BRIEFING

Plugging the AFIR gaps: the true cost of in-port emissions

How current shore power rules cost hundreds of millions every year in health and climate damages

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Summary

Air pollution and climate emissions from ships at berth impose a heavy and unaddressed burden on European port communities and local economies. While the Alternative Fuels Infrastructure Regulation (AFIR) took an important first step by mandating Onshore Power Supply (OPS) for large container and passenger vessels, several blind spots leave over half of all in-port emissions unregulated.

Key data points

19,300

On average and each year, a ship pollutes as much SOx in port as 19,300 cars

€750 million

The annual air pollution damages caused in Europe by ships not required to connect to OPS

x2

When taking external costs into account, fossil fuels are already twice as expensive as electricity

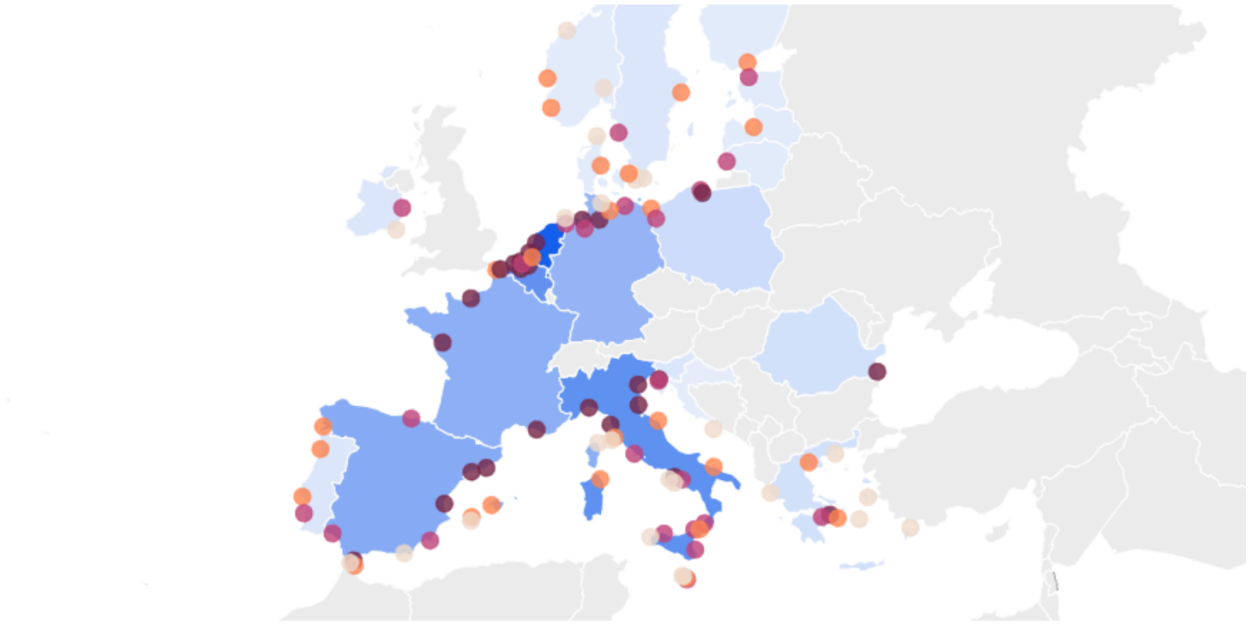
To quantify the cost of inaction, we evaluated at-berth emissions across the 100 largest EU ports using CE Delft's Handbook on the External Costs of Transport. Based on 2024 MRV data, in-port emissions cost €2.53 billion every year in health damages and climate abatement costs. Covering only the electricity demand from large unregulated ship types would already save €500 million annually, while tackling boilers would save another €714 million. Shipping companies effectively offload these costs onto public budgets, making fossil fuels appear artificially cheap. Once all impacts are counted, using electricity when at berth is half as expensive as burning fossil fuels.

While AFIR successfully kickstarted early shore power roll-out, its narrow scope leaves significant volumes of emissions unaddressed. Beyond health and climate impacts, this partial coverage creates uncertainty and deprives port authorities, network operators , and investors from the predictability they need to develop and deploy the required infrastructure. Providing a clear time horizon for the provision of shore power to all ships is essential to share infrastructure costs, reduce electricity prices and permanently clean up air in ports.

Current AFIR gaps cost €1.56 billion every year, with damages concentrated around the busiest ports

Total costs per country (million €) 0 350

Costs per port Very low Low High Very high



Source: T&E (2026) • Based on 2024 MRV and AIS data. All unregulated GHG and air pollution costs. Ports split into quartiles (million €/year): under 2.2, 2.2 to 6.6, 6.6 to 17.4, 17.4 to 253.2

T&E

Recommendations for the AFIR review

01	**Provide a timeline for the inclusion of all ship types, starting with Ro-Ros and offshore vessels** to cover all in-port emissions and guarantee long-term certainty for shore power investments.
02	**Include vessels between 400 and 5000 GT,** prioritising already regulated ships, to accelerate the decarbonisation of small ships and increase infrastructure utilisation.
03	**Introduce battery charging infrastructure requirements** to ensure battery-electric vessels access the necessary charging infrastructure.
04	**Assess the electrification potential of boilers,** and support the development of pilot projects to prove feasibility and accelerate deployment.
05	**Require Member States and ports to provide a roadmap for electrification** to anticipate future electricity demand.

01

The AFIR blind spots

Every year, millions of tonnes of air pollutants and greenhouse gases are emitted in and near European ports. Every additional tonne released in the atmosphere degrades local air quality, harms local communities and reduces our chances to reach Europe's climate goals. While the AFIR is key to deploying shore power in ports, it falls short of fully tackling ports' pollution problem.

1.1 The in-port emission problem

Around 5% of total European shipping emissions occur in ports, rising to 10% at the global level. In 2024, this amounted to 6 million tonnes of CO_2, 3206 tonnes of SO_x, 54,941 tonnes of NO_x and 1463 tonnes of PM10 released directly in or near the 100 largest ports we analysed. These emissions impose a heavy toll on public health systems and further exacerbate climate breakdown. In the busiest port cities, ships pollute more than the local passenger car fleet. Across the 100 ports we analysed, each large ship emits on average as much sulphur as 19,300 cars every year. Air pollutants like particulate matter or sulphur oxides cause diseases like child asthma, lung cancer or diabetes, with heart disease and stroke being the most common causes of premature deaths from air pollution. According to EMSA, shipping emissions could become the main transport-related source of adverse health impacts in coastal European cities by 2030, and research has shown that port cities residents living close to the harbour have more chances to develop natural, cardiovascular and respiratory mortality. Today, in-port shipping emissions cost European countries around €1.72 billion every year in health damages.

The 11,796 large ships stopping in EU ports in 2024 emitted as much sulphur as 228 million cars, an average of 19,300 cars per ship.

Most ships rely primarily on auxiliary engines to produce electricity on board when in ports. However, instead of running fossil-fuelled engines when at berth, vessels can plug into Onshore Power Supply (OPS) to draw electricity from the grid, instantly cutting in-port air pollution and greenhouse gas emissions. This technology has been known for decades, and is now mature and proven. To speed up deployment, the 2023 AFIR review introduced requirements that core and comprehensive TEN-T ports provide OPS to at least 90% of port calls by container, passenger, and cruise ships above 5000 GT in 2030. These rules only apply for ports with minimum traffic. To ensure these systems are actually used, the FuelEU Maritime regulation mirrors AFIR with a mandatory connection requirement for shipowners.

