil	Closed system	OSS

[1] For all substances proper risk management and storage procedures should be followed.

CAS no.[1]	Substance	Operating material type	Open/closed system	Location of occurrence of substances[1]
128-39-2	2,6-di-tert-butylphenol	Hydraulic oil, Transformer Oil	Closed system	OWT, OSS, OCP
1317-38-0	Copper oxide	Antifouling (ICAF)	Open System	OCP (some OSS)
1330-43-4	Disodium tetraborate, anhydrous	Grease, Coolant	Closed system	OWT, OSS, OCP
1330-78-5	Tris(methylphenyl) phosphate	Hydraulic oil, Gear oil	Closed system	OWT, OSS, OCP
13539-13-4	2,5-bis(octyldithio)-1,3,4-thiadiazole	Gear Oil, Grease, Lubricant	Closed system	OWT, OSS, OCP
140-31-8	2-piperazin-1-ylethylamine	Coating	Closed system	Coating (several locations) (corrosion protection)
142-87-0	Sodium decyl sulphate	Fire protection	Closed Risk Accidents	OSS and OCP (helicopter deck) (fire protection)
		Fire protection	Closed system	OSS and OCP (helicopter deck) (fire protection)
147880-09-9	AMINES, POLYETHYLENEPOLY	Lubricant	Closed system	Offshore Sub Station
151006-58-5	1-Dodecene dimer with 1-Decene, hydrogenated	Grease	Closed system	Offshore wind-turbine
25154-52-3	Nonylphenol	Coating	Closed system	Coating (several locations)
2634-33-5	1,2-benzisothiazol-3(2H)-one	Fire protection	Closed Risk Accidents	OSS and OCP (helicopter deck) (fire protection)
2682-20-4	2-methyl-2H-isothiazol-3-one	Fire protection	Closed Risk Accidents	OSS and OCP (helicopter deck) (fire protection)
67124-09-8	1-(tert-dodecylthio)propan-2-ol	Hydraulic oil	Closed system	OWT, OSS, OCP
68442-69-3	Benzene, C20-24 (even numbered) sec-alkyl derivs.	Gear Oil	Closed system	OWT, OSS, OCP
68649-42-3	Dialkyl(C1-C14)dithiophosphoric acid, zinc salt	Gear Oil, Grease, Hydraulic oil, Lubricant	Closed system	OWT
722503-68-6	Benzenesulfonic acid, methyl-, mono-C20-24-branched alkyl derivs., calcium salts	Lubricant	Closed system	OWT, OSS, OCP
7439-92-1	Lead	Batteries	Closed system	OWT, OSS, OCP

CAS no.[1]	Substance	Operating material type	Open/closed system	Location of occurrence of substances[1]
7439-97-6	Mercury	Sacrificial anodes	Open System	OWT, OSS, OCP (corrosion protection)
7440-02-0	Nickel	Other	Closed system	OWT, OSS, OCP
7440-43-9	Cadmium	Sacrificial anodes	Open System	OWT, OSS, OCP (corrosion protection)
7440-50-8	Copper	Other	Closed system	OWT, OSS, OCP
7440-66-6	Copper	Lubricant	Closed system	OWT, OSS, OCP
7440-66-6	Zinc	Coating, Other	Closed system	Antifouling (several locations)
		Sacrificial anodes	Open System	OWT, OSS, OCP (corrosion protection)
7440-74-6	Indium	Sacrificial anodes	Open System	OWT, OSS, OCP (corrosion protection)
756-13-8	Perfluoro-2-methyl-3-pentanone	Fire protection	Closed system	OSS and OCP (helicopter deck) (Fire protection)
7681-52-9	Sodium hypochlorite	Other	Closed system	OWT, OSS, OCP
		Antifouling	Open System	OCP (some OSS) (antifouling)
80-05-7	Bisphenol A	Coating, Other	Closed system	Coating (several locations) (corrosion protection)
		Leaching from coatings	Open System	Coating (several locations) (corrosion protection)
8028-48-6	Orange, sweet, ext.	Other	Open system	Offshore Converter Station (Discharges in open systems)
8042-47-5	White mineral oil (petroleum)	Hydraulic oil, Transformer oil, Lubricant, Other	Closed system	OWT, OSS, OCP
8052-41-3	Stoddard solvent	Other	Closed system	Operational material used in the flange connections of monopiles with the transition pieces (during installation)

CAS no.[1]	Substance	Operating material type	Open/closed system	Location of occurrence of substances[1]
		Other	Open system	OWT (Discharges in open systems)
9016-45-9	Nonylphenol, ethoxylated	Hydraulic oil	Closed system	OWT, OSS, OCP
91-20-3	Naphthalene	Fuel	Closed Risk Accidents	OSS and OCP (Bunkering)
		Other	Closed system	OSS and OCP
94270-86-7	N,N-bis(2-ethylhexyl)-ar-methyl-1H-benzotriazole-1-methanamine	Gear Oil	Closed system	OWT, OSS, OCP
	Fluorosurfactant/component	Fire protection	Closed Risk Accidents	OSS and OCP (helicopter deck) (Fire protection)

[1] CAS numbers represent a unique numerical identifier assigned by the Chemical Abstracts Service

1.2 Introduction to WP3 report

1.2.1 Objectives

Work Package 3 provides an overview of measures and technologies that are suitable to avoid or at least reduce the risk that substances identified as priority substances (WP1) are entering the marine environment.

The aim is a document that helps the permitting authority BSH as well as applying industry, to identify appropriate technologies and procedures to reduce emissions of the priority substances. This will focus both on avoidance due to procedures and maintenance as well as actual technologies, construction requirements or materials used.

The permitting authority BSH has already identified a set of requirements to avoid emissions from offshore wind structures (BSH, 2020 – now also updated for 2023).

For each area of interest, the relevant German legislation is put into context in particular as the AwSV is not applicable in all locations of wind farm development (only near shore).

To prevent emissions or reduce the risk of accidental emission into the marine environment for the identified sources, the whole life cycle of offshore wind farm structures will be addressed, including the installation, operation and decommissioning phase. The proposed best available techniques will be evaluated with respect to the Ordinance on facilities for handling substances that are hazardous to water (AwSV, 2017) and other national guidelines as well as recommendations from technical institutes.

Currently, no specific technical guideline applies in the German exclusive economic zone (EEZ) regarding the application and use of substances which are hazardous to the aquatic environment other than the FEP2023. The German Ordinance on Facilities Handling Substances that are Hazardous to Water (AwSV) on the application and use of substances which are hazardous to the aquatic environment for the application onshore is only applicable by law for coastal waters (12 nautical miles) and not in the EEZ where most offshore wind installations are being built.

However, the site development plan (BSH, 2020 and 2023) gives general technical requirements to minimise emissions as much as possible. So far, the structural security measures for applications involving high amounts of liquid operational materials need to be ensured on an individual basis.

Guidelines including security measures and best practice for handling of hazardous substances specifically for the application on offshore wind structures – as regularly submitted by the windfarm operators - limit the risk of accidents or spillage due to structural measures. The risk of emissions of materials applied in a principally closed system with a higher risk for accidents is mostly associated to human failure. This emphasizes the importance of strict routines, safety protocols and experienced personnel for the maintenance procedure on offshore structures.

