For our Environment

18. March 2026

Scrubber on Ships – Impact on the marine environment

Overview of the exhaust gas cleaning system technology

1 Why are scrubbers installed on board?

The global sulphur limit for marine fuels used in international maritime transport is 0.50 %. In Sulphur Emission Control Areas (SECAs) as the North Sea and the Baltic Sea are designated, the limit is 0.10 %. This is regulated in the MARPOL Convention[1] in its Annex VI, Regulation 14. The International Maritime Organisation (IMO) permits alternative compliance methods such as Exhaust Gas Cleaning Systems (EGCS) – also known as scrubbers – as an equivalent[2] to the use of low-sulphur fuels. The European Sulphur Directive[3] transfers the international requirements of the IMO into European legislation. At national level, the requirements are laid down in the Maritime Environmental Behaviour Regulations[4] which implements the EU Directive on national level. The use of EGCS is currently – and will presumably continue to be – more financially attractive. Low-sulphur fuels, especially distillates[5], are more expensive than higher-sulphur heavy fuel oils, which can still be used on ships with an scrubbers installed.

The number of ships with EGCS has been increasing significantly worldwide, in particular since 2019 (Figure 1). At the beginning of 2025, well over 5,000 scrubbers are installed on oceangoing ships (GISIS, 2025), which corresponds to around one third of the global merchant fleet in terms of deadweight of the ships.

1 MARPOL: International Convention for the Prevention of Pollution from Ships
2 MARPOL Annex VI Regulation 4 „Equivalents"
3 Directive (EU) 2016/802
4 SeeUmwVerhV (in German only); SeeUmwVerhV_eng.pdf
5 Such as Marine Diesel Oil (MDO) and Marine Gasoil (MGO) according to ISO 8217:2024

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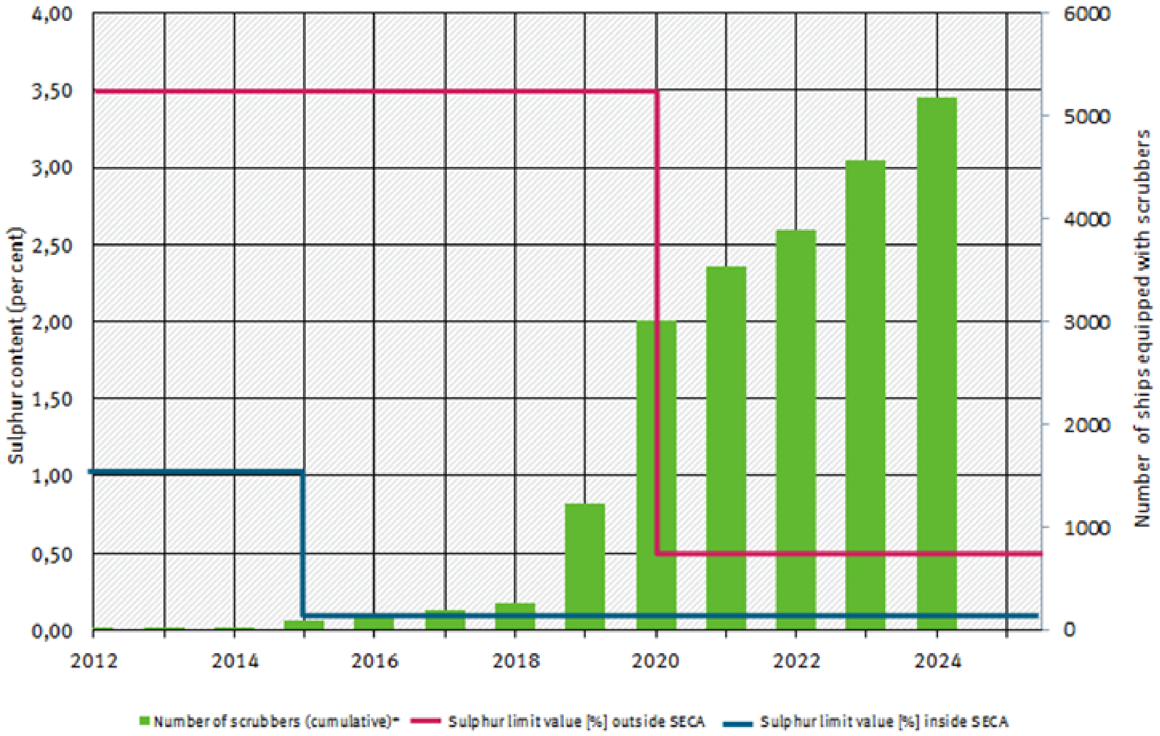
Figure 1: **Number of oceangoing ships equipped with EGCS worldwide and development of sulphur limits since 2010**



* The figures take into account the scrubber installations authorised and reported to GISIS by the end of the respective year.

