BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

Helmholtz-Zentrum hereon

Chemical Emissions from Offshore Wind Farms

Summary of the Project „OffChEm“

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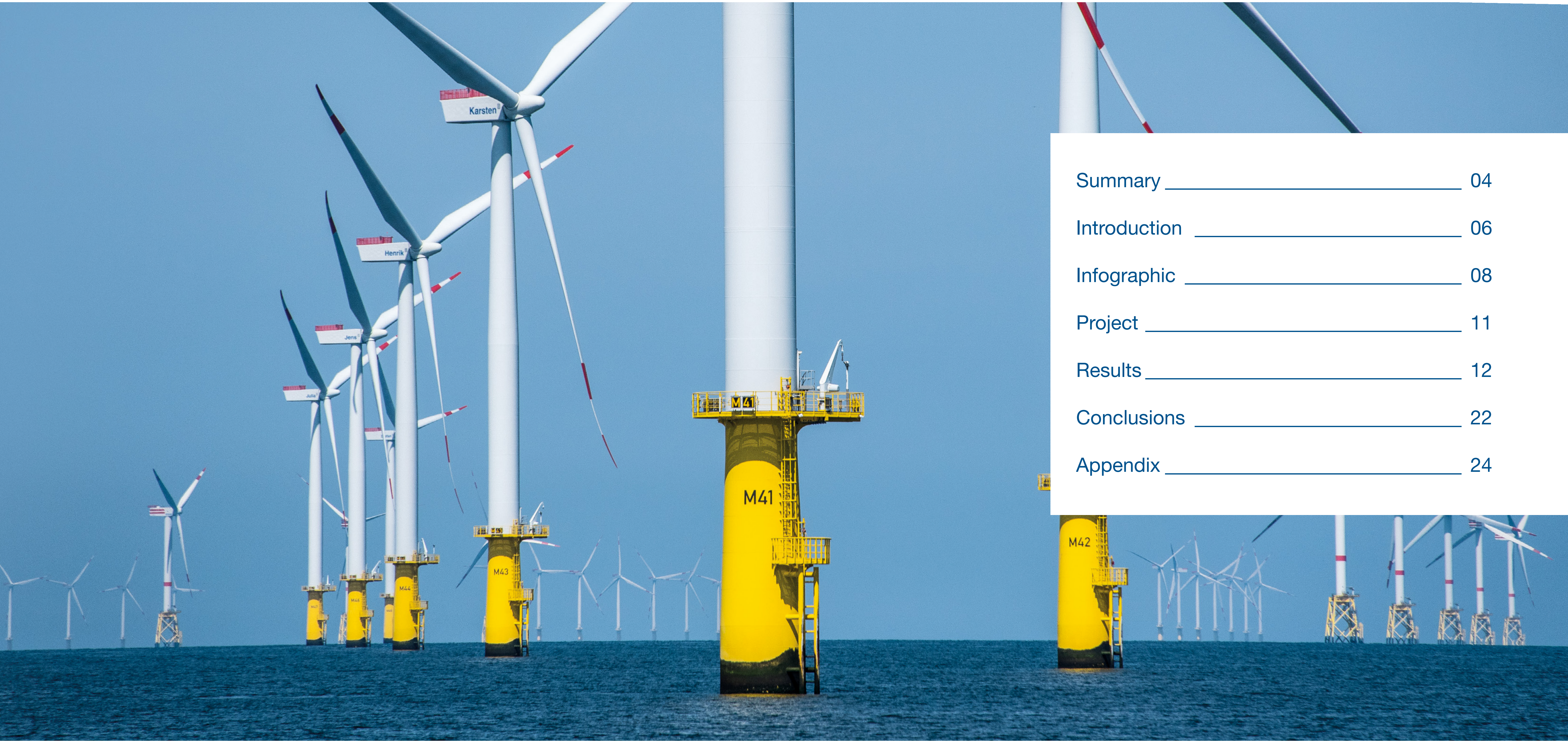


Federal Maritime and Hydrographic Agency
in cooperation with the Helmholtz-Zentrum Hereon

SUMMARY

Within the project "Chemical Emissions from Offshore Wind Farms" (OffChEm), methods have been developed to assess possible chemical emissions from the corrosion protection of wind farms. Thus, for the first time, an extensive data set on the current situation in the North Sea could be collected.