1.2 The gaps in the regulation

The AFIR mandate has been instrumental in jump-starting shore power deployment across Europe. Recent data from the European Maritime Space shows that over 100 connection points were installed in European ports in recent years, with roughly 450 more in the pipeline. However, the regulation remains incomplete:

- **First, many large ships are left out.** Mandates only cover container, passenger and cruise ships, meaning that bulk carriers, tankers, Ro-Ros, general cargo, and offshore and service vessels are not required to connect. Even if every regulated ship connects in time by 2030, auxiliary emissions from other ship types – or 20% of in-port costs – would not be covered.

- **Second, small vessels are ignored.** By targeting only ships above 5000 GT, the regulation misses around 3% of Europe's in-port damages. While representing a small share of emissions, vessels between 400 and 5000 GT usually run shorter and predictable coastal routes, have lower energy needs and can be electrified at a smaller cost, making them good candidates for OPS.

- **Third, there are no rules for battery-charging infrastructure.** With around 500 battery-electric vessels already navigating in European waters and the fleet expanding beyond passenger segments, this may create an important bottleneck. Because shore power and charging infrastructure share grid capacity and connection points, they should be planned together.

- **Finally, boilers are excluded completely** as current rules only require electrical energy demand to be replaced with OPS. Contrary to the general assumption that boilers cannot be electrified, mature alternatives exist and technical solutions can be deployed today. Integrating them should be considered, alongside more dedicated pilot projects and feasibility studies to accelerate deployment.

These regulatory gaps not only lock in air pollution for port cities and local communities, but also create planning uncertainty for port authorities, terminal operators and grid authorities. Upgrading grid infrastructure requires massive capital investment and long lead times of up to five years. Without a predictable long-term roadmap covering all vessel types, investors have limited incentives and risk facing underutilised infrastructure and high connection costs.

Finally, AFIR reviews are set every 5 years, meaning that the next revision will take place in 2032, two years after the current regulatory deadline. To prevent this two-years void while electrification momentum keeps building, the EU should establish a clear timeline for the inclusion of all ships now. Providing this long-term horizon will give port authorities and investors the confidence and certainty they need to accelerate the deployment of onshore power supply across European ports.

02

Counting the cost of inaction

To evaluate the true economic impact of not deploying OPS, we analysed at-berth emissions from Europe's 100 largest ports and quantified their health and climate impact using CE Delft's Handbook on the External Costs of Transport. The approach puts a monetary value on the direct consequences on healthcare systems from toxic air pollution and the cost of cutting greenhouse gas emissions to meet EU climate objectives.

2.1 Overall health and climate damages

Exposure to air pollutants such as sulphur oxides, nitrogen oxides or particulate matter significantly raises the risks of respiratory infections, lung cancer, and cardiovascular disease, making air pollution the single largest environmental health risk in the EU. The damage costs that we used to quantify health impacts, which vary per country and population density, are defined in the methodology. We calculated climate-related financial impacts, driven by greenhouse gases such as carbon dioxide or methane, based on the investments needed to keep global warming levels below 2°C.

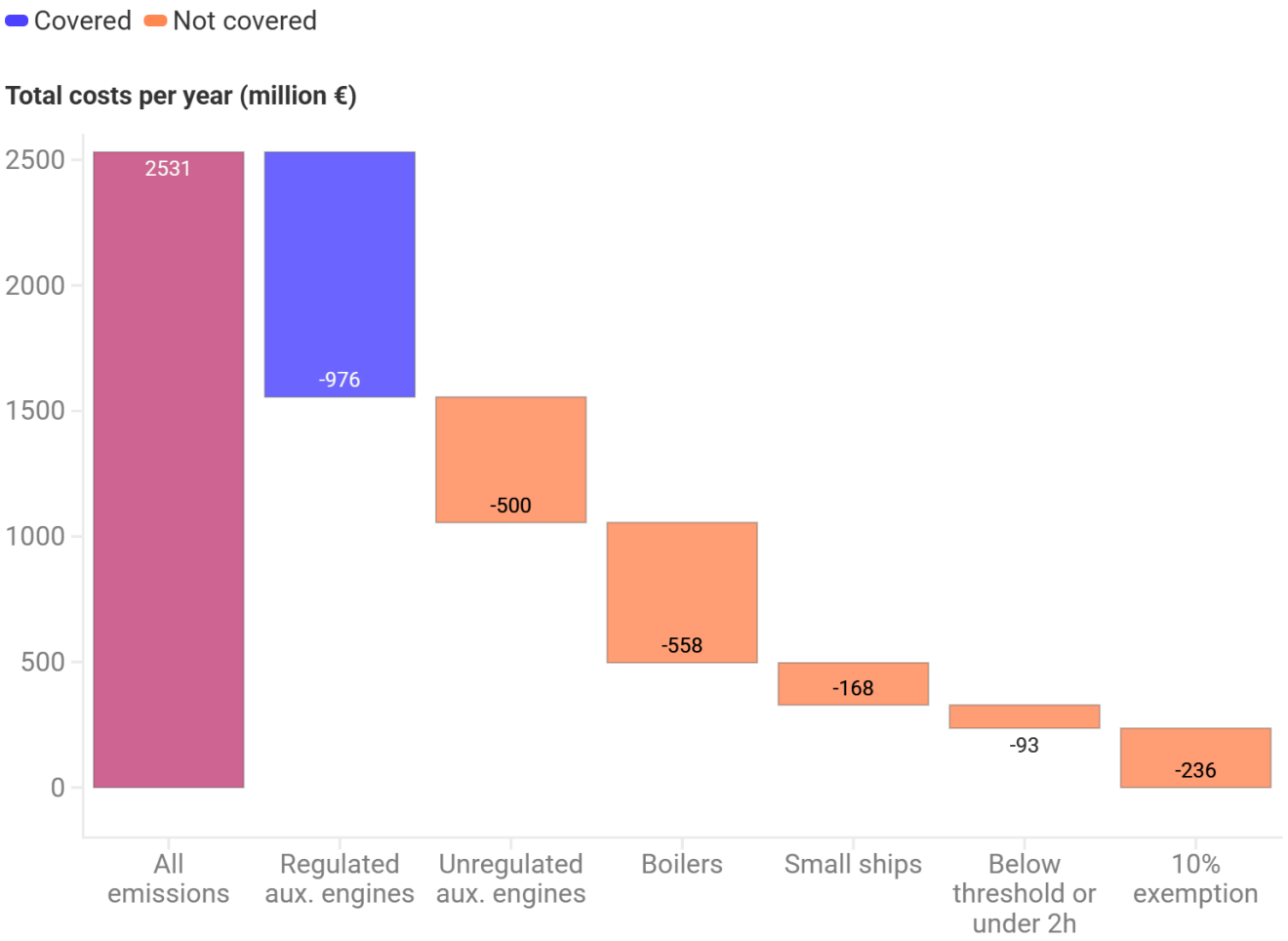
In total, in-port emissions have an external cost of €2.53 billion every year, split between air pollution damages and GHG abatement costs. Health costs represent a consistent 68% of the total, reaching €1.72 billion in total at the EU level, while climate costs account for the remaining 32%, or €812 million annually. Large container and passenger ships represent half (53%) of external costs, or €1.34 billion per year. The remaining emission costs are split between other large vessels (€1.03 billion), and vessels between 400 and 5000 GT (€168 million).

Current rules only require auxiliary engine emissions to be replaced with electricity, excluding emissions from boilers. Furthermore, 10% of all calls, calls below the traffic threshold, and calls of less than two hours are exempted. Across all segments, these four exemptions represent 3.2 million tonnes of CO_2, 1756 tonnes of sulphur oxides and 12,361 tonnes of nitrogen oxides emitted every year by ships above 5000 GT. Together, they cost €887 million in health and climate costs, over a third (38%) of the total in-port costs from these vessels.