Source: UBA, own illustration based on GISIS, 2025

EGCS discharge very large volumes of discharge water into the oceans and harbour areas worldwide through their operation. Requirements for operation and discharge water are regulated in the 'EGCS Guidelines'[6]. However, these guidelines only contain specifications for a limited number of parameters (pH value, turbidity, polycyclic aromatic hydrocarbons (PAH) and nitrate content). As the environmental impact of the large discharge volumes and their pollutant load is high there are concerns about the use of this technology

The original target of MARPOL ANNEX VI Regulation 14 to reduce air pollutant emissions from seagoing vessels, in particular sulphur-containing particulate emissions, has at least been partially achieved[7]; albeit at the cost of allowing the alternative use of scrubbers, which continues the use of heavy fuel oils containing hazardous substances and their release into the marine environment directly via the EGCS process.

2 How does an EGCS work?

Scrubbers are an exhaust gas cleaning technology in which water is sprayed into the exhaust gas flow to partially remove sulphur oxide (SO_x) from the exhaust gas. There are different systems in use: open loop (OL), closed loop (CL) and hybrid systems.

[6] Resolution MEPC.340(77): 2021 Guidelines for Exhaust Gas Cleaning Systems in MEPC 77/16/Add.1

[7] A study commissioned by Canada shows: when using heavy fuel oil with EGCS, the emissions of PM (particulate matter) can be up to 70 % higher and BC (Black Carbon) up to 81 % higher than when using low-sulphur distillate fuels in medium-speed diesel engines and more than 4.5 times higher in low-speed diesel engines (Comer et al., 2020).

How does the chemical process work in the scrubber?

The SO_x in the exhaust gas, consisting mainly of sulphur dioxide (SO_2), react with the water during the exhaust gas cleaning process to form sulphurous acid (H_2SO_3; equation 1). This sulphurous acid decomposes in water, releasing protons to form bisulphite (HSO_3^-; equation 2) or sulphite (SO_3^{2-}; equation 3). The protons (H^+) released in these reactions represent the actual acid. The sulphite is largely oxidised to sulphate by the dissolved oxygen in the seawater (SO_4^{2}, equation 4). To neutralise the acid formed this way, the natural buffer capacity of the seawater – mainly hydrogen carbonate ions (HCO_3^-) – are used in EGCS in OL mode or the OH^- ions of the added caustic soda in CL mode.

$$SO_2 + H_2O \rightleftharpoons H_2SO_3 \quad \text{Equation 1}$$

$$H_2SO_3 \rightleftharpoons H^+ + HSO_3^- \quad \text{Equation 2}$$

$$HSO_3^- \rightleftharpoons H^+ + SO_3^{2-} \quad \text{Equation 3}$$

$$SO_3^{2-} + \tfrac{1}{2} O_2 \rightleftharpoons SO_4^{2-} \quad \text{Equation 4}$$

