NATURAL RESOURCES DEFENSE COUNCIL

REPORT

SETTING THE COURSE FOR GREEN SHIPPING IN CHINA

— A Review of International Strategies to Further Low/Zero-Emission Shipping

JULY 2020

NATURAL RESOURCES DEFENSE COUNCIL

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For two decades, the Natural Resources Defense Council (NRDC) has been a thought leader and trusted adviser to our partners in China. With a highly effective team of more than 30 people based in our Beijing office, we have worked hard at both the national and local levels to recommend, develop, and help implement innovative laws, policies, technologies, and market tools that conserve natural resources, curb pollution and accelerate China's transition to a clean, low-carbon economy. NRDC's Beijing Representative Office is registered under the Beijing Municipal Public Security Bureau and supervised by the National Forestry and Grassland Administration of China.

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EXECUTIVE SUMMARY

For the past four decades, China's vast network of coastal and inland ports, and extensive inland waterway system, have been integral to the efficient freight network supporting the country's extraordinary economic growth. Now, domestic shipping is receiving a boost from China's new *Three-year Action Plan for Winning the Blue Sky War* ("Blue Sky Defense Plan"), which aims to shift freight from trucks to other modes that produce less pollution, such as shipping and rail. Ships are doubtless a cleaner freight mode than trucks on a per ton-km basis, as one ship can carry much more cargo and travel longer distances than a truck, and diesel marine engines traditionally have a higher thermal efficiency than diesel truck engines.[1] However, ships have also been subject to less stringent emission standards. Over 70 percent of inland waterway vessels currently in operation were launched before any marine air pollution regulations existed in China. In major port cities, such as those in the Yangtze River and Pearl River deltas, shipping has become one of the main sources of local air pollution. As land-based sectors face increasingly tougher standards, shipping's share of pollution will continue to increase if left unchecked.

Since 2016, China has phased in more stringent standards to lower the sulfur content of marine fuel used in China's territorial waters and on inland rivers, which considerably reduced sulfur oxide (SO_x) and particulate emissions from ships. The country has also adopted air emissions standards for domestic ships and introduced additional measures to control nitrogen oxides (NO_x) emissions. However, the NO_x control measures affect only a small fraction of vessels and are likely to have a limited effect on curbing NO_x, which is a precursor of ozone and contributes to ambient particulate levels. Considering the rising level of ozone pollution seen in most Chinese cities and the need to continue curbing particulate pollution that poses severe health risks, stronger measures to reduce NO_x emissions from shipping are critical.

To support China in reaching these goals, this report reviews programs introduced in Europe and the United States to curb air pollution from domestic shipping, with a focus on those that target NO_x emissions. The results of these programs can assist in formulating effective clean air policies for inland and coastal shipping in China.

Air emissions from domestic shipping in Europe and the United States are primarily regulated through clean fuel requirements and emission standards for new marine engines. The latest set of marine engine standards that were adopted in Europe and the United States are designed to drive the development and uptake of advanced NO_x control technologies, including selective catalytic reduction (SCR) systems and liquefied natural gas (LNG) propulsion, which can reduce NO_x emissions by at least 80 percent under ideal operating conditions. Recognizing the lengthy service life of most vessels, some European countries and California have also introduced in-use vessel emission requirements and financial schemes as an incentive to upgrade NO_x control technologies. These approaches have been successful in slashing NO_x emissions from domestic vessels. NO_x emissions from ships in Norway, for instance, decreased by about 40 percent from 2007 to 2016. A shore power mandate, which requires berthing ships to turn off auxiliary engines and use shore-side electricity, has also been imposed in Rotterdam and California to minimize air pollution at ports. In the past few years, Norway, the United Kingdom, and the Netherlands launched comprehensive programs to further the transition to low- and zero-emission shipping, with the goal of reducing both climate and air pollution, while making their shipping industry more competitive in a carbon-constrained world.

RECOMMENDED POLICY STRATEGIES TO REDUCE SHIPPING EMISSIONS

China is now developing its 14th Five-Year Plan (2021-2025), which will effectively open the door to new policies that could steer the shipping sector towards low/zero-emissions and green growth. Drawing from the successes of programs adopted abroad, we recommend these policy strategies for consideration:

- Tighten marine engine emissions standards so they align with the latest United States (U.S.) and European Union (EU) standards, to stimulate the uptake of commercially available NO_x technologies in China's domestic vessel fleet.
- Adopt emission requirements for all inland and coastal vessels currently in use; set those requirements based on the strictest standards in order to accelerate the replacement, repowering, or retrofitting of vessels with high emissions.
- Expand the shore power mandate to include all inland waterway vessels when they are docked in ports or in anchorage areas waiting to pass through dams.
- Establish a zero-emissions goal for ships that operate near densely populated areas and serve fixed routes, consider setting a long-term goal of zero emissions for domestic shipping and devising a long-term strategy for advancing zero-emission shipping.
- Provide grants and offer emissions-based incentives to support the shipping industry in adopting NO_x emissions control and low/zero-emission solutions, and developing landside fuel supply infrastructure.

For shipping to continue its role as the spark plug for China's economic growth and support the nation's fight for cleaner air, China's shipping sector should transition towards low or zero emissions. As the world's biggest shipbuilder, such a transition would also help China maintain its leading role in the shipbuilding industry and contribute to global efforts to achieve decarbonized shipping for the future.

* Unless otherwise stated, "domestic shipping in China" in this report refers to coastal and inland shipping in mainland China.

1

INTRODUCTION

China has the world's most extensive navigable inland waterway system, and a long coastline with more than 50 coastal ports.[2] The country's inland and coastal shipping and port network plays a critical role in supporting the country's burgeoning trade and facilitating the ongoing economic growth of inland and coastal cities. Since the early 2000s, shipping activities in China have grown substantially, keeping pace with the country's rapid economic growth. The volume[i] of freight turnover handled by China's inland ports increased tenfold from 2002 to 2018, while coastal ports saw a sevenfold (coastal ports) increase. The volume of freight passing through sea ports has more than quintupled.[3]

TABLE 1. SHIPPING INDUSTRY CONTRIBUTION TO LOCAL AIR POLLUTION IN KEY PORT CITIES AND REGIONS, BASED ON VESSEL EMISSION INVENTORY [11]

PORT CITY/REGION	NO_x	SO_2	$PM_{2.5}$	YEAR OF STUDY
Hong Kong	37%	52%	41%	2017
Shanghai	25%	17%	5%	2015
Shenzhen	16%	59%	5%	2013
Tianjin	9%	10%	3%	2013
Pearl River Delta	12%	14%	4%	2015
Yangtze River Delta	12%	7%	1.3%	2015
China coastal provinces	9%	10%	NA	2013

Includes air emissions from oceangoing, coastal, and river vessels. Covers only primary $PM_{2.5}$. NA stands for not available.

Shipping is expected to take on an even more prominent role, after the State Council announced a plan in 2018 to adjust the country's transportation structure to combat air pollution.[4] The plan aims to foster a shift of freight cargo from road to ship and rail. Ships and trains are considered the more environmentally friendly method to move freight, in terms of energy use per unit of cargo-distance (ton-km).

However, like trucks and other equipment powered by diesel fuel, ships emit toxic air pollutants. Shipping accounts for a significant share of local air emissions, particularly SO_x and NO_x, in large Chinese port cities and regions (Table 1). In the Yangtze River Delta and the Pearl River Delta, shipping increased fine particle ($PM_{2.5}$) concentration in the summer by over six micrograms per cubic meter in Hong Kong, four micrograms per cubic meter in Shenzhen, and over two micrograms per cubic meter in Shanghai, Guangzhou and Jiaxing in 2015.[5] Emissions from ships impact not only coastal regions, but also inland regions hundreds of kilometers away from the sea.[6] Studies have shown that shipping activities pose obvious health risks. $PM_{2.5}$ and ozone pollution from oceangoing vessels caused about 18,000 premature deaths in China in 2013.[7] Domestic and seagoing shipping caused 2,500 particulate matter (PM)-related and 1,200 ozone-related premature deaths in the Pearl River Delta region, and about 3,600 PM-related premature deaths in the Yangtze River Delta region in 2015.[8]

Of the 124,000 inland waterway vessels now in operation in China, over 70 percent launched before any marine air pollution regulations were enacted in China.[9] Data from real-world emissions tests of these vessels is limited, but findings indicate some inland waterway vessels create more emissions per unit of fuel burned[10] than the most outdated trucks allowed to legally operate in China (China III trucks).[ii] These trucks are banned from operating in the center of a growing number of large Chinese cities because of their high emissions,[iii] while high-emitting legacy vessels still navigate freely along inland waterways.

