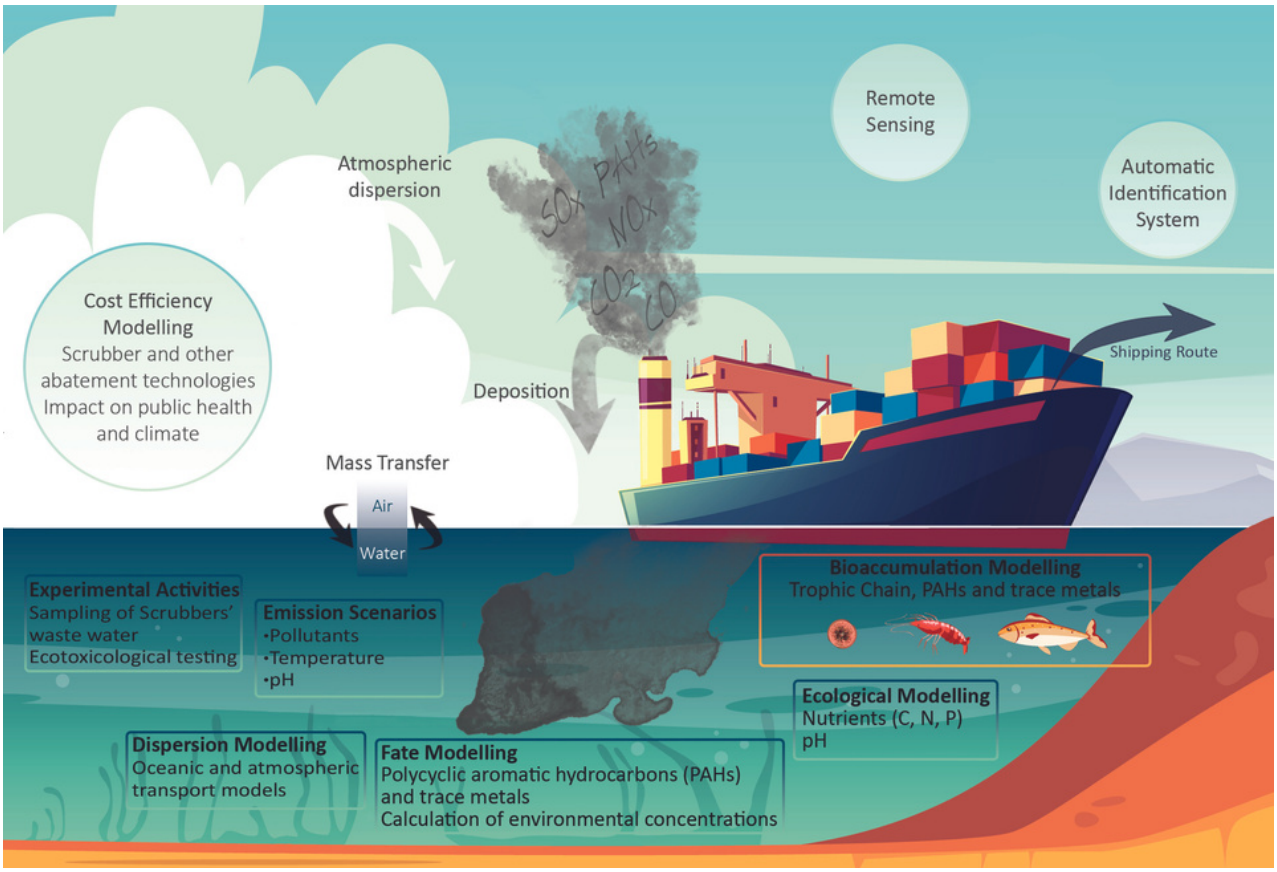
EMERGE

Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions

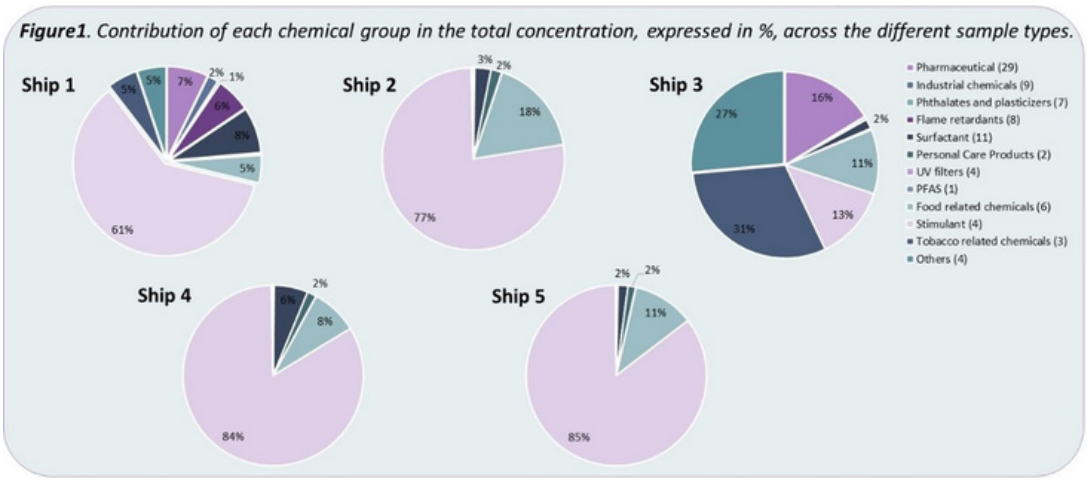


IMPLEMENTATION

The project will include measurements and modelling on actual vessels. Those will focus on abatement techniques and will include emissions to, and concentrations in water, air and marine biota.
A wide spectrum of models will be used, including those for ocean circulation, biogeochemical processes, atmospheric dispersion and the bioaccumulation of pollutants.

Comprehensive chemical characterization of greywater discharges from ships

A comprehensive analysis of greywater emissions from ships was conducted to evaluate the possible environmental and human health risks associated with their release to the marine environment.



Composition Profiles of the chemical groups identified in the samples

The study used sophisticated analytical methods based on high resolution mass spectrometry to comprehensively characterize greywater, by combining wide scope target and suspect screening approaches.

Samples from cargo ships that docked at Helsinki port (Finland) were obtained from the Baltic Sea Action Group.

For target analysis, a method that allows for the identification of more than 700 compounds was used. Suspect screening was also conducted using the vendors software Compound discoverer 3.1 (Thermo Fisher Scientific), and the associated databases for the identification of more than 1500 compounds. A total of 105 substances were tentatively identified, 86 through target and 19 additional compounds by suspect screening. Furthermore, 44 out of the 87 target compounds could be further validated and quantified by analytical standards.

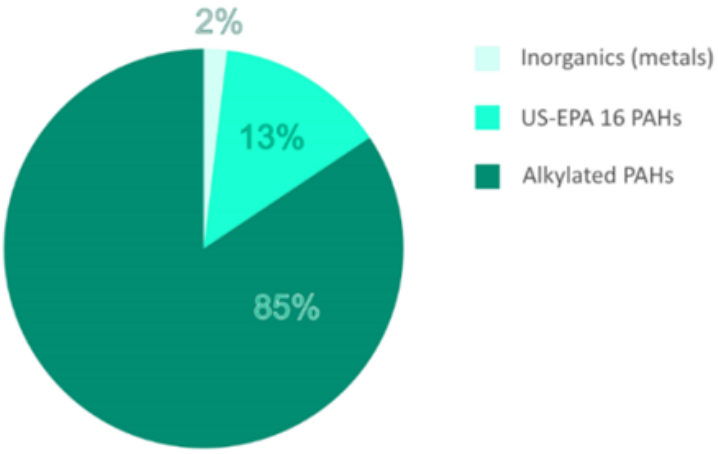
The substances identified covered several chemical classes, such as pharmaceuticals, personal care products, perfluoroalkyl substances, surfactants, plasticizers, stimulants, tobacco, and food related chemicals.

This comprehensive approach enabled the identification of previously overlooked compounds, emphasizing the importance of wide scope screening methods in identifying potentially harmful chemicals.