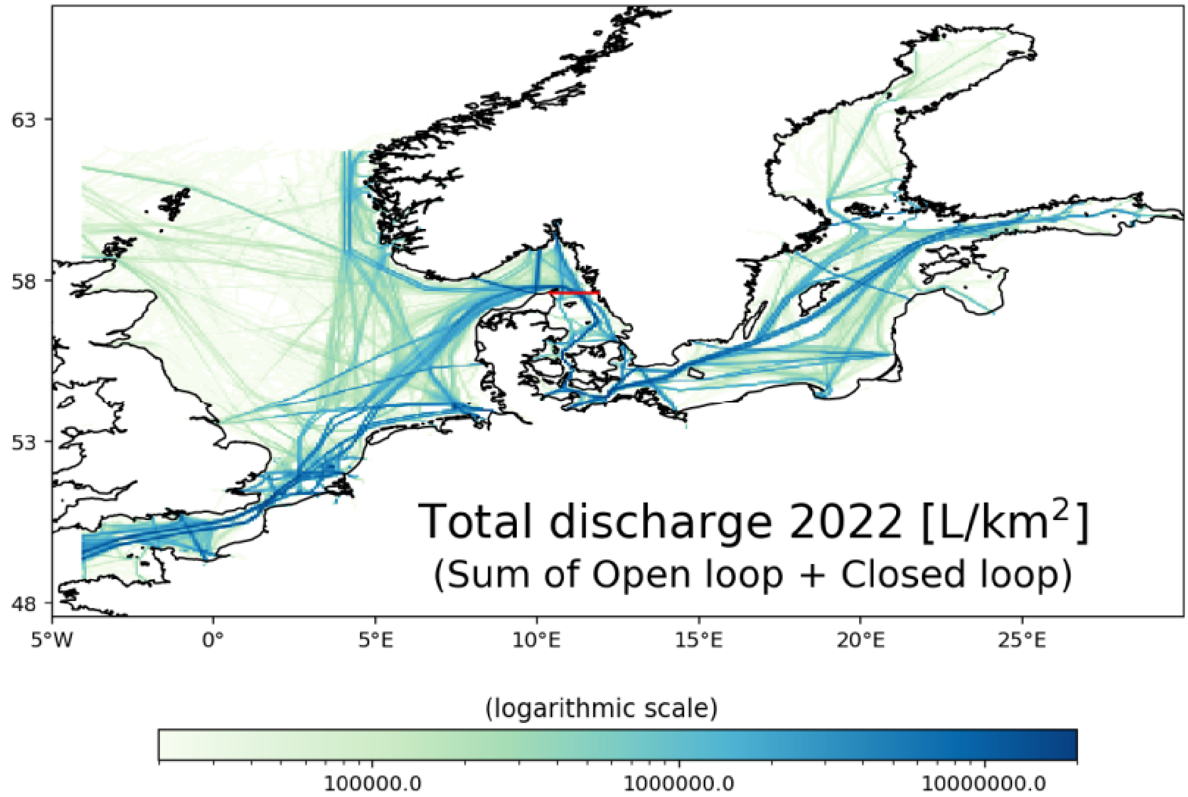
After the scrubbing process, the discharge water has a very low pH value (up to pH 3) and is therefore partially diluted on board before discharge. The discharge water contributes to the acidification of the oceans and reduces the buffer capacity of the seawater depending on the physical and chemical parameters of the water, such as temperature, salinity and alkalinity (Karle, Turner, 2007).

All EGCS use large to very large quantities of (sea) water as a cleaning medium, which is then usually discharged directly into the sea as discharge water.

For example, around 300 million cubic metres of scrubber discharge water were discharged into the Baltic Sea in 2022 (Jalkanen et al., 2024a; Stegert et al., unpublished). For the OSPAR[8] maritime area (North-East Atlantic including the North Sea and the Bay of Biscay) a study models an input of 622 million cubic metres for 2020 (Jalkanen et al., 2022). For the North Sea alone, including the English Channel, it was 485 million cubic metres in 2022 (Stegert et al., unpublished). The discharges mainly occur along the main shipping routes and ferry connections, which are predominantly close to the coast (Figure 2).

[8] OSPAR: Convention for the Protection of the Marine Environment of the North-East Atlantic

Figure 2: **Distribution of modelled EGCS discharge water discharges in the North Sea and the Baltic Sea (red line marks the boundary for the calculations of EGCS discharge into the North Sea and Baltic Sea) for the year 2022**



