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Shore power needs and CO_2 emissions reductions of ships in European Union ports: Meeting the ambitions of the FuelEU Maritime and AFIR

Authors: Liudmila Osipova and Camilla Carraro
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Summary

This study explores the role of shore power in decarbonizing maritime transportation in the European Union (EU) based on two recently adopted regulations: the FuelEU Maritime regulation and the Alternative Fuels Infrastructure Regulation (AFIR). The FuelEU Maritime regulation requires that from January 1, 2030, container and passenger ships (including cruise ships) greater than or equal to 5,000 gross tonnage (GT) must connect to shore power in main EU ports listed in the trans-European transport network (TEN-T). Ships using alternative zero-emission technologies are exempted from this requirement. The AFIR aims to regulate shore power supply and incentivize infrastructure development in TEN-T ports.

To provide insights for policymakers and EU Member States, this study estimates the energy needs of ships that berthed in 489 EU ports in 2019. We consider the installed shore power infrastructure in EU ports and calculate the additional power installations necessary to meet regulatory targets. We explore 16 policy scenarios by considering ship types, sizes, and energy demands, as well as increasing the ambitions of the regulations and including more EU ports. Additionally, we estimate CO_2 emissions from berthing ships in EU ports and assess the effectiveness of the proposed regulations in reducing them.

We estimated that about 15,700 ships spent more than 2 hours at-berth in the 489 major EU ports in 2019, demanding nearly 5.9 terawatt-hours of energy; nearly 70% of this energy demand came from TEN-T network ports. The most energy-consuming ship types were tanker, passenger, and cruise ships (67% of the total at-berth energy demand), which were also key contributors of at-berth CO_2 emissions.

Currently, 51 ports in 15 EU coastal Member States have shore power infrastructure, supplying 309 MW of power, 283 MW of which are intended for container, passenger, and cruise ships. We estimate the EU needs to triple or quadruple its installed shore power by 2030 to meet the current ambitions of the FuelEU Maritime regulation and AFIR, depending on whether Member States supply enough shore power to satisfy the

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION average or maximum demand of container, passenger, and cruise ships. Half the energy consumed at-berth in EU ports is attributed to Italy, Spain, and France, mainly because of cruise shipping traffic.

This analysis demonstrates the current limitations of existing regulations in terms of CO_2 emissions, which can also be used as an indicator for assessing the potential to reduce at-port air pollution. The current level of ambitions of the FuelEU Maritime regulation and AFIR will only lead to a 24% reduction in the EU's estimated annual 4.37 Mt at-berth CO_2 emissions.

This study concludes with four policy recommendations:

1. To achieve a 100% at-berth reduction in CO_2 emissions, the forthcoming revision of both regulations should include a requirement for all ships greater than or equal to 400 GT to connect to shore power in EU ports. We estimate that to eliminate all at-berth CO_2 emissions from ships would require nearly 2,000 MW of additional shore power installation to meet average at-berth annual energy demands, and about 3,300 MW for peak energy demand.
2. Boilers should be also retrofitted, electrified, or connected to shore power facilities, just like auxiliary engines, since they are responsible for 44% of all at-berth CO_2 emissions.
3. Technical and logistical challenges should be addressed in the regulations, such as an unclear delegation of responsibilities between ship operators and port authorities, voltage and frequency incompatibility, berth space availability, charging time spans, and power quality.
4. Clear goals should be established for the share of renewables in the electricity grid used for shore power supply.

Introduction

In July 2023, the Council of the European Union adopted two new regulations within the "Fit for 55" package: the FuelEU Maritime regulation and the Alternative Fuels Infrastructure Regulation (AFIR) (European Parliament and Council, 2023b, 2023a). Shore power is expected to contribute to reducing at-berth greenhouse gas (GHG) emissions and help to curb air pollution in ports. Thus, according to the FuelEU Maritime regulation, Article 6, starting January 1, 2030, container and passenger ships greater than or equal to 5,000 gross tonnage (GT) will connect to shore power and replace their electricity needs in the major EU ports listed in the trans-European transport network (TEN-T).[1]

When a ship is connected to a shore power supply, its life-cycle GHG emissions are counted as zero in the FuelEU Maritime regulation (even though there are emissions associated with electricity production). Vessels that use comparable alternative zero-emission technologies (e.g., batteries and fuel cells) do not have to connect to shore power. The regulation includes other exceptions (see Table 1). The decision to limit the application of the FuelEU Maritime regulation to only passenger and container ships was supported by the 2018 Measurement, Reporting, and Verification report data, showing that these ship categories have the highest emissions per ship while moored at the quayside.

1 The TEN-T network is a Europe-wide network of railway lines and terminals, roads, airports, inland waterways, maritime shipping routes, and ports. The Core TEN-T Network includes the most important nodes and aims to be completed by 2030; the Comprehensive TEN-T Network includes regional nodes and is to be completed by 2050. All ports in the TEN-T network are listed in the Annex II of the 2013 Regulation (European Commission, 2013), and revised in 2021 (European Commission, 2021).

The AFIR, Article 9, regulates shore power supply by incentivizing sufficient infrastructure development with a standardized shore-side electricity supply chain in TEN-T network ports. Even though the AFIR and the FuelEU Maritime regulation were developed simultaneously, they are only partially harmonized. For example, the AFIR generally has more additional requirements and exemptions than the FuelEU Maritime regulation related to the port calls volume in the regulated ports, limiting shore power supply to 90% of the demand, and exempting ports with fewer averaged port calls and ports located on remote islands (see Table 1). More broadly, the differences between the AFIR and the FuelEU Maritime regulation could lead to obstacles in implementation.

Currently, an agreement has been reached for both regulations between the European Commission, the European Parliament, and the Council of Member States. The policies will be revised in a few years. Accordingly, understanding how much shore power is needed in addition to the existing supply and what emissions reductions can be expected under different policy requirements is critical for moving forward. Since port electrification is expected to play a role in EU maritime decarbonization, it is important to understand how current regulations are limited in terms of CO_2 emissions reductions and how they can be improved through revision.

This study estimates the energy needs of the ships berthing in 489 ports in the EU in 2019 and translates their energy demand into the power installation requirement, assuming different levels of CO_2 emissions reduction. We assessed how much shore power was already installed by EU coastal Member States and calculated how much more power installation would be needed to cover the energy demand for each scenario. We explored 16 policy scenarios by increasing the CO_2 emission reduction benefits of the regulations and including more EU ports, ship types, sizes, and energy needs. Additionally, we estimated CO_2 emissions in ports from berthing ships and used these numbers as a proxy to assess the effectiveness of the regulations for reducing GHG emissions. We considered which improvements would lead to the highest CO_2 emissions reductions and how much more power installations would be required to strengthen reduction targets.