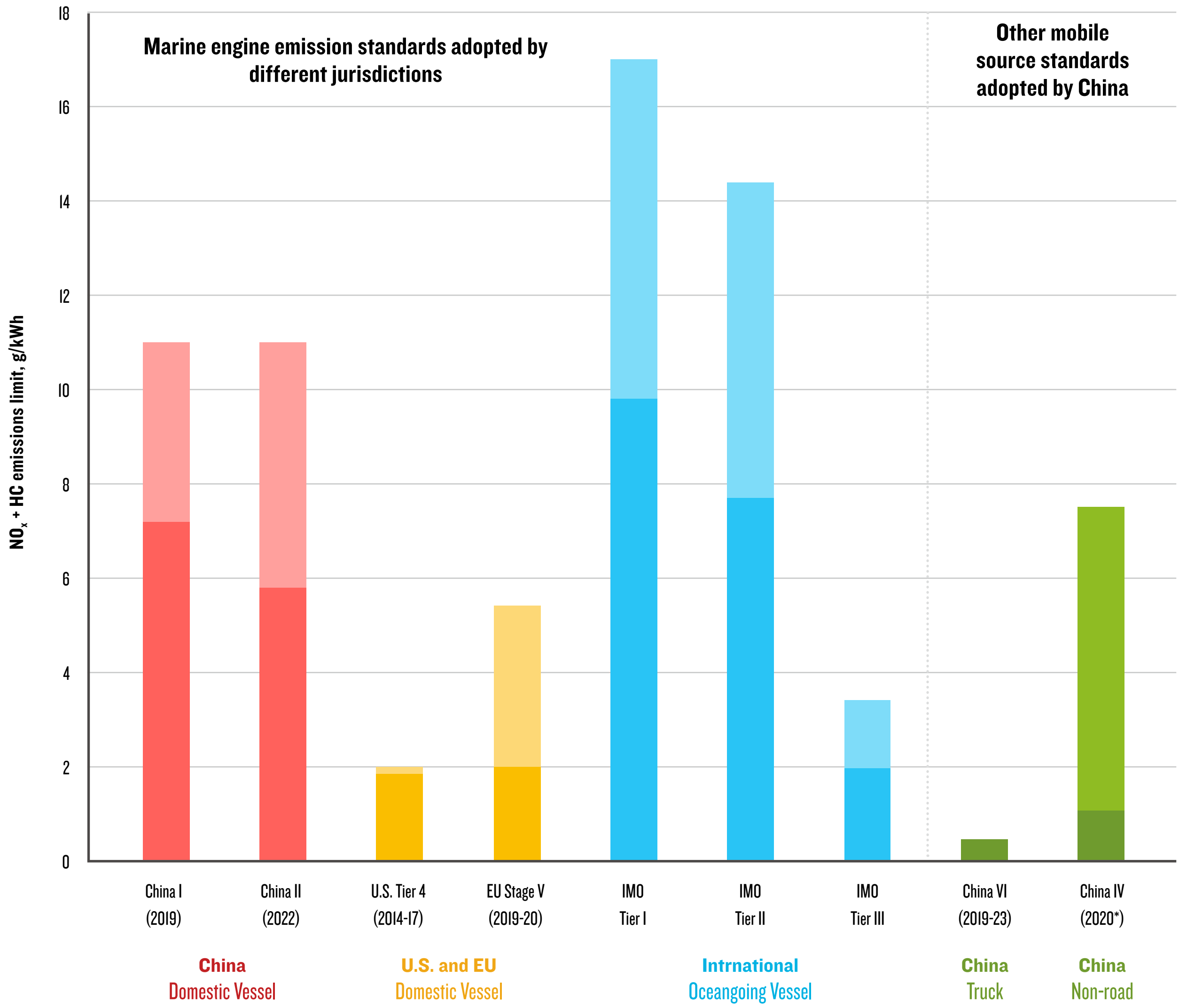
Even though the first set of Chinese emission standards for marine engines (China I and II standards, the red bars in

[i] Equals quantity of cargo (in tonnes) multiplied by the transport distance (in kilometers).

[ii] Vehicle air emissions standards were first introduced in China in the 1980s, but those standards were very weak. The "China" emissions standards for vehicles, were developed based on European regulations and introduced in 2000. The vehicle emission standards were tightened progressively over the past two decades, from China I to the latest China VI standards. To accelerate the retirement of high-emitting vehicles, the Air Pollution Prevention and Control Action Plan released by the State Council in 2013 mandates that yellow-label vehicles, including all trucks that comply with China II or older standards, shall be scrapped by 2017. Since 2018, China III trucks are the most outdated trucks that can lawfully operate in China.

[iii] Beijing, Shanghai, Nanjing, Dalian, Ningbo, Suzhou and other cities have prohibited China III or older diesel trucks from operating in their city centers. Cities or provinces that have imposed traffic restrictions on diesel trucks can be found at http://www.360che.com/law/191021/119279_all.html.

FIGURE 1. NO_x EMISSIONS STANDARDS FOR MARINE ENGINES, TRUCKS, AND NON-ROAD EQUIPMENT ADOPTED BY DIFFERENT JURISDICTIONS



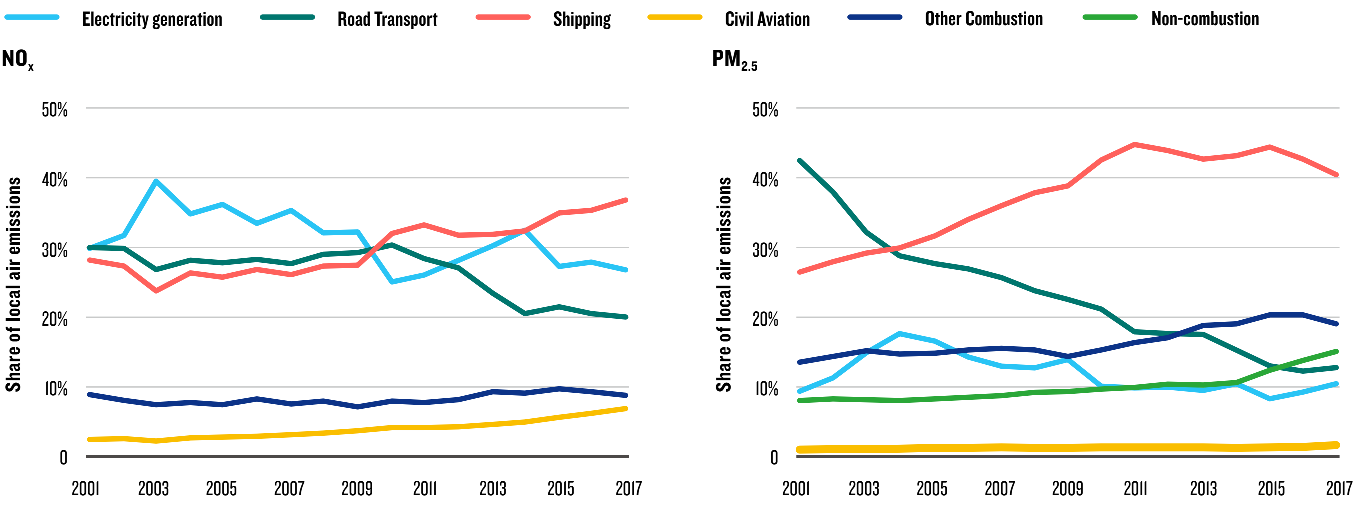
Light-colored portion of the bars indicate the range of NOx standards that vary by engine power, displacement, or speed.

The NO_x standards for China's domestic vessels vary by engine displacement and power, and the NO_x standards for China's non-road engines. EU's inland waterway vessels and U.S. domestic vessels are on the basis of engine power, and the International Maritime Organization (IMO) standards for oceangoing vessels vary by engine maximum operating speed. IMO standards for oceangoing vessels regulate NO_x emissions only. Implementation dates are listed in parentheses.

* The implementation date for the China IV non-road emissions standards is December 2020 in the amendment of the proposed China IV non-road engine emission standards, which was released in February 2019. However, by the time of writing the amendment had not been adopted, so the implementation date is not fixed, and could change.

Figure 1) were adopted in 2016, these standards are far less stringent than the latest standards imposed on trucks and non-road equipment (the green bars in Figure 1). If emissions requirements for new and in-use ships are not tightened further, shipping's share of air pollution will grow as land-based sources face increasingly stricter regulations. Hong Kong is a notable example—ships have become the city's largest source of sulfur dioxide (SO_2), NO_x, and PM, as tougher regulations have been imposed on other pollution sources (Figure 2), while shipping was left unregulated until 2014.

FIGURE 2. SHARE OF NITROGEN OXIDE (NO_x) AND FINE PARTICLE ($PM_{2.5}$) POLLUTION IN HONG KONG BY LOCAL EMISSION SOURCE (PERCENT), 2001 TO 2017 [12]



In order to control air pollution from ships, in 2016 China gradually implemented the groundbreaking Domestic Emission Control Area (DECA) regulations.[13] The regulations initially required the use of 0.5 percent sulfur fuel while ships were at berth at China's main ports. The regulations were later expanded to cover all ships operating inside the three DECA regions. In 2019, the 0.5 percent sulfur fuel requirement was extended to any vessel plying China's territorial waters. In addition, oceangoing vessels operating in parts of the Yangtze and Xijiang (a tributary of the Pearl River) rivers that are designated as inland river DECAs have been required to use 0.1 percent sulfur fuel since January 1, 2020. Oceangoing vessels plying Hainan waters will also have to meet this requirement, starting in 2022 .

Additional requirements were also added in the DECA regulations to combat NO_x emissions. Cruise ships, as well as shore power-capable oceangoing vessels and some of the China-flagged ships (including inland waterway vessels), are required to use shore power whenever they dock at berths with shore power connections. Also, marine engines installed on China-flagged vessels constructed on or after January 1, 2022 will need to meet IMO Tier III NOx standards when operating in Hainan waters or inland river DECAs.

After the regulations took effect, air quality monitoring data showed a noticeable reduction in SO_2 levels, ranging from 26 to 52 percent at China's largest port cities.[14] However, even after 2022, the Tier III NO_x requirements will only affect a small fraction of vessels visiting China.[15] In addition, the shore power requirements can only reduce at-berth emissions, which account for less than 20 percent of the total NO_x emissions from shipping in China.[16] Hence the effect of the DECA regulations on reducing NO_x emissions is expected to be limited.

As China continues its fight to combat $PM_{2.5}$ pollution, it is confronted with increasingly severe ozone pollution.[17] For shipping to continue its role as a spark plug of trade and development while also supporting China's pursuit of cleaner air, stricter control on shipping emissions is needed, particularly NO_x emissions, which are a precursor of ozone and contribute to $PM_{2.5}$ pollution. This report reviews the programs adopted abroad that target inland and domestic coastal ships, the two vessel types that countries have the national jurisdiction to regulate. Considering the success of China's DECA regulations in tackling sulfur and particulate pollution from ships, this report focuses mostly on policies for regulating NO_x pollution, although some policies discussed can tackle multiple air pollutants and climate impacts.