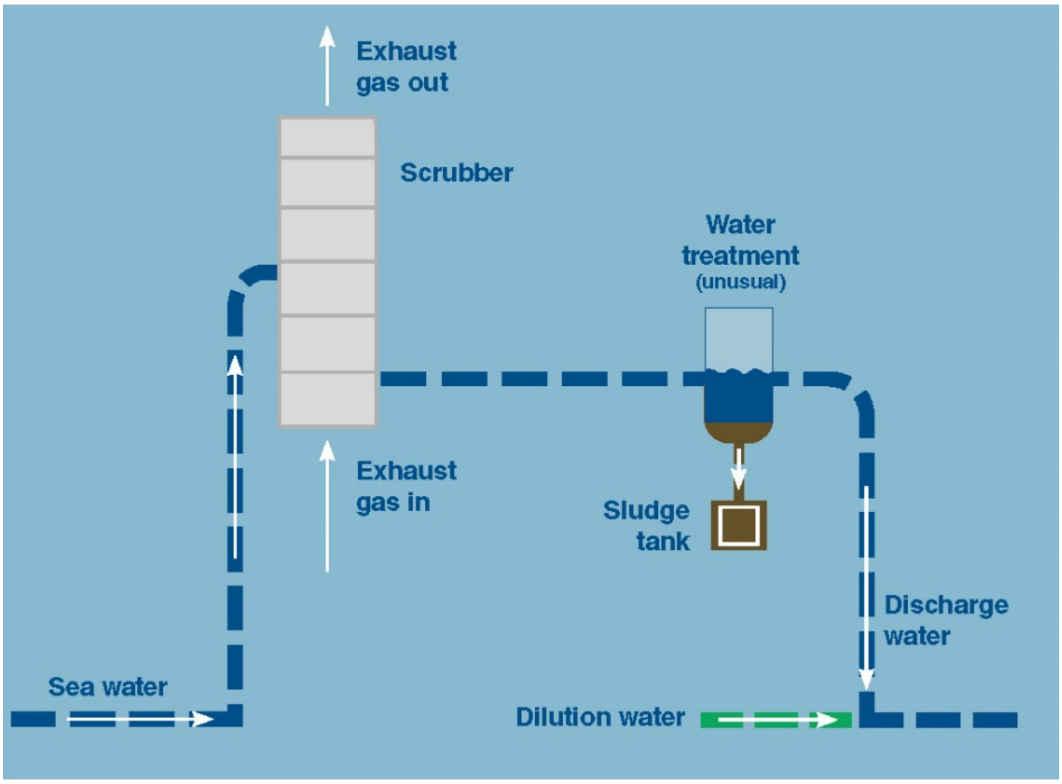
Source: Stegert (generated from results of the MoSAb project, unpublished)

2.1 Open Loop EGCS

Open Loop (OL) systems use seawater, which is taken in during the journey and sprayed in the exhaust gas flow. The buffer capacity of the seawater is used to remove the sulphur dioxide from the exhaust gas. In this process, very large quantities of water are used (50 - 90 m^3/MWh[9]; Marin-Enriquez et al., 2023). When discharged back into the marine environment the discharge water is heated, has a lowered pH value and is contaminated with hazardous substances and nitrate. A 'water treatment' with separation of sludge, as shown in Figure 3, is not common and only included for completeness. In order to comply with the limit value according to the 'EGCS Guidelines' for the pH value, the discharge water can be diluted with seawater on board. The other limits values apply directly after the scrubber, without dilution. The vast majority of EGCS used worldwide – around 85% – are OL systems (GISIS, 2025).

[9] For a medium-sized container ship, an engine output of 12 MW and a discharge volume of 60 m^3/MWh can be assumed in normal operation. This results in a discharge of 720 m^2 per hour which corresponds approximately to the quantity of 4,000 bathtubs (180 litres each) per ship per hour.