The research was done from 2017 to 2021 by the Federal Maritime and Hydrographic Agency in cooperation with the Helmholtz-Zentrum Hereon (formerly known as Helmholtz-Zentrum Geesthacht). Trace metals in seawater and in the sediment could then be quantified with the help of the newly developed methods. In the laboratory, the researchers analysed the components of various galvanic anodes, known as sacrificial anodes. These are often used as corrosion protection for offshore wind farms.

The researchers identified the following elements for further investigations in the field: aluminium, zinc, indium, gallium, lead and cadmium. The elements indium and gallium can be used as tracers for sacrificial anodes. They rarely occur naturally and no other human sources are known in the open sea.

In total, four ship campaigns were conducted in the area of offshore wind farms in the Exclusive Economic Zone in the German Bight. The collected data shows that concentrations of the selected elements in both water and sediment are within the range of the known variability for the study area.

However, the researchers observed locally elevated concentrations for the elements indium, gallium, zinc and aluminium in the water during certain weather conditions. Locally elevated concentrations were also found in the sediment, especially for lead.

Nevertheless, no direct effects from the use of sacrificial anodes on the marine environment are currently apparent based on this data as well as the prevailing dilution and distribution processes. However, such chemical emissions could increase further as a result of the ongoing development of offshore wind energy.

Therefore, the Federal Maritime and Hydrographic Agency supports the development and use of procedures, which are as environmentally friendly as possible. In the future, wind farm projects should increasingly use impressed current cathodic protection systems. These are associated with very low chemical emissions into the marine environment.

INTRODUCTION

The development of offshore wind energy production in the North Sea and Baltic Sea is an important part of the energy transition. Currently, more than 1500 wind turbines and 30 transformer and converter platforms are already in operation in German marine waters. The German Federal Government makes clear that there is a considerable need for further development, especially in the Exclusive Economic Zone of the North Sea. However, every offshore installation represents an intervention into the marine environment.

The question is, whether offshore installations are a relevant source of chemical emissions into the marine environment and thus contribute to further pollution.

Impact of Offshore Wind Energy

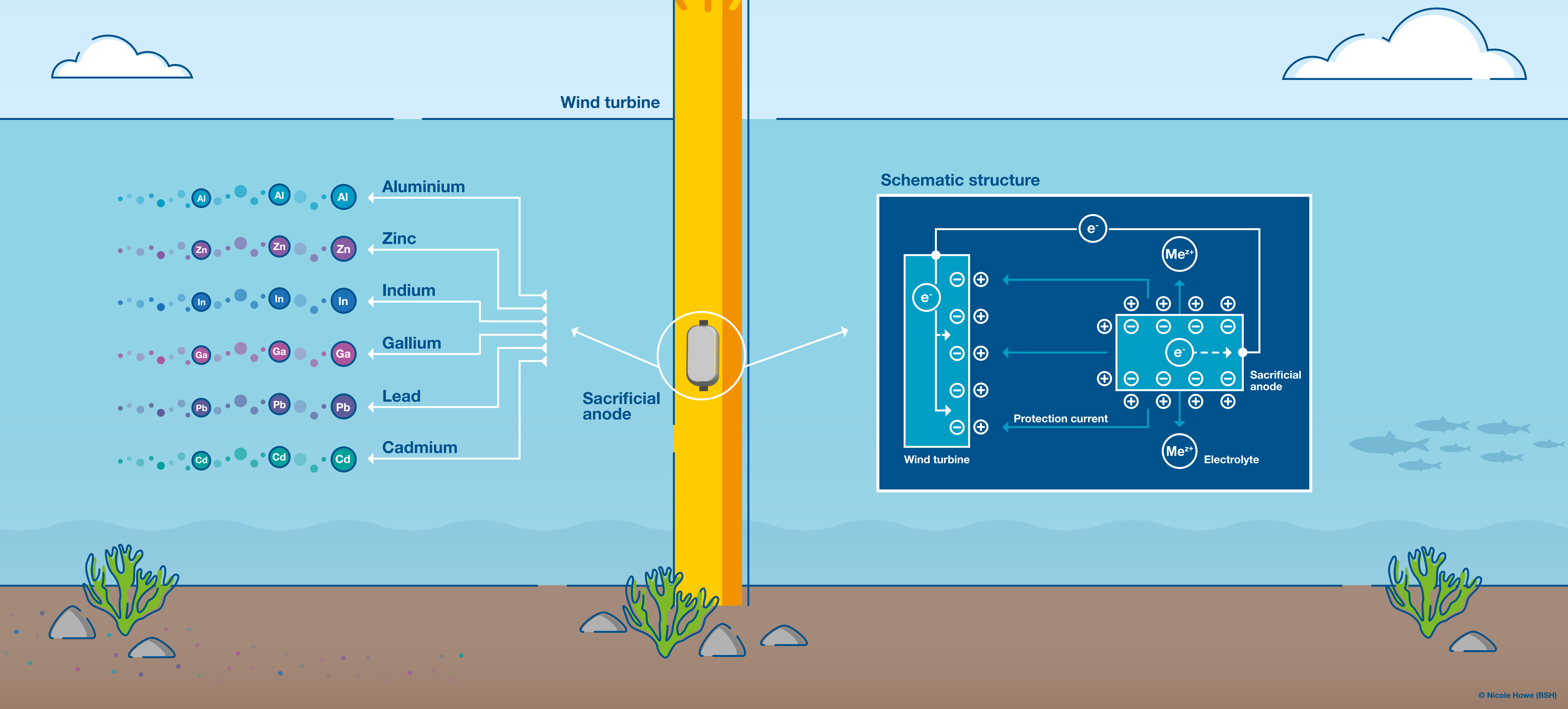
In the past, researchers have already investigated various effects of wind farms, such as the generation of underwater noise, the alteration of habitats and the influence on current patterns. In contrast, there is little information available about the chemical emissions from wind farms, such as organic pollutants and metals, as well as their potential impacts. However, offshore wind farms must be protected from corrosion due to the strong corrosive conditions in the marine environment. This is essential for the structural integrity and the stability of the installations. However, some techniques for corrosion protection could lead to long-term chemical emissions into the marine environment. Offshore wind farm operators, frequently use galvanic anodes, known as sacrificial anodes, for protecting wind farms from corrosion in the submerged zone. These are also applied in water engineering and in shipping.