Taking all these exemptions into account, we find that AFIR currently covers less than 40% of all in-port costs. This gap amounts to €1.56 billion each year in health and climate costs.

60% of all in-port costs are left out under current AFIR rules

These emissions cost €1.56 billion each year in health and climate damages



Source: T&E (2026) • Based on 2024 MRV and AIS data. Threshold for non-covered types is 100 port calls. Aux. engines only include ships > 5000 GT. Small ships include all their emissions.

Pricing in-port emissions

CE Delft's Handbook on the External Costs of Transport provides a methodology for monetising the external impacts of shipping emissions. **On air pollution**, the handbook calculates the damage costs from pollutant emissions on public health, ecosystems and infrastructure, in euros per kilogram. The impact is quantified by putting a price on the consequences of pollution: premature deaths, work days lost to poor health, asthma, lung cancers, etc. It is then multiplied by the estimated increased incidence of these effects. The detailed list of health impacts can be found in the methodology.

Values differ by country and by setting (urban or rural) to reflect the fact that absolute exposure is lower in low density areas. Air pollution prices are estimates, not observed values: they rest on modelled exposure and on willingness-to-pay valuations of health, notably the value of a life year lost. Hence they can be subject to changes as estimates are refined.

On greenhouse gas emissions, the methodology sets an abatement cost per tonne of CO_2-equivalent. It bases this price on the cost of cutting emissions enough to meet the Paris Agreement goal of limiting warming to 2°C. Calculating damages from warming would be too complex to compute accurately, so we used the costs for the EU to comply with its binding climate targets. The resulting price is €133 per tonne up to 2030 (in 2025 euros). Methane and nitrous oxide are converted into CO_2-equivalents. The total emissions are then multiplied by the price per tonne.

2.2 Damages per port

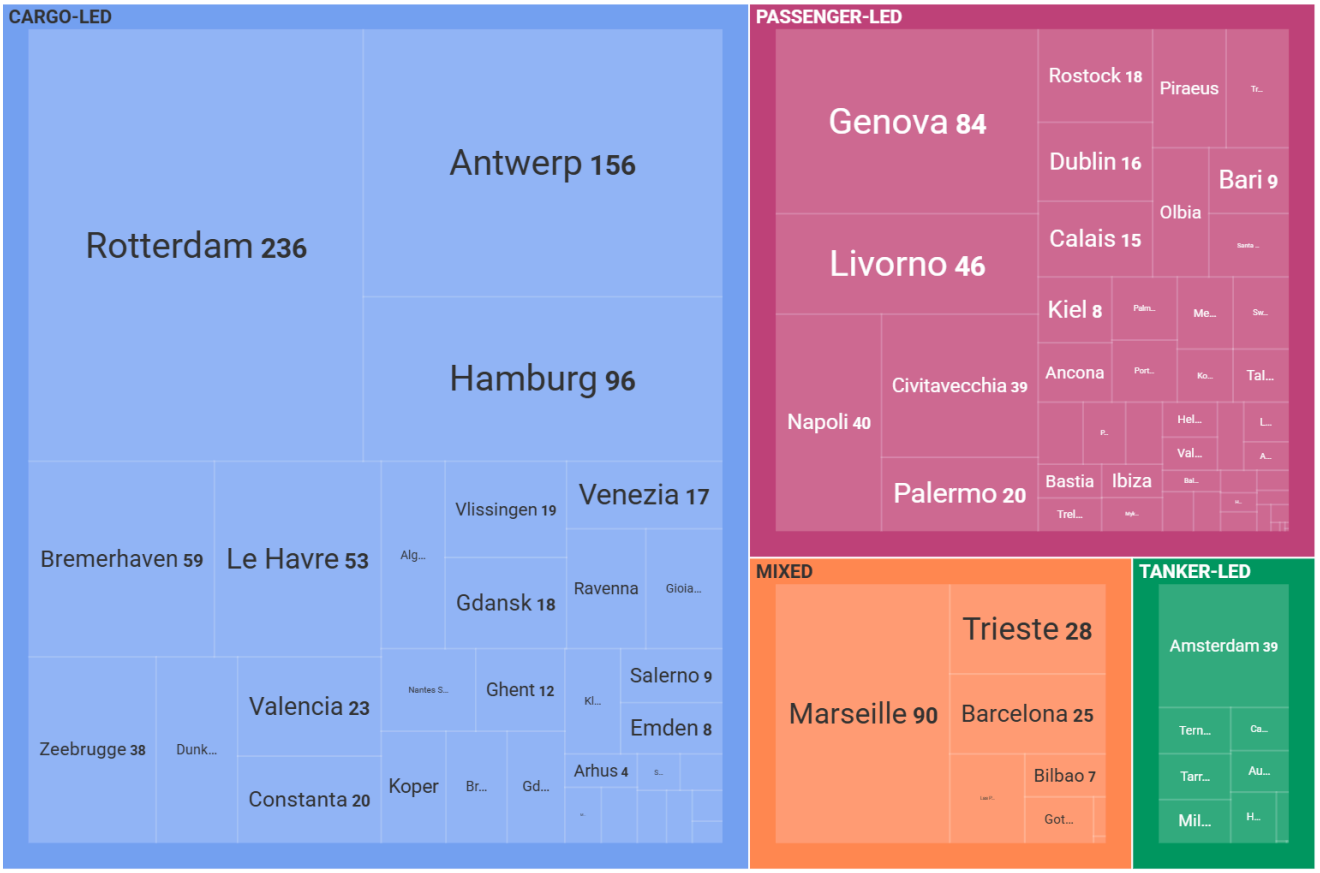
Due to their usually larger operational scale and size, cargo-led ports bear the highest overall cost. **Health impacts average €28.8 million per year in cargo-led ports, against €9.5 million in passenger-led ports and €8.1 million in tanker-led ports.** We categorised ports by dominant traffic type based on which vessel type has the highest air pollution damage, with all ports listed in Annex 3. Crucially, the concentration of damages in Europe's largest industrial ports also coincides with the fact that these ports typically benefit from industrial grid capacities and better access to financing. This positions them well to lead the market and deploy shore power at scale.

Across the ports analysed, 47 are passenger-led ports, 32 are cargo-led, 10 tanker-led and 8 are mixed ports. Major industrial ports like Rotterdam, Antwerp, Hamburg fall under the cargo category and are the most polluted ones, while ports like Genova and Livorno are mostly impacted by passenger ships. Notably, the port of Amsterdam is designated as a tanker port, meaning the majority of in-port damages come from tankers that are exempt from shore power requirements. The 100-call minimum traffic threshold has a limited impact on total emissions, because our analysis focuses on Europe's largest ports and because ports tend to specialise in specific sectors to maximise their throughput.

Large industrial ports face the heaviest air pollution damages

Their strong industrial base, however, also makes them well placed to expand shore power

Health damages (million € per year)



Source: T&E (2026) • Based on 2024 MRV and AIS data. All emissions from ships > 5000 GT. Port categories based on highest source of air pollution per ship types in port. Bulkers and containers grouped in cargo.