Figure 3: Schematic figure of the operation of Open Loop EGCS



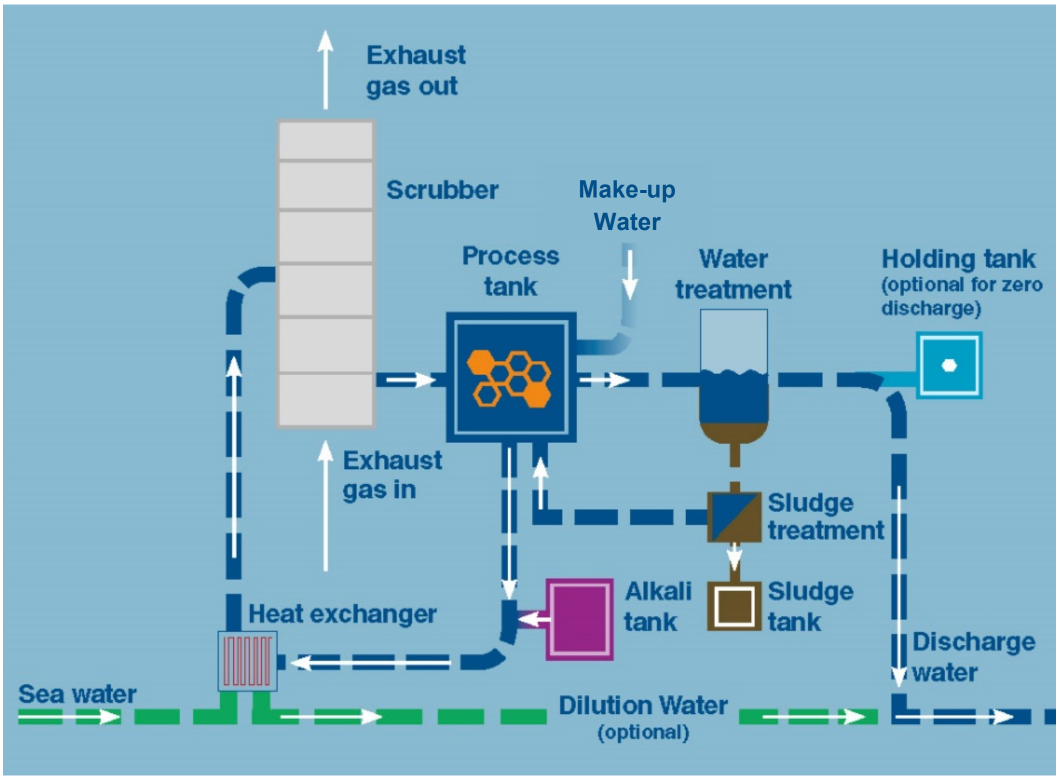
Source: Marin-Enriquez et al, 2023

2.2 Closed Loop EGCS

Closed loop (CL) systems use seawater or fresh water to which caustic soda or other alkaline solutions are added in order to achieve the desired buffer capacity for the scrubbing process. A large portion of the water is recirculated, but must be cooled via a 'heat exchanger' before being used again. A small portion of the water is separated, partially cleaned (in the 'water treatment' unit) and stored in tanks ('zero discharge mode'). The residues ('sludge') produced during the water treatment must be disposed of properly in the harbour. The stored discharge water, also called 'bleed-off water', can either be disposed of in the harbour or – which is common practice – pumped into the sea outside areas with a discharge ban.

Less than 1% of EGCS worldwide are CL systems (GISIS, 2025).

Figure 4: Schematic diagram of the operation of Closed Loop EGCS



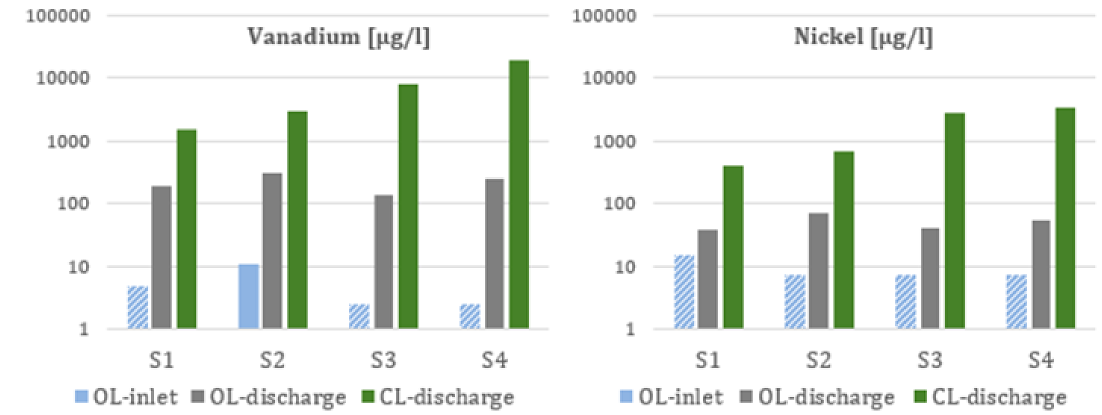
Source: Marin-Enriquez et al, 2023 (edited in 2025)

Due to the recirculation of the water, the amount of discharge water produced by CL systems is significantly lower (0.45 m^3/MWh, Marin-Enriquez et al., 2023) than that of OL systems. As a result, the pollutant concentrations in the 'bleed-off water' from EGCS in CL mode are higher than those from OL operation, despite water treatment. Nevertheless, the pollutant load of the 'bleed-off water', i.e., the amount of pollutants per energy output of the ship's engine (g/MWh), is lower than in OL operation due to the water treatment and the sludge separation.