The compilation of best available techniques in WP3 could be used as a very first step towards the preparation of a Best Available Techniques Reference (BREF) for offshore wind structures.

1.2.2 Definitions and Assumptions

Best Available Techniques (BAT) as defined in the IPPC directive (2010/75/EU, article 3.10) describes “best” as the most effective technique in preventing or reducing emissions and impacts to the environment as a whole. In understanding the purpose of BATs the following definitions of the IPPC directive (2010/75/EU, article 3 (10 a-c)) (EC 2010) needs to be understood as well:

a. “Techniques“ includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
b. “available techniques” means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
c. ”best” means most effective in achieving a high general level of protection of the environment. For clarity, this encompasses techniques that can be used to address both routine (foreseen) and unintended (accidental) emissions and other impacts on the environment.

WP3 will provide a first step towards a “Best Available Techniques”-document by addressing suitable technologies for the identified potential sources of contamination and installation features where hazardous substances are used and applied. Where possible the identified technologies will be generalized to general recommendations for technical installations or construction measures.

The proposed measures will be subjected to a gap analysis against the existing regulations in the AwSV and other technical guidance such as the FEP in order to identify gaps or in order to have the relevant guidance to support the use of the best available techniques.

Finally, it is noted that best available techniques are evolving over time with new techniques being developed and brought to maturity. Also, with windfarms being built with a life span of several decades (most with a life span of 25 years), retrospective constructive changes may be difficult to achieve in the weight and space limited offshore environment. This means that retrofitting installations or updating existing installations may be difficult as the space available and the possibility for extra weight on existing platforms are severely limited. Therefore, focusing on suitable technologies as part of the permitting process will be highly beneficial.

2. Emission Prevention at Offshore Wind Farms

2.1 Introduction to approach

WP3 provides a guidance document on how to avoid or reduce emissions to the marine environment from the list of priority substances from WP1.

This approach makes a distinction between risk management approaches that are valid for all areas of installation, operation and decommissioning and actual technologies that prevent or reduce emissions.

For the possible pathway of substances to the marine environment a clear distinction between open and closed systems has been made during the identification process in WP1. Open systems are systems that are in direct contact with the marine environment, such as corrosion protection measures. Most other operations are associated with closed systems, e.g. systems that are designed in a way to contain the harmful substances and that therefore, if working, operated and maintained properly, will not result in any contact of the harmful substances with the marine environment. Further, closed systems with a higher risk for accidents are distinguished, which have a large risk of direct exposure of the substances to the marine environment. The most relevant operations of this category are e.g. fire protection, waste water or bunkering procedures.

A risk management-based approach is summarised in Section 3.1 Risk Management. Here the collection of measures that are not tangible are given. These protocol and procedures may be the most relevant way to reduce emissions as the largest risk for emission from closed systems is associated with accidental spills, sub-optimal maintenance and inexperienced personnel.

The risk management chapter also highlights the available guidance from AwSV (that could be used as guidance for the permitting authorities even if the development is outside the areas where following the legislation is mandatory. The chapter will be concluded with recommendation how to further strengthen this risk management approach.

For the technological areas that can be found on the Offshore Wind turbine (OWT), Offshore substation (OSS) and Offshore converter platform (OCP) there is a divide between areas that are well establish with little to none technical advances expected as the current technology or approach is mature and procedures on how to deal with and emissions are well defined and mature.

For these areas (namely storage incl. bunkering and general requirements for technical installation) a short overview of the available legislation is given, however, no additional measures are suggested. Here the biggest factor in reducing emissions is to ensure that these regulations are followed, and maintenance operations/inspections are carried out as required.

For the other areas that have been identified to have a higher risk of emissions to the marine environment are approached in the following way:

Description of the available technologies (where relevant also technology that is no longer acceptable (but potentially still tolerated), the existing legislative support and the recommendation on how to move forward.

The following areas will be addressed:

- Corrosion protection (anodes and coatings) (can be found on OWT, OCP and OSS)
- Fire protection (usually on OCP or OSS)
- Wastewater and rainwater discharge (OCP and OSS)

Per technology the relevant AwSV regulation is mentioned that could be applied to this area. The themed approach has been chosen above the location of hazardous materials as storage and corrosion protection may be relevant both at OSS and OWT. However, Table 1 gives further information.

A frequent source of dispute with both onshore and offshore operations is the contradiction between different regulations of unrelated subjects. Some requirements that would be best practice in terms of protection of the environment may lead to a direct contradiction of safety regulations (e.g. a threshold at a door to keep fluids contained in a specific area versus the requirement off threshold free doorways for trip hazard free evacuation routes). These potential conflicts have not been investigated in detail other than the techniques identified have been applied in offshore wind structures and may therefore appear as a conflict free application.

A general remark that is outside the scope of the study but relevant in the context of emission avoidance, is that the study in WP1 revealed the difficulty to investigate hazardous components in operational materials. The difficulties arise from the problem to find appropriate information about its components in e.g. material safety data sheets (MSDS) and the behaviour of the compounds in mixtures as they are used. An improved availability of information provided by the manufacturers can enable a more undeceived handling of materials, allows for broader and easier investigation for substitutes and raise awareness about risks.

Lastly, it will be not possible to mitigate all risks of emission, even with the most stringent regulations. An environmental risk will therefore remain. In this context the "As Low As Reasonable Practicable" (ALARP) principle as commonly used in the risk assessment of the process industry could be applied, which refers to manage risk to a level As Low As Reasonable Practicable (see e.g. TÜV, 2003)

3. Best Environmental Practice and Best Available Technologies

The design of the technical installation is crucial to the safe and efficient operation of the offshore wind park. The description of suitable environmental practice and available technologies is supplemented by the legislative base from the AwSV and the Flächenentwicklungsplan 2020 and 2023. Even though, these are not legally valid in the EEZ, the application of the relevant articles from the AwSV could help to level the playing field in the offshore wind sector between coastal and offshore wind parks while allowing sharing expertise with other specialists.

3.1 Risk Management

Substances that are used in the general operation and maintenance of a wind farm and associated technical installation are often contained in closed systems but need to be exchanged or replaced during the operation. This means that the accidental release of these substances into the marine environment is commonly experienced during these activities. In order to reduce the risk of accidental release, the AwSV and the Flächenentwicklungsplan 2020 and 2023 focus on measures to reduce risk such as emergency planning and documentation.

Risk reducing measures can be classified into 3 categories:

- Sound design and documentation of installation
- Maintenance manuals and plans that ensure that inspection and maintenance of the installation is carried out in good time
- Emergency protocols and emergency measures to be followed when combating accidental releases of substances

The documentation and maintenance of the installations requires well-educated personnel that is well-equipped and acquainted with the offshore work and the installation in particular. A culture of safety and "doing it right" will help to avoid accidents. However, due to economic pressures cutting corners in maintenance activities, using non-fully-qualified staff and, in particular stretching the time between inspections, all increase the risk of accidental releases of substances.

3.1.1 Legislative support

The risk management approach for operation and maintenance is reflected in the following chapters of the AwSV and the FEP (BSH, 2023).

The AwSV Chapter 3, Section 3, Paragraph 43 "Anlagendokumentation" requires that information on the installation are readily available, documenting the design, the substances used, safety measures etc. This documentation also needs to be provided in case the owner of the installation changes. It is important that the documentation is continuously updated.