2.3 Damages per segment

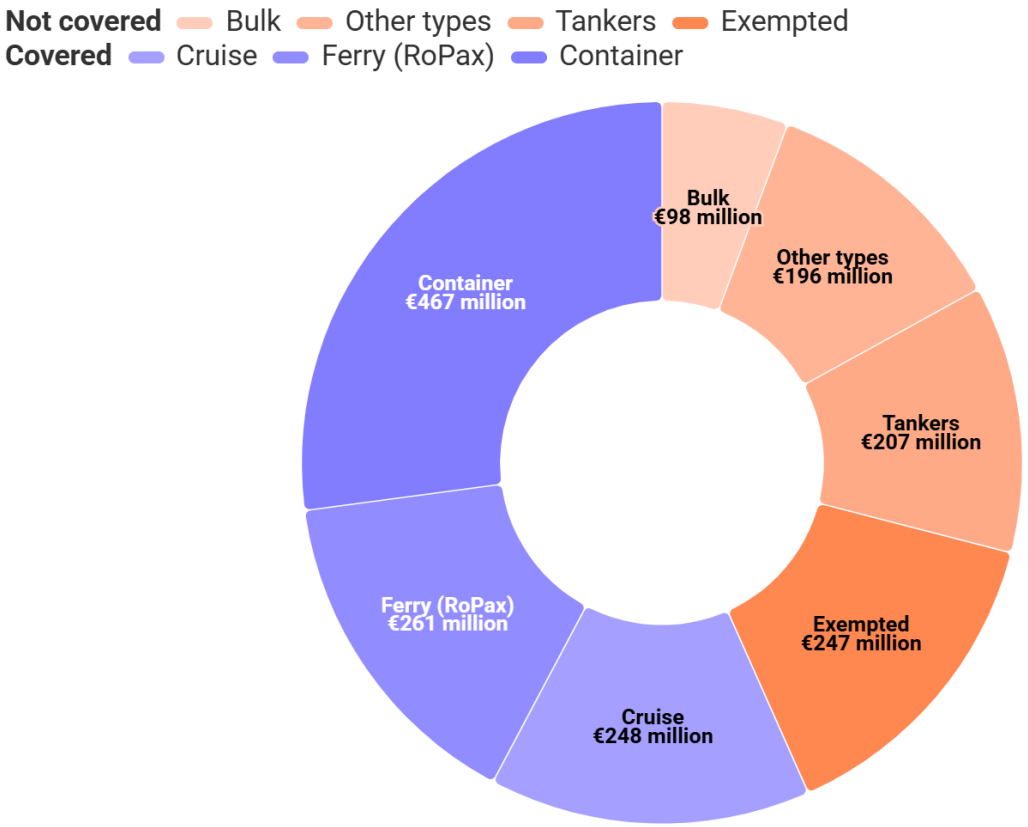
We broke down emissions across segments with sufficient traffic in EU ports, and split them between vessels from 400 to 5000 GT and vessels above 5000 GT. For each subcategory, we split emissions between regulated and unregulated emissions, and isolated auxiliary engine emissions from emissions left unaddressed, namely boilers, the 10% operational exemption, the traffic threshold and calls of less than two hours. The methodology and detailed analysis is available in Annex 1.

In total, air pollutant and greenhouse gas emissions from all large vessels, including boilers and auxiliary engines, cost €2.36 billion every year. Auxiliary engines account for 73% of these costs, for a total of €1.72 billion. 35% come from unregulated ships, causing €601 million in health and climate costs every year. Extending the mandate to non-regulated ship types - while maintaining the 10% rule and the traffic threshold - would save €500 million each year, including €402 million in air pollution damages and €98 million in climate-related costs. While representing

smaller volumes of emissions than container ships or ferries, segments like Ro-Ros and offshore vessels are well-suited for electrification, with some ports already planning for the inclusion. Rather than leaving them out indefinitely, the EU should set a clear timeline for the inclusion of these ships to give shipping companies and ports authorities the confidence and certainty needed to invest in retrofits and grid infrastructure, while accelerating standardisation across all sectors.

43% of auxiliary engine costs are unaddressed under current AFIR rules

Including more ship types could save €500 million every year



Source: T&E (2026) • Based on 2024 MRV and AIS data. Only ships above 5000 GT. Auxiliary engines only. Exemptions include calls below the traffic threshold, port calls under two hours and 10% of all port calls.

We find that small ships used around 588 GWh per year in 2024 across the 100 ports we analysed. This translates into the emission of 338 tonnes of SO_x, 3484 tonnes of NO_x, 106 tonnes of PM2.5 and 501,982 tonnes of CO_2e. **In total, small vessels calling in EU ports cost €168 million every year, €102 million in health damages and €67 million in climate costs.** Operating mostly on coastal and short-sea routes, small vessels usually have lower energy and power requirements, which makes them well-suited for OPS. Expanding OPS requirements to include smaller vessels would also synergise well with their inclusion in the European carbon market

(ETS), as using shore power would allow shipowners to avoid surrendering allowances for emissions generated at berth.

Looking at specific ship types, we find that **the average cruise ship costs €1.45 million every year in health and climate costs, reaching €5.3 million on average for the 10% most costly vessels, against €1.08 million for a ferry and €333,000 for a container ship.** Ro-Ros are few (271 ships), so their total impact is limited (€104 million per year for all the large ships). Individually, however, the average Ro-Ro costs around €385,000 per year, more than a container ship. Yet, and despite the fact that their regular and frequent routes make them ideal candidates for electrification, these ships are not required to connect under current AFIR rules. Leading ports like Rotterdam or Hamburg are already planning and deploying shore power infrastructure for these ships. EU policymakers should close this gap before the regulation falls behind reality, and Ro-Ros should be prioritised for inclusion in the upcoming AFIR review.

2.4 The problem of boilers

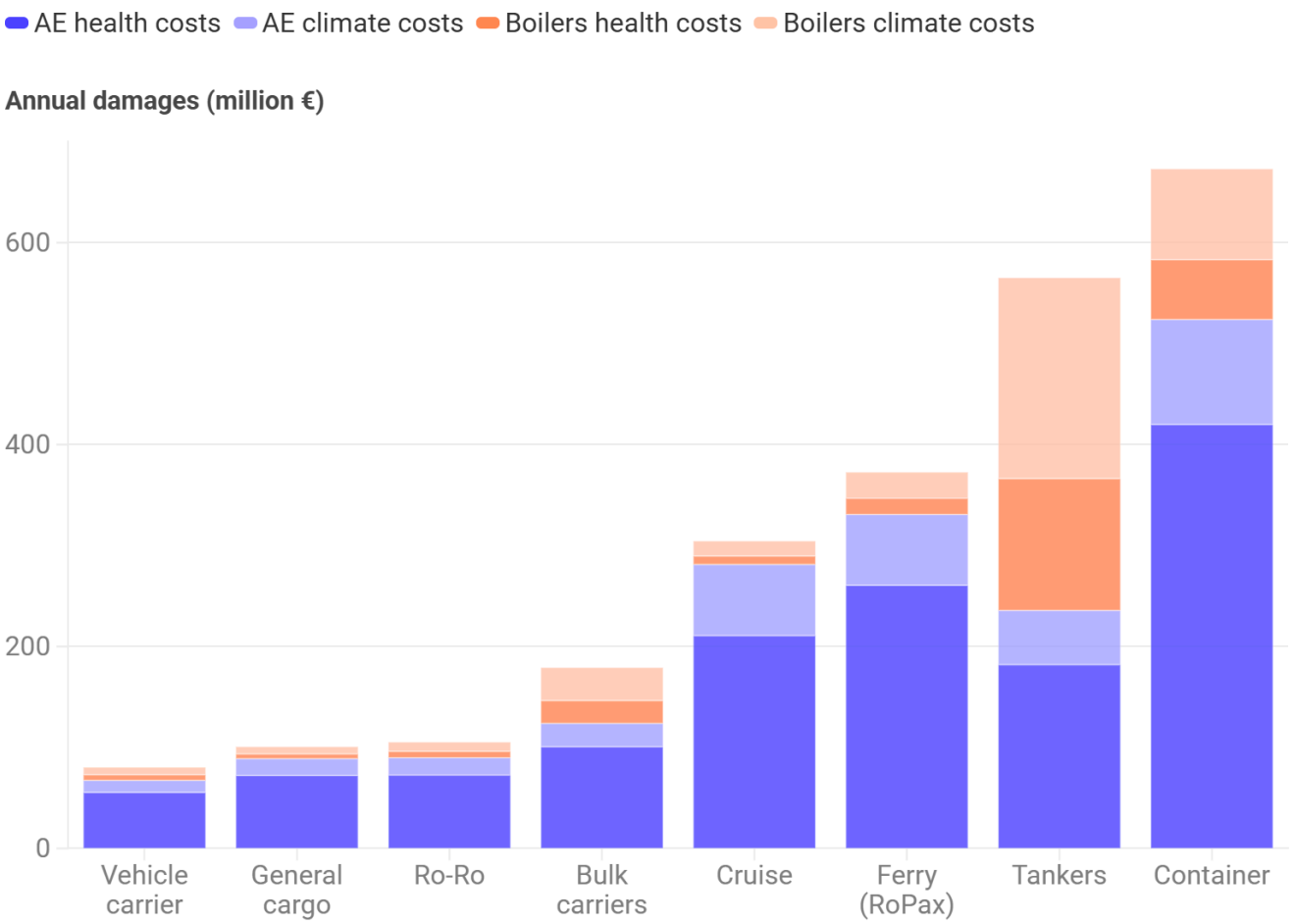
Besides auxiliary engines, which power onboard systems like lighting, navigation equipment, communications, or pumps, ships often carry boilers to generate heat. While some ships use them for basic needs like onboard hot water, other segments such as tankers rely heavily on boilers to heat and maintain their cargo at the right temperature. These boilers are almost entirely run on fossil fuel and generate important volumes of air pollutants and greenhouse gases.