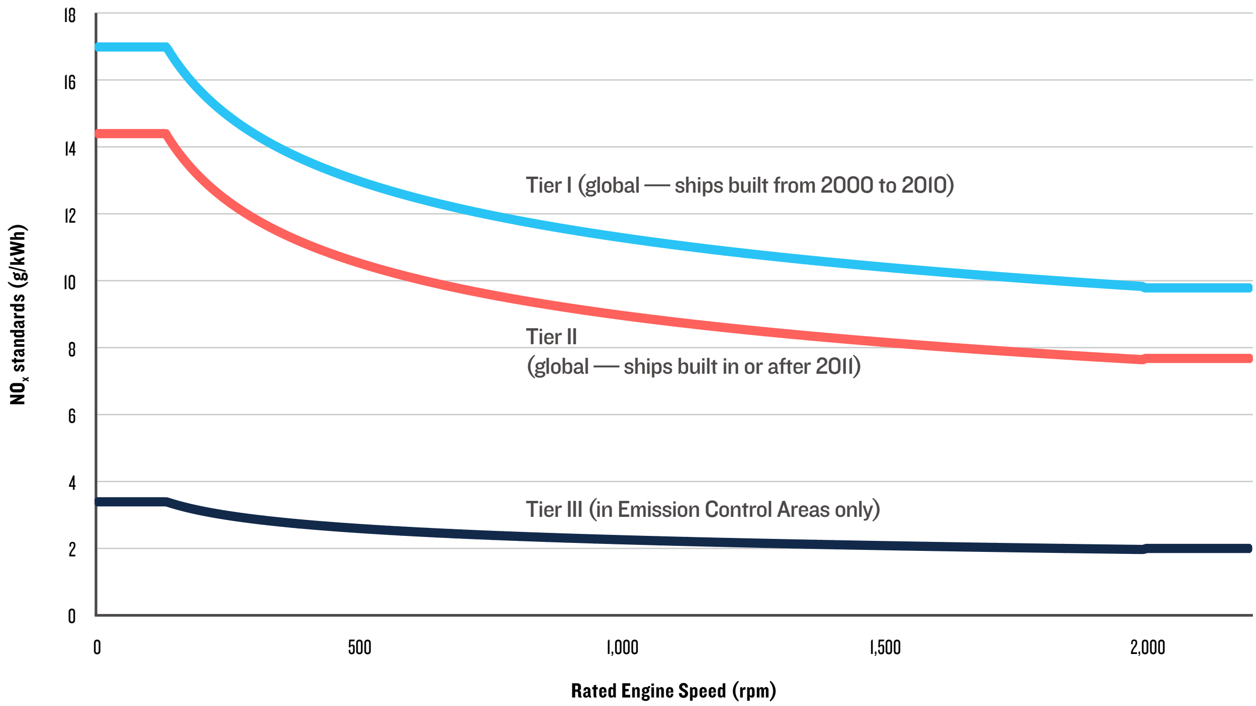
[iv] China-flagged vessels that are subject to the shore power requirement (named OPS-regulated fleet) include: public service vessels, inland waterway vessels (except for tankers), vessels engaged in direct voyages between the sea and the river (called river-sea vessels), container vessels, cruise ships, ro-ro passenger ships, passenger ships at 3,000 gross tonnage or above, as well as dry bulk ships at 50,000 gross tonnage or above that are engaged in domestic coastal voyages. New public service vessels, inland waterway vessels and river-sea vessels in the OPS-regulated fleet that are constructed on and after January 1, 2019 were required to use shore power at ports in the DECAs as of July 1, 2019. New coastal container vessels, cruise ships, ro-ro passenger ships, passenger ships and dry bulk ships in the OPS-regulated fleet that are built on or after January 1, 2020 were required to have ship side shore power systems installed . All the vessels in operation in the OPS-regulated fleet need to be retrofitted and start using shore power whenever possible from January 1, 2022 onward.

2

TECHNOLOGIES AND FUELS FOR CONTROLLING NO_x EMISSIONS FROM SHIPPING

NO_x emissions form when fuels are burned at a high temperature. Lowering the engine's combustion temperature reduces NO_x emissions, but causes incomplete combustion and increased particulate emissions. National, regional and international authorities have therefore implemented emissions standards for marine engines to drive improvements in engine design and the adoption of advanced technologies for controlling emissions of NO_x and PM, as well as other air pollutants.

FIGURE 3. NO_x EMISSION STANDARDS STIPULATED BY THE INTERNATIONAL MARITIME ORGANIZATION



For oceangoing vessels, the International Maritime Organization (IMO) established a set of three-tier standards for NO_x emissions from marine engines (see Figure 3). The IMO Tier I and II are global standards that apply to new oceangoing ships built in or after 2000 and 2011 respectively. The IMO Tier III standards apply within four Emission Control Areas (ECAs) designated by the IMO, to ships built after the ECA standards were implemented. In the North America ECA and the U.S. Caribbean Sea ECA, ships constructed from 2016 and onwards are subject to the IMO Tier III standards. In the North Sea and Baltic Sea ECAs, the affected ships are those built in or after 2021. The Tier III standards are 80 percent lower than the Tier I standards. See Appendix I for the locations of the four IMO ECAs.

European countries, the U.S., and China have also set their own emission standards for vessels that operate in their territorial waters and inland waterways. Standards currently in effect in Europe, the U.S. and China are the EU Stage V, U.S. Tier 4 and China I standards (see Figure 1 for their respective NO_x + HC requirements). Section 3.2 provides further discussions of the various marine engine emissions standards.

To meet increasingly stringent emissions requirements, engine manufacturers have improved engine design and applied the following measures to tackle NO_x emissions:

- **Selective Catalytic Reduction (SCR)**

  SCR is an engine aftertreatment technology that uses ammonia (carried on board in the form of urea) to reduce NO_x to nitrogen and oxygen with the use of a catalyst. It is the dominant NO_x control technology for mobile and non-road pollution sources and has the longest history of marine applications. SCR systems have been installed on over 1,000 vessels worldwide, of which more than 250 are retrofitted vessels.[18] It can achieve the IMO Tier III, U.S. Tier 4, and EU Stage V standards (see Table 2).[19]

- **Exhaust Gas Recirculation (EGR)**

  EGR is an in-cylinder air handling technology that mixes a portion of exhaust gas with intake air to reduce peak combustion temperatures. It has been used on land applications for years but is relatively new for marine uses.

EGR technology has been demonstrated on slow speed, two-stroke engines as the sole NO_x control technology to meet the IMO Tier III NO_x requirement.[20]

- **Alternative fuels**

Among all the available alternative fuels, liquefied natural gas (LNG) is the most commonly used fuel in the marine sector, with 177 vessels[v] currently in operation.[21] The level of NO_x emissions reduction depends not on the type of fuel, but on the combustion principle on which an engine operates, i.e., Otto cycle versus Diesel cycle.[vi] LNG-powered vessels with Otto-cycle marine engines can meet the Tier III requirement without exhaust aftertreatment. Otto-cycle engines can be run on gas alone, or as dual-fuel engines on both diesel and natural gas. LNG engines that operate on the diesel cycle, on the other hand, emit 40 to 50 percent less NO_x emissions than the Tier I level, so need to be operated with another NO_x control system, such as SCR or EGR, to achieve the Tier III NO_x requirement.[23]

Other types of alternative fuel, such as electricity, methanol and liquid petroleum gas, have been adopted in the maritime sector. Over 70 fully electric vessels and about 300 hybrid electric vessels are in service or on order worldwide, mostly for ferry services. In comparison, less than 20 methanol- or LPG-powered vessels are in service or on order.[24] Stena Line Germanica, a ferry retrofitted with a hybrid methanol-diesel system in 2016, reported its NO_x emissions reduced to 60 percent below the Tier I requirement.[25]

- Water-based technologies

NO_x emissions can be controlled by introducing water into the combustion process to reduce peak combustion temperatures. There are three main water-based technologies under development:

  - Intake Air Humidification: Combustion air is saturated with water vapor.
  - Direct Water Injection: Water is injected either into the intake manifold or directly into the combustion cylinder.
  - Water-in-fuel Emulsion: Emulsification of water into fuel.

Each of these water-based technologies has been tested, but none met the Tier III standard alone (Table 2). These technologies also require onboard water storage, so are better suited to ships serving shorter routes where frequent water refilling is possible.[26]

For ease of comparison, Table 2 summarizes the emissions performance, and the key characteristics of each of the measures described above.

In addition to adopting these emission control technologies and fuels, optimizing port calls to reduce the time a ship spends at port and minimize fuel combustion while docking, e.g., by using shore power, are also key to slashing air emissions. Some leading ports, such as Rotterdam, Long Beach, and Los Angeles, have launched digital platforms for shipping companies to communicate with port operators and related service providers to exchange real-time information about their port visits to avoid delays. Port call optimization is outside of the scope of this report. More information can be found in news reports.[27]

[v] Not including LNG-powered inland waterway vessels in China.

[vi] International combustion engines can be divided into two general classes, Otto cycle and Diesel cycle, based on the method of combustion. An Otto-cycle engine takes a mixture of fuel and air, compresses and ignites the air-fuel mixture using a spark or a small amount of fuel. A Diesel-cycle engine takes air, compresses it, then injects fuel into the highly compressed air. The heat in the compressed air spontaneously ignites the fuel.