The AwSV Chapter 3, Section 3, Paragraph 44 "Betriebsanweisungen" addresses the emergency planning and required monitoring to identify potential accidental release. Here the need to continuously update these plans is anchored in the AwSV. Also, the requirement for training for personnel is made mandatory and has to be carried out on a least a one-yearly basis. The manuals and operational information must be made accessible to the relevant personnel at any time.

The Flächenentwicklungsplan 2023 Chapter 6.1.12 (also in „technical installations)" repeats the requirement for emergency plans to protect the marine environment from accidental releases.

For the maintenance operation the AwSV defines in Chapter 3, Section 2, Paragraph 23 "Anforderungen an das Befüllen und Entleeren" the procedures relevant for the maintenance of installation in terms of filling and emptying containers/systems. Requirements are also described for larger containers in terms of overflow protection and other safety measures such as self-closing emergency valves.

The internal review and monitoring commitments of the operators are recorded in AwSV Chapter 3, Section 3, Paragraph 46 "Überwachungs- und Prüfpflichten des Betreibers" clearly stating the requirement to regularly test safety equipment as well as setting the minimal intervals for such internal reviews. Any identified short-coming will need to be addressed (see also AwSV Chapter 3, Section 2, Paragraph 48 "Beseitigung von Mängeln") within 6 months (small shortcomings) or immediately for dangerous or extensive shortcomings.

External audits are to be carried out by specialists and are documented in AwSV Chapter 3, Section 2, Paragraph 47 " Prüfung durch Sachverständige".

3.1.2 Recommendations

The following recommendations are made to go beyond the legislative context.

- Regular training for staff working offshore in particular areas (e.g. turbines)
- Strengthen focus on compliance and accountability with environmental management systems: These measures can be supported by a working environmental management system that ensures the continuous improvement of the operation using a review cycle of identifying issues, addressing them and monitoring the success and developing a plan to improve further. Some wind farms in Europe (e.g. Tidal Transit Flotation; Cadeler, Van Oord, Ocean Wind) already decided to get certified under ISO 14001. ISO 14001 sets out the criteria for an environmental management system and can be certified by accredited institutions (accredited via the Deutsche Akkreditierungsstelle). It maps out a framework that a company or organization can follow to set up an effective environmental management system.

The key elements of a working and certified HSE management system in regards to marine emissions are summarised below:

- An operational Health, Safety and Environment (HSE) management system (or equivalent such as ISO 14001 and ISO 45001), that addresses health, safety and environmental management over the whole organization. This ensures that suitable guidelines on the storage and handling of hazardous substances will be in place, regularly reviewed and if necessary improved. Some wind farms are already ISO certified for HSE.
- Appropriate HSE documentation in place (manuals, guidelines), to ensure the necessary measures are clear and can be followed. This will allow for controlling hazards and an accurate emergency response. It also allows for continuous improvements by recording incidents.
- Spill Contingency or Emergency Response Plans for situations of accidental releases ensure swift action and preparation of countermeasures where necessary. On a smaller scale a risk assessment will give a good overview of the possible risk to the environment (and health and safety) involved.

- Appropriately trained personnel with necessary procedures to follow in place. As facilities and equipment can be adjusted over time (not always with appropriate records), experienced personnel is a valuable resource to anticipate the changed situation or make judgement calls based on their experience.

The best risk management approach for assuring ongoing operational effectiveness is to record reasons for, and consequences of, all unintended releases of operation materials occurring during day-to-day operations, in order to take the necessary corrective actions to reduce release frequency (NORSOK S-003, 2007).

3.2 Technical Installations

3.2.1 Technical Installation

In principle no emissions should be released into the marine environment. A permit can be requested from the BSH which will require an assessment of alternatives and a comprehensive study of the emissions. This is relevant for the construction, operation and decommissioning of the wind farms.

3.2.2 Legislative support for installation

AwSV Chapter 3, Section 1, Paragraph 14 "Bestimmung und Abgrenzung von Anlagen" identifies the parts that belong to a technical installation so not only the installation itself but also storage containers and pipelines and that are relevant for the release of hazardous substances in the marine environment.

The Flächenentwicklungsplan 2023 Chapter 6.1.12 „Emissionsminderung" clearly states that emissions have to be avoided if possible and otherwise reduced as far as possible. This ensures that the wind farms are in compliance with article 1 paragraph 1 number 4 of the United Nations Convention on the Law of the Sea and article 5 paragraph 3 and article 48 paragraph 4 of the Offshore Wind Energy Act (WindSeeG, 2016).

Risk analysis and emergency planning as well as detailed concepts on the design and operation of the windfarm including emission streams should be an integral part according to BSH Standard Konstruktion 2015 – Chapter 2.6 Rückbau and Standard Konstruktion 2015 – Chapter 5.1.1 Betriebstrukturen von Offshore Stationen – Einteilung in Gefahren, -Schutz- und Sicherheitsbereiche and Standard Konstruktion 2015 – Chapter 5.2.1 Betriebstrukturen von Offshore Stationen – Entwicklungsphase – Vorbemerkungen (BSH, 2015).

In terms of preventing emissions from entering the marine environment, in the AwSV Chapter 3, Section 2, Paragraph 17 "Grundsatzanforderungen", the basic principles for a safe design are listed including:

- Containing water polluting substances inside the installation
- Highlight leaks within the installation
- Appropriate disposal of leakage or drops
- Collect and dispose leakage during operation or accidents (ensure that facilities can collect and can be disposed)

Double walled pipes or tanks are not required to have collection facilities for leaks as they are already double contained (AwSV Chapter 3, Section 2, Paragraph 18 " Anforderungen an die

Rückhaltung wassergefährdender Stoffe“ and AwSV Chapter 3, Section 2, Paragraph 21 “Besondere Anforderungen an die Rückhaltung bei Rohrleitungen“).

3.2.3 Recommendations for technical installation

Important is the fact that visual inspection for leakages must be possible, however, large parts of the wind farms will not be manned meaning that inspections are regular but with larger intervals making detection of leakage by visual means challenging. If possible, Supervisory control and data acquisition (SCADA) systems (digital systems that record and analyse data in real-time) should be used to help monitoring.

3.3 Storage

The storage of operational materials (oils, grease, etc.) and other materials for e.g. maintenance purposes (cleaners, paints etc.) are required for the smooth operation of offshore wind farms and offshore transmission structures.

Operational/ maintenance materials may be stored in bulk (e.g. diesel for generators) or in smaller quantities in tanks or other containers. Storage in this context includes both the actual storage or temporary holding of substances within fixed containment on the facility as well as handling, referring to the loading onto the facility and the transfer on the facility.

In storage there is a risk for an unintended release of the materials into the marine environment due to their presence on the offshore structure. Such unintended release can happen on the facility or off the facility (e.g. during the diesel bunkering process). The spill volume can be small due to small volume leaks or loss of containment of small quantities or more severe with larger spills. Additional to the loss of containment, leaks or spills can also happen as part of the scheduled maintenance operation (e.g. exchange of lubrication oils) and may result in smaller quantities released.