Across the fleet of large ships, boilers represent 27% of combined costs, amounting to €640 million every year. This share varies between ship types, ranging from 12% for general cargo to 22% for container ships, and up to 59% of tankers' total costs. Tanker boilers alone, including gas carriers, cost €331 million every year in health and climate costs.

By only requiring ports to cover electrical demand, the current AFIR leaves boiler emissions entirely unregulated. Contrary to the general assumption that boilers cannot be electrified, mature alternatives exist, and hybrid, mixed or full-electric boilers are commercialised for newbuilds and retrofits. While vessels can already combine electric and oil boilers in a mixed setting (a well-established solution), electric-only solutions are in an earlier development phase and more research and support is needed to accelerate the uptake. While challenges, notably around standardisation, remain, technical solutions can be deployed today. The AFIR review should include measures, including dedicated pilot projects and feasibility studies, to support early movers and accelerate the deployment of these technologies.

Large vessels' boilers annually cost €640 million in health and climate damages

Tankers represent 52% of these costs



Source: T&E (2026) • Based on 2024 MRV and AIS data. Only ships above 5000 GT. AE: auxiliary engines. Tankers include oil, chemicals and liquid tankers, gas carriers.

03

The true economics of OPS

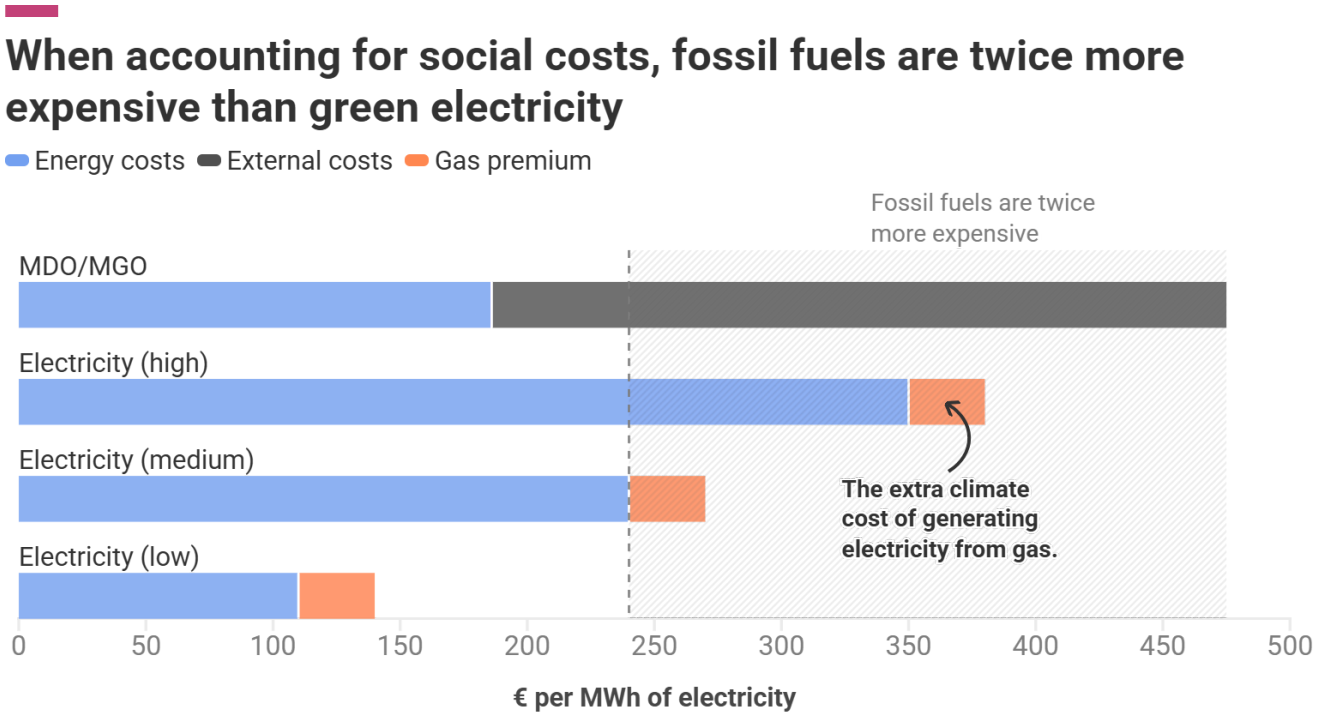
Shipping emissions remain largely ignored as an externality, and the severe health and climate costs they cause are rarely factored into the economic assessments of shore-side electricity. While climate costs are partially internalised through the EU Emission Trading System (ETS), pollution costs are entirely offloaded onto local health systems. In this section we evaluate the gap between what shipowners pay and the true cost they impose on society, a gap that fundamentally distorts the economic comparison between fossil fuels and clean shore side electricity.

3.1 Factoring in hidden costs

In ports, fossil fuels enjoy an uneven playing field. Contrary to electricity, marine fuels are generally exempt from energy taxes, which gives them a comparative advantage at berth. In addition, their environmental impact is almost entirely borne by port communities and the public budget, rather than the shipping companies causing the pollution.

Using CE Delft's prices, we calculated the hidden health and climate premium per unit of energy consumed at berth. While the EU ETS puts a price on carbon, the amount paid by shipowners falls far short of covering the real societal costs of their emissions. In 2025, ETS allowances cost on average €73 per tonne of CO_2e, while CE Delft's Handbook puts the carbon abatement cost at €133 per tonne.