TABLE 2. EMISSIONS REDUCTION POTENTIAL, COSTS, AND OTHER CONSIDERATIONS OF COMMON NO_X CONTROLS [28]

NO_X CONTROL TECHNOLOGY	NO_X REDUCTION COMPARED WITH TIER I	FUEL PENALTY AND MAIN OPERATING COSTS	OTHER CONSIDERATIONS
Selective Catalytic Reduction (SCR)	> 80%	• Small fuel penalty due to back pressure increase (<1% of fuel consumption) • Urea cost amounts to 7-10% of fuel cost • Catalyst replacement every 3 to 5 years • Fuel savings from efficiency gain (2-4% of fuel consumption depending on engine optimization)	• Retrofittable and ready for two- and four-stroke engines • Operates best with low sulfur fuel (<= 0.1% sulfur content) to avoid catalyst deactivation when exhaust temperature is low • Ammonia slip (i.e., unreacted ammonia passing through the catalyst to the atmosphere)
Exhaust Gas Recirculation (EGR)	40-80%	• 4-6% of fuel cost • Caustic soda for neutralizing recirculated exhaust gas	• Ready for two-stroke engines • Slightly higher capital cost than SCR, but lower operating costs • Operates best with low sulfur fuel to avoid corrosion of the EGR system
Liquefied Natural Gas (LNG)	80-90% for lean burn Otto-cycle engines About 50% for diesel-cycle engines	Fuel cost saving depends on cost differences between diesel and LNG	• Retrofittable, but requires more onboard fuel storage space, or more frequent bunkering • Lack of refilling infrastructure remains a big obstacle for widespread adoption • Methane slip may offset greenhouse gas (GHG) reduction benefits for Otto-cycle engines
Intake Air Humidification	40-70%	Low	• Retrofitting four-stroke engines possible • More practical for ships operating on shorter routes as requires onboard water storage
Direct Water Injection	Up to 60%	1 - 2.5%	• Retrofitting two- and four-stroke engines possible • More practical for ships operating on shorter routes as requires onboard water storage
Water-in-fuel Emulsion	20-40%	Low	• Retrofitting two- and four-stroke engines possible • More practical for ships operating on shorter routes as requires onboard water storage

3

POLICY MEASURES FOR DRIVING THE USE OF CLEAN SHIPPING TECHNOLOGIES AND FUELS

Europe and North America have introduced a range of policies for accelerating the uptake of cleaner fuels and emission control technologies in the marine sector. These measures can be broadly grouped into five categories:

(1) Adopting marine fuel quality standards
(2) Adopting marine engine emission standards
(3) Implementing in-use vessel emissions standards/requirements
(4) Reducing port emissions by mandating the use of shore power
(5) Accelerating the deployment of low- and zero-emission fuels and technologies through incentives and mandates

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3.1 ADOPTING MARINE FUEL QUALITY STANDARDS

Tightening the fuel sulfur limit is traditionally the first step taken to control diesel engine emissions. This can reduce SO_x emissions and the formation of secondary particulates (sulfate), as well as enable the deployment of advanced NO_x and PM emission control devices, including SCR, EGR, and Diesel Particulate Filter (DPF) systems, which can be damaged or deactivated by sulfur in fuel.[29, vii] If these advanced emission control systems only operate with low sulfur fuel, the capital and operational costs can be greatly reduced.[30]

Domestic vessels that are registered locally and engaged in domestic trade in the U.S. and China, and inland waterway vessels in the EU, are required to use fuel with no more than 10 or 15 parts per million (ppm) of sulfur (0.001% or 0.0015% of sulfur) (see Appendix II). The strict sulfur requirement paves the way to introduce stringent regulations on marine engines that demand the use of advanced emission control systems.

For oceangoing vessels, the IMO regulates SO_x (and indirectly, PM) emissions by setting global sulfur standards for marine fuel. The current global fuel sulfur limit is 5,000 ppm (0.5 percent) of sulfur. In the four ECAs designated by the IMO, ships are required to use fuel with no more than 1,000 ppm (0.1 percent) of sulfur.

3.2 ADOPTING MARINE ENGINE EMISSION STANDARDS

Although toughening fuel sulfur standards is effective in terms of lowering sulfur emissions from shipping and, to a lesser extent, particulates, its direct impact on NO_x emissions is limited. Engine emission regulations, incentives, or both, have been introduced along with increasingly tougher fuel standards to drive the adoption of the emission control technologies, including those discussed in Section 2.

Europe and the U.S. established legislation to regulate air emissions (SO_x, NO_x, PM, hydrocarbon, and carbon monoxide) from engines installed on inland waterway vessels and domestic vessels in the late 1990s.[31] The U.S. Environmental Protection Agency (USEPA) introduced emissions standards for marine engines that are applicable to different engine categories. For engines used to provide propulsion power on many types of domestic vessels, such as pushboats, tugboats, supply vessels, fishing vessels, and harbor vessels, as well as auxiliary engines (Category 1 and 2 engines[viii]), the U.S. standards have been progressively toughened from the U.S. Tier 1 standards to the current Tier 4 standards. For large marine engines used to provide propulsion power on

vii For SCR systems, sulfur causes ammonium sulfate formation that deactivates the catalyst. For EGR systems, high sulfur fuel leads to the corrosion of the EGR components. EGR systems designed to operate with high sulfur fuel need to be built with a different grade of stainless steel, which makes them more expensive. In addition, for ships that operate on high sulfur residual oil, sulfur and particles in the re-circulated exhaust gas in the EGR system can damage the engine, requiring more frequent cleaning of the re-circulated exhaust gas. Regarding DPFs, sulfur in fuel severely reduces the efficiency of catalyzed DPFs, as sulfur dioxide in the exhaust is converted to sulfate during catalytic regeneration (cleaning up of DPFs). This requires catalyzed DPFs to operate with ultra-low sulfur fuel,with no more than 10-ppm sulfur content.

viii In the U.S. marine engine regulations, marine engines are grouped into three categories, Category 1, 2 and 3, based on displacement per cylinder. Category 1 and 2 marine engines cover engines with per-cylinder displacement below 30 liters, and they typically range in size from about 500 to 8,000 kW. Category 3 engines are engines with per-cylinder displacement at or above 30 liters, and they typically range in size from 2,500 to 70,000 kW.

oceangoing ships (Category 3 engines), the U.S. emissions standards align with the IMO standards.[32]

In Europe, the Central Commission for the Navigation of the Rhine (CCNR) introduced emissions standards to regulate air pollution from inland waterway vessels that operate on the Rhine River and in Belgium.[ix] The two-tier standards introduced by the CCNR, known as the CCR1 and CCR2 standards, entered into force in 2003 and 2007 respectively. In 2004, the EU adopted the Stage IIIA standards for non-road mobile machinery, which for the first time introduced EU-wide emission standards for engines used on inland waterway vessels. The EU Stage IIIA was phased into effect from 2007 to 2009.[x] The EU Stage IIIA and the CCR2 standards, which are comparable in stringency, were reciprocally recognized by the EU and CCNR.[33] In 2016, the EU adopted the Stage V standards, which set considerably stricter emissions limits that were similar in stringency to the U.S. Tier 4 standards. The EU Stage V standards entered into force from 2019 to 2020, and are the current standards recognized by both the EU and the CCNR.[34]

As discussed in Section 2, marine engines installed on oceangoing vessels are subject to a three-tiered NO_x emission standards stipulated by the IMO. The current U.S. and EU standards, and the IMO Tier III standard, are set at a level that aims to force the use of advanced NO_x emission control technologies (SCR or EGR system), or alternative fuels (such as LNG or electricity).

In China, the Maritime Safety Administration (MSA) required all inland waterway vessels to comply with the IMO Tier I and Tier II NO_x standards beginning in 2011 and 2015 respectively.[35] In 2016, the Ministry of Ecology and Environment (formerly the Ministry of Environmental Protection) adopted the first set of marine engine emission standards for domestic ships (inland, coastal, and fishing vessels), known as China I and II standards. The China I standard took effect on July 1, 2019, and China II will become effective on July 1, 2021.[xi] The China I and II standards cover all pollutants regulated by the U.S. and Europe, plus methane emissions, but are more lenient than the current standards in the U.S. and EU, which are the EU Stage V and U.S. Tier 4 standards (see Figure 1, where the red bars show China's NO_x standards, and the orange bars depict U.S. and EU requirements).

Typically, engine emission standards are only imposed on new and remanufactured engines. By continuously toughening emission standards for new vessels, vessel fleet emissions can be reduced through natural attrition, but it takes a long time to realize the full emission benefits as vessels have a lengthy service life.

3.3 IN-USE VESSEL REQUIREMENTS

In recognition of the long lead time required for new marine engine standards to realize their potential benefits, many cities and regions in Europe and the U.S. have imposed emission requirements for vessels already in operation. When implemented alongside increasingly stringent new vessel emission standards, in-use requirements can accelerate cleaner air emissions from the entire fleet by prompting the vessels to be retired, repowered, or retrofitted.

The in-use standards introduced below are set based on air emissions from ships. Some regions have imposed restrictions on black smoke from vessels as an indirect way to control in-use vessel emissions. While the black smoke restriction programs can foster better engine maintenance, they cannot induce upgrades that lower NO_x emissions, so are not discussed here. A summary of selected programs adopted to date is available in Appendix III.

3.3.1 CALIFORNIA'S COMMERCIAL HARBOR CRAFT REGULATION

In 2007, the California Air Resources Board (CARB) introduced the Commercial Harbor Craft (CHC) Regulation, which includes emission requirements for vessels in operation. The regulation was introduced because harbor crafts were found to be the third highest source of PM emissions from the operation of the ports of Long Beach and Los Angeles.[36] As of January 2009, regulated vessels[xii] with propulsion and auxiliary engines meeting pre-U.S. Tier 1 or Tier 1 emission standards must be upgraded to comply with the

[ix] The emission standards are established in the Rhine Vessel Inspection Regulation (RheinSchUO) set by the CCNR. The CCNR is an supranational government body established for securing a high level of security for navigation of the Rhine and environs. CCNR has five member states: Germany, Belgium, France, the Netherlands, and Switzerland.