3.3.1 Legislative Support Storage

With respect to the handling and storage of substances that can have an impact on the marine environment, the AwSV describes in Chapter 3, Section 3, Paragraph 26 ”Special requirements for installations for the storage, filling, production, treatment or use of solid substances hazardous to water” the minimum requirements for the storage of substances. Therefore, the containment, storage specification and storage area (surface) need to be considered in the design to ensure appropriate facilities for substances stored. These also apply to AwSV Chapter 3, Section 3, Paragraph 31 ”Special requirements for barrel and container storage”, with the addition that storage in tanks will require retainment facilities (bund walls) that can contain between 1 and 3% of the tank volume. For mobile storage containers, this can be reduced to storage on appropriate sealed floors if material for spill absorption is within easy reach and the installation is supervised.

3.3.2 Recommendations for Storage

Recommendations for the handling and storage of hazardous substances are limited if appropriate design is followed as indicated in the legislation.

Two items are highlighted for consideration during permitting: the design of the actual storage facilities and the actual substances stored.

For clarity the main design items for establishing “safe” storage areas are listed below.

The following design items should be included (for storage in bulk or tanks):

- Non-return valves for transfer pumping of substance (e.g. bunkering of diesel or kerosene) and self-draining and overfill protection in containment.
- Diesel/ kerosene storage in double walled tanks or with appropriate containment and must be inspected by independent third party.
- Maintain equipment with supplier guidance and ensure appropriate record of the maintenance.
- Establishing bunded areas (containment area) of adequate size and drainage.
- Define containment barriers, if necessary, in between or at entries/exits of containment areas (e.g. acids and bases)
- Consider dedicated drain to chemical spill tanks. Have spill kits in place (absorption material) and ensure proper disposal (if recycling is not possible).
- Protect piping installation and hose couplings against damage from handling operations (including drop protection on critical structures and equipment).
- Ensure for each storage item of operational material the presence of a label with amount, name, major hazardous components and toxicity information (at location and in documentation e.g. material safety data sheets).
- Regular inspection (and training) of spill response.
- Regular inspection of storage facilities.

On the substances itself a Regulatory Review of the substances should be conducted in order to determine whether operational materials used are subject to REACH requirements or other regulatory requirements (UK Department of Energy and Climate Change, 2016). This will ensure in a permitting stage that alternative substances are considered. As earlier noted, access to substances information via safety data sheets is not always easy and could be improved.

3.4 Bunkering

Bunkering can be considered as part of storage, however, due to the large volumes involved and the actual focus of pumping of fuel into the storage facilities it is mentioned separately. Bunkering is the supplying of petroleum products (mostly fuel) (referred to as bunker) on ships or offshore installations. While bunkering the petroleum products are pumped from the vessel to the tanks at the offshore installation. During the pumping operation the connection is particular sensitive to accidents that could result in loss of connection and with that a significant spill to the marine environment.

3.4.1 Legislative Support Bunkering

The International Maritime Organisation began enforcing on 1 January 2020 the so called IMO 2020 regulation of MARPOL Annex VI to minimise bunkering's environmental impact (MARPOL, 2020) directed mostly towards air emission. Also the AwSV describes in Chapter 3, Section 3, Paragraph 30 ” Besondere Anforderungen an Anlagen zum Laden und Löschen von Schiffen sowie an Anlagen zur Betankung von Wasserfahrzeugen” the requirements for a safe bunkering operation such as shut-off valves on both sides of the connection and pipelines above the water surface.

Additional measures are as mentioned in the Flächenentwicklungsplan 2023 Chapter 6.1.12 „Emissionsminderung“ overflow warning systems, secondary containments and emergency spill kits. Preparation of protocols of the bunkering activities as well as seizing of activities that may interfere (e.g. the operation of cranes) is also required.

3.4.2 Recommendations Bunkering

The documented procedure with respect to bunkering seem to be sufficient to minimise accidents if procedures and protocols are followed and emergency procedures are in place.

3.5 Fire Protection

On structures of the offshore wind industry, different types of fire extinguishing systems are present such as permanently installed systems and handheld extinguishers. Depending on the technical components within a room or certain unit, different extinguishing agents are applied, such as inert gases, mixtures with water, film building materials or powder-based materials. As inert gases mostly nitrogen and CO_2 are applied.

In case of usage, liquid or powder based extinguishing agents are collected within collecting trays and are disposed in the sump tank or appropriate container for the disposal on shore. Since most of the technical components on offshore structures are located within enclosed spaces, the risk of emissions entering the water is low. In case of an accident on the outside area such as the top deck of an OSS/OCP, extinguishing material (ABC powder) from handheld devices might end up in the water.

A more critically assessed scenario is the activation of the fire-system on the helicopter deck on the OSS or OCP. On the helicopter deck, the presence of kerosene and the possibility of hydrocarbon flammable liquid fires make the application of a film building material necessary. The applied film floats on the surface of most hydrocarbon fuels and suffocates the fire. As film building material AFFF (Aquatic film forming foam) foams are widely applied. Those AFFF foams often include PFAS materials (per- and polyfluoroalkyl substances), which can be further distinguished into substances belonging to the families of PFOS (perfluorooctane sulfonate), PFOA (perfluorooctanoic acid), PFNA (perfluorononanoic acid) and PFHxS (perfluorohexane sulfonic acid).

Even with a fully functioning system, the possibility of false alarms rises the changes of discharge of AFFF foams into the marine environment. The alarms can be triggered by for example hot exhaust gases. The water and foams used for firefighting should be collected in the drainage system of the helideck and designed in a way to be able to contain any spilled fluid and the water/foam used for fire fighting. Special attention should be given to ensure that any liquids collected will be extinguished and not (re)-ignited.

3.5.1 Available techniques

The EU directive 2019/1021 prohibits the application of extinguishing agents, which include PFAS materials over a certain limit (EU Directive 2019/1021 (European Union, 2021)). For PFOS substances the concentration needs to be equal to or below 10 mg/kg if present in substances or mixtures. For PFOA and any of its salts, the concentration needs to be equal to or below 0.025 mg/kg when present in substances or mixtures, while for PFOA related compounds the concentration limit is given to 1 mg/kg. An acceptation is made for PFOA, as its salts and compound can be used in firefighting foams for liquid fuel fires. The application of those is allowed till 4th July 2025 under the restrictions, that those materials are not used for training or test purposes, and it can be ensured, that all released materials can be contained.

A recent study of the European Commission and the European Chemical Agency (ECHA) investigated the use of PFASs in firefighting foams and alternatives to PFAS-containing firefighting foams (EU/ECHA 2020). In this study, an overall assessment of the technical feasibility, economic feasibility and availability of seven alternatives for PFAS was undertaken. The results of the study showed that alternatives are generally available, technical feasible and have already been implemented by many user sectors identified. However, efficiency and safety of fluorinated *versus* fluorine-free firefighting foams is currently highly debated.