INFOGRAPHIC

How sacrificial anodes work

A sacrificial anode (galvanic anode) is a piece of metal that protects steel structures from corrosion underwater by dissolving ("sacrificing") itself. However, this results in the release of components from the sacrificial anode into the marine environment. Different amounts are released depending on the foundation type and its coating, as well as the environmental conditions.

According to current experience, about 150 to 750 kilograms of the anode material are released into the marine environment per wind turbine per year.



Corrosion Protection: Input of Metals

On the one hand, the protection current prevents the corrosion of steel structures. On the other hand, it dissolves the sacrificial anode, and thus leads to components, such as aluminium or zinc, entering the marine environment. The amount of sacrificial anodes needed for the lifetime of offshore wind farms (25 years) varies greatly depending on foundation type, coating and local environmental conditions.

Galvanic anodes in the area of offshore wind energy typically consist of aluminium-zinc-indium alloys (approximately 95% aluminium; 2.5 to 5.75% zinc; 0.015 to 0.04% indium). The galvanic anodes can also contain harmful heavy metals in small quantities, such as cadmium, lead and copper which might be released into the marine environment as well.

According to current knowledge, there are no field studies so far that investigate the metal situation around offshore wind farms. Therefore, it is currently not possible to assess, whether offshore installations contribute significantly to the metal input of the North Sea, nor is it possible to assess potential impacts on the marine environment in the future.