Marin-Enriquez et al. (2023) examined discharge water samples from different ships and different EGCS systems and observed that the concentrations of vanadium (V) and nickel (Ni) in the discharge water from EGCS in CL mode are on average about 40 times higher (V: 1,500–19,700 µg/l; Ni: 410–3,470 µg/l) than in discharge water from EGCS in OL mode (V: 140–308 µg/l; Ni: 40–73 µg/l). The CL 'bleed-off water' also contained oil concentrations between <0.1 and 8.1 mg/l; these were on average 4.6 times higher than the oil concentrations in OL discharge water. The sum of the 16 EPA-PAHs[10] in the discharge from CL mode ranged between 6.9 and 150 µg/l, whereas in OL discharge water it ranged between 1.7 and 55.6 µg/l (Marin-Enriquez et al., 2023).

[10] EPA-PAK: List of 16 PAHs compiled by the US Environmental Protection Agency, which are frequently examined in environmental samples as representatives of the group of PAHs.

Figure 5: Vanadium und Nickel concentrations in EGCS discharge water[11]



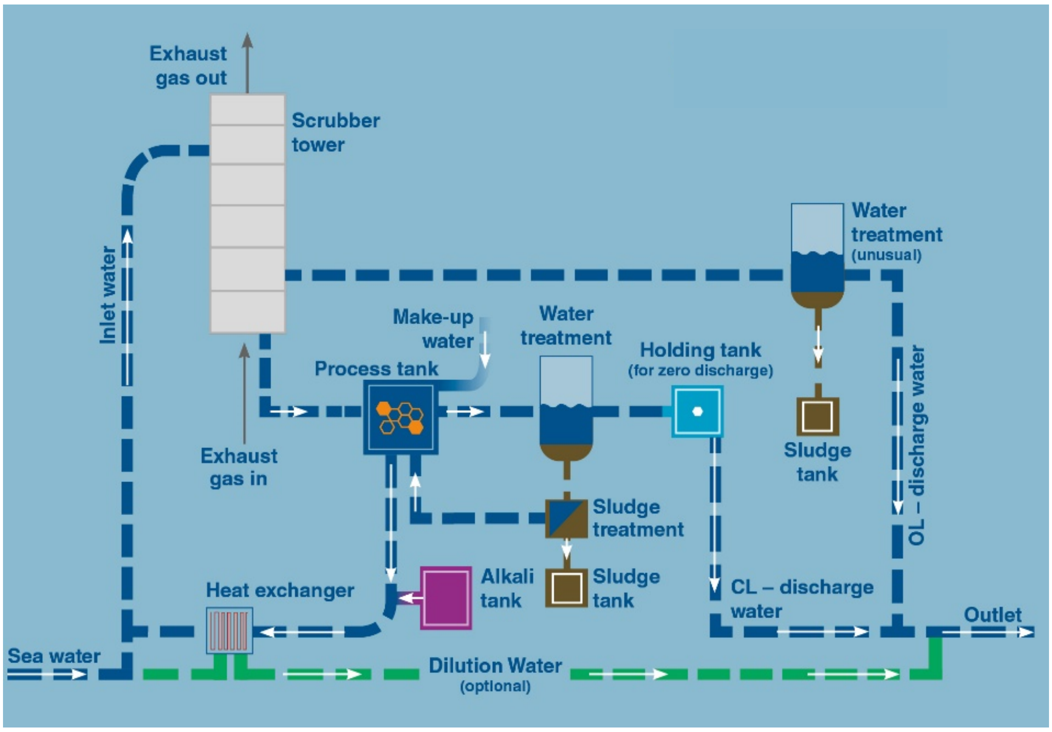
Striped bars indicate that the result was below the limit of quantification (LOQ). In that case, the assigned value is LOQ/2. A logarithmic scale is used in both diagrams.

Source: Marin-Enriquez et al., 2023 (2025 graphically edited).

2.3 Hybrid EGCS

Hybrid EGCS can be operated in OL and CL mode. Approximately 15% of scrubbers in use worldwide belong to this category (GISIS, 2025). The advantage from the ship operator's perspective is the greater flexibility due to the possibility of switching between operation modes.

Figure 6: Schematic diagram of the operation of Hybrid EGCS



Source: Achten et al., 2024 (2025 graphically edited by BSH[12])

[11] S1 – S 4: Anonymized identification of the sampled ships; "OL inlet" is the sampling point before the EGCS process. All samples were taken from the piping system inside the ship.