This study shows what in-port CO_2 abatement can be achieved by 2030 with the current requirements for port electrification, and what improvements can be made in the next revision of FuelEU Maritime and AFIR to accelerate decarbonization. Additionally, it clarifies what energy and power needs individual Member States might have in the coming years and how much additional shore power would need to be installed to meet and exceed “Fit for 55” shore power targets.

Table 1. Important elements of the EU shore power requirements in the FuelEU Maritime regulation and AFIR.

	FuelEU Maritime (Article 6)	AFIR (Article 9)
Electricity/ Power supply	Ships should connect and use shore power supply for all their electrical demand while at-berth.	Ports shall be equipped to provide a minimum of 90% of the demand for shore-side electricity supply (sufficient shore-side power output), depending on the volume of port calls (see Main Exemptions below).
Ship type, size, mode	Container and passenger ships (including cruise ships) greater than or equal to 5,000 GT while moored at the quayside.	Seagoing container and passenger ships (including cruise ships), other than ro-ro and high-speed passenger craft, greater than or equal to 5,000 GT while moored at the quayside.
Ports included	Port of call[2] as covered by AFIR Article 9. After 2035, extension to other EU ports with installed shore power, and extension to any ports by a unilateral decision of a Member State after consulting relevant stakeholders.	TEN-T core and comprehensive network ports, excluding remote islands not connected directly to the electricity grid.
Implementation Timeline	January 1, 2030. Some changes in policy exemptions starting in 2035 (see below).	January 1, 2030
Main exemptions	• Port calls for ships moored at the quayside for less than 2 hours. Unscheduled, non-systematic, and temporal port calls; emergency port calls. • Port calls for ships using zero-emission technologies such as on-board fuel cells, on-board electrical energy storage, and on-board power generation from wind and solar energy listed in Annex III of the regulation, including future updates. • Port calls for ships that are unable to connect to shore power due to unavailable connection, incompatible points, or insufficient or unstable shore power availability. After 2035 this exemption can be applied only to a maximum 10% of the ship's total number of port calls, or to a maximum 10 port calls during relevant reporting period.	• Port calls exempt from the FuelEU Article 6. • Ports with average number of annual port calls over the last 3 years below 100 for seagoing containerships, or below 40 for seagoing ro-ro passenger ships and high speed passenger craft; below 25 for seagoing passenger ships other than ro-ro passenger and craft. • Ports on islands in outermost regions, Ceuta, and Melilla not connected to the electricity grid. In-force until the connection has been completed or there is sufficient locally generated electricity capacity from non-fossil energy sources.

Methodology

Allocating berthing ships in EU ports

We estimated the number of ships at-berth at EU ports, their characteristics, and corresponding energy demand using the International Council on Clean Transportation's (ICCT) Systematic Assessment Vessels Emissions (SAVE) model. SAVE combines Automatic Identification System (AIS) and IHS Markit data and estimates hourly energy use, fuel consumption, and emissions from the global fleet (Olmer et al., 2017). We updated the SAVE model's assumptions to harmonize it with the International Maritime Organization's (IMO) 4th GHG Study (Faber et al., 2020). The analytical steps we used in this study are provided below.

First, we identified all ports in 22 EU coastal states reported in the World Port Index (WPI) dataset, the most up-to-date publicly available dataset containing geolocation points of major ports and terminals worldwide (National Geospatial-Intelligence Agency, 2019). After identifying ports, we marked those listed in the TEN-T core and comprehensive ports list in the European Commission guidelines for the development of the TEN-T (European Commission, 2021).

2 Port of call is defined as an event when a ship stops in a port to load or unload cargo or to embark or disembark passengers. Stops for the sole purposes of refuelling, obtaining supplies, relieving the crew, going into dry-dock, or making repairs to the ship and/or its equipment; stops in port because the ship is in need of assistance or in distress, ship-to-ship transfers carried out outside ports; and stops for the sole purpose of taking shelter from adverse weather or rendered necessary by search and rescue activities are excluded (Article 3 of the EU Monitoring, Reporting, and Verification; EU MRV).

After earmarking the EU-only ports, we applied a one nautical mile (1 nm) buffer to each port's geolocation.[3] We selected all ships' locations (data points) using the SAVE model applied to 2019 global shipping traffic. Each SAVE data point reports a ship type, size, engine type, energy demand, and operational phase (cruising, maneuvering, berthing, and anchoring) for every shipping hour. When shipping points are located within a 1 nm radius of a port and have a speed over ground of less than 1 knot, the operational phase is assigned as berthing, in accordance with the IMO 4th GHG Study (Faber et al., 2020). Main engines typically turn off at-berth and anchor, while auxiliary engines and boilers still work at-berth for electricity and heat generation. The auxiliary engine and boiler energy use depend on the ship type, size, and engine specifications. We estimated energy demand for each ship berthing within 1 nm of the EU ports, using energy demand assumptions consistent with the IMO 4th GHG study (see Faber et al. (2020) for further details). We filtered all ships greater than or equal to 400 GT berthing in EU ports for at least 2 consecutive hours.

Estimating ships' power demand in ports

To estimate how much power is needed to be installed at EU ports to provide enough energy for the EU fleet, we assumed that each port would have to install enough power to satisfy an average energy demand of simultaneously berthing ships. For that, we calculated how much energy concurrently berthing ships need for every hour and estimated an average energy consumption per ship type. We also estimated and reported the maximum energy demand reflecting the short-term peak consumption and the average time ships to spend in ports.

To account for typical power loss due to inductive loads by pumps and compressors on board ships, we applied a power factor (PF = 0.9) following the guidelines of the European Maritime Safety Agency (2022):

$$P_{av} = \frac{E_{av}}{PF};\ P_{peak} = \frac{E_{max}}{PF}$$

Where:

P_{av}, P_{peak} (MW)	power required to cover per hour mean (peak) energy demand for ships at-berth in a port.
E_{av}, E_{max} (MWh)	averaged (maximum) energy consumption per hour for ships at-berth in a port.
PF	power factor equal to 0.9.

We estimated the power demand for each EU Member State by calculating energy and power demand for each port and then aggregating the results for each country. Because some Member States already have shore power installations, we retrieved data on the shore power installed in ports from the European Alternative Fuels Observatory (2022) and the Alternative Fuels Insight platform (DNV, 2022). Data included the number of connectors per shore power installation, types of vessels that can be connected, voltage (low/high, from 0.4–11 kV), and maximum available power supply (from 0.055–10 MW). See Table A1 in the appendix for more information.

Policy scenarios and CO_2 emissions

We evaluated 16 policy scenarios that could be considered when policymakers revise the FuelEU Maritime regulation and AFIR. We modeled combinations of ship sizes, ship types, and ports as shown in Table 2. For each scenario, we calculated at-berth CO_2 emissions using the SAVE model based on fuel carbon intensity, vessel speed, and time

3 Since 1 nautical mile does not represent actual port boundaries and because the center point of the buffer is based on the location of the port listed in the WPI, the method might underestimate actual in-port energy demand. While the results may underestimate emissions at the individual port level, when considering countries overall, the scale of the data is appropriate for analysis.

at-berth. We estimated how much additional shore power would need to be installed for each scenario, considering that some ports already have shore power in place.