PROJECT

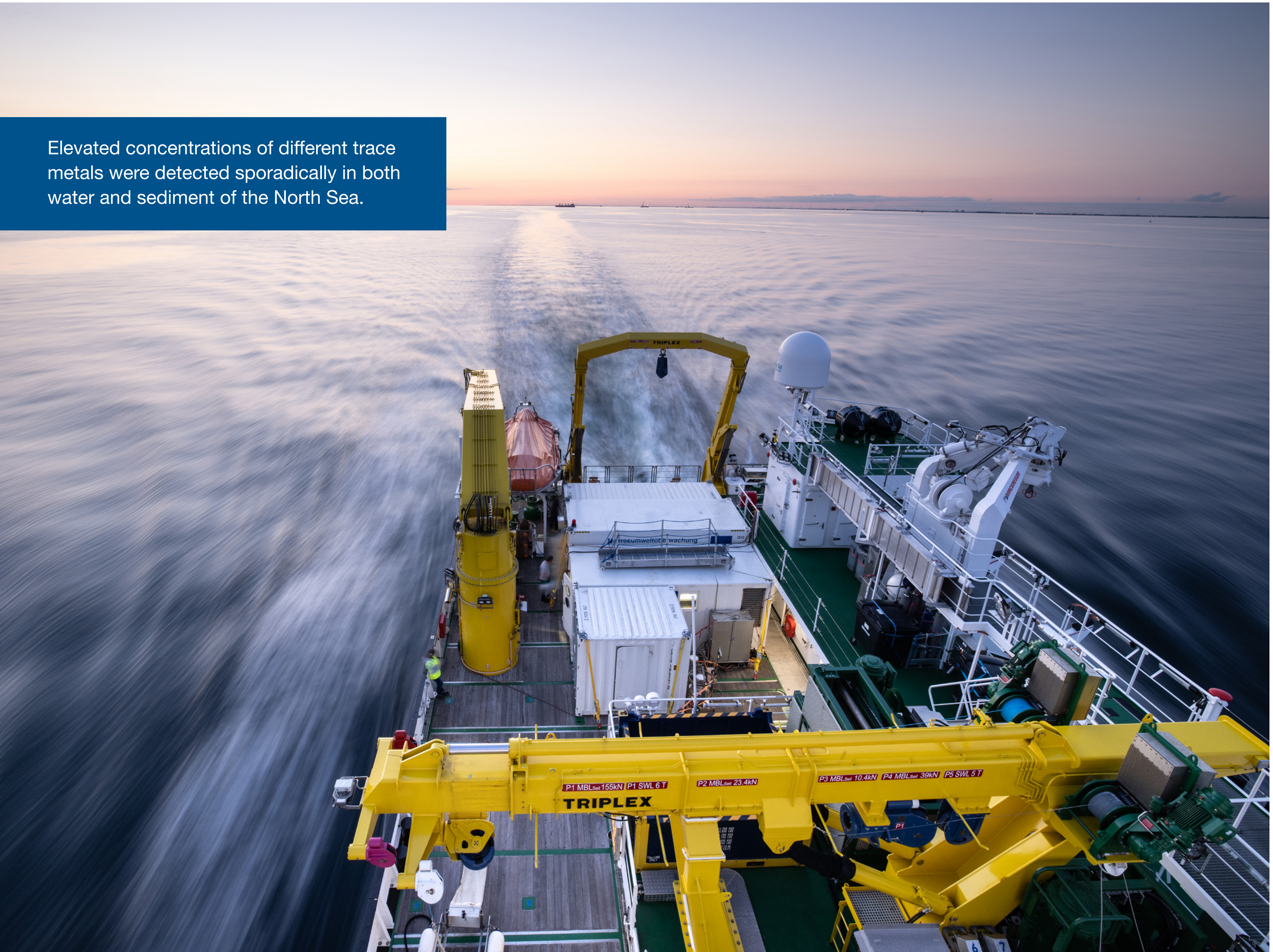
Chemical Emissions from Offshore Wind Farms

Within the project OffChEm, researchers have developed methods to identify potential chemical emissions from the corrosion protection of wind farms. Thus, the project team could generate for the first time a comprehensive data set assessing the current situation around wind farms in the North Sea. From 2017 to 2021, the Federal Maritime and Hydrographic Agency worked together with the Helmholtz-Zentrum Hereon (formerly known as Helmholtz-Zentrum Geesthacht) to do this research.

RESULTS

Method, Laboratory Study and Field Study

Elevated concentrations of different trace metals were detected sporadically in both water and sediment of the North Sea.



- The researchers developed and validated reliable methods to analyse trace metals in water, sediment and biota
- In the laboratory, they characterised the chemical composition of various sacrificial anodes. This enabled the researchers to identify the most critical components for the environment as well as possible tracers for chemical emissions from the corrosion protection of offshore installations.
- The team carried out several field studies in the North Sea to generate for the first time a comprehensive data set on the occurrence and distribution of trace metals around offshore wind farms (in water and in sediment).
- The measured concentrations of selected elements in water and in sediment are largely within the normal variability of the German Bight (see Table 1 and 2 in Appendix).
- Elevated concentrations of aluminium, zinc, indium, gallium (in water) and lead (in sediment) were sporadically detected.

The elements indium and gallium are typical tracers for sacrificial anodes.