Once both local air pollution and real climate impacts are priced in, we find that marine fossil fuels are twice more expensive than shoreside electricity. If shipping companies were forced to pay for their full impact, including the air pollution they cause in ports, they would face an extra cost of €0.25 per kWh of electricity generated on board by auxiliary engines. This is equivalent to an additional €1318 per tonne of marine diesel burned in these engines.



Source: T&E (2026), FIER (2026) • Electricity prices from FIER 2026. External costs include health and climate costs, net of ETS. MDO priced at €1000/t.

3.2 The need to expand the mandates

In-port emissions are an urgent problem, which costs Europe €2.53 billion in pollution and climate damages every year. Leaving the burden on local communities and public health systems while fossil fuels are artificially kept cheap is no longer defensible, especially with electrification being a mature technology. Yet, under current AFIR rules more than half of these costs remain unaddressed. Polluting vessels like tankers and Ro-Ros are left out, small coastal ships are excluded despite their electrification potential, and boiler emissions, which represent over 28% of the costs, will remain uncovered. At the same time, battery-electric vessels are entering European waters without a framework for the provision of charging infrastructure.

Charging battery-electric vessels

Due to rapid technological progress and falling prices, battery propulsion has become a viable option for coastal shipping. Our 2026 ferry study shows that 52% of existing ferries could rely on battery-electric propulsion by 2035, with 20% being already cheaper than fossil fuels in 2025. And this transition is already visible.

Globally, there are more than 2000 battery-electric ships in operation, including hybrids and full electric, with 1000 more in orderbooks. In Europe, the Alternative Fuels Observatory counts around 500 battery-electric vessels. As the electric fleet expands beyond passenger

segments into tugs, offshore vessels and general cargo, more dedicated charging infrastructure will be needed. The availability of shore-side infrastructure is now one of the main bottlenecks for the wider deployment of battery-electric vessels, with ports often lacking the grid capacity and connections to charge them.

Onshore power supply and battery charging infrastructure share the same grid, the same electrical infrastructure and sometimes the same connection points. They should therefore be planned together, and future demand from battery-electric ships should be integrated into planning to optimise deployment and accelerate the decarbonisation of European ports.

The upcoming review is a critical opportunity to fix these gaps. Grid upgrades take years to plan and build, meaning that port authorities and operators need a predictable long-time horizon to invest in expensive infrastructure. Waiting for the next review in 2032 (two years after the current deadline) would mean losing precious time while the technology and the fleet are moving ahead.

European policymakers have an opportunity to show ambition by expanding the mandate to small vessels, integrating battery charging, addressing boilers, and setting a clear plan to bring all ships into the framework. Only a binding timeline will give ports, shipping companies, shore power companies and grid utilities the certainty they need to make zero-emission ports a reality.

Annex 1. Sectoral analysis

The sectoral analysis breaks down emissions across segments with sufficient traffic in EEA ports. For large vessels above 5000 GT, we assess the total health and climate costs for each segment, comparing regulated ship types (container and passenger ships) against unregulated ship types. We then isolate auxiliary engine emissions from those left unaddressed, namely boilers, 10% operational exemption, calls under two hours, and the traffic threshold.

Among vessels above 5000 GT, tankers, including gas carriers, are the most harmful unregulated segment and cause €563 million every year in total health damages and climate costs. While most of their impact comes from their extensive use of boilers, tankers remain the most polluting unregulated segment when considering auxiliary engines alone, with engine emissions amounting to €232 million per year. By comparison, auxiliary engines from large bulk carriers' cost €109 million annually, while those on Ro-Ros and General cargos cost €89 million each.

As vessels between 400 and 5000 GT are not required to register their emissions in the EU's MRV, we estimated their impact using T&E's bottom-up emissions model. The model uses AIS data to detect port stops and values defined in the Fourth IMO GHG study to estimate energy demand and emissions at berth. Small ships' AIS coverage is sparser, and the mean port stop duration for small ships is lower, making port stop detection much harder. In consequence, our findings are likely conservative and miss part of the air pollution and greenhouse gases emitted at berth, particularly from service vessels, tugs, or offshore ships.

Looking at specific ship types, we find that average costs are higher than median costs because the biggest ships pull the numbers up. A median cruise ship costs around €970,000 in health and climate damages every year, against €830,000 per year for a ferry and €250,000 for a container ship.

Annex 2. Methodology

Scope. We studied the external costs of emissions from auxiliary engines and boilers of ships at berths in 97 important EEA ports (all ports with MRV data out of a list of 100 TEN-T ports; the estimate for ships of 400 to 5000 GT covers all 100). Throughout the briefing, regulated ship types refers to vessel types within the scope of AFIR, while covered emissions refers to emissions that must be replaced with OPS. For example, a container ship is a regulated segment, but only its auxiliary engine emissions are covered. Conversely, tankers are entirely unregulated, leaving all their emissions uncovered.

Data sources.

- At-berth CO_2 per ship: 2024 EU MRV (THETIS-MRV) database.
- Port stay durations: 2024 AIS voyage data, processed by us
- Ship type, fuel, scrubber, and engine and boiler power at berth: our vessel database based on Clarksons and IHS
- Emission factors for air pollutants: our internal modelling, derived from the Fourth IMO GHG study (2020)
- Emission prices: CE Delft Handbook on the External Costs of Transport (2019), restated in 2025 euros using Eurostat's HICP. We use CE Delft Environmental prices handbook (2024) for sensitivity
- Port coverage: the 97 ports we analysed cover 71% of the at-berth CO_2 reported by the ships in scope (5.5 of 7.7 million tonnes). The 6.0 million tonnes quoted in this briefing add 0.5 million tonnes for ships of 400 to 5000 GT, which are not in the MRV.

Ships above 5000 GT. We calculated fuel consumption at berth from each ship's reported berth CO_2. First, we set the fuel used per port call. Fuels are attributed iteratively; we test each condition and attribute the fuel based on the first valid one: LNG for LNG-powered ships, VLSFO for stays of two hours or less outside SECAs, HFO for ships with a scrubber where discharge is allowed, and MDO/MGO for the rest of calls.

We then derived fuel from CO_2 using the emission factor of each fuel, split it between auxiliary engines and boilers in proportion to their power demand at berth, and spread it over the ship's calls by time at berth. Values were spread over all EEA port calls of a ship, and we then kept only the ports in our sample.

We expressed SO_x as mass of pollutant per mass of fuel, and NO_x and PM as mass of pollutant per kilowatt-hour of energy produced. For CO_2e, we used the MRV values, with some data cleaning corrections for specific cases where CO_2e diverged drastically from the corresponding CO_2 values. We tagged each call by:

- The ship type: whether it is mandated by AFIR
- The port: whether it is above or below the minimum call threshold (100 calls for containers, 40 for Ro-Ro passenger ships, 25 for other passenger ships. Non-mandated types are set at 100 calls)
- The call duration: calls below two hours are excluded from coverage and call count

Where AFIR applies, we assumed that the 10% exemption for calls would be uniformly distributed, and therefore energy would be exempted in the same proportion. Hence, we treated 90% of auxiliary engine energy as covered and 10% as exempted.

Ships of 400 to 5000 GT. These ships are not in the MRV, so we estimated energy from AIS time at berth. We used T&E's bottom-up model to estimate energy consumption, fuel consumption and emissions based on ship voyages. We took the power ratings of auxiliary engines and boilers from the Fourth IMO GHG study. We calculated air pollutant and GHG emissions based on the same emission factors as for large ships, and split them between boilers and auxiliary engines.