Thereby, the discussions about AFFF and FFF (Fluorine Free Foams) are very confusing for all parties, concerned consumers, authorities and manufacturers (EUROFEU, 2019). The balance between safety and protection of lives and property and the potential risk to the environment is delicate. According to EU/ECHA (2020), IPEN (2018) and environmental protection associations, FFF are viable alternatives to AFFF. However, there is no consensus to approve that FFF meet all needs encountered by end users. LASTFIRE, a consortium of international oil companies, performed many specific tests on various kinds of firefighting foams. LASTFIRE concludes that "*as yet, no commercially available fluorine free foam has shown the same level of consistency or high performance that had become the norm with good quality Multi-purpose AFFFs or fluorine protein foams*" (Lastfire, 2017). In the study of Yu et al. (2020), the conclusion was drawn, that the adverse effect of oil on the stability of AFFF is much less than that of FFF. However, the authors state that „By adjusting the foam expansion ratio, the fire extinction performance of the fluorine-free foam can be comparable to that of the fluorinated foam, and the burnback performance is significantly enhanced" (Yu et al.,2020). The application of fluorine free alternatives, even for challenging applications e.g. on airports or refineries, where large amounts of liquid fuels are stored have been documented, e.g. from the Danish royal air force (IPEN, 2018) or some refineries with large storage tanks in Norway (IPEN, 2019).

In summary, the PFAS based foams will be phased out, however, how the transition will look like is unsure. The wish is that future products are free of PFAS and other harmful substances, biodegradable and not significantly more expensive.

Vanguard Fire & Security Systems in Texas claims that Fluorine-Free Firefighting Foam is already used in many airports, military bases and oil and gas facilities around the world. Fluorine-free firefighting foam is a synthetic-based foam that contains surfactant blends and polysaccharides. It doesn't contain PFAS, and it's biodegradable. It's currently the most popular type of PFAS-free firefighting foam on the market (VanGuard, 2022)

It should be noted that besides the substances used for the fire foams, the technical installation may also result in environmental benefits. Deck integrated firefighting systems (DIFFS) are preferred opposed to Fixed Monitor System (FMS) due to the following factors: rescue operation can continue while spraying, automated system does not rely on human operation, less susceptible to wind and obstruction of nozzles due to debris (Aluminium Offshore, 2016-2023).

3.5.2 Legislative Support

According to the site development plan 2023 (BSH, 2023), PFAS containing firefighting materials are excluded from their application on offshore helicopter landing areas.

In a fire emergency, the mixture of foam building material and liquid is captured in the sump tank of the structure. Thus, the volume of the sump tank should be designed as such, that all volume of potential hazardous materials in a fire emergency can be captured, additional to common filling levels according to the EU regulation 2019/1021.

Lastly, firefighting exercises should only be performed with water (not foam). This is also reiterated in the Flächenentwicklungsplan Chapter 4.4.1.11 „Emissionsminderung and the AwSV Chapter 3, Section 2, Paragraph 20 "Rückhaltung bei Brandereignissen".

3.5.3 Recommendations

It will be necessary to closely follow the development of firefighting foams in the future to make good permitting decisions balancing the ban of PFAS containing fire foams and alternatives that are equally reliable and effective.

Where possible, fire supressing systems could be used to combat fire at an early stage (less suitable for helicopter decks). Via detectors the fire will be registered, and the area will be filled with an inert gas, aerosol, or foam. Furthermore, measures to reduce the risk of "false alarms" should be implemented.

3.6 Corrosion Protection

The offshore structures experience the influence of a very harsh environment. Aggressive salt water, sun exposure, temperature changes and cyclical changing conditions support corrosion at steel parts of the structures. As a result, corrosion is next to fatigue issues the most probably failure and degradation mechanism for steel structures offshore (Price, 2017). Therefore, corrosion protection systems are essential to protect the steel construction against corrosion in the harsh marine environment during their lifetime of approx. 25 years and are an important factor for the long-term stability of the offshore structure. The following three corrosion protection concepts are applied in the offshore environment:

a) Passive protection by coatings (e.g. epoxy resins and polyurethane)

b) Active cathodic protection systems using galvanic sacrificial anodes (GACP) or impressed current cathodic protection systems (ICCP)

c) Corrosion allowances ("thicker steel")

The application of the different concepts is based on the chosen protection strategy and the application location at the structure. The structure parts are associated to three different zones:

1. Seabed and underwater zone
2. Splash zone (SZ), tidal zone (TZ) and low water zone (LWZ)
3. Zone under atmospheric conditions distinguished into a:
    a. zone under *external (outdoor)* atmospheric conditions
    b. zone under *internal* atmospheric conditions.

Each zone is associated to a corrosivity category and can be associated to a corrosion protection system using passive or active protection or even both. Especially the splash zone is undergoing the most extreme corrosion category of "extreme corrosivity". This zone is influenced by tidal conditions, waves, sunlight, salt splash, biofouling and floating objects e.g. sea-ice in the Baltic Sea. Corrosion in this zone is extreme due to high chloride concentrations, moisture and changes of pH and oxygen during the wet and dry cycles. Therefore, the steel structures (e.g. the transition piece) is protected by coatings also due to the mandatory colour for these parts of the offshore structure (in Germany: RAL1023) (Kirchgeorg et al., 2018). Further, often a corrosion allowance is applied in this area with cathodic protection below mean water level (Syrek-Gerstenkorn, 2019). In the constantly submerged zone typically cathodic protection is applied in form of galvanic anode cathodic protection systems or impressed current cathodic protection systems for the water exposed steel inside and outside the foundation structures (Syrek-Gerstenkorn, 2020). Steel parts in fully atmospheric conditions are typically protected by coatings.

3.6.1 Coating

Coatings need to withstand extreme conditions offshore in the individual corrosivity zones. According to the VGB Standard Corrosion Protection Part 2 (VGB, 2018b) the coating requirements include strong adhesive characteristics, resistance against impacts, resistance against water immersion through water, humidity or salt splash spray, sun radiation and cyclic influences of the previous besides abrasion resistance and colour authenticity. Coatings are typically applied in areas exposed to the marine atmosphere as well as in the splash/tidal areas (Syrek-Gerstenkorn, 2020). Protective coatings can be divided in four types:

1. Inorganic coatings (e.g. ceramic, carbon)
2. Organic coating (e.g. epoxy, polyurethane)
3. Organic-inorganic hybrids
4. Metallic coatings

While the first three type of coatings represent a passive protection with barrier effect, the metallic coatings have further an active component of cathodic protection. According to Price (2017), the most commonly applied coatings for offshore structures are organic and very recently in the offshore wind industry also metallic coatings or rather a combination of both (TWI, 2018).

3.6.1.1 Organic coatings

Price (2017) is giving some example of typical organic coating systems for individual exposure zones of OWTs. If applied in combination with cathodic protection, the organic coatings need to be designed for this combined application. Based on the corrosivity zone a minimum number of coats (MNOC) and a nominal dry film thickness (NDFT) need to be reached (VGB 2018b).

Epoxy resins (EP) and polyurethane (PUR) based coatings are a state-of-the-art technique for corrosion protection in a wide range of marine applications (shipping, harbours and offshore infrastructures) and are an artificial barrier to separate the steel from the corrosive environment (Kirchgeorg et al., 2018). The coatings are applied onshore on the steel structure, to ensure a sufficient surface preparation and application of the coatings, which is crucial for the performance of the pint system (Price, 2017). Organic coatings can be applied in different parts of the monopiles where the areas with direct contact with water are the most relevant for potential chemical emissions to the seawater. Different coatings are applied in German Offshore Wind farms. They may consist of a priming layer (e.g. EP-Zn or 1C/2C PUReZn, EP or EP) and 2–4 layers of intermediate or top coatings (EP or 1C/2C PUR) (Kirchgeorg et al., 2018). The number of layers and dry film thickness (up to 700 µm or more) of the coating depends on the applied type of coatings systems and which technical standard is referred to. An overview of applied layers in the German wind energy sector can be found in Momber and Marquardt (2018).