LABORATORY STUDY

Analysis of Trace Metals

It was a challenge to develop a method for the reliable analysis of trace metals in seawater and sediment samples from the North Sea. On the one hand, the elements, which are typical for the corrosion protection, needed to be distinguished from the naturally occurring ones in the marine environment. On the other hand, the sample characteristics are in general complex and the examined elements are mostly present only in very low concentrations in the marine environment.

The methods based on the inductively coupled plasma tandem mass spectrometry (ICP-MS/MS) allow to quantify up to 39 elements in water samples and 73 elements in sediment samples - with the required low detection limits.

Components of Sacrificial Anodes

The chemical characterisation of different sacrificial anodes on aluminium-zinc-basis showed that these contain up to 15 other elements for zinc anodes and 26 other elements for aluminium anodes besides their main components (Reese et al. 2020). The contents of elements largely corresponded to the manufacturer’s specifications.

In the area of offshore wind energy, mainly sacrificial anodes based on aluminium are used which consist of aluminium, zinc, and indium. Heavy metals such as lead, and cadmium which are harmful for the environment, were only found in very small quantities. In contrast, sacrificial anodes based on zinc, contained higher quantities of lead and cadmium.

For the field studies, elements have been identified that fulfil at least one of the following criteria: (1) high quantity, (2) high toxicity, (3) availability of comparative data or assessment criteria and (4) possibility to assign them to sources (known as tracers).

Based on these criteria, the researchers selected the elements aluminium, zinc, indium, gallium, lead and cadmium for further investigations. The elements indium and gallium can be used as tracers for sacrificial anodes, as they rarely occur in the sea naturally and no other human sources are known so far in the open sea.

FIELD STUDY

Investigations in Wind Farms in the North Sea

In total, four ship campaigns were done with the research vessels LUDWIG PRANDTL (Hereon) and ATAIR (BSH) around offshore wind farms in the Exclusive Economic Zone in the German Bight in the years 2016, 2018, 2019 and 2020.

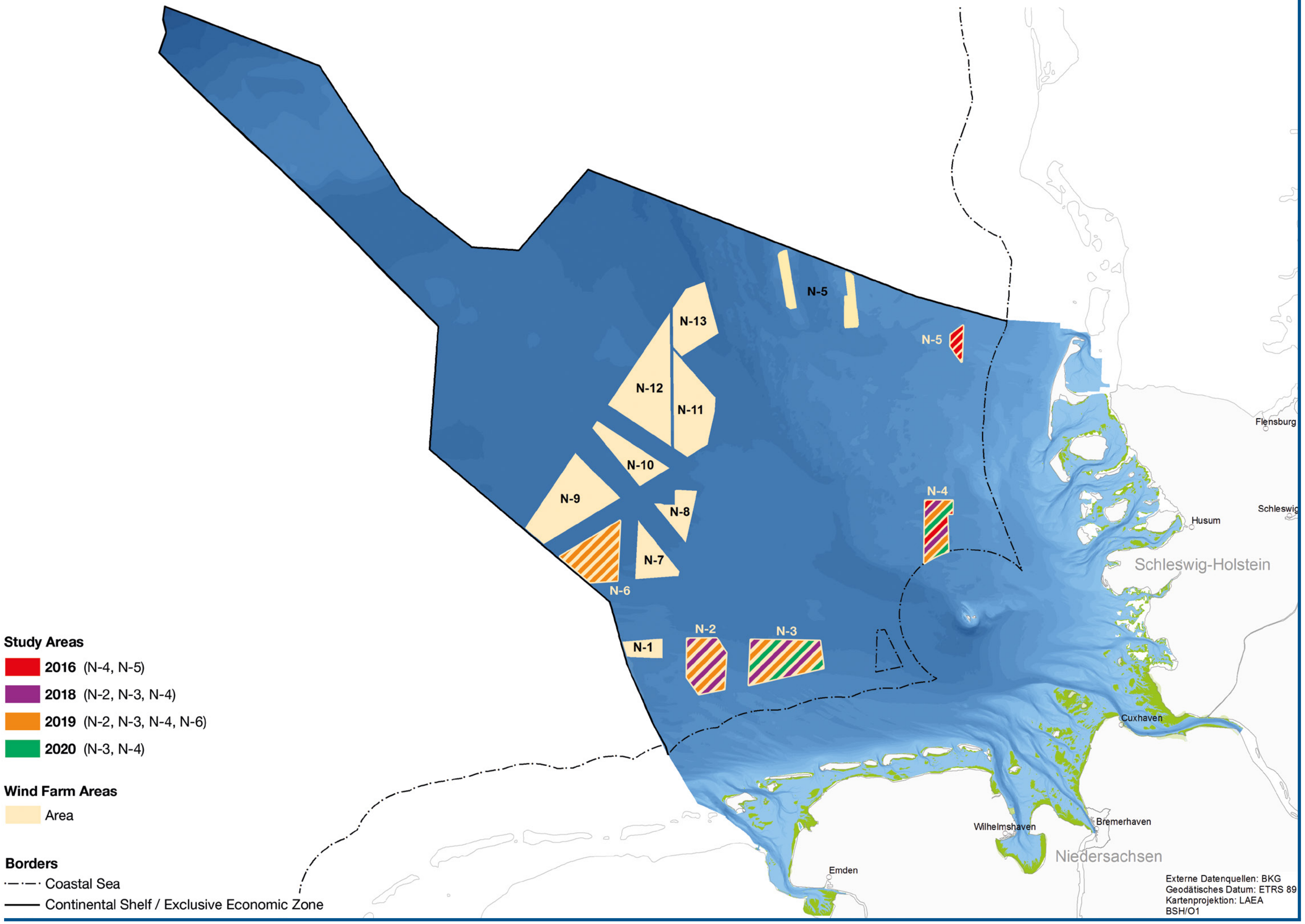
The study areas were the wind farms in the area N-4 north of Helgoland and in the areas N-3 and N-2 north of the East Frisian islands.