[12] Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie)

What exactly is the ‘zero-discharge-mode’?

CL EGCS or hybrid systems in CL mode also discharge water, known as ‘bleed-off water’, into the marine environment. However, depending on the size of the tank, they can store the ‘bleed-off water’ on board for a certain period of time, allowing ships to pass through areas where discharge is prohibited without discharging any water. The designation of areas with discharge bans is therefore not to be seen as a ban on technology.

According to MARPOL Annex VI Regulation 14, all ships, including ships with installed EGCS (OL, CL or hybrid) have the choice of switching to compliant fuels that meet the sulphur limit (‘fuel changeover procedure’).

3 What are the environmental impacts of using scrubbers?

The discharge water quality criteria for turbidity, pH and PAH in the ‘EGCS Guidelines’ are not sufficient to consequently prevent environmental pollution, as the limit values are primarily aimed at avoiding acute effects. Protection against long-term and cumulative effects is therefore not ensure. This has been demonstrated by various studies[13].

The composition of scrubber discharge water is very complex and depends mainly on scrubber operation (such as exhaust gas cleaning effect, operating mode, water flow rate, water treatment) as well as engine performance, fuel quality, and level of complete combustion completeness. During the scrubbing process, not only sulphur oxides but also other pollutants, some of which are classified as persistent, toxic, and bioaccumulative, are released into the marine environment (Marin-Enriquez et al., 2023). These include metals such as vanadium, nickel, copper, iron, and zinc, as well as nitrate, PAHs, and oil residues. Further, the exhaust gas heats up the discharge water and turns it acidic (pH value down to 3) due to the dissolution of sulphur oxides (Marin-Enriquez et al., 2023). This has an impact on the buffer capacity and thus on the carbon dioxide (CO_2) absorption capacity of the oceans. It is estimated that for every ton of SO_X discharged into the sea via scrubber discharge water, the absorption capacity of atmospheric CO_2 is reduced by half a ton (ICES, 2020). Dulière et al. (2020) have modelled the annual pH decrease (acidification) caused by the discharge of EGCS discharge water from OL systems for the English Channel and the southern North Sea. It corresponds to acidification caused by climate change of about 2 to 4 years and therefore, accelerating this effect. Research projects such as ImpEx[14] and EMERGE[15] have also shown that the “pollutant cocktail” in scrubber discharge water has harmful effects on marine organisms even when considered threshold values for selected hazardous substances are not exceeded. This can result in sum in effects exceeding the effects caused by the individual substances.

[13] Schmolke et al. (2020); Marin-Enriquez et al. (2023) and Jalkanen et al. (2024b)
[14] “ImpEx – Environmental Impacts of Exhaust Gas Cleaning Systems for the Reduction of SO_x on Ships” (Marin-Enriquez et al., 2023)
[15] EMERGE – Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions (https://emerge-h2020.eu/about-emerge/)

Figure 7: **Samples of EGCS discharge water from the ImpEx measurement campaign: left side from OL, right side from CL mode of the hybrid systems from ships S1 to S4**[16]

Source: Achten et al., 2024.

Some countries, such as Sweden, Denmark and Finland, have already introduced discharge bans in their territorial seas (12 nautical miles zone). These have been in force since July 2025 for discharges from EGCS in OL mode and will apply to discharge water from EGCS in CL mode from 2029. In addition, around 45 countries worldwide have implemented regional or local discharge restrictions, but these mainly relate to the discharge water from OL mode in ports or port areas and a discharge ban there (ICCT, 2023). In Germany, discharge into inland waterways and ports located on them is prohibited. Discharge into territorial seas and the German exclusive economic zone is permitted if the requirements of the ‘2021 EGCS Guidelines’ are met. In addition, some ports have introduced specific regulations regarding scrubber discharges (BSH website[17] and SeeUmwVerhV, 2019).

4 What is the German Environment Agency aiming for?

The current national status assessments for the implementation of the European Marine Strategy Framework Directive (MSFD)[18] show that both the German waters of the North Sea and the Baltic Sea are not achieving the good environmental status. One reason is that concentrations of hazardous substances remain too high and inputs must therefore be reduced or prevented.