Due to abrasion smaller pieces or particles of coatings can be emitted into the environment during the lifetime of an offshore structure. Since the coatings are often based on artificial materials such as polyurethanes, polyacrylates, epoxies or polystyrenes they contribute to the chemical and microplastic pollution although their polymer concentration can be lower than other microplastics (Gaylard, 2021). The amount of microplastic entries emitted from offshore wind structure coatings is probably small compared to the emissions from antifouling coatings of vessels (Gaylard, 2021).

Coatings are applied and harden onshore, which reduces emissions and avoids the release of not fully cured coating material directly into the water. However, it is unknown how frequently coatings are maintained offshore, which might be an additional source of emissions (especially from the application process), but it is difficult to quantify (Kirchgeorg et al., 2018). In the study of Burkhardt (2015), four different epoxies have been investigated after 1 and 7 days of hardening regarding their influences on the ecotoxicology. The materials are declared for the application as cover coating in seawater according to the authorisation lists of the Bundesanstalt für Wasserbau (BAW, Karlsruhe)(BAW, 2001). Depending on the tested product various toxic effects could be observed including hormonal effects related to Bisphenol A (BPA). Similar effects have been observed in the study of Vermeirssen (2017) and Bell (2020a). Bell (2020a) identified 4tert-butylphenol as a hardener in epoxy resins as the main contributor to acute and estrogenic effects and recommends replacing the substance by higher molecular weight phenols. However, the observed effects in these studies under laboratory conditions are going to be diluted under real applications and actual toxic effects cannot be derived from this study (Burkhardt, 2015). Further, the coating of offshore structures is performed onshore, thus the hardening of the coating is not taking place in the aquatic environment.

Kwon (2017) state that assuming the level of plastic particle density in the open ocean, the resulting concentration of additives in water or other environmental media is likely to be extremely low and will therefore not pose a risk to marine organisms. According to the modelling work of Koelmans (2016), the risks associated with leaching additives in plastic (BPA and nonylphenol) in plastic ingestion was negligible for fish and may occasionally be relevant for marine worms and therefore are not likely to constitute a relevant exposure pathway.

3.6.1.2 Metallic coatings

Metallic coatings with a cathodic protection effect are based on aluminium or zinc particles applied on the steel surface. The application on the steel surface takes place via e.g. thermal spraying (TSA – thermal sprayed aluminium) or cold spraying. Metallic coating for OWTs are recently tested in the CROWN project (Cost reduction of offshore wind now – TWI, 2018) and have been applied in combination with an epoxy top coating at the Arkona windfarm in the Baltic Sea (Syrek-Gerstenkorn, 2019). Depending on the applied anode metal, the metal coating release aluminium (TSA) or zinc (TSZ) into the aquatic environment. Emissions from the TSA aluminium coatings, assuming a mass reduction of 90% over the structure lifetime, is identified to 38 kg/year per foundation for an exemplarily windfarm.

3.6.1.3 Cathodic protection

Cathodic protection systems are the most commonly used active corrosion protective techniques for all kinds of steel-constructions like ships and infrastructures in marine and harbour environments. Through the supply of current, a permanent reduction in potential is achieved to slow down the oxidation processes. The protective current can be generated by galvanic “sacrificial” anodes or ICCP systems. Those provide the protection current for the polarization of the metal surface by either the galvanic reaction of a less noble material compared to the steel structure (GACP) or the active current (ICCP) (Kirchgeorg et al., 2018). The cathodic protection can be applied alone or in combination with a suitable coating on the steel structure. However, the application of sacrificial galvanic anodes is just permitted with appropriate coating suited for galvanic protection (BSH, 2015). ICCP system are the preferred cathodic protection system, since it does not associate the emission of large amounts of metals contrary to galvanic anodes (BSH, 2020). For complex structures also hybrid systems are applied, combining ICCP and galvanic anodes. Thereby, galvanic anodes are placed in areas, so called shadow zones, where no sufficient protection by ICCP can be provided (Source: Emission concepts of individual windfarms).

3.6.1.4 Sacrificial/galvanic anodes

For offshore structures aluminium-based galvanic anodes are preferred and mainly used. Zinc anodes are becoming less common, which might be related to the restrictions of BSH to limit the amount of zinc to a minimum. However, zinc cannot be excluded completely, since it is necessary for activation and to avoid passive oxide films on the anode surface (Kirchgeorg et al., 2018).

Composition of the anodes varies, however, aluminium anodes are normally used in offshore applications for the European Standard EN 12496:2014 and the NORSOK standard M503 (2007) (see Table 2). Alternative information is given also in DNV-RP-B401(2010) and ISO 15589-2 (2012), which give similar compositions.

Table 2: Chemical composition of aluminium anodes according to EN 12496:2014 and NORSOK M503

Metal	Mass percentage (%)	
	EN 12496:2014	NORSOK M503
Aluminium	94.1-96.6	93.8-97.1
Zinc	3-5.5	2.5-5.75
Indium	0.016-0.040	0.015-0.040
Iron	≤0.09	≤0.09
Silicium	≤0.12	≤0.10
Copper	≤0.006	≤0.003
Cadmium	≤0.002	-
Other impurities (each)	≤0.02	-
Other impurities (total)	≤0.1	≤0.02

However, the comprehensive investigations of Reese (2020) showed, that there are significantly more metal compounds within sacrificial anodes than described in the official standards. Thus, for the widely applied aluminium anodes in total 25 other metals have been found. Amongst other, lead and gallium has been found to be included to similar amounts as indium and cadmium.

According to Bell 2020b, aluminium anode material does not cause acute toxicity on the tested marine organisms of bacteria, algae or amphipods at the concentrations which are expected to be released during cathodic protection at offshore wind structures. However, long-term or accumulative effects like the trophic transfer of metals within the marine food web remain uncertain and therefore cannot be ruled out (Bell 2020b). From the metals that were identified in the investigated structures indium, cadmium and mercury are listed as possibly hazardous substances to the marine environment at high concentrations. Additionally, copper is currently being assessed for its potential as an endocrine disruptor (ECHA, n.d. c). Although lead was not identified in the investigated structure, Reese (2020) found similar amounts of lead in sacrificial anodes as compared to copper. Lead is known as toxic and environmentally critical. Other metals identified by Reese (2020) are shown in Table 3, including the mean emission (g) per lifespan (27 years) and the calculated mean emission per year (kg/year) for the protection of a coated monopile foundation in seawater by 2,164 kg aluminium galvanic anode. The metals identified by Reese (2020) are not identified in the investigated structures. However, there are chances that these substances are present in the investigated structures (OWT/OSS/OCP) in very low amounts. Reese (2020) estimated the emission from these metals as being equal to or lower than 0.05 kg/year. The composition of additional metals in aluminium anodes may vary and it is impossible to estimate the expected emission from additional metals from the investigated structures based on the paper by Reese (2020). Therefore, additional metals cannot be further discussed.