In addition, punctual investigations were conducted in the areas N-5/N-6 and at other stations in the coastal sea. The study areas are shown in Figure 1.

During the ship campaigns, the researchers took water samples with Niskin bottles and surface sediment samples with a box corer. As far as possible, they processed and filtrated the water samples on board.

The sediment samples were frozen and sieved in the laboratory of the Helmholtz-Zentrum Hereon (< 20 µm fraction). Afterwards, the researchers analysed the metal content of the samples using the developed method in the laboratory of the Helmholtz-Zentrum Hereon.

Figure 1: Overview of the investigated wind farm areas in the North Sea.



Trace Metals in Water

The concentrations of aluminium, zinc, indium, gallium, lead and cadmium in the water samples are shown in Table 1 (see Appendix).

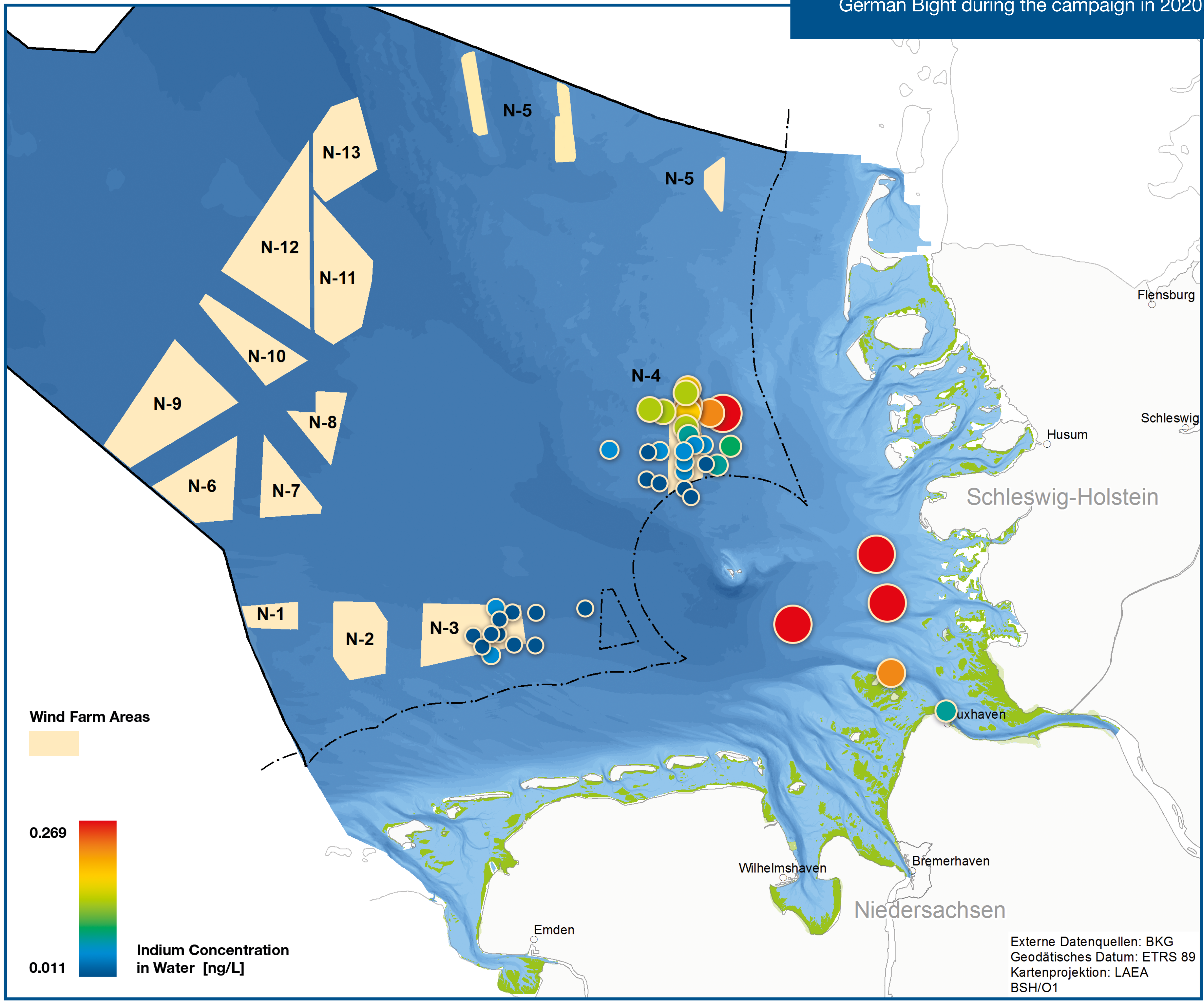
The concentrations of the elements were compared with data from the long-term monitoring by the Federal Maritime and Hydrographic Agency. Since aluminium is not measured as part of the marine environmental monitoring, the aluminium concentrations were compared with data from literature studies.

In the area N-4, the researchers observed a south-north gradient with regard to elevated concentrations of aluminium, zinc, indium and gallium in water, particularly in 2018 and 2020 (see Figure 2). This indicates a possible enrichment along the prevailing south-north current along the coast.

In addition, zinc showed to be strongly dependant on the seasons. In contrast, the researchers could not detect any elevated concentrations of the harmful elements cadmium and lead.

Furthermore, they observed static conditions in the surrounding of wind farms during certain weather conditions, which minimised the exchange and mixing of water. This in turn could lead to locally elevated concentrations of elements from the corrosion protection systems.

Figure 2: Concentration of indium in the surface water in/around offshore wind farms in the German Bight during the campaign in 2020.