Since both regulations have exemptions that are technically difficult to evaluate due to data limitations, we disregarded the exemptions in Table 1, except for the ships staying at-berth for less than 2 hours (we only considered ships staying longer than 2 hours). We assumed all at-berth electricity demands should be met in agreement with the FuelEU Maritime regulation, as opposed to the AFIR's requirement to satisfy 90% of the electricity demand (see Table 1).

Keeping these limitations in mind, we first estimated how much CO_2 could be avoided if only TEN-T ports were equipped with shore power for container and passenger ships greater than or equal to 5,000 GT, as implied by the AFIR. We then estimated CO_2 emissions for auxiliary engines and boilers independently since the regulations refer only to ships' electricity demand, meaning that boiler power demand is most likely excluded, given that boilers produce steam and heat but not electricity. However, as described later, boilers can be connected to shore power and could be electrified on board of a ship.

Table 2. Policy scenarios analyzed. Scenario 7 (baseline) is covered by the FuelEU Maritime regulation and AFIR. Scenario 10 (best case) shows the most progressive coverage of ports and ship types.

Scenario	Ports	Ships	GT	Engines
Scenario 1	EU ports	Container + passenger + cruise	≥400	auxiliary
Scenario 2	EU ports	Container + passenger + cruise	≥400	auxiliary + boiler
Scenario 3	EU ports	Container + passenger + cruise	≥5,000	auxiliary
Scenario 4	EU ports	Container + passenger + cruise	≥5,000	auxiliary + boiler
Scenario 5	TEN-T ports only	Container + passenger + cruise	≥400	auxiliary
Scenario 6	TEN-T ports only	Container + passenger + cruise	≥400	auxiliary + boiler
Scenario 7[a]	**TEN-T ports only**	**Container + passenger + cruise**	**≥5,000**	**auxiliary**
Scenario 8	TEN-T ports only	Container + passenger + cruise	≥5,000	auxiliary + boiler
Scenario 9	EU ports	All types	≥400	auxiliary
Scenario 10[b]	**EU ports**	**All types**	**≥400**	**auxiliary + boiler**
Scenario 11	EU ports	All types	≥5,000	auxiliary
Scenario 12	EU ports	All types	≥5,000	auxiliary + boiler
Scenario 13	TEN-T ports only	All types	≥400	auxiliary
Scenario 14	TEN-T ports only	All types	≥400	auxiliary + boiler
Scenario 15	TEN-T ports only	All types	≥5,000	auxiliary
Scenario 16	TEN-T ports only	All types	≥5,000	auxiliary + boiler

[a] Baseline scenario covered by the FuelEU Maritime regulation and AFIR

[b] Best case scenario; most progressive coverage of ports and ship types

Results

At-berth energy demand by ship type and Member State

We identified 489 ports in 22 EU coastal Member States in the WPI dataset where ships greater than or equal to 400 GT were at-berth for at least 2 hours. Of those, 189 belong to the TEN-T network (73 core and 116 comprehensive ports). The actual number of ports in the EU could be higher since the WPI database includes only major international ports with considerable shipping traffic.

Table 3 and Table 4 show the number of ships, mean berthing hours, and affiliated energy demand for auxiliary engines and boilers in EU ports. We recorded 15,722 unique ships greater than or equal to 400 GT berthing in 489 EU ports for at least 2 hours in 2019. Of these, 9,388 ships (60%) were greater than or equal to 5,000 GT. In total, the fleet required 5,886 GWh of energy at-berth in 2019, 72% of which was consumed by ships greater than or equal to 5,000 GT.

Within this sample, we identified 13,314 unique ships greater than or equal to 400 GT for 189 TEN-T ports, with 7,869 ships (59%) greater than or equal to 5,000 GT. The estimated energy demand for ships berthing in TEN-T ports was 4,093 GWh, 75% of that was from ships greater than or equal to 5,000 GT. This implies that TEN-T ports cover less than 70% of the ships' energy demand at-berth.

Table 3. Number of ships at-berth for 2 hours or longer EU ports in 2019, reported by ship type.[4]

	EU ports (489 ports)		TEN-T ports (189 ports)	
Ship type	**≥400 GT**	**≥5,000 GT**	**≥400 GT**	**≥5,000 GT**
Container	1,428	1,395	1,258	1,228
Passenger	800	359	639	327
Cruise	242	191	237	189
Cargo	6,688	4,337	5,810	3,626
Tanker	3,679	2,734	3,066	2,201
Others	2,885	372	2,304	298
Total	**15,722**	**9,388**	**13,314**	**7,869**

Table 4. Energy demand (GWh) of ships at-berth in EU ports for more than 2 hours in 2019.

	EU ports (489 ports)						Ten-T only (189 ports)					
	≥400 GT			≥5,000 GT			≥400 GT			≥5,000 GT		
Ship type	**aux**	**bo**	**aux+bo**	**aux**	**bo**	**aux+bo**	**aux**	**bo**	**aux+bo**	**aux**	**bo**	**aux+bo**
Container	232	121	353	228	117	345	189	99	288	185	96	281
Passenger	978	335	1,313	853	217	1,070	766	251	1,017	679	173	852
Cruise	1,032	208	1,239	1,006	145	1,150	775	150	926	759	109	868
Cargo	623	211	834	441	169	611	420	148	567	301	118	420
Tanker	419	979	1,398	286	673	959	270	589	859	179	396	575
Others	741	8	749	92	5	97	432	5	436	63	3	65
Total:	4,024	1,863	5,886	2,906	1,326	4,232	2,852	1,241	4,093	2,165	895	3,060

Cargo ships are the most common ship type (43%–46% of the total, depending on which ports and ship sizes were included), with a relatively low energy demand (14% of the total). In contrast, despite their small absolute number in the fleet (242 ships), the energy demand of cruise ships is 21%–28% of the total. Overall, passenger, cruise, tanker, and cargo ships are responsible for 81%–90% of total at-berth energy demand (Table 4). However, energy demand can vary port-by-port for different ship classes, depending on the port terminals available (e.g., cargo or cruise terminals) and typical operation types.

Figure 1 shows the proportion of energy demand for auxiliary engines and boilers for different ship types. In total, we estimated that in all EU ports, auxiliary engines use 68% of the energy at-berth, while boilers use the remaining 32%. However, this

4 Ship types were aggregated from ship classes reported in the IMO 4th GHG Study (Faber et al., 2020), as follows: Container: container ships; Passenger: ferry-pax only and ferry-ropax ships; Cruise: cruise ships; Cargo: bulk carriers, general cargo, refrigerated bulk, ro-ro and vehicles; Tanker: chemical tankers, liquified gas tanker, oil tankers and other liquid tankers; Others: yacht, service-tug and service-other, offshore, and miscellaneous.

distribution differs by ship type. Thus, tankers, the most energy-intensive ship type, use 70% of their energy to run boilers, while the remaining ship types spend 66%–99% of their energy demand to power auxiliary engines.