New Insights from EMERGE Project Shed Light on Environmental Impacts of Ship Exhaust Gas Cleaning Systems: Major findings for the Baltic, North and Mediterranean Seas and other areas

During the last period of the EMERGE project's duration, three fundamental deliverables were produced, summarizing four years of comprehensive research work aimed at understanding the environmental impacts of Exhaust Gas Cleaning Systems (EGCS). These deliverables, namely D6.1- "Baltic and North Sea report," D6.2- "Mediterranean Sea report," and D6.3- "Report on environmental impacts of shipping in other areas," were formulated within the framework of WP6 - "Synthesis and integration of the results." These reports followed the well-established DAPSIR (Driver-Activity-Pressure-State-Impact-Response) framework, under which information, findings and conclusions from previous work packages were synthesized, including investigations into direct emissions from shipping to both the marine environment and the atmosphere, assessment of marine environmental impacts, and evaluations relating to human health and climate change implications.

D6.1 primarily concentrated on the Baltic Sea and the North Sea (including the English Channel) regions, with specific emphasis on the EMERGE case study areas situated in Öresund and the Solent Strait. Conversely, D6.2 adopted a multi-scale approach, spanning from the regional Mediterranean scale to the city scale in the case study areas of Eastern Mediterranean (Piraeus, Greece) and Northern Adriatic (Venice, Italy) and to local hotspot locations. Furthermore, D6.3 served as a complementary effort, extending the EGCS effluent dilution methodology to a pan-European scale, with a future possibility for global scale applications, aiming to determine the health and climate impacts originating from ship emissions. Notably, the inclusion of findings from the Aveiro case study, situated beyond the domains of D6.1 and D6.2, enriched the scope of the assessments undertaken in D6.3.