In the sediment, elevated metal concentrations were measured sporadically.

Trace Metals in Sediment

It should be noted that the elevated concentrations for indium, cadmium, and lead in the sediment were also found in the area N-4. This could indicate a special situation of sources in this area, based also on the elevated concentrations in water. However, it should be noted that the elevated concentrations were only for lead sporadically above the known variability of the German Bight. The causes cannot yet be clearly identified.

CONCLUSIONS

Components from Anodes detected in North Sea

The data shows that the concentrations of the selected elements both in water and sediment are predominantly within the range of the known variability in the study areas. For the first time, data could be generated for the tracers indium and gallium in the German Bight.

Due to the static conditions and south-north currents during certain weather situations, elevated concentrations for the elements aluminium, zinc, indium and gallium could be observed. Locally elevated concentrations were also found in the sediment, especially for lead.

The high dynamics in the area and the associated large-scale water exchange contribute to the measured concentrations that were mostly within the range of the known variability for the German Bight. Based on this data and the prevailing dilution and distribution processes, there are currently no direct effects discernible due to the use of sacrificial anodes.

However, due to the continuous operation and development of offshore wind energy, the chemical emissions from corrosion protection will further increase.

A more environmentally friendly alternative to sacrificial anodes are impressed current cathodic protection systems.

The project results are made available to the expert network from the Federal Ministry for Digital and Transport (BMDV), where they are contributing to the thematic field "Environment and Transport" and the main topic "Building and Construction Emissions".