Valuation. We multiplied the tonnes of each pollutant by the prices of the CE Delft Handbook:

- For air pollutants, the Handbook gives prices by country and population density. We applied urban or rural prices for NO_x and PM depending on the port town's population. Metropolitan prices were not used to give a conservative estimate.
- The Handbook's air pollutant prices cover four types of damage: health effects (premature death from reduced life expectancy, and illness such as chronic bronchitis, hospital admissions for respiratory and cardiovascular disease, restricted activity days and lost working days), crop losses, damage to buildings and materials, and biodiversity loss.
- We valued PM as PM2.5, assuming a conversion rate of 92% from PM10 mass to PM2.5 mass.
- We priced greenhouse gases in CO_2e at €133 per tonne, based on the abatement cost of meeting the Paris Agreement goal. A climate abatement cost is the marginal cost of GHG emissions necessary to reduce emissions to meet a specific target. In general, it is set by the most expensive measure needed to meet an emissions target in the cheapest way. It is used in place of climate damage estimates, which vary widely with modelling, and treats the political target as a proxy for what society is willing to pay to avoid warming.
- For ships of 400 to 5000 GT, we converted the bottom-up methane and nitrous oxide estimates with global warming potentials of 34 and 298.

Price sensitivity for costs. We re-ran the valuation with the prices of CE Delft's 2024 Environmental Prices Handbook, restated in 2025 euros, first one at a time and then together. For greenhouse gases, we took the 2024 value of its central path, €180 per tonne CO2e. For air pollutants, we took its EU27 urban and rural prices for NOx, SOx and PM2.5. These prices have no

country split, so they shift costs between countries; we use them for the EU total only. The table below gives the total damages of all ships in our sample.

Air pollution prices / GHG prices	CO2e at €133 (2019 Handbook, used here)	CO2e at €180 (2024 Handbook)
2019 Handbook, by country (used here)	€2.53 billion	€2.82 billion (+11%)
2024 Handbook, EU27	€2.44 billion (−4%)	€2.72 billion (+8%)

We also applied the 2019 Handbook's rural prices at every port, in place of urban prices at all but 12. This is a lower bound, since berths sit next to towns and cities. The Handbook has a single SOx price per country, so only NOx and PM2.5 costs change. Applying the Handbook's metropolitan PM2.5 prices at the 27 ports in agglomerations above 0.5 million inhabitants raises damages by 11%.

Area prices	Ships above 5000 GT	Ships of 400 to 5000 GT	Total	Change
Urban and rural (used here)	€2.36 billion	€168 million	€2.53 billion	–
Rural at all ports	€1.73 billion	€130 million	€1.86 billion	−27%
Metropolitan at the 27 metropolitan ports	€2.62 billion	€185 million	€2.81 billion	+11%

Car comparison. We compared the at-berth SO_x of ships above 5000 GT with the SO_x emissions from cars from each port. We sourced car numbers based on Eurostat's cars per 1000 inhabitants at the regional level, multiplied by the port municipality population, less battery-electric cars. Diesel cars, including diesel hybrids, use diesel fuel consumption; all other combustion cars, including petrol hybrids and LPG or CNG cars, use petrol fuel consumption.

We assumed each car emitted SO_x equal to the legal maximum of 10 ppm, the EU road-fuel limit, times the fuel it burned in a year: we pulled fuel use per km from the COPERT factors of the EMEP/EEA Guidebook 2023, weighted by the country's diesel and petrol shares, times km per car per year from JRC-IDEES 2023.

We divided a port's ship SO_x by SO_x per car to get the number of cars that emit as much as its ships. We summed over the 97 ports with data and divided them by the emissions from all ships in our sample (11,796 unique vessels): the yearly at-berth SO_x of an average ship equals that of about 19,300 cars. We counted only exhaust.

Fuel versus electricity. We compared, per MWh of electricity delivered on board, the all-in cost of an auxiliary engine burning marine diesel with the price of shore power. We used three pricing scenarios for shore power: the minimum, central and maximum prices reported by FIER (2026)

for the European Parliament's TRAN committee. These are published high-voltage tariffs, which bundle electricity, grid charges, taxes, infrastructure recovery and service fees.

For the genset, we assumed an auxiliary engine burning MDO/MGO. The table below lists the fuel and carbon inputs:

Input	Value
Fuel consumption	186.1 g per kWh
Engine efficiency	45.3%
Fuel price before ETS	€1000 per tonne
ETS price	€73.43 per tonne of CO_2e

We took the ETS price from the 2025 average of the International Carbon Action Partnership (ICAP) and applied it to all berth CO_2e. We included ETS costs as a separate cost entry, and deducted it from GHG costs, since the ETS is a way to internalize carbon emissions' external costs.

A fuel price of €1000 per tonne, below the 2026 levels for MDO/MGO, gives €186 per MWh, within the €150 to €200 that FIER (2026) gives for the direct fuel cost of onboard generation.

We derived the emissions per kWh from the Fourth IMO GHG study and priced them with the CE Delft Handbook, restated in 2025 euros. For air pollutants, we used the average prices of the Handbook's Table 14: rural prices for NO_x and $PM_{2.5}$, and the single price for SO_x.

Pollutant	Emissions per kWh	Price per tonne
CO_2e	607.7 g	€133
NO_x	11.2 g	€16,710
SO_x	0.364 g	€14,456
PM2.5	0.174 g	€92,835

We divided the all-in cost of fuel by the shore power price to get the ratio. In the central case, fuel costs two times as much as shore power, and between 1.4 and 4.3 times across the highest and lowest shore power prices. With FIER's lower fuel-only cost of onboard generation (€150 per MWh, about €806 per tonne of fuel), the central ratio is 1.8, ranging from 1.3 to 4.0.

Costs	Low OPS prices	Central OPS prices	High OPS prices
Electricity costs (€/kWh)	0.11	0.24	0.35
Fuel / OPS ratio for MDO/MGO at €1000 per tonne	4.3	2.0	1.4
Fuel / OPS ratio for FIER's €150 per MWh	4.0	1.8	1.3

As a further sensitivity, we replaced our rural air pollution prices used for the electricity comparison with those of the 2024 Environmental Prices Handbook from CE Delft, for the EU27 and re-stated in 2025 euros. The central ratio then ranges from 1.9 to 3.1.

Air pollution prices	Central ratio
Current 2019 prices	2.0
2024 Handbook, lower	1.9
2024 Handbook, central	2.3
2024 Handbook, upper	3.1

Limitations. We used one year (2024) in place of AFIR's three-year call average. We did not cover ports outside the TEN-T list. We used no dispersion modelling, so emissions costs reflect average exposure by country and area type, not local conditions.

In addition, some costs are not included in the damages, such as noise pollution. Climate prices are also uncertain. Our CO_2e price is the CE Delft (2019) short-to-medium-run value, which is lower than the central prices in CE Delft's 2024 Environmental Prices Handbook (see table below). The 2024 number is our interpolation based on the 2021 and 2030 numbers.

Source	Applies to	Central, per tonne CO_2e (2025 €)
CE Delft (2019), used here	Up to 2030	€133
CE Delft (2024)	2024 (interpolated)	€180

Annex 3. Costs per port

Emission costs in € million per year (2025€), from 2024 at-berth emissions in the 100 ports analysed, central price view, ships above 5000 GT.

- AE regulated: auxiliary-engine (AE) emissions of ship types mandated under AFIR at ports above the call threshold, including the 10% exemption share.
- AE unregulated: AE emissions of non-mandated ship types and of mandated ships at ports below the threshold.
- AB: boiler emissions of all ships, which AFIR does not cover.
- Total costs = AE regulated + AE unregulated + all AB.