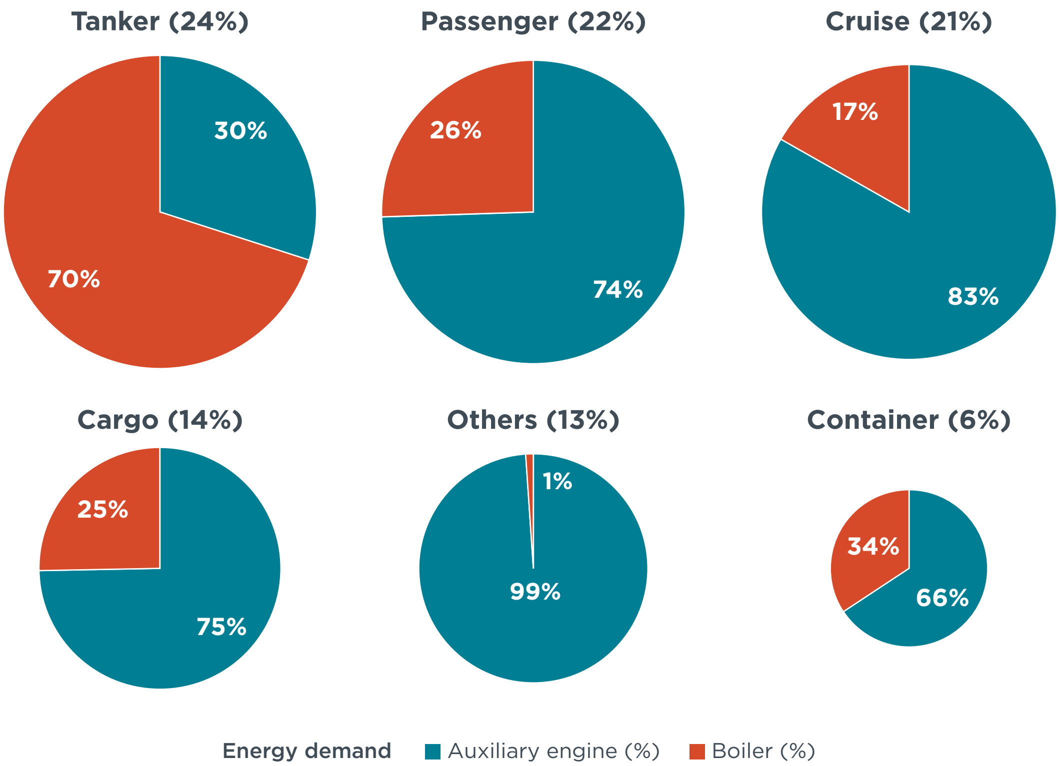

Figure 1. Total energy demand of auxiliary engines and boilers in EU ports (includes all ships ≥400 GT). Size of pie represents relative proportion of total energy demand.

Figure 2 shows the geographical distribution of the at-berth energy demand per EU Member State and shore power installations. Italy has the highest energy requirement for ships greater than or equal to 400 GT (1,316 GWh), followed by Spain (1,152 GWh) and France (536 GWh). Ships berthing in ports in these three countries require roughly 3,000 GWh of energy, which is more than half of the total energy demand in EU ports. Half the combined energy demand in Italy, Spain, and France is from cruise and passenger ships (1,517 GWh).

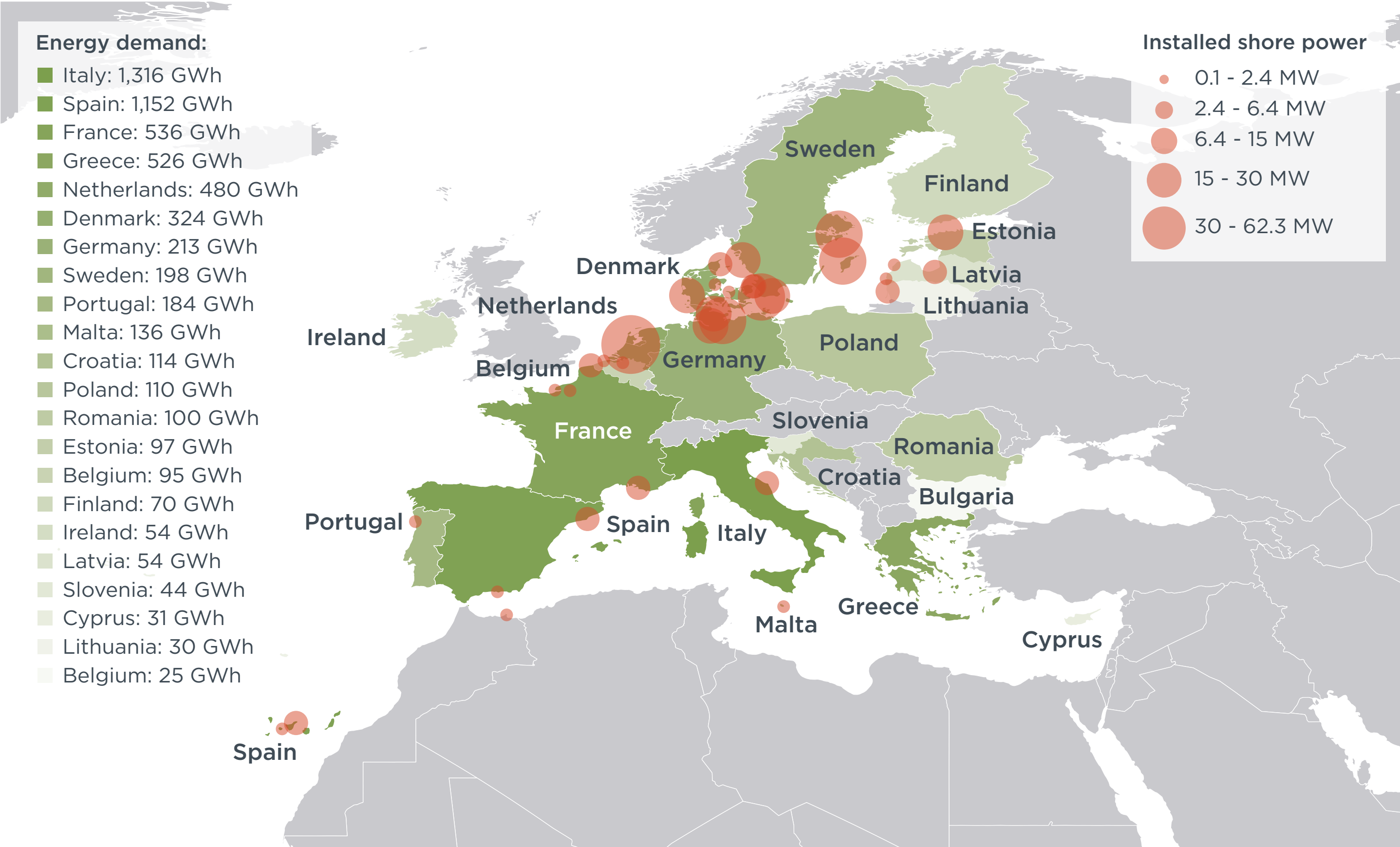

Figure 2. At-berth energy demand of ships ≥400 GT by EU Member State and available existing power installations in EU ports.