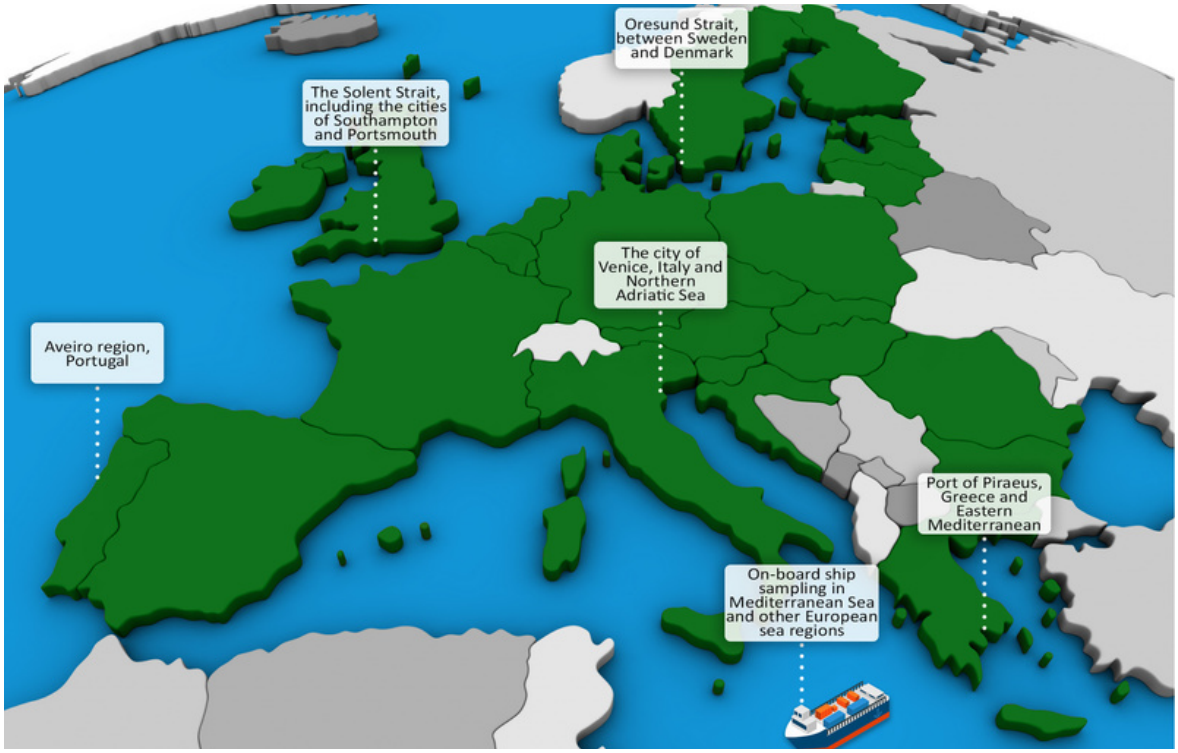
Relative contribution to the average cumulative risk quotient, calculated for open loop EGCS effluent from the EMERGE onboard campaign

Results indicated a substantial increase in EGCS effluent discharge volumes by 2050, particularly in the Baltic and Mediterranean Seas, posing increased risks to marine life. Whole Effluent Testing (WET) underscored the deleterious effects of EGCS discharges on marine species, with invertebrates and copepods being notably vulnerable, potentially disrupting marine food webs. Moreover, analysis revealed a complexity in EGCS effluent composition, with alkylated polycyclic aromatic hydrocarbons (PAHs) posing considerable risks to marine ecosystems (Figure 1). Economic assessments highlighted the profitability of EGCS-equipped vessels, which may impede the transition towards sustainability. Consequently, prioritizing decarbonization efforts emerges as crucial for mitigating EGCS-related environmental degradation and advancing marine conservation goals.

For more comprehensive information, readers are directed to:

1) D6.1- "Baltic and North Sea report,"
2) D6.2- "Mediterranean Sea report,"
3) D6.3- "Report on environmental impacts of shipping in other areas,"
4) Jalkanen, J. P., Fridell, E., Kukkkonen, J., Moldanova, J., Ntziachristos, L., Grigoriadis, A., ... & Kerstin, M. (2024). **Environmental impacts of exhaust gas cleaning systems in the Baltic Sea, North Sea, and the Mediterranean Sea area.** Finnish Meteorological Institute, Helsinki, Finland, January 2024, 181pp, ISBN: 978-952-336-189-8 https://doi.org/10.35614/isbn.9789523361898