Further investigations could contribute to better assess possible medium to long-term effects of such chemical emissions on the marine environment. Through long-term monitoring of the critical elements, possible accumulations from the corrosion protection of offshore installations could be observed and evaluated in the future.

In the context of the follow-up project OffChEm II, the research on chemical emissions from offshore installations is continued. Here the focus is now on the Baltic Sea.

In addition, the Federal Maritime and Hydrographic Agency supports the development and use of environmentally friendly techniques. Impressed current cathodic protection systems should be used more frequently in the future, as they are associated with very low chemical emissions into the marine environment.

Appendix - Data

Table 1: Measured metal concentrations in surface water sampled in and around offshore wind farms in the North Sea during ship campaigns from 2016 to 2020, in comparison with data from the long-term marine environmental monitoring by BSH (2010 to 2014, Zn = zinc, Cd = cadmium, Pb = lead, In = indium, Ga = gallium) and in comparison with data from literature studies respectively (Kremling et al. 1999, Al = aluminium).

	Concentration range [ng/L]	Concentration range [ng/L]	Concentration range [ng/L]	Concentration range [ng/L]	Known variability in North Sea [ng/L]
Year	2016	2018	2019	2020	
Zn	306–795	440–2180	490–1860	247–841	63–3800
Cd	10–18	10–23	20–41	17–37	12–52
Pb	2–17	6–17	5–21	2–13	10–520
Al	78–292	170–530	210–670	< 450	8–1200
In	0.05–0.15	< 0.05	0.01–0.07	0.03–0.27	unknown
Ga	2–4	< 10	2–5	1–4	unknown

Table 2: Measured mass fractions of metals in surface sediments (< 20µm fraction) sampled in and around offshore wind farms in the North Sea during ship campaigns from 2016 to 2020 in comparison with data from the long-term marine environmental monitoring by BSH (2010 to 2016).

	Range of mass fractions [mg/kg]	Range of mass fractions [mg/kg]	Range of mass fractions [mg/kg]	Range of mass fractions [mg/kg]	Known variability in North Sea [mg/kg]
Year	2016	2018	2019	2020	
Zn	200–790	151–532	108–817	160–780	128–1068
Cd	0.2–0.8	0.16–0.63	0.09–1.07	0.3–0.7	0.1–3.8
Pb	95–371	55–266	47–413	68–420	53–258
Al	no Data	2.2–5.9 %	1.3–9.0 %	5.8–9.0 %	5.4–8.9 %
In	0.08–0.19	0.08–0.14	0.065–0.187	0.11–0.27	unknown
Ga	16–27	14.5–19	11–22	8.6–19.6	unknown

Appendix - Publications

Kirchgeorg, T., Weinberg, I., Hörnig, M., Baier, R., Schmid, M.J., Brockmeyer, B. (2018): Emissions from corrosion protection systems of offshore wind farms: Evaluation of the potential impact on the marine environment. Marine Pollution Bulletin, Volume 136, 257-267, doi:10.1016/j.marpolbul.2018.08.058

Reese, A., Voigt, N., Zimmermann, T., Irrgeher, J., Pröfrock, D. (2020): Characterization of alloying components in galvanic anodes as potential environmental tracers for heavy metal emissions from offshore wind structures. Chemosphere, Volume 257, 127182, doi:10.1016/j.chemosphere.2020.127182

Zimmermann, T., von der Au, M., Reese, A., Klein, O., Hildebrandt, L., Pröfrock, D. (2020): Substituting HF by HBF4 – an optimized digestion method for multi-elemental sediment analysis via ICP-MS/MS. Anal. Methods, 2020, doi:10.1039/D0AY01049A

Ebeling, A., Zimmermann, T., Klein, O., Irrgeher, J., Pröfrock, D. (2022): Analysis of Seventeen Certified Water Reference Materials for Trace and Technology-Critical Elements. Geostandards and Geoanalytical Research, 46, 2, 351 – 378, doi:10.1111/ggr.12422

Investigation of potential environmental emissions from cathodic corrosion protection systems used in North Sea offshore wind farms - Part 1. Trace metal distribution in the water body, in progress

Investigation of potential environmental emissions from cathodic corrosion protection systems used in North Sea offshore wind farms - Part 2. Trace metal distribution in the sediment, in progress

Imprint

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BSH Project-Website
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