[x] The implementation dates for EU standards refer to the dates for placing the engines on the EU market; the standards took effect one year earlier for engines that applied for type approval.

[xi] These dates refer to the implementation dates for placing the engines on the market. For engines that need to apply for type approval, the implementation dates take effect one year earlier.

[xii] Vessels regulated under this rule include ferries, excursion vessels, tugboats, towboats, push boats, crew and supply vessels, and barge and dredge vessels.

standard in effect at the time of compliance (U.S. Tier 2 or Tier 3 standards), over the period of 2009 to 2022. The year by which each vessel must comply with the in-use requirement depends on the engine model year—the older the engine, the earlier it has to meet the emission standard in effect at the time.[37,xiii] Overall, vessel owners are given two to 15 years of lead time (time between the adoption of the rule until they were required to take action), allowing them to schedule vessel replacement, engine retrofit, or repower at a time that is least costly for them, such as during dry docking.[38]

California offers financial support to owners who choose to improve vessel emissions performance ahead of the compliance schedule,[xiv] or owners with vessels that are not currently covered by the in-use regulations (e.g., fishing vessels). Ships that are not used often are offered a compliance pathway for their low use.[xv]

In addition to the in-use vessel emission standards, the CHC Regulations require every commercial harbor craft that operates in California to:

- Use ultra-low sulfur fuel (with sulfur content not more than 15 ppm)
- Have a non-resettable hour meter installed on each engine to measure the number of operating hours
- Submit a report to CARB providing vessel and engine information, and
- Meet the current new engine emission standards when replacing an engine on an existing vessel or installing engines on a newly built vessel (new passenger ferries are required to be even cleaner than the standard in effect at the time of acquisition).

The recordkeeping and reporting requirements help CARB implement and enforce the regulation, and also better understand the emission performance and operational profile of the vessel fleet, which is helpful for deliberating future standards.

With the above requirements for in-use and new vessels, combined with financial support for early movers and natural vessel turnover, CARB has projected by 2023 the average NO_x emissions of California's CHC fleet will reach U.S. Tier 2 level, or 51 percent below pre- U.S. Tier 1 (i.e., pre-control) level.[39] So far, the in-use requirement has been achieved through engine replacement. CARB is now engaging in pre-rulemaking activity to amend the CHC Regulations. Two of the amendments being considered are strengthening the in-use vessel requirement further to U.S. Tier 4 standards, and accelerating the adoption of zero-emission technologies.[40]

3.3.2 IN-USE VESSEL EMISSIONS REQUIREMENTS IN ROTTERDAM AND NORWAY

In Rotterdam, inland waterway vessels not meeting the CCR2 standards will be prohibited from entering the port starting in 2025.[41] CCR2 is similar to the China I and II standards in terms of NO_x requirements but stricter in regard to the PM requirement.[42] In order to encourage ship owners to use cleaner inland barges, and facilitate reaching the 2025 target, port dues at Rotterdam are set based on emissions level (see Section 3.5.1.3.). After the EU implemented the more stringent EU Stage V emission standards, the CCR2 standards are considered not sufficiently stringent. Under the Netherlands Green Deal, a sustainability label is being developed for inland waterway vessels that can allow for replacement of the CCR2 requirement[xvi] (see Section 3.5.2.2. for discussions of the Netherlands Green Deal).[43]

Norway adopted a more ambitious policy, which requires all ships travelling in two Norwegian fjord areas classified as World Heritage Sites to be emissions-free no later than 2026.[44]

[xiii] The compliance dates can be found in *California Code of Regulations § 93118.5. Airborne Toxic Control Measure for Commercial Harbor Craft,* Tables 7-10.

[xiv] One example of the state-run incentive programs is the Carl Moyer program. It offers grants to reduce smog forming and toxic emissions (such as NO_x emissions) from older engines and equipment beyond the state regulatory levels. The Carl Moyer program provided grants to a large share of in-use vessels that have engines replaced to comply with the CHC requirement ahead of schedule. More information about California's incentive programs can be found at https://ww2.arb.ca.gov/our-work/topics/incentives.

[xv] See *California Code of Regulations § 93118.5. Airborne Toxic Control Measure for Commercial Harbor Craft,* paragraph (e)(6)(C)4. Low-usage vessels are those that operate 300 hours annually or less in the regulated categories, or 80 hours if in barge and dredge. If the owner can demonstrate that a vessel will not operate more than the number of qualifying hours for low-usage vessels, the vessel is considered in compliance. The proof could include records of the vessel engine's total annual hours of operation for the calendar year immediately preceding the compliance date, and documentation that projects future annual hours of operation.

[xvi] Personal communications with Jarl Schoemaker of Port of Rotterdam Authority, April 30, 2020.

FIGURE 4. A SHORE POWER CONNECTION CABINET AT ROTTERDAM (LEFT), AND THE INSTRUCTION ON THE CABINET SHOWING HOW TO CONNECT TO SHORE POWER AND TO STOP POWER SUPPLY (RIGHT)

Photo credit: Freda Fung

By 2030, only low- or zero-emission vessels can access other fjords and Norwegian waters.[45] These low and zero-emission requirements push owners of all cruise ships and tourist vessels sailing along the Norwegian coast to plan a transition to zero-emission technologies.

3.4 SHORE POWER MANDATES

Shore power can be readily adopted for inland waterway vessels because the shipside modification required to connect to a quayside electricity supply is relatively simple. Using shore power while a ship is at berth can eliminate air emissions in the port area, and also reduce climate pollution (if the electricity grid is clean), noise nuisance, and vibration. California and Rotterdam have mandated the use of shore power, with the former targeting oceangoing vessels, while the latter focuses on inland waterway vessels.

California's shore power regulations, enacted in 2014, require container vessels, refrigerated cargo ships, and cruise ships to reduce onboard auxiliary engine power generation by using shore power or an alternative technology when berthing at the six largest ports in California. The requirement ratcheted up from a 50 percent reduction of fleet-wide auxiliary energy use in 2014, to 70 percent in 2017, and 80 percent in 2020. While these regulations have been successful in significantly reducing air emissions at ports, air pollution from oceangoing vessels is expected to grow beyond 2020 due to continued growth in shipping activities.[46] CARB has therefore proposed extending the shore power requirements to cover new vessel types, such as tanker vessels and roll-on/roll-off vessels (vessels for transporting vehicles), and tanker boilers, as well as more ports.[xvii]

In Rotterdam, a port by-law was adopted in 2010, prohibiting the use of generators or running of main or auxiliary engines on board a berthed inland ship, in order to reduce air pollution and noise nuisance.[47] Inland waterway vessels shall comply by connecting to shore power, unless the dock is not equipped with a shore power connection. To support compliance, the government has installed shore power connections at all public berths (371 connections for inland barges and two for river cruises) (Figure 4) and launched a mobile phone app that makes it easy for skippers to find available shore-power-capable berths and make payments.[48]

[xvii] More information can be found at the CARB website: https://www.arb.ca.gov/ports/shorepower/shorepower.htm

3.5 ACCELERATING DEPLOYMENT OF LOW- AND ZERO-EMISSION FUELS AND TECHNOLOGIES THROUGH INCENTIVES AND MANDATES

In conjunction with regulatory requirements, some regions in Europe have a long tradition of using financial incentives to spur the development and commercialization of advanced NO_x control technologies. More recently, these programs have been extended to support low- and zero-emission solutions.

3.5.1 ENVIRONMENTALLY DIFFERENTIATED TAXES OR FEES

Sweden and Norway have pioneered the use of environmentally differentiated tax or fee schemes to encourage the use of emission control technologies and clean fuels in the marine sector. An environmentally differentiated tax or fee can be applied to both new and in-use vessels. The Norwegian program assesses the total tax/fee based on a vessel's annual NO_x emissions, while the Swedish program assesses fairway dues based on the NO_x emissions rate of each vessel.

3.5.1.1 Norwegian NO_x Tax and NO_x Fund

In 2007, Norway introduced a NO_x tax for all sectors, including shipping, land-based industries, oil and gas extraction, fishing, rail, and aviation.[xviii] Entities that operate engines exceeding 750 kW, boilers over 10 MW, or conduct flaring activities are subject to a NO_x tax [at Norwegian krone (NOK) 22.69, or Renminbi (¥) 17[xix], per kg of NO_x emitted in 2020]. Alternatively, regulated entities can join the NO_x Fund by paying a NO_x fee (at 10.5 NOK or ¥8 per kg of NO_x for shipping in 2020), in lieu of paying the much higher NO_x tax.[49] Entities joining the NO_x Fund need to commit to meeting an agreed annual NO_x reduction target and develop a long-term plan for reducing their NO_x emissions. Failure to reach the target will result in the tax being re-imposed.

Participating entities are also eligible to apply for funding support for up to 80 percent of capital investments on NO_x control measures, though they must first carry out the most cost-effective measures at their own expense.[50] Vessel owners who opt for technologies and fuels that can potentially be carbon-free, such as hydrogen or electricity, or can meet the IMO Tier III NO_x standard, are eligible for greater financial support (see Table 3).