CASE STUDIES, MODELLING AND EXPERIMENTS

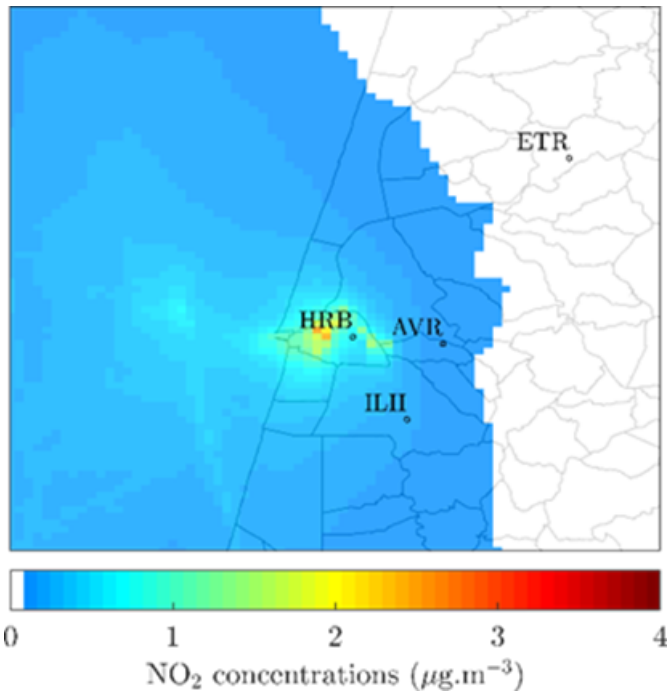


Case study map

SELECTED OUTCOMES

Impact of shipping on a sensitive nature area where a port exist – Aveiro case study

One of the case studies of EMERGE project is in a very sensitive area - the Aveiro lagoon region, a Natura 2000 area where a medium-sized port is located (Portugal country).



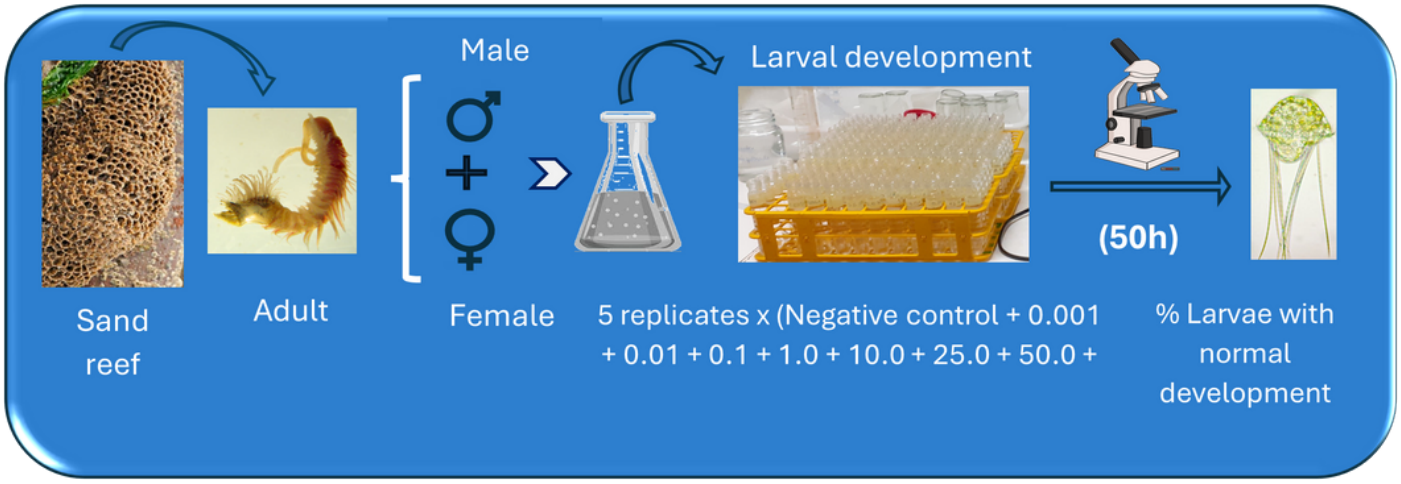
Contribution of shipping emissions to the atmospheric NO2 concentration (Aveiro case study area)

Air quality and water modelling tools were applied to assess the impact of the shipping emissions (to air and water) of the main critical pollutants in the region. Additionally, ecotoxicological bioassays were performed to evaluate the impact of scrubber-water discharge on the most sensitive stages of marine invertebrates, and on the post-exposure feeding inhibition of crustacean and bivalve species.

The results show that there is an increase in pollutant concentrations due to shipping emissions, which is most relevant for NOx and SO2 (up to a 30% shipping contribution).

Regarding water, although the port is located in this sensitive region, there is no significant degradation of the water quality, mainly because the ships operating in this area do not have scrubber equipment (non-SECA region).