Installed shore power in EU ports

We estimated that 51 ports (almost exclusively in the TEN-T network) in 15 EU Member States are equipped with 340 shore power connectors (Table A1). Shore power installations vary by ship type, maximum power supply, and voltage (high/low). The current shore power network supplies around 309 MW, of which 283 MW is provided for container, passenger and cruise ships. The most common low-voltage connectors in the EU have a voltage of 0.4 kV, while the most common high-voltage connectors have a voltage of 6.6 kV. As of 2022, Sweden has the largest power supply in the EU (100 MW); the Netherlands has the second largest (68 MW) with the largest number of connectors mainly designed for container and cruise ships (105 and 38 connectors respectively). Germany has the third largest with 46 MW installed mainly in cruise terminals (Figure 3 and Table A1). Together, these three countries comprise 69% of all shore power available in the EU.

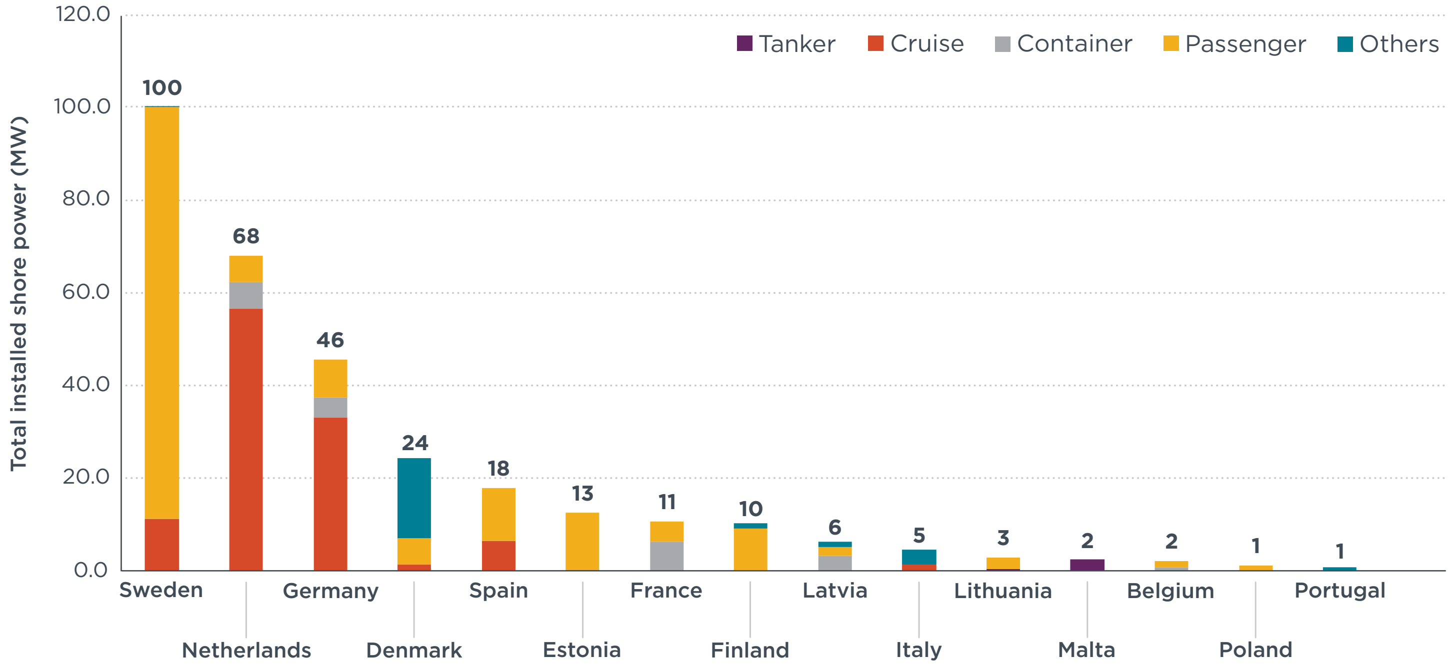

Figure 3. Installed shore power by country by vessel type.

Additional shore power installation requirements in EU ports

Figure 4 and Figure 5 show the power demand requirements in the coastal EU Member States based on the average and maximum energy demand of berthing ships and their distribution per ship type. Generally, we estimated that ports would need to install another 1,929 MW of shore power, in addition to the currently installed 309 MW, to cover the average annual energy demand of ships at-berth in 2019. To cover maximum annual energy demand would require installing an additional 3,342 MW of shore power (Figure 4). When only container, passenger, and cruise ships are considered, the additional power installations requirements are 1,327 and 2,034 for average and maximum demands, on top of the already installed 283 MW.

For TEN-T network ports, the required power installation is 1,000 MW for mean demand and 1,846 MW for the maximum demand, where 73% (mean demand) and 64% (maximum demand) belong to container, passenger, and cruise ships. Furthermore, Figure 4 shows the share of power needs for auxiliary engines and boilers. Boilers will require 36% of all needed power for ships berthing in EU ports; 29% of that power is needed for boilers on container, passenger, and cruise ships.

The largest additional shore power installations will be needed in Italy, Spain, and France, mainly due to high cruise ship traffic (Figure 5). Indeed, cruise ships alone in these three countries would account for 59%–63% of needed power.