The combination of the NO_x tax and NO_x Fund, alongside other funding schemes (see Section 3.5.2.1.), has successfully spurred the uptake of NO_x control technologies in Norway's maritime sector, especially with regard to the use of the SCR system, and LNG and electric propulsion. At present, more than 30 percent of the world's ships with SCR systems in operation are in Norway.[52] By 2026, Norway will be home to over one-fifth of the world's LNG-powered vessels, and 44 percent of battery-powered vessels, counting all vessels in operation and on order.[53, xx] From 2007 to 2016, NO_x emissions from ships in Norway were cut by about 40 percent.[54]

TABLE 3. MOBILE SOURCE NO_X CONTROL MEASURES ELIGIBLE FOR NO_X FUND SUPPORT AND THE SUPPORT RATE[51]

NO_X FUND SUPPORT RATE FOR MOBILE SOURCE CONTROL MEASURES (PER KG OF NO_X REDUCED)	
200 NOK (¥151)	**400 NOK (¥301)**
NO_x abatement technologies, including SCR and EGR	Energy conversion: LNG, electrification, hydrogen
Energy efficiency measures	Hybrid battery power
Engine modifications reducing NO_x	Energy efficiency measures combined with Tier III measures (e.g., SCR, EGR, LNG)
Replacement of engines with NO_x cleaning technology	Engine replacement combined with NO_x control technologies that meet Tier III standards (e.g., SCR, EGR, LNG)

xviii With regard to shipping, the NO_x tax is assessed based on emissions from vessels within Norwegian territorial waters and domestic shipping, even if part of the voyage takes place outside Norwegian territorial waters (250 nautical miles [nm] off the Norwegian coast). All ships in international traffic are tax-exempt, including vessels operating in direct traffic between Norway and foreign ports. For more information, see Becqué et al. (2018) in endnote 55.

xix Throughout this report, exchange rates are based on the midpoint reference rate for RMB yuan set by the People's Bank of China as of February 21, 2020 (http://www.pbc.gov.cn/zhengcehuobisi/125207/125217/125925/index.html).

xx The data used for deriving Norway's share of the world's LNG-powered vessels does not include LNG-powered inland waterway vessels in China.

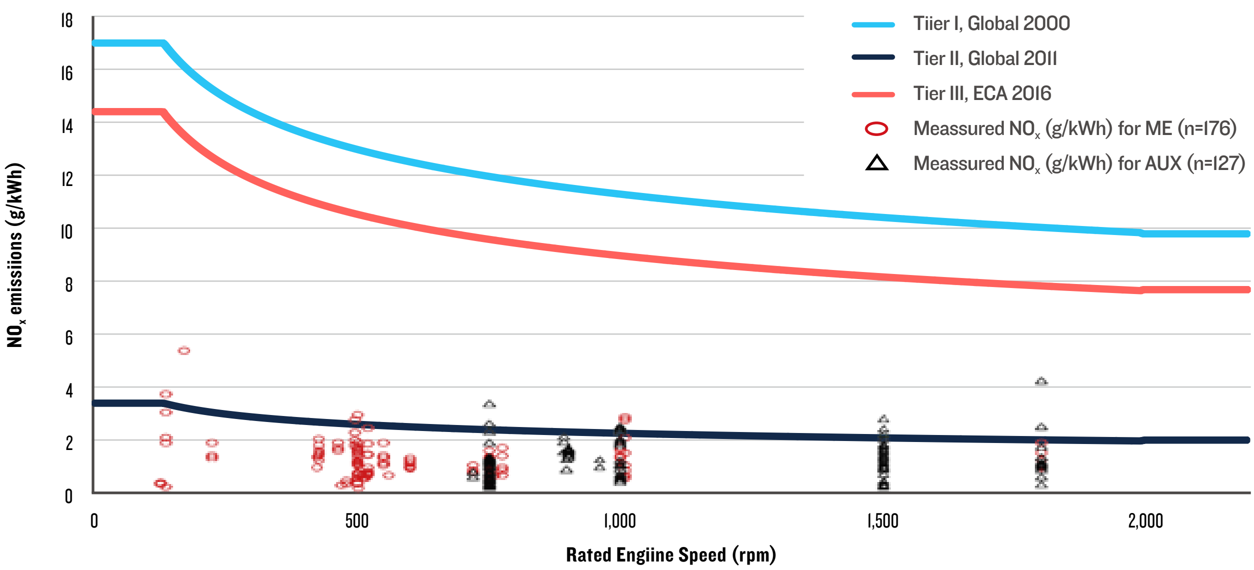
3.5.1.2 Swedish Environmentally Differentiated Fairway Dues

Sweden adopted an emissions-based fairway dues scheme in 1996. The Environmentally Differentiated Fairway Dues program was designed to encourage deeper reductions in NO_x and SO_x emissions from vessels, beyond regulatory requirements, by offering a stepwise reduction of the gross tonnage portion of the fairway dues, based on a vessel's NO_x emissions and fuel sulfur level.[xxi] The scheme has been revised several times, as regulations gradually tightened. In 2015, after the 0.1 percent ECA fuel sulfur standard took effect, the fairway dues rates were updated to vary only in terms of the NO_x emissions level. The latest revision was made in 2018, with the scheme now based solely on the Clean Shipping Index (CSI) score. The CSI is an independent reporting and labeling scheme of environmental performance for ships and shipping companies, that was launched in Sweden by shipping industry stakeholders and large Swedish export and import companies.[xxii] A ship's CSI score reflects its performance in relation to air and climate pollution, chemical use, and water and wastewater management.[55]

When the program was first launched, it was recognized that substantial investments in installing effective NO_x controls, such as the SCR system, could take more than ten years to be recovered through reduced fairway dues. Grants were therefore offered to subsidize investments on NO_x controls from 1998 through 2001. The grants ended in 2002, as they were considered to be too costly.[56]

Even though the total number of vessels receiving fairway dues discounts for superior NO_x performance was small (64 vessels from 2007 to 2016), the scheme was successful in terms of driving the early adoption of NO_x control technologies. SCR was the preferred technology, adopted by 76 percent of ships that were granted reduced fairway

FIGURE 5. NO_x EMISSIONS LEVEL OF SHIPS EQUIPPED WITH SCR AND GRANTED A PORT DUES DISCOUNT UNDER THE SWEDISH ENVIRONMENTAL DIFFERENTIATED FAIRWAY DUES SCHEME[58]



ME stands for main engine, and AUX for auxiliary engine. Red circles depict the measured main engine NO_x emissions level of vessels equipped with SCR systems and granted a port dues discount, while black triangles present the measured auxiliary engine NO_x emissions level of those vessels.

Reprinted from Selma Brynolf et al., "Compliance Possibilities for the Future ECA Regulations Through the Use of Abatement Technologies or Change of Fuels," *Transportation Research Part D*, 28 (2014): 6-18, Copyright (2020), with permission from Elsevier.

xxi To be granted reduced fairway dues, shipping companies must provide the Swedish Maritime Administration with a measurement of the NO_x emissions of all main and auxiliary engines in accordance with ISO 8178 standards. Ammonia slip at the funnel after the SCR should also be measured and provided to the authority, to demonstrate that the amount slipped is lower than 10 ppm NH_3 (later revised to 20 ppm NH_3). Evidence of urea use shall also be provided, such as readings of urea consumption and urea purchase notes.

xxii The CSI scoring methodology was developed by a technical committee comprised of researchers and representatives of the maritime authority and shipping industry from Sweden. For more information, see https://www.cleanshippingindex.com/.

TABLE 4. ENVIRONMENTAL PERFORMANCE-BASED PORT DUES SCHEME FOR INLAND WATERWAY VESSELS AT ROTTERDAM[61]

PORT DUE SURCHARGE OR DISCOUNT	ENVIRONMENTAL PERFORMANCE OF INLAND WATERWAY VESSEL MAIN ENGINE
10% surcharge	Not meeting CCR2 NO_x and PM emission standards
No discount	Meeting CCR2 NO_x and PM standards
15% discount	Granted a valid Green Award certificate, and meeting CCR2 NO_x and PM standards
30% discount	At least 60% cleaner than CCR2 PM and NO_x standards
100% discount	**Granted a Green Award Platinum certificate for zero-emission operation**

dues for low NO_x emissions. The NO_x reductions achieved by each ship were significant—emissions testing data collected through 2009 show that most of the SCR-equipped ships that were granted reduced fairway dues performed even better than the IMO Tier III NO_x standard (Figure 5).[57, xxiii]

3.5.1.3 Differentiated Port Dues at Rotterdam

Rotterdam, Europe's largest port and a logistic hub of oceangoing and inland waterway vessels, has introduced multiple measures for tackling vessel emissions. For inland waterway vessels, the port adopted a five-tier port dues structure to motivate ship owners to control ship emissions (see Table 4). Various discounts are offered to ships that are cleaner than the Central Commission for the Navigation of the Rhine's CCR2 standard, while port dues surcharges are imposed on ships whose emissions exceed the CCR2 standard. In 2018, the port announced that inland waterway vessels certified by Green Award as zero-emission (i.e., ships granted the Green Award's Platinum certificate)[xxiv] can enjoy a 100 percent discount on port dues.[59] The differentiated port dues scheme is currently under review, following the adoption of the EU Stage V emission standards that superseded the CCR standard.[60]

Rotterdam also offers port dues discounts to oceangoing vessels (including coastal ships not registered in the Netherlands) that perform better than current standards. The discount is assessed based on a ship's score under the Environmental Ship Index (ESI), which is a third-party rating scheme that assesses the NO_x, SO_x, and CO_2 emissions of ships. A ship with an ESI score above 30 is eligible for a 10 percent discount on the gross tonnage portion of the port dues. The discount is doubled if the NO_x part of a ship's ESI score is over 30, which can be attained, for example, by using LNG or the SCR system.[62] On top of the ESI discount, Rotterdam offers a 15 percent discount to Green Award-certified LNG tankers, chemicals/gas tankers, and crude/product tankers[xxv] to reward companies for investing in improving the management, and environmental and safety performance of their ships.[63]

3.5.2 COMPREHENSIVE MEASURES FOR PROMOTING LOW- AND ZERO-EMISSION FUELS AND TECHNOLOGIES

With rising public awareness of climate change, efforts to clean up air pollution from ships in Europe and North America have gradually shifted to target both air pollution and climate

[xxiii] Based on the latest available public data. It should be noted that the test cycle used in Sweden is different from that of the IMO, which covers several low load points that are challenging for SCR operation. See Brynolf et al. (2014) in endnote 58.