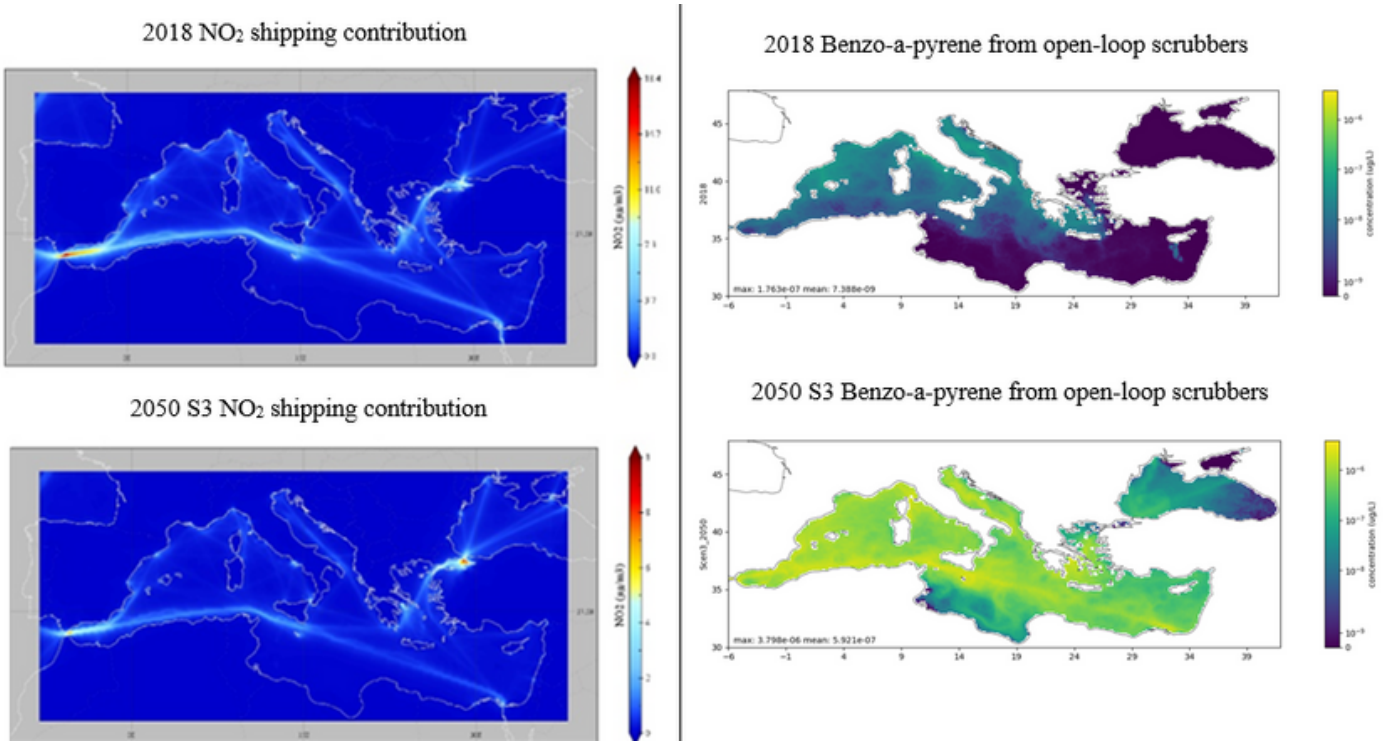
Nevertheless, if scrubbers-water (SW) were discharged in this area, the ecotoxicological tests performed with three types of SW indicate that the majority of the tested species would reveal observation effect concentration for the different scrubber-waters, as well as concentrations of metals.



Larval development bioassay scheme with the polychaeta Sabellaria alveolata

Mediterranean Sea report

The EMERGE Mediterranean Sea report was finalized in December 2023 and includes a synthesis of results from experimental and modelling studies obtained in all previous Work Packages, aiming to present an integrated assessment of the impact of shipping emissions on the air and water quality of the Mediterranean region. The DPSIR (Drivers-Pressures-State-Impact-Response) methodological framework has been used as an integrated approach to quantify the contribution of shipping to air pollution (legislated pollutants, trace metals and Polycyclic Aromatic Hydrocarbons - PAHs) and water pollution (trace metals, PAHs, nutrients and seawater acidification) under 2018 baseline conditions and under two future emission abatement scenarios for 2050, both considering high increase in ship traffic. The first scenario (S3) refers to the designation of Mediterranean as SECA and NECA (Sulphur and Nitrogen Emission Control Area respectively), assuming also high use of open loop scrubbers for SOX control and Selective Catalytic Reduction (SCR) for NOX control, while the second scenario (S8) considers the introduction of alternative fuels (LNG and methanol), but not designation of Mediterranean NECA and no scrubbers/SCR in use.