Table 3: Overview of estimated emissions of other metals from Reese (2020) for the protection of a coated monopile foundation (extraction of mean emissions > 10 g over 27-year lifespan)

Substance	Mean emission (kg) over 27 year lifespan	Calculated mean emission (kg/year)
Manganese	1.3	0.05
Bismuth	1.4	0.05
Gallium	0.22	0.01
Vanadium	0.25	0.01
Nickel	0.083	0.003
Potassium	0.026	0.001
Lead	0.018	0.001
Magnesium	0.011	0.0004

Sacrificial cathodic protection systems should not be installed internally in completely sealed structures such as monopiles (Delwiche et al., 2017). The chemical reaction of sacrificial anode systems can cause an acidification of the internal water from the natural pH value of 8 to values below 5 after a few weeks (Delwiche et al., 2017). This drop in pH value can cause damage to sensitive cables and other fitting inside the monopile and also accelerates the consumption of the anodes itself (VGB 2018d). Additionally, hydrogen sulphide and carbon monoxide gasses are emitted. To prevent an acidification of stagnant water e.g. replenishment holes can be foreseen at the steel design phase, to ensure a sufficient replenishment of the internal water due to tidal currents and waves.

3.6.1.5 Impressed current cathodic protection (ICCP)

Impressed current cathodic protection is an emerging technique in offshore wind farm construction that actively protects the submerged zones from corrosion and is already used for ships and water waterways infrastructure (Kirchgeorg et al., 2018). According to VGB (2018d) the following ICCP systems have proved themselves in seawater conditions:

- Metal oxide coated titanium (MOX), high specific current density
- Magnetite anodes, can be used with high driving voltages; resistant to acid and chlorine gas
- Platinum-coated titanium/niobium/tantalum, high specific current density

These systems have no significant emissions.

However, also ICCP systems should not be applied in a completely sealed environment, since the chemical reaction with the sea water leads to the production of free chlorine and locally low pH values (Duncan (2016), VGB/BAW Standard (2018d), SP0176-2007-SG).

3.6.2 Legislative Support

According to the Flächenentwicklungsplan 2023, Chapter 6.1.12 "Emissionsminderung", corrosion protection has to be low in emissions. The use of sacrificial anodes is only acceptable in combination with coatings, and heavy metals (mercury, cadmium, lead, copper), and in particular zinc are to be reduced as much as technically feasible. Anodes which are mainly made from zinc are prohibited all together.

According to the German site development plan (BSH, 2023), ICCP systems are to be preferred over galvanic anodes, since no large metals emissions are associated with this corrosion protection technique. For complex structures also hybrid systems are applied, combining ICCP and galvanic anodes. Thereby, galvanic anodes are placed in areas, so called shadow zones, where no sufficient protection by ICCP can be provided (Emission concept).

3.6.3 Recommendations

Technologically, the use of ICCP is more cost efficient and results in very low emissions to the marine environment. Cost efficiency is mostly due to the significant lower need for anodes (over the windfarm lifetime of 25 years) and possibility to check performance via sensors (no costly visits test performance offshore) (e.g. ICCP Offshore Wind turbine protection). The anodes are more costly than sacrificial anodes and also the need for an external power sources requires resources and space. Retrofitting installations with ICCP instead of sacrificial anodes is not always possible due to space limitations and may economically not be feasible depending on the remaining lifetime of the asset as the sacrificial anodes are cheaper.

However, new platforms should be designed with ICCP systems for corrosion protection. The used anodes can differ in composition (titanium, graphite, scrap metal etc.) but they all perform better in terms of emissions than the standard sacrificial anodes. Another advantage is that the ICCP can, with appropriate sensors be monitored in real-time onshore ensuring the proper operation. ICCP has its limitation in brackish water as the electric conductivity of the salt water reduces. However, this can be balanced by using higher current systems (MATCOR, 2023).

Further research is currently being carried out on the monitoring of emissions from anodes into the marine environment in the OffChEm II study (Construction and Construction-related Emissions". The research is currently being continued as part of the follow-up project "Chemical emissions from offshore wind turbines: possible influences on the marine environment and their assessment" (OffChEm II) Hereon and BSH) (OffChem, 2022)

3.7 Discharges in open systems

The discharge of potentially contaminated water into the sea can negatively affect the marine environment. A drainage system should be designed in a way to cope with planned and unplanned (accidental) releases. Areas that are not subject to contaminations (such as roofs of facilities) can discharge directly to sea. Other areas where contamination could happen regularly due to e.g. maintenance operations or presence of technical installations will warrant the collection of drain water and possible treatment prior to discharge.

Three types of waste water streams are distinguished:

- Surface water
- Cooling water
- Grey / Black water

3.7.1.1 Surface water

Surface water, like e.g. rainwater or cleaning water, is under normal conditions discharged into the sea. However, the drainage of certain areas with higher risk of spilling of oils is connected with an oil-separator. An oil-separator filters contained oil in operational water. The Site development plan (BSH, 2023) limits in Germany the remaining amount of oil in the oil-separator discharge to 5 ppm (DIN EN 858-1). In the case of an exceedance of this limit, the discharge is redirected into the sump-tank to prevent higher concentrations of oil entering the marine environment. This procedure is automated and controlled via a remote monitoring and control systems (SCADA). The control systems need also to ensure, that in the case of a fire emergency on the helicopter deck or maintenance work with hazardous materials, the mixture of water and extinguishing foam/ drainage water is not directed to the normal drainage system including the oil-separator, but rather redirected to a sump tank via a bypass. The sump tank needs to be designed in such, that the full amount of fire extinguishing liquid of the helicopter deck can be captured additional to a common filling level.

3.7.1.2 Seawater extractions and discharge for cooling circuits and freshwater supply

On the OSS and OCP platforms cooling circuits are required for cooling of technical components such as transformers. Further, in some cases the water is used amongst others for sanitary purposes, in the workshop or mixing for firefighting foam. The applied cooling circuits can be implemented by open or closed cooling circuits. Open cooling circuits extract seawater for cooling, while closed cooling circuits are self-contained circuits and cooled via a cooling unit or heat exchangers. According to the German Site development plan (BSH, 2023) closed cooling circuits are preferred over open systems. The permit for an open cooling system during the design phase is only applicable in the case that the required cooling performance cannot be achieved with a closed system. Open cooling systems require antifouling measures to prevent marine growth, antifouling is discussed in a later chapter.

3.7.1.3 Discharge of grey and black water

Platforms like OCPs are frequently accommodated over the year. The presence of people requires a concept for the wastewater treatment of black (wastewater including faecal matter from toilets, etc.) and grey water (free of faecal matter just slightly polluted, such as sewage from showering, bathing, laundries, etc.). There are two main concepts for wastewater treatment: the disposal onshore and the wastewater treatment offshore. In the first case, the wastewater is collected in mobile or static tanks and transported by ship to shore for disposal. In this case, there are no emissions to be expected. However, the transport of wastewater per ship bears risks at challenging weather conditions. Further, the disposal reliability can be terminated in ongoing bad weather periods. The second option is the wastewater treatment on the platform. According to the Site Development Plan (BSH, 2023), sewage treatment plants need to be certified at least by standards of MARPOL MEPC 227(64). This guideline gives limits for e.g. total suspended solids (TSS) amounts, thermotolerant coliforms, biochemical oxygen demand, nitrogen and phosphorus. For the water treatment, different systems can be applied such as a combination of micro floatation and UV-disinfection or an ultrafiltration system (see MARPOL MEPC.227(64)). For kitchen wastewater an oil-separator system/grease trap can be in front of the wastewater treatment stage. Biological wastewater treatment is normally not designed for longer unmanned periods, but these periods can be bridged by usage of nutrient solutions to keep the microbial community alive (Yara, 2021). The solid contents of the treated wastewater need to be reduced to the allowed amounts according to MARPOL and has to be disinfected/freed from most bacteria. The major emissions from the treated wastewater are nutrients which are expressed as total nitrogen (sum of inorganic nitrogen in ammonium, nitrite and nitrate) and total phosphorus.