The discharge of EGCS discharge water has been assessed as a relevant source of pollution. Measures to ban the discharge of scrubber discharge water are being developed and implemented at national, regional, and international level:

- The German MSFD programme of measures [19] includes the following measure: Developing of “Requirements for the discharge and disposal in ports of discharge water from ship exhaust gas cleaning systems” (UZ2-02[20]). This includes, as one option, the designation of discharge restrictions/prohibitions in specific areas.
- The HELCOM Baltic Sea Action Plan[21] includes the measure (S22) “Roadmap to reduce the input of pollutants from Exhaust Gas Cleaning Systems discharge waters”. The roadmap was adopted in December 2025 and has the objective to develop a HELCOM Recommendation

16 S1 – S 4: anonymized identification of the ships sampled in the measurement campaign
17 BSH-Website „Abgasreinigungsanlagen“ (in German only)
18 Berichte Art. 8-10 - Zustandsbewertung - Mitglieder Verwaltung - Meeresschutz (in German only with an Englisch summary)
19 https://mitglieder.meeresschutz.info/de/berichte/massnahmenprogramm-art-13.html (in German only)
20 UZ2-02_Kennblatt_Scrubber.pdf (in German only)
21 BSAP – Baltic Sea Action Plan of HELCOM (Baltic Marine Environment Protection Commission)

aiming at a harmonized approach in territorial seas, internal waters and ports to implement a discharge ban on discharge water from EGCS by the end of 2026.

- As part of the North-East Atlantic Environment Strategy 2030[22] options for regulating the discharge of EGCS discharge water near the coast are being developed (see box).

OSPAR adopted regional discharge bans

In June 2025, the OSPAR contracting parties adopted two measures at their ministerial meeting in Vigo: a legally binding 'OSPAR Decision', which includes a ban on discharges in harbours and internal waters, and a recommendation for a discharge ban in territorial seas (12 nautical mile zone). Both will apply from July 2027 for EGCS in OL mode and from January 2029 for EGCS in CL mode.

The Vigo Declaration[23] emphasises the intention to extend the geographical scope of the legally binding 'OSPAR Decision' to territorial seas by 2027, subject to a further impact assessment.

The German Environment Agency (UBA) is actively involved in the development and introduction of effective measures and is committed to a coordinated and ambitious approach. All measures aim to reduce the input of relevant pollutants in order to protect the oceans. As a complete ban on scrubber systems does not currently achieve a political majority either at the IMO or at regional level, the current aim is to introduce discharge bans for certain areas ('Zero Discharge Zones') in the near future. The relevant areas include coastal areas such as territorial seas and protected areas already designated by the IMO, such as PSSAs[24]. Most of the Baltic Sea is designated as PSSA, for example. In their study, Marin-Enriquez et al. (2023) also confirmed that the establishment of 'Zero Discharge Zones' is highly effective. Therefore, this measure also supports the activities of HELCOM and OSPAR as well as the German MSFD programme of measures regarding scrubber discharge water.

According to UBA and others experts, the designation of 'Zero Discharge Zones' are an important first step. In the long term, the aim should be to only allow low-sulphur distillate fuels, which would make the use of EGCS obsolete. This would reduce pollutants directly at its source and would significantly reduce the pollution of the oceans.

5 Research projects on behalf of UBA

For many years, UBA has been observing closely the technical development in EGCS, in particular with regard to the discharge water and its environmental relevance and impact. UBA has commissioned several research projects and published most of their results[25].

- Impacts of Scrubbers on the environmental situation in ports and coastal waters; TEXTE | 65/2015[26].

- SWS – Environmental Protection in Maritime Traffic – Scrubber Wash Water Survey; TEXTE | 162/2020.

- ImpEx 'Status quo' – Environmental Impacts of Exhaust Gas Cleaning Systems for Reduction of SO_x on Ships – Analysis of status quo; TEXTE | 83/2021.

[22] NEAES – North-East Atlantic Environment Strategy
[23] 'Vigo Declaration'
[24] PSSA – Particularly Sensitive Sea Areas
[25] The result of the MoSAb project will be published in 2026
[26] Authors: Lange, B.; Markus, T.; Philipp Helfst, L. / German version: TEXTE | 83/2014

- ImpEx – Environmental Impacts of Discharge Water from Exhaust Gas Cleaning Systems on Ships. Final report of the project ImpEx; TEXTE | 27/2023.
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