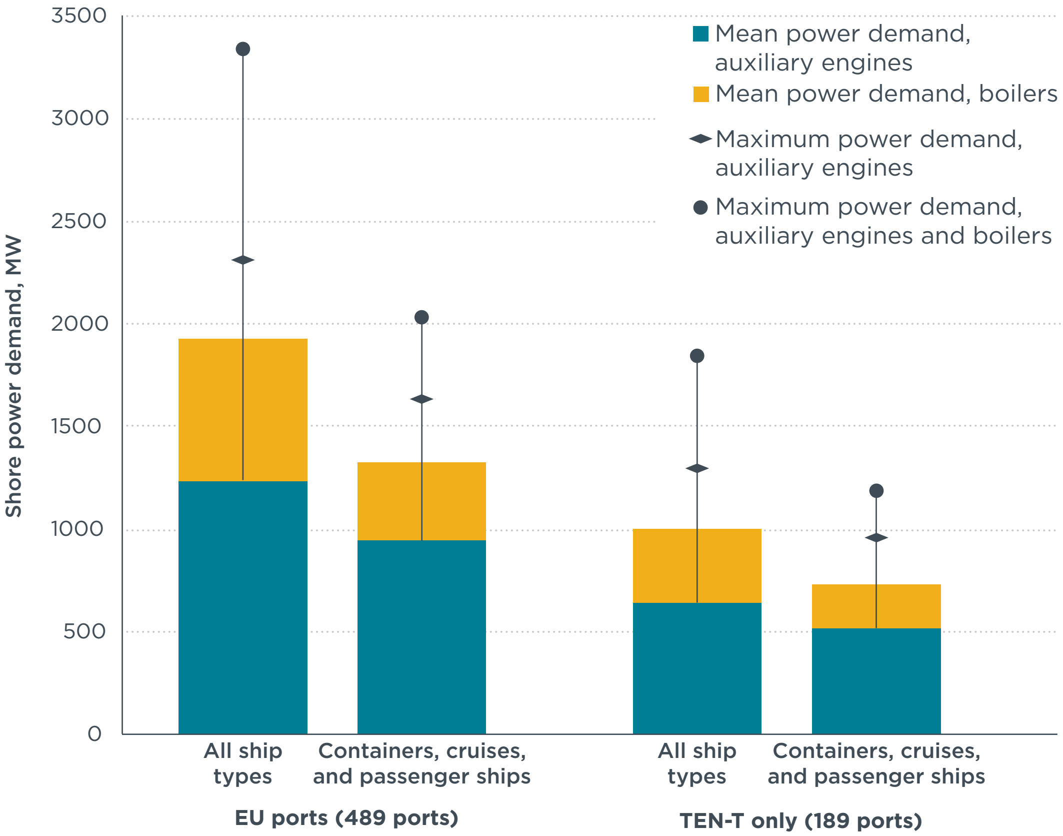

Figure 4. Additional shore power needed to cover ships' energy demand in EU ports in 2019.

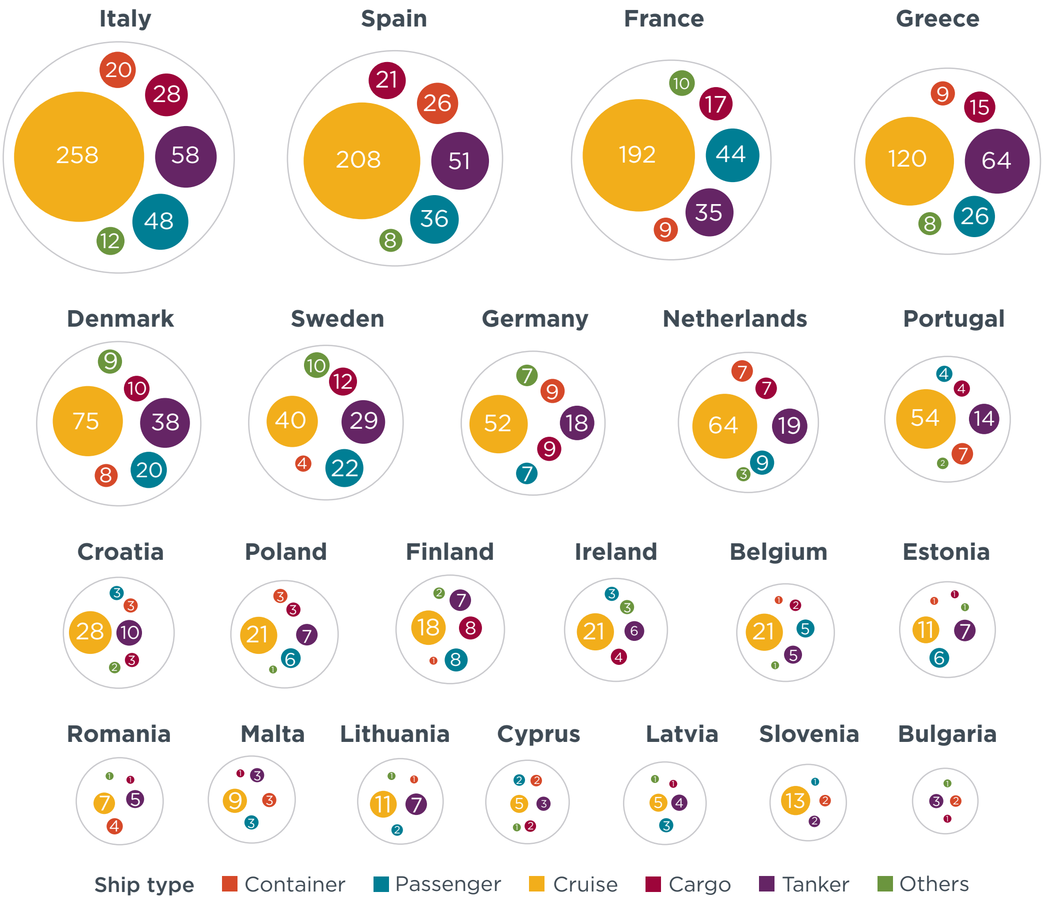

Figure 5. Average power demand for each EU coastal Member State estimated per ship type. The size of the bubbles reflects the relative power demand for each country. The plot does not reflect already-installed power.

At-berth CO_2 emissions reduction and additional shore power demand under different policy scenarios

Figure 6 shows how much CO_2 was emitted in 2019 by ships at-berth within 1 nm of ports, and how much of these emissions could have been avoided if additional conditions were introduced in the FuelEU Maritime regulation and AFIR, including different ship types and sizes, additional ports, and boilers energy demand.

We estimated that all ships greater than or equal to 400 GT and berthing for at least 2 hours in 2019 emitted 4.37 Mt of CO_2. The AFIR covers only the electricity needs (auxiliary engines) of container and passenger ships, including cruise ships, equal to or greater than or equal to 5,000 GT and berthing in TEN-T network. Therefore, out of the total 4.37 Mt of CO_2 emissions, only 1.03 Mt, or 24% of emissions, will be avoided.

If the geographical scope of the regulations remains the same (TEN-T-only ports), but is extended to other ship types and sizes, potential CO_2 emissions reduction could reach 30%–40%, depending on the scenario (Figure 6). Moreover, emissions could be reduced by up to 69% if all power demand (i.e., auxiliary engines and boilers) were included and would need to be covered by shore power. If the geographical scope of the regulations was extended to other EU ports (including those outside of the TEN-T network), emissions reduction could reach 56% when shore power covers only electricity demand and 100% when all power demand is covered.