[xxiv] Green Award certification for inland waterway vessels is granted by assessing a ship's air emissions. Green Award's Platinum certificate is currently awarded to ships that operate without exhaust emissions continuously for three hours a day. The length of time for emission-free operation for the Platinum certification could be strengthened later when it is deemed appropriate. More information can be found at https://www.greenaward.org.

[xxv] Crude and product tankers are two types of oil tankers: Crude tankers move large quantities of unrefined crude oil from the point of extraction to refineries, while product tankers transport refined products like gasoline, diesel and jet fuel, from refineries to points near consumer markets.

change. The agreement reached at the IMO in 2018 to reduce global shipping emissions by at least 50 percent by 2050 underscored climate urgency, while also increased pressure on the shipping industry and major maritime nations to step up their efforts on shipping decarbonization.

Enhancing the energy efficiency of ships using existing technologies, such as improving power and propulsion systems, enhancing vessel aerodynamics and hydrodynamics, and optimizing speed and logistic chains, can achieve considerable reductions in GHG emissions. For instance, Maersk, the world's largest container shipping line, has lowered CO_2 emissions per unit of cargo moved by 60 percent from 2008 to 2018 through energy efficiency measures.[64] However, with the projected steady growth of shipping activities, substantial uptake of low- and zero-carbon fuels and propulsion technologies is essential to achieve IMO's goal for 2050. Given that typical vessel lifespans are between 20 to 30 years, low- and zero-emission fuels and technologies will need to be market-ready by around 2030.

As markets for low- and zero-emission fuels and propulsion technologies are still emerging, widespread adoption of zero-emission propulsion technologies would require significant investments by ship owners, ports, and fuel suppliers. Grants and market-based solutions are critical at this stage for advancing research and development (R&D) and stimulating deployment. Norway has been at the forefront of supporting the development of sustainable shipping through the NO_x tax and NO_x Fund discussed above, as well as other funding and policy instruments. More countries are now following suit.

3.5.2.1 Funding and Mandates in Norway for Advancing Low- and Zero-Emission Shipping

For more than a decade, Norway has applied a range of policy measures, including funding schemes, an emissions tax and fee, and public procurement policies, to spur development and boost demand for low- and zero-emission technologies for the shipping industry. It considers a green transition in the maritime sector to be not only crucial for tackling climate change and improving air quality, but also an opportunity to build the expertise of Norwegian industries along the entire value chain for green shipping.[65]

Providing incentives for the use of environmentally-friendly fuels has been a core element of Norway's green shipping policies, with LNG, electricity, and advanced biofuels considered to hold the greatest potential. In the past few years, the policy focus has shifted towards climate change, and electric propulsion and hydrogen fuel cells are receiving increasing attention.[66] As 98 percent of Norway's electricity production comes from renewable energy sources, ships with these two types of propulsion can be truly zero-emission.[67]

Owing to its past and current efforts towards advancing sustainable shipping, Norway is now the world leader on LNG and battery-electric propulsion for maritime use. In June 2019, the country stepped up its efforts by releasing an action plan on green shipping and announced a target to cut greenhouse gas emissions from domestic shipping and fisheries by half by 2030.[68] The main funding schemes and the public procurement policies that have been introduced for advancing low- and zero-emission maritime solutions are summarized below.

Funding schemes for accelerating R&D and piloting low- and zero-emission vessels

To spur technological development and support demonstration projects, the Norwegian government has allocated grants that totaled tens and hundreds of millions of Norwegian Krone (NOK) for low- and zero-carbon shipping projects, including construction of bunkering infrastructure, through various funding schemes. Three of the most important schemes are:

- ***Enova:*** An enterprise under the Ministry of Climate and Environment, Enova's mission is to reduce greenhouse gases, strengthen energy security, and spark innovation on energy and climate technologies that can facilitate Norway's transition to a low-carbon society.

  Since 2015, Enova has provided more than NOK 1.6 billion (¥1.2 billion) of funding to support the construction of different types of low- and zero-emission vessels, as well as electricity charging facilities.[69] For vessel types not suited to fully-electric operation, such as fast ferries and coastal container ships, Enova, together with Innovation Norway and the Norwegian Research Council, is jointly managing a PILOT-E funding scheme that offers grants to develop battery and fuel cell solutions.[70] Vessels that are eligible for Enova support must be registered in Norway and conduct a significant

© Photo by Freda Fung

part of their operations in Norwegian territory or within the Norwegian Economic Zone.[71]

In addition, Enova provides funding for building onshore infrastructure that enables the low-carbon transition. Since 2015, NOK 500 million (¥377 million) has been allocated to develop shore power infrastructure at Norwegian ports.[72] In 2018, three counties in western Norway (Hordaland, Møre og Romsdal, and Sør-Trøndelag) received NOK 480 million (¥362 million) to build a ferry-charging infrastructure, catalyzing the deployment of battery electric and plug-in hybrid ferries.[73]

- ***Innovation Norway:*** Innovation Norway supports Norwegian companies and industries in developing a competitive edge through innovation. Regarding maritime-related projects, it offers grants to promote the development, commercialization, and demonstration of new maritime technologies, and the retirement of old vessels. An estimated NOK 73 million (¥55 million) of funding was given to the maritime industry in 2017. Innovation Norway also offers grants—about NOK 25 million (¥19 million) a year—through an innovation contract scheme designed for small- and medium-sized enterprises that are seeking to develop new, innovative products, services, and technologies in close cooperation with pilot customers. In addition to offering grants, Innovation Norway provides innovation loans and low-risk loans for innovation projects on green shipping.[74]

  Innovation Norway's support is primarily directed to short-sea shipping. Companies receiving funding or loans must be registered in Norway, and the vessels in question must primarily operate in Norwegian coastal waters.[75]

- ***Klimasats:*** To support county governments that wish to acquire climate-friendly high-speed vessels, a temporary funding scheme has been set up through the Klimasats program,[xxvi] which offers grants to county authorities for reducing greenhouse gas emissions and facilitating a transition to a low-emission society. NOK 25 million (¥ 19 million) and NOK 77 million (¥58 million) of the Klimasats funding have been earmarked to subsidize the procurement of climate-friendly high-speed vessels in 2018 and 2019 respectively.[76]

Norway's green procurement requirements for low- and zero-emission technologies

To stimulate demand for low- and zero-emission solutions for maritime transport, the Norwegian Parliament decided in 2017 that low- or zero-emission technologies should be a requirement in public tenders for the national ferry services,

[xxvi] The Klimasats is a financial support scheme established in 2016 by the Norwegian government to support projects that reduce greenhouse gas emissions at the municipality and county level.

when the technology allows for it. While this requirement is not mandatory for county governments procuring ferry services, they are encouraged to follow it.[77] The various funding schemes discussed above and the NO_x Fund have enabled national and local governments to include stricter environmental requirements in their calls for tenders. As a result, Norway has seen a rapid uptake of battery technologies on ferries. As of 2019, 33 ferry routes in Norway are partly or all electric, and 63 battery-powered ferries are expected to go online in Norwegian fjords by 2021.[78]

3.5.2.2 Efforts of Other European Countries to Transition to Zero-Emission Shipping

- ***The Netherlands***

The Dutch Green Deal for Shipping was signed in the Netherlands in June 2019, with the goal of fostering emission-free and climate-neutral inland and sea shipping by 2050. Signed by the government, port authorities, shipping and logistics industry members, shippers, banks, and research institutes, the Green Deal stipulates ambitious CO_2 emission goals for both inland and seagoing shipping. CO_2 emissions from inland shipping aim to be reduced by at least 40 percent by 2030, and to zero by 2050, while CO_2 emissions from sea shipping would be slashed by 70 percent as of 2050.

The Green Deal also includes dozens of measures for curbing air and climate pollutants from shipping. One of those measures is the launch of a sustainability label for inland waterway vessels that will enable ships to qualify for harbor dues discounts, or secure funding from grants and finances from banks. To combat NO_x pollution, the Dutch government released 79 million euros (¥598 million) as grants for retrofitting inland waterway vessels in operation with SCR systems over the period of 2020-29. In addition, the Ministry of Infrastructure and Water Management will set aside 15 million euros (¥114 million) for the inland shipping sector to encourage innovations, such as the purchase of clean engines. Five million euros (¥38 million) have been earmarked for research into new technologies to make maritime transport sustainable. The signatory parties are committed to having at least one innovative zero-emission oceangoing vessel in service and at least 150 inland vessels fitted with a zero-emission powertrain by 2030.[79]

Port cities in the Netherlands also play a leadership role in advancing the transition to low-/zero-emission shipping. For instance, the Port of Rotterdam launched a series of initiatives to stimulate the development and uptake of low-/zero-emission solutions for inland, coastal and oceangoing shipping, including:

- Incentive scheme to support climate-friendly shipping: The port offers five million euros (¥38 million) of funding from 2019 through 2022 to support projects for developing and demonstrating low emission alternative fuels for oceangoing vessels. Port funding can cover at most 40 percent of the project costs. Fuels that are eligible for support must be biofuel or synthetic fuel, or involve the use of electricity or fuel cells. The fuels should also result in more than 50 percent carbon emissions reduction compared to conventional fuels, and be bunkered at the Port of Rotterdam.[80]
- *Twenty-megawatt shore power project in the Calandkanaal powered by wind:* In 2019, Heerema Marine Contractors, Eneco and the Municipality and Port of Rotterdam collaborated to develop the shore power system to supply electricity for Heerema's crane vessels mooring along the Calandkanaal. It will be the world's biggest shore power connection for offshore vessels. Electricity will come from the adjacent Landtong Rozenburg windpark. The reduction in total emissions is expected to equal to taking 5,000 diesel cars off the road, drastically reducing local air emissions and noise.[81]
- *Mobile shore power system for coastal vessels:* In December 2019, the Port and Municipality of Rotterdam launched a pilot project near the center of Rotterdam at Parkkade, to test out the technical and commercial feasibility of different mobile shore-power systems for coastal vessels. With a cost of half a million euros (¥3.8 million), this trial will test five different mobile shore power systems that are powered by a:
  - i. Battery integrated with a biofuel-powered generator
  - ii. Battery combined with a blue diesel[xxvii] generator and solar panels

[xxvii] Blue diesel refers to diesel recovered from waste oil, most notably used cooking oil.

iii. LNG-powered gas engine

iv. Bio-LNG-powered turbine

v. Hydrogen-based fuel cell unit combined with a small battery

Each of these mobile systems is to be tested for two to four weeks, with emissions and noise level measured and compared to using the vessel's onboard generators. Participating vessels receive free electricity. Following this pilot, the port has set aside 1.5 million euros (¥11.4 million) for starting a second pilot with a focus on shore power concepts for large oceangoing vessels.[82]

- *World Ports Climate Action Program:* In September 2018, Rotterdam and ten other leading ports in the world[xxviii] joined hands to launch the World Ports Climate Action Program, an international initiative aiming to:

i. Increase efficiency of supply chains using digital tools

ii. Advance common and ambitious public policy approaches aimed at reducing emissions within larger geographic areas

iii. Accelerate development of in-port renewable power-to-ship solutions and other zero-emission solutions to control emissions while ships berth

iv. Accelerate the development of commercially viable sustainable low-carbon fuels for maritime transport and infrastructure for electrification of ship propulsion systems

v. Accelerate efforts to fully decarbonize port cargo-handling facilities

An action plan for each of the above tasks is being developed, setting out a timeline of actions and milestones over a five-year period (2019-2023).[83]

Long before the Dutch Green Deal was adopted, Amsterdam had rolled out measures for boosting the uptake of zero-emission shipping. In 2013, the municipality of Amsterdam stipulated that all canal tour boats must be emissions-free by 2025. Canal tour boat companies in Amsterdam have been gradually converting tour boats from diesel to electric.[84] Fast chargers are also being installed along the canals.[85] In 2019, the city extended the 2025 zero-emissions requirement to all canal boats.[86] As of 2020, three-quarters of the 550 commercial vessels on the canal already qualified as emissions-free.[87]

United Kingdom

In July 2019, the United Kingdom (UK) announced a Clean Maritime Plan, which set out a vision for the UK to take a proactive role in driving the transition to zero-emission shipping in UK waters, and become a world leader in this field by 2050.[88] The plan recognizes that transiting to zero-emission shipping can tackle air pollution and greenhouse gases, while creating opportunities for clean maritime growth in the UK.

To this end, the plan stipulates the following key policy commitments:

- Exploring the use of non-tax incentives and the existing Renewable Transport Fuel Obligation to encourage the uptake of low carbon fuels
- Launching a green financing scheme to support a zero-emission shipping transition
- Launching a study to identify and support potential zero-emission shipping clusters across the UK, which will serve as demand and supply hubs for zero-emission fuels, with fuel production, supply and storage infrastructure
- Providing seed funding and government grant support, and establishing an award scheme for stimulating green maritime innovations in the next few years; this includes £1.3 million (¥11.8 million) of funding to support clean maritime innovation

The short-term goal of the plan is for all new ships in UK waters to be designed with zero-emission-capable technologies by 2025. By 2035, several clean maritime clusters will be built, and low or zero-emission marine fuel bunkering should be readily available across the UK.

[xxviii] Other participating ports include: Amsterdam, Antwerp, Barcelona, Gothenburg, Hamburg, Le Havre, Long Beach, Los Angeles, New York and New Jersey, and Vancouver.

4

LESSONS LEARNED FROM INTERNATIONAL EXPERIENCES

For more than a decade, European countries and California have implemented a range of regulatory measures and incentive schemes to combat air pollution from domestic shipping (see a summary in Table 5). These policy measures have resulted in the widespread use of low sulfur fuels and catalyzed the development and commercialization of emission control technologies in the marine sector that can substantially reduce NO_x emissions from ships, such as SCR systems, natural gas, and electric propulsion. Some lessons can be drawn from these countries' experiences.

TABLE 5. SUMMARY OF POLICY MEASURES FOR ADVANCING LOW/ZERO-EMISSION SHIPPING

	NORWAY	THE NETHERLANDS	CALIFORNIA, U.S.	UNITED KINGDOM
New vessel requirement	Low/zero-emission propulsion for new ferries serving national routes	Inland waterway vessels comply with EU Stage V emission standard	Harbor crafts comply with U.S. Tier 4 emission standard	• EU Stage V • All new vessels be zero-emission by 2025
In-use vessel requirement	• NO_x Tax/Fund • Vessels in World Heritage Fjords be zero-emission by 2026 • Vessels in all fjords and Norwegian waters be low/zero-emission by 2030	*National* • CO_2 emissions from inland shipping be reduced by at least 40 percent by 2030, and to zero by 2050 • CO_2 emissions from sea shipping be reduced by 70 percent by 2050 *Rotterdam* • All vessels comply with CCR2 standard by 2025 • Inland barges must use shore power *Amsterdam* • All canal boats be zero-emission by 2025	• Harbor crafts upgraded to meet U.S. Tier 2 or 3 standard • Oceangoing vessels must use shore power for 80 percent of vessel calls	
Grants and incentives	• NO_x Fund support for NO_x abatement solutions • Enova, Innovation Norway and Klimasats funding for building low/zero-emission vessels, and supporting bunkering and shore power infrastructure	*National* • Dutch Green Deal funding for supporting the purchase of clean engines, and studies of sustainable maritime technologies *Rotterdam* • Port dues determined by emissions levels • Funding for developing and demonstrating low-emission alternative fuels for oceangoing vessels • Funding for trials of low-/zero-emission shore power systems for coastal and oceangoing vessels	Carl Moyer and other incentive programs to support adoption of low-NO_x/carbon technologies that go beyond compliance	Funding for supporting green maritime innovation

4.1 MANDATORY PROGRAMS COMPLEMENTED WITH INCENTIVE POLICIES ARE NEEDED TO SPUR DEPLOYMENT OF COMMERCIALLY AVAILABLE NO_X MITIGATION TECHNOLOGIES AND DEVELOPMENT OF ZERO-EMISSION SOLUTIONS

Technologies exist that can successfully reduce NO_x emissions from ships. There is also rapid development of low/zero-emission maritime technologies, particularly for use on ferries and coastal vessels. Increasingly stricter regulations, in combination with incentive programs, are driving wider deployment of these technologies. The regulatory certainty provided by mandatory programs, be they the Norwegian NO_x Tax, the marine engine standards of the EU and U.S., or the in-use vessel emissions requirements in California and Rotterdam, have stimulated the development and gradual uptake of low-/zero-emission maritime technologies. Incentive programs are essential complements to these mandatory approaches, as developing and deploying these technologies face substantial hurdles from high upfront capital costs, and/or a lack of bunkering infrastructure. However, regulatory programs are ultimately needed to drive widespread adoption.

4.2 CLEANING UP IN-USE VESSELS IS ESSENTIAL

Due to the long service life of vessels, programs that target the in-use fleet are critical in achieving significant emissions reductions for the entire fleet. Increasingly tougher emissions requirements for new vessels are being used as a benchmark for incentive programs targeting in-use fleets in California and European countries. This boosts the uptake of low- and zero-emission technologies through the repowering or replacement of in-use vessels. The long lead time of the in-use emissions requirements set by California, Rotterdam, and Norway allows vessel owners to pick the best timing to replace or repower their vessels, further enhancing compliance.

4.3 MAJOR SEAFARING NATIONS LAUNCH PARALLEL EFFORTS TO COMBAT AIR AND CLIMATE POLLUTION FROM SHIPS

While tackling NO_x pollution from shipping remains a top priority for major maritime nations, more countries are launching programs to accelerate the uptake of zero-emission shipping. Those that are at the forefront of promoting low- and zero-emission technologies, including Norway, the UK, and the Netherlands, are seeing this as a triple-win opportunity for combating air pollution, tackling the climate crisis, and stimulating green growth. While the development of low- and zero-emission shipping technologies is still nascent, the number of low- and zero-emission vessels is growing, thanks to funding and regulatory support from major maritime nations. Some of the newest vessels are being equipped with large capacity batteries to serve long distance routes (up to 80 km on a single charge). Appendix IV lists a selected group of fully electric and plug-in hybrid vessels that are now in operation.

5

GREEN SHIPPING RECOMMENDATIONS FOR CHINA

Air quality, and particularly fine particle and ozone pollution, remains a top concern as China enters its 14th Five-Year planning period, especially in the key regions of the Blue Sky Defense Plan. As these air pollution regions cover many cities and provinces along the coast and on major inland waterways, toughening controls on shipping emissions should be a key part of the clear air policies in the next Five-Year Plan.

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The Blue Sky Defense Plan released by the State Council in 2018, and the corresponding local plans, stipulate a number of measures to target shipping. These measures include promoting the uptake of "new energy" (such as LNG or electricity) for use in vessels, encouraging