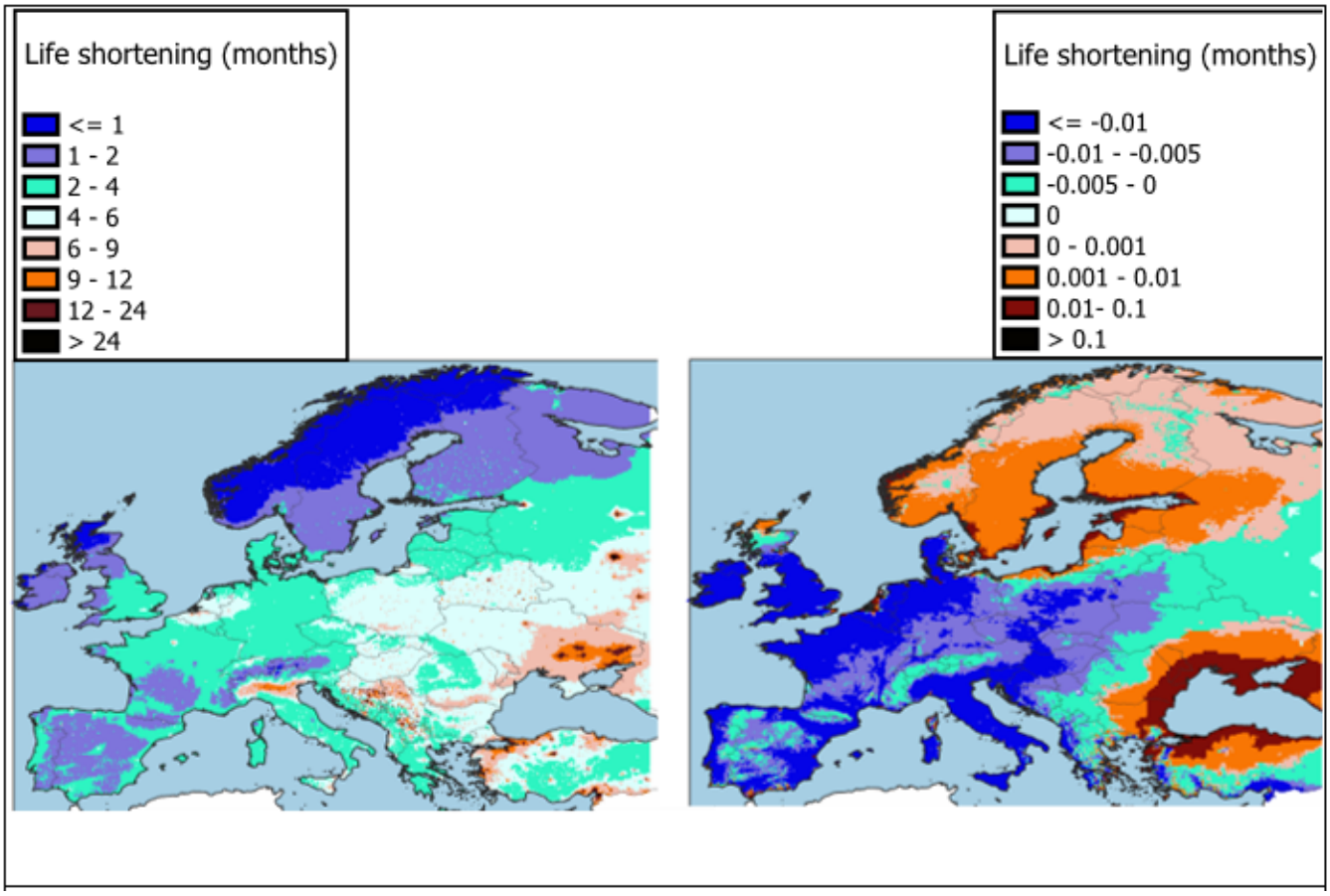


Efficiency of emission reduction scenario S3 compared to the 2018 baseline in shipping contribution on air quality (NO2 concentrations, left) and water quality (Benzo-a-pyrene concentrations, right).

Increased shipping air pollutant emissions and water discharges are observed during late spring to early autumn period, coinciding with higher shipping traffic. In terms of water quality, regional scale and case study results from Piraeus and the Northern Adriatic Sea areas suggest the significant contribution of shipping to pollutant loads along the shipping lanes and offshore, as rivers and other land-based sources dominate near the shore. Regarding air emissions, the findings highlight the mitigation of shipping related SO2 and PM2.5 contributions in both examined scenarios, while emphasizing the superior performance of S3 in controlling NO2 contributions. In 2018, the shipping contribution to total deposition of nitrogen on the Mediterranean Sea is 25%, while in the case of sulphur deposition it reaches up to 34%. Considering the impacts to ecosystems and health, the higher impacts on eutrophication of terrestrial ecosystems and human health arising from S8 are attributed to its higher NOX emissions. Model results also demonstrated significant short-term and local effects on marine primary production related to coastal eutrophication issues, due to point and pulsed nitrogen emissions from shipping.