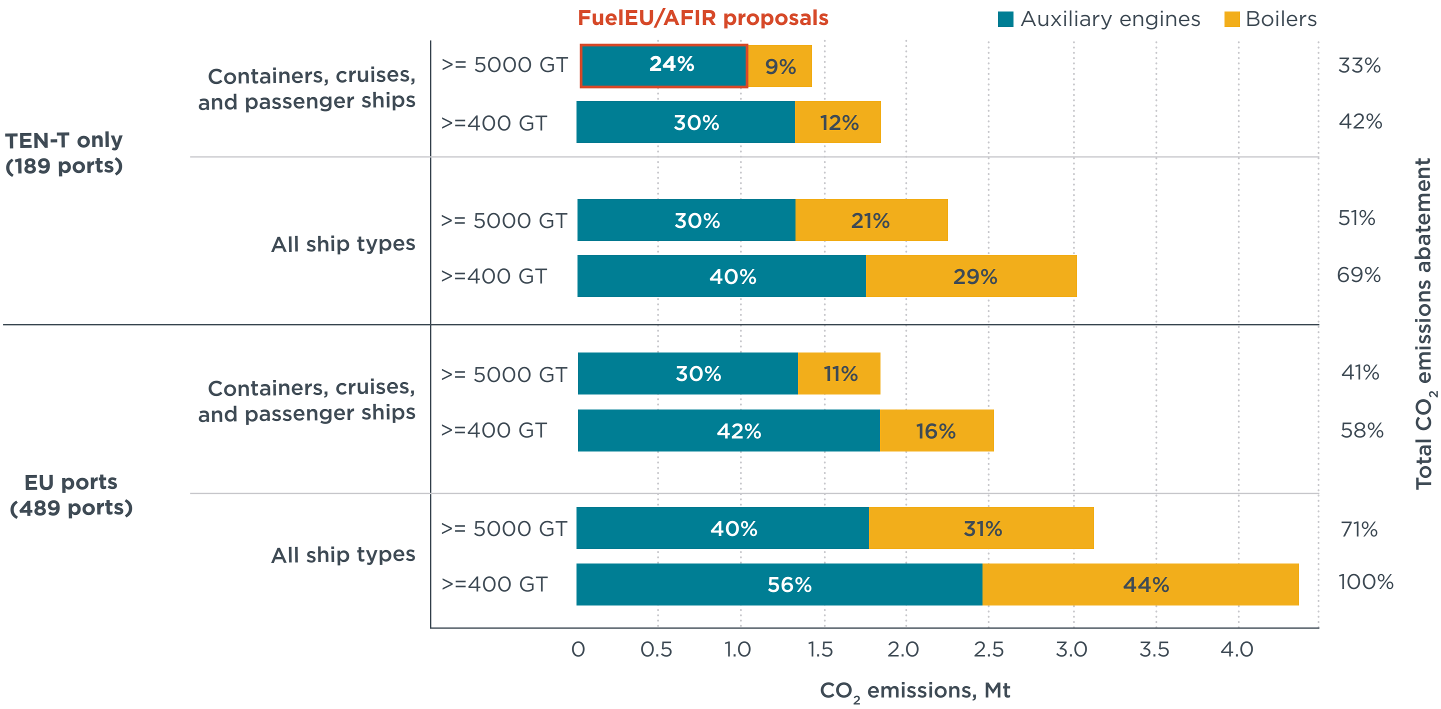

Figure 6. Annual CO_2 emission reduction potental under different policy scenarios.

Discussion

Additional shore power installations requirements

Based on at-berth auxiliary energy consumption in major ports in the TEN-T network, we estimated the EU would need to install an additional 518 MW (average demand) or 959 MW (peak demand) to fulfill the current ambitions of the FuelEU Maritime on top of the already installed 283 MW of shore power for container, passenger, and cruise ships. This implies that to satisfy the FuelEU Maritime ambitions by January 1, 2030, ports would need to install an additional 74 MW (or 137 MW for the peak demand) each year between 2024 and 2030.

Raising the ambitions of the FuelEU Maritime regulation and AFIR to ship types other than container, passenger and cruise ships, including smaller ships and boilers, would require 1,000 MW of installations for average demand or 1,846 MW for peak demand. This is roughly twice as much as in the baseline scenario. This would be expected, since the energy demand of ships not included in the regulation is almost equal to the energy demand of container and cruise ships combined (2,231 GWh for all containers and passenger ships; and 1,863 GWh for cargo ships, tankers, and other ships in TEN-T network). While requiring smaller ships greater than or equal to 400 GT to use shore power will not involve additional power installations in ports because they demand less power than larger vessels, it might considerably increase the need for additional terminal connectors because of the higher number of vessels berthing concurrently. Finally, expanding shore installations to ports outside the TEN-T network would requires four times more power installations when compared to the FuelEU Maritime regulation (1,929 MW for average demand and 3,342 MW for peak demand).

At-berth CO_2 emissions reduction potential

Meeting the AFIR and FuelEU Maritime regulations' current ambitions would reduce the total annual at-berth CO_2 emissions (4.37 Mt of CO_2) by just 24% (1.03 Mt of CO_2). Increasing the level of ambitions by including at-berth electricity demand for all ship types greater than or equal to 400 GT could reduce CO_2 emissions by 42%; adding other than TEN-T ports would help to avoid 58% of the total CO_2 emissions.

However, maximizing CO_2 emission reduction benefits from shore power installations is only possible when shore power replaces the energy demands of both auxiliary engines and boilers. Ships would have to plug into shore power or directly electrify boilers, not just auxiliary engines; CO_2 emissions savings could reach 69% in TEN-T network ports and 100% if all other ports are included. In fact, the original COM Fuel EU proposal included all energy demand of ships while at-berth, but this was scaled back, in part due to the misconception that boilers do not produce high GHG emissions since they demand relatively less energy. On the contrary, we found that boilers are responsible for 44% of at-berth emissions in EU ports, and 29% in TEN-T ports. Furthermore, we found that 34% of the at-berth energy demand of container ships falls on boilers, while for tankers, this share is as high as 70%.

Another common misconception was that existing technologies have considerable limitations, and boilers cannot be connected to the shore power as easily as auxiliary engines. However, there are technological solutions already available on the market. For example, PARAT Halvorsen AS, based in Norway, has sold four models of electrified boilers since 2010, varying in size and voltage. Their electrical circulation steam boilers can reach a capacity of up to 5,000 kW and can be retrofitted on ships; their gas/fuel-fired/electric boiler can connect to onshore power while at-berth with an additional capacity of 600 kW. On the larger side, the PARAT's high-voltage electrode boiler has up to 60 MW of capacity. It can be installed at new vessels or mounted in a port (PARAT Halvorsen AS, 2023c, 2023a, 2023b). These examples demonstrate that boilers need not be powered by fossil fuels; boilers can be retrofitted, connected to shore power facilities, or directly electrified.