Port	Cntr	Cat	Total costs	AE regulated	AE unregulated	Boilers (AB)
Rotterdam	NL	Cargo	338.8	112.9	102.6	123.3
Antwerp	BE	Cargo	216.1	76	74.7	65.4
Marseille	FR	Mixed	123.4	67.4	25	31
Hamburg	DE	Cargo	120.4	81.3	15.8	23.3
Genova	IT	Pax	110.6	77.3	13.1	20.2
Le Havre	FR	Cargo	73.8	40.3	12.4	21.1
Bremerhaven	DE	Cargo	72.5	41.6	19.4	11.5
Livorno	IT	Pax	59.2	36.9	13.1	9.2
Amsterdam	NL	Tanker	56	2.8	30.6	22.6
Zeebrugge	BE	Cargo	52.2	10.7	31.8	9.7
Napoli	IT	Pax	51.3	40.3	3.6	7.4
Civitavecchia	IT	Pax	49.8	43.3	2.1	4.4
Barcelona	ES	Mixed	47.6	28.3	6	13.3
Valencia	ES	Cargo	42.6	28.8	2.6	11.2
Trieste	IT	Mixed	40.4	12.9	12.3	15.2
Algeciras	ES	Cargo	38.9	15.9	7.6	15.5
Dunkerque	FR	Cargo	34.1	15.2	11	7.8
Piraeus	EL	Pax	32.1	22.6	1.6	8

Port	Cntr	Cat	Total costs	AE regulated	AE unregulated	Boilers (AB)
Constanta	RO	Cargo	31.5	4.8	15.7	11.1
Gdansk	PL	Cargo	31.2	9.4	9.8	11.9
Vlissingen	NL	Cargo	25.6	2.1	17.1	6.5
Palermo	IT	Pax	25.2	21.6	1.5	2.1
Las Palmas de Gran Canaria	ES	Mixed	24.9	12.9	4.9	7.1
Venezia	IT	Cargo	23.2	7.7	9.8	5.7
Gioia Tauro	IT	Cargo	23	14.4	3.1	5.5
Rostock	DE	Pax	22.9	8.3	10.2	4.4
Dublin	IE	Pax	21.6	9.7	7.8	4.1
Ravenna	IT	Cargo	21.2	4.4	11.3	5.5
Nantes Saint-Nazaire	FR	Cargo	19.3	1.5	10.2	7.6
Calais	FR	Pax	18.7	9.8	7.1	1.8
Tarragona	ES	Tanker	17.2	0.8	7.8	8.6
Ghent	BE	Cargo	16.7	0	11.3	5.4
Santa Cruz de Tenerife	ES	Pax	16.6	9.4	2.8	4.4
Klaipeda	LT	Cargo	16.6	7	4.7	4.9
Gdynia	PL	Cargo	16.5	6.7	5.3	4.5
Koper	SI	Cargo	16.5	5.8	6.7	4
Olbia	IT	Pax	15.8	13	1.4	1.4
Travemuende	DE	Pax	15.7	10.2	4	1.6
Bilbao	ES	Mixed	15	2.1	5.8	7.1
Cartagena	ES	Tanker	14.5	1.2	5	8.2
Bremen	DE	Cargo	13.7	0	11.1	2.7
Huelva	ES	Tanker	13.7	0.7	5.2	7.8

Port	Cntr	Cat	Total costs	AE regulated	AE unregulated	Boilers (AB)
Goteborg	SE	Mixed	12.7	3.5	3.8	5.4
Palma Mallorca	ES	Pax	12.6	10.5	0.5	1.6
Sines	PT	Cargo	12.4	3.2	1.8	7.4
Milazzo	IT	Tanker	12	1.1	4.6	6.3
Malta Freeport	MT	Cargo	11.7	5.4	1	5.3
Augusta	IT	Tanker	11.6	0	4.7	6.9
Bari	IT	Pax	11.5	8.2	2	1.4
Terneuzen	NL	Tanker	11.5	0	7.2	4.3
Salerno	IT	Cargo	11.5	5.8	3.9	1.8
Tallinn	EE	Pax	10.9	6.8	1.3	2.8
Swinoujscie	PL	Pax	10.9	5.8	2.7	2.3
Emden	DE	Cargo	10.6	0	8.9	1.7
Kiel	DE	Pax	10.3	9.3	0.3	0.8
Ancona	IT	Pax	9.7	7.5	1	1.2
Valletta	MT	Pax	9.4	6.1	1	2.3
Messina	IT	Pax	9.1	8.1	0.2	0.8
Port of Bergen	NO	Pax	8.9	7.4	0.6	0.9
Lisbon	PT	Pax	8.6	4.9	1.1	2.5
Kobenhavn	DK	Pax	7.7	5.6	0.6	1.6
Agio Theodoroi	EL	Tanker	6.9	0	1.8	5.1
Helsinki	FI	Pax	6.9	4.1	1.4	1.4
Piombino	IT	Pax	6.8	3.3	2	1.6
Mykonos (Mikonos)	EL	Pax	6.7	5.9	<0.1	0.7
Stockholm	SE	Pax	6.5	5.1	0.5	0.9
Trelleborg	SE	Pax	6.3	3.7	1.6	1

Port	Cntr	Cat	Total costs	AE regulated	AE unregulated	Boilers (AB)
Oslo	NO	Pax	6.1	5.5	<0.1	0.5
Thessaloniki	EL	Cargo	6	2.2	1.3	2.6
Ibiza	ES	Pax	5.9	5.1	0.1	0.7
Arhus	DK	Cargo	5.8	2.9	1.6	1.3
Vigo	ES	Cargo	5.8	2.3	2.2	1.3
Riga	LV	Cargo	5.1	1.4	2.1	1.6
Bastia	FR	Pax	4.8	3.4	0.9	0.5
Port of Porto	PT	Cargo	4.4	1.7	1.1	1.6
Szczecin	PL	Cargo	4.1	0.1	2.8	1.2
Stavanger	NO	Pax	4.1	3.6	0.2	0.3
Almeria	ES	Pax	3.8	2.3	0.8	0.8
Rodhos	EL	Pax	3.7	3	0.1	0.6
Ballygerry	IE	Pax	3.5	2	1	0.5
Malmoe	SE	Pax	3.5	2.1	0.7	0.7
Lavrion (Laurium)	EL	Pax	2.6	1	0.7	0.9
Ystad	SE	Pax	2.3	1.7	0.2	0.3
Igoumenitsa	EL	Pax	2.2	1.3	0.5	0.4
Ceuta	ES	Mixed	2	0.3	0.7	0.9
Hirtshals	DK	Pax	1.8	0.8	0.8	0.3
Moerdijk	NL	Cargo	1.7	0.5	0.5	0.6
Trapani	IT	Pax	1.1	0.6	0.2	0.2
Molde	NO	Pax	0.8	0.8	<0.1	0.1
Portoferraio	IT	Pax	0.7	0.5	0.1	0.1
Port of Chios	EL	Mixed	0.3	0	0.2	0.1
Cirkewwa	MT	Tanker	0.2	0	<0.1	0.2
Marina Grande	IT	Pax	0.2	0	0.1	<0.1

Port	Cntr	Cat	Total costs	AE regulated	AE unregulated	Boilers (AB)
Korcula	HR	Pax	0.1	0.1	<0.1	<0.1
Mgarr	MT	Pax	*<0.1*	*0*	*<0.1*	*<0.1*
Porto d'Ischia	IT	Pax	*<0.1*	*0*	*<0.1*	*<0.1*
Tarifa	ES	Tanker	*<0.1*	*0*	*<0.1*	*<0.1*

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Further information

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