Ecotoxicological testing of scrubber water samples on a suite of planktonic bioindicators of nearshore environments proved that toxic effects are possible at very low scrubber water concentrations (<0.1% dilution). In contrast, the mesocosm ecotoxicology experiments in Eastern Mediterranean indicated no negative effects of scrubber effluent (up to 1 % dilution) on plankton natural communities. PAH-degrading natural bacteria in mesocosms as well as pathways associated with PAH degradation to simple compounds were observed concurrently with a fast shrinkage of concentrations of several PAHs below the Limit of Detection (LOD).

The findings of the Mediterranean study suggest temporal and spatial variations in the effectiveness of the two abatement scenarios studied. In addition, in the areas where shipping contribution is predominant, the two scenarios appear to result in competing effects on the atmospheric and marine environment, with S3 simulations indicating improvements in atmospheric quality and impairment of the marine water quality and S8 producing the opposite results. For this reason, any policy recommendations on shipping emission control for the Mediterranean region should be filtered through a comprehensive Cost Benefit Analysis.



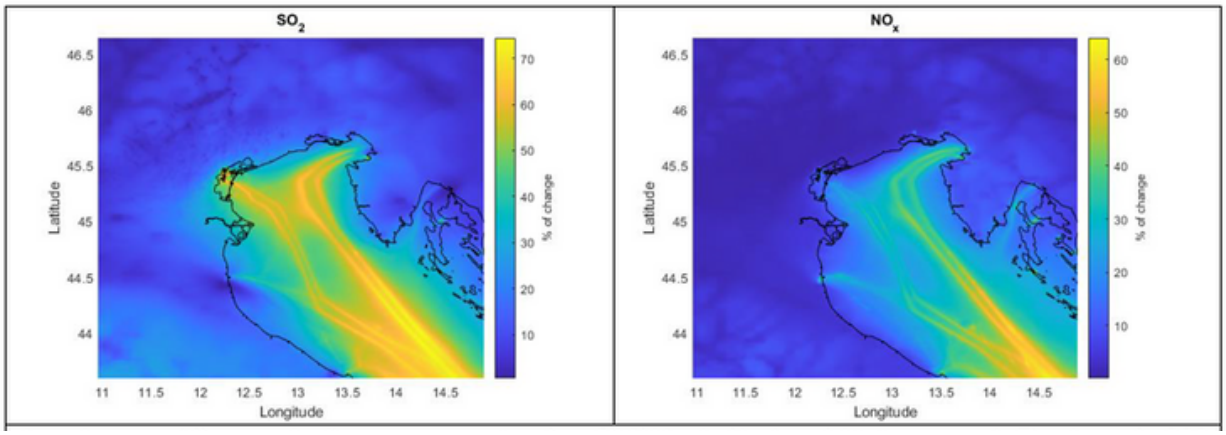
Loss of life expectancy attributable to PM2.5 exposure, expressed in months of life lost, for the Scenario S3 (left panel) and the difference between Scenarios S3 and S8 (right panel).

Northern Adriatic case-study

A **comprehensive assessment of shipping impacts** on air quality and on the marine environment has been performed for the Northern Adriatic case-study ,led by the University Ca' Foscari of Venice, Italy, following the DAPSIR framework and exploiting a portfolio of experimental and modelling approaches, in some cases developed ad-hoc to address EMERGE research questions.

Air emissions and discharges to marine waters from shipping were estimated by Finnish Meteorological Institute using STEAM model for the baseline year 2018 and for two selected scenarios (S3-S8) in 2050, allowing for the evaluation of shipping contribution in comparison with other pollution sources.

ChemicalDrift model (0.01x0.01 degrees resolution) was applied to simulate the environmental fate and transport of lead, cadmium, benzo(a)pyrene and fluoranthene in the marine environment. Findings showed a limited contribution of shipping to coastal pollution, but a more relevant role in the open sea both for the baseline and the two scenarios, with S3 highlighting a clear increase in ship-borne pollutants concentration. The outcomes of bioaccumulation modelling (with Merlin-Expo tool), targeting current offshore shellfish farms, showed that for the four target chemicals concentrations in mussels simulated for the “high-scrubber scenario” S3 in 2050 are expected not to exceed the maximum levels acceptable in seafood (bivalve molluscs) set by the EU Regulation 915/2023. As for nutrient emissions, shipping emissions of nitrogen account for only 6% of the riverine input and therefore have limited impact on the long-term overall Northern Adriatic biogeochemical cycles under current and future scenarios. Results of the newly developed Lagrangian-Eulerian biogeochemical model (0.0025x0.0025 degrees resolution) demonstrated that short-term and local effects on primary production due to pulsed point emissions of nitrogen from shipping could be expected.