Challenges of shore power installation

While not a focus of this study, it is important to note that there are technical and operational challenges to shore power installation. These include voltage and frequency incompatibility, berth space availability, charging time spans, and power quality (Khersonsky et al., 2005; Li & Du, 2020). Ship operators and ports must address each issue to ensure vessels can connect to shore power using converters and transformers to avoid blackouts, system breakdowns, electrical faults, and overvoltage problems (European Maritime Safety Agency, 2022). This requires additional investment and clear delegations of responsibilities between ship operators and port authorities (which could be reflected in regulations).

Another technological obstacle relates to remote islands which may not be directly connected to the main electricity grid. However, some EU islands are already pioneering electricity production from 100% renewable sources while being exempted from shore power installation requirements in the AFIR (Balogh, 2021; European Commission, 2023). For instance, Kotrikla et al. (2017) estimated that all at-berth emissions in the port of Mytilene, Greece, could be eliminated by installing a hybrid energy system including four 1.5 MW wind turbines combined with 5 MW photovoltaics; excess energy could be injected into the island's grid. Thus, the timely expansion of regulations to ports on islands could drive the uptake off-grid renewable energy. Furthermore, the example set by remote islands could incentivize continental ports to consider installing their own in-port renewable energy systems instead of relying solely on grid electricity.

Conclusions and recommendations

This study evaluates the shore power requirements and potential reduction of CO_2 emissions from ships in major EU ports within the existing scope of the "Fit for 55" regulations: the FuelEU Maritime regulation and AFIR. We identified 51 ports across 15 EU coastal Member States equipped with 309 MW of shore power, primarily in passenger and cruise terminals, but the current capacity falls short of energy demand, requiring additional power installations. When the FuelEU Maritime regulation and AFIR take effect, the EU will have to triple or quadruple its installed shore power, depending on if Member States supply enough shore power to satisfy the average or maximum power demand, with Italy, Spain, and France requiring the most investment in shore power.

We estimated that current regulatory ambitions will only achieve 24% of CO_2 emissions reduction of the total at-berth emissions in all EU ports from ships greater than or equal to 400 GT. We explored 16 policy scenarios and estimated how much additional power would be needed to increase emission reduction ambitions. Thus, the analysis emphasized the role of boilers in the energy consumption of different ship types, with boilers accounting for 26%–34% of at-berth energy demand for passenger and container ships and up to 70% for tankers. Incorporating boilers' energy demand and extending requirements to smaller ships (greater than or equal to 400 GT) would require a 15% increase (26% for peak demand) in additional power installation while nearly doubling CO_2 emissions savings (from 24%–42%). Including all other ship types in the regulations would require 1.5–2 times the power but could nearly triple the CO_2 benefits, covering up to 69% of all at-berth CO_2 emissions. For total CO_2 at-berth emissions reductions, the EU would need to install an additional 2,000 MW of shore power to cover average demand and about 3,300 MW for peak demand.

This research provides insights into the shore power needs and CO_2 emission reduction potential from ships in major EU ports. By addressing the identified gaps and enhancing shore power infrastructure, the EU can make greater progress towards a cleaner, more sustainable maritime transportation sector. Besides reducing GHG emissions, the installation of shore power could bring additional benefits, including reducing air pollution at ports and decreasing premature mortality rates caused by shipping emissions. Therefore, this study recommends considering improvements in the regulatory requirements and expanding coverage to include a broader range of ship types, sizes, and ports.

Therefore, policymakers could consider the following recommendations:

1. To achieve a 100% reduction in CO_2 emissions, the forthcoming revision of both the FuelEU Maritime regulation and AFIR should require all ships greater than or equal to 400 GT to connect to shore power in EU ports.
2. Boilers should be also retrofitted, electrified, or connected to shore power facilities, just like auxiliary engines, since they are responsible for 44% of all at-berth CO_2 emissions.
3. Technical and logistical challenges should be addressed in the regulations, such as an unclear delegation of responsibilities between the ship operators and port authorities, voltage and frequency incompatibility, berth space availability, charging time spans, and power quality.
4. Clear goals should be established for the share of renewables in the electricity grid used for shore power supply.

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Appendix

Table A1. Shore power installations in EU countries (European Alternative Fuels Observatory, 2022; DNV, 2022). “Tankers” includes tankers and LNG carriers; “Others” includes OSV, special service, and small ships. “H” refers to high-voltage, and “L” refers to low-voltage. Bulgaria, Cyprus, Greece, Hungary, Ireland, Romania, and Slovenia are excluded from the table due to missing data on shore power installations.

Country	Tankers			Cruises			Containers			Passenger			Others			Total Power, MW
	N connectors	Max Power (MW)	Voltage	N connectors	Max Power (MW)	Voltage	N connectors	Max Power (MW)	Voltage	N connectors	Max Power (MW)	Voltage	N connectors	Max Power (MW)	Voltage	
Belgium	0	0	—	0	0	—	1	0.8	H	1	1.25	H	0	0	—	2.1
Denmark	0	0	—	1	1.3*	n.a.	0	0	—	5	5.7	L/H	44	17.33*	L	24.3
Estonia	1	0.1	L	0	0	—	0	0	—	18	12.4	L	0	0	—	12.5
Finland	0	0	—	0	0	—	0	0	—	7	9.13*	L/H	6	1.05	L	10.2
France	0	0	—	0	0	—	6	6.25*	L/H	3	4.32	H	0	0	—	10.6
Germany	0	0	—	5	33.1	H	2	4.4	H	3	8.17	L/H	0	0	—	45.7
Italy	0	0	—	2*	1.4*	n.a.	0	0	—	0	0	—	2	3.2	L	4.6
Latvia	0	0	—	0	0	—	2	3.2	H	4	2	H	23	1.15	L	6.4
Lithuania	1	0.4	L	0	0	—	0	0	—	6	2.4	L	0	0	—	2.8
Malta	1	2.4	H	0	0	—	0	0	—	0	0	—	0	0	—	2.4
Netherlands	0	0	—	38	56.5	L	105	5.8	L	2	5.62	H	0	0	—	67.9
Poland	0	0	—	0	0	—	0	0	—	1*	1.17*	n.a.	0	0	—	1.2
Portugal	0	0	—	0	0	—	0	0	—	0	0	—	9	0.74	L	0.7
Spain	0	0	—	2	6.4	H	0	0	—	12	11.5*	L/H	0	0	—	17.9
Sweden	0	0	—	2*	11.3*	n.a.	0	0	—	24	88.7	L/H	1*	0.07*	n.a.	100.1
TOTAL	**3**	**2.9**		**50**	**110**		**116**	**20.45**		**86**	**152.36**		**85**	**23.54**		**309.3**

* Missing data were interpolated based on averaged values. When information on the number of connectors was unavailable, we assumed one connector per berth. When the type of vessel was unspecified, we assumed connectors were used for the other ship type. Finally, when the maximum power was not provided, we extrapolated an average value per connector based on data for the same vessel category.