According to the German Site development plan (BSH, 2023) the collection of grey and black water with a disposal onshore is preferred over the water treatment on platforms. Water treatment systems for un-manned platforms or platforms which are only accommodated during maintenance procedures are in general not allowed. MARPOL MEPC 227(64) aims to reduce the emission of nitrogen and phosphor compounds. The chlorination of wastewater is not allowed, due to the generation of hazardous secondary compounds.

3.7.1.4 Legislative Support

The German Site development plan (BSH,2023) gives clear guidance with respect to the limits of oil, nutrients and suspended matter either directly or by referring to MARPOL MEPC 227 (64).

Additional the AwSV specifies clearly in Chapter 3, Section 2, Paragraph 19 ”Drainage requirements” how to deal with rainwater run-off from different areas such as transformers or cooling aggregates. In principle all water contaminated with substances posing a risk to the marine environment should be collected and either treated or disposed as contaminated water. An oil separator should be provided to ensure the separation of oil containments in drain water. Exceptions can be made for rainwater discharges if those comply with the conditions for discharge to sea. In the absence of specific regulation, the MARPOL regulation should apply.

The AwSV specifies further in Chapter 3, Section 2, Paragraph 22 ”Requirements for the use of waste water systems as collection facilities” how drainage should be dealt with.

The guidance from the German Site development plan (BSH, 2023) Chapter 6.1.12 „Emission reduction“ can be summarized in the following points:

- Cooling facilities should be designed as closed systems to avoid the emission of anti-fouling chemicals. If the cooling capacity cannot be reached with closed cooling facilities and an open system is not avoidable, an assessment of alternative anti-fouling methods and their impacts to the environment will be required. To reduce the application of anti-fouling emissions, the natural growth cycles of marine growth (e.g. seasonal) should be taking into account if possible.

- Collection and treatment of wastewater onshore is clearly preferable compared to treatment offshore. Sufficiently large storage facilities will be required. However, to reduce wastewater streams alternative methods could be deployed such as combustion toilets or water efficiency measures to reduce the produced wastewater stream. Only for constantly manned structures an offshore treatment may be considered where effluents have to comply with the relevant MARPOL regulations. Chlorination of wastewater is not acceptable and alternative techniques such as UV light disinfection should be considered.
- Drain water streams will need to pass through an oil separator in case of possible contamination with hydrocarbons. Facilities for continuous tests through appropriate sensors and remote operation system should ensure that oil content of the wastewater stream is less than 5ppm (Site development plan, 2023).
- A special area of concern is the helicopter deck where under usual operation the drainage water will only be subjected to oil content test before being discharged. However, in case of a fire and use of firefighting materials, the run-off will be required to be collected separately for treatment and not discharged into the sea.

3.7.1.5 Recommendations

There are no significant recommendations for the management of wastewater. During the design, it should be taken into account that most offshore structures are unmanned most of the time, hence the functioning of the drainage system needs to be ensured without personnel in place and sufficient containment should be provided over a certain period of time for the case of dysfunction. The functioning of the drainage system should be tested periodically. Therefore, accessible drains with suitable sampling points for monitoring should be taken into consideration for a suitable design. For the monitoring the use of SCADA systems is recommended allowing for an automated process that can be controlled from shore.

3.8 Antifouling & Cleaning

At this stage, open cooling circuits are still present on OCPs and to some extent on old OSS platforms, since the required cooling performance cannot be satisfied with closed cooling circuits. However, there have been new concepts on closed subsea cooling systems for OCPs in Offshore wind (see e.g. FSCC design in Espedal, 2019). In the case of open cooling circuits, antifouling measures are needed to prevent marine growth at the sea-water extraction and inside the system. Possible antifouling measures are e.g. the installation of copper-anodes, which produce copper oxide (referring to Cu^{2+}) due to a redox reaction, so called Impressed Current Antifouling Protection System (ICAF) also known as Marine Growth Prevention System (MPGS). The reaction of the copper oxide results in a release of copper ions in very small amounts; referring to Cu^{2+}. Another possible antifouling system is the electric-currents-initiated redox reaction of the natural sea water salt (sodium chlorite) content to sodium hypochlorite, which is functioning as an antifouling solution. The concentration of sodium hypochlorite at the production cell is reduced from the intake of the open system till the outlet. At the outlet, concentrations of 0.1-0.3 ppm sodium hypochlorite are present (e.g. ECOLCELL). However, during the production process of sodium hypochlorite a wide uncontrolled range of chloride containing substances may be formed, from which some may have potential PBT properties (Van Hattum et al., 2004). According to a study of the Danish Ministry of the Environment (Escudero-Oñate, 2015), the expected concentrations of sodium hypochlorite in e.g. cooling water treatment are expected to be extremely low. The low concentrations and the high reactivity of the substances indicate that they do not pose and environmental hazard (Escudero-Oñate, 2015). Another possibility for antifouling measures is the application of UV-disinfection as it is also used for waste-water treatment. However, according to López-Galindo (2010), the UV disinfection is not as effective in prohibiting marine growth and merely slows down the process of marine growth.

Antifouling systems are further required for disinfection for fresh water supply, where seawater is desalinated for application purpose at e.g. the kitchen and sanitary facilities.

3.8.1 Legislative support

The German Site development plan (BSH,2023) gives clear guidance that open cooling systems and with that the need for anti-fouling is highly undesired. This means that the insistence of the developer on an open system needs to be well documented and supported.

3.8.2 Recommendations

No significant recommendation.

3.9 Substitution of substances

If possible, the substitution of harmful substances for less harmful substitutes are highly desirable especially if they can fulfil the same requirements. Where available the chapters on the technical areas suggest suitable substitutes that are currently on the market. An example is the substitution of sacrificial anode with ICCP or using less harmful anti-fouling coatings and using fire protection foams without PFC’s. Research however continues and besides the use of substitutes in open and high-risk systems, a substitution of substances in the closed systems is also desirable as these substances may be more environmentally friendly in disposal. Substitutes will be viewed in a holistic manner in terms of impacts as substitutes that may be less harmful to the marine environment may in fact have a bigger contribution to other emissions, energy consumption or need larger volumes to achieve the same result. As such also cost considerations may also play a role in the investigation of suitable substitutions.

3.9.1 Recommendations

Procedures to ensure that the newest available technologies are used in the design phase of wind farm developments should be integrated in the permitting process by challenging the developers on the avoidance of using hazardous substances identified in WP1.

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