Annual average difference of pollutant concentrations from SILAM for the Northern Adriatic case-study. The change for SO2 and NOx is defined as the difference of contaminants concentrations between simulations with shipping emissions and without shipping emissions. Results are presented in percentage change

Shipping contribution to air quality was investigated by FMI using **SILAM model** (0.01x0.01 degrees resolution). Current contribution from shipping to surface concentration resulted to be mainly limited to shipping lines and to the vicinity of the harbours for SO2 and NOx, while changes in O3 and PM2.5 extend much further, covering the whole case-study region.

Moreover, S3 and S8 future scenarios have been explored through regional air modelling with SILAM at 0.05x0.05 degrees. A significant reduction in monthly mean concentrations of SO2 is expected in both S3 (SECA introduced for the Mediterranean) and S8 (transition to LNG and methanol). PM2.5 from ships is also simulated to decrease by roughly 7-8% in both scenarios.

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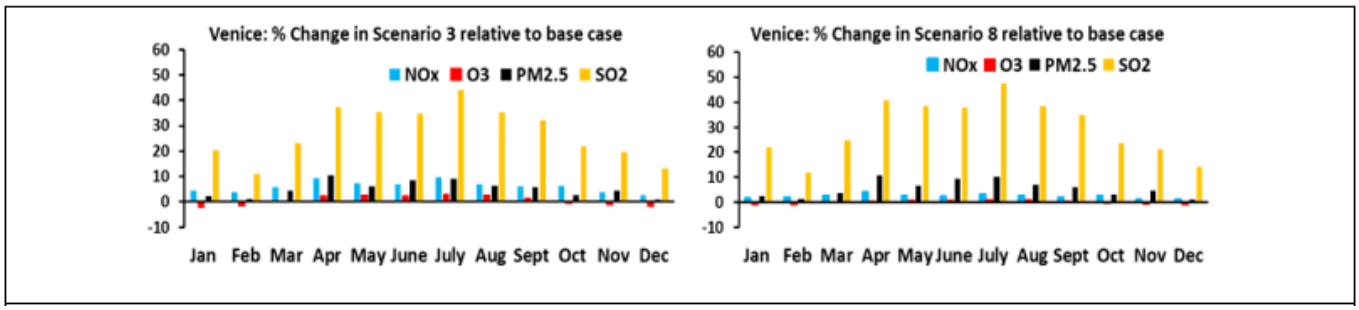
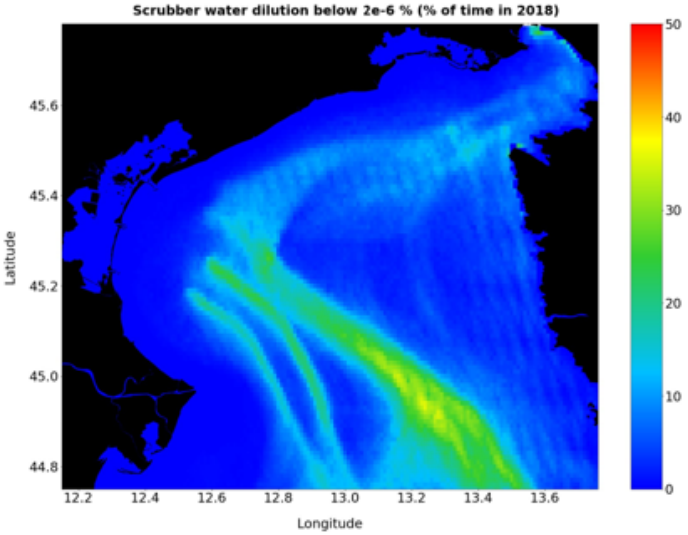


Percentage change in scenarios 3 and 8 relative to base case scenario 2018 in the monthly mean concentration of pollutants NOx, O3, PM2.5, and SO2

Ecotoxicological testing of scrubber water samples on a suite of planktonic bioindicators representative of Northern Adriatic nearshore environments proved that toxic effects are possible at very low scrubber water concentrations (<0.1% dilution for copepods and bivalve larvae) (Picone et al., 2023). Effects on copepods might have significant consequences at the ecosystem scale, altering food availability for the upper trophic levels and favouring the transfer of toxicants accumulated in their tissue to higher trophic levels, including species of commercial and recreational value. The modelling of scrubber water dilution for the Northern Adriatic CS area revealed that a continued release of scrubber water over several days could lead to concentrations comparable to those detected in the ecotoxicological studies to cause adverse effects on the tested species.



% of frequency of exceedance of scrubber water exposure over the derived PNEC in one year under current conditions

According to a risk assessment approach, the PNEC (Predicted No Effect Concentration) derived from EMERGE bioassays (equal to 2*10-6 %) can be exceeded by the estimated exposure to scrubber water under current conditions up to 30% over the year, and this exposure is estimated to increase significantly under S3 future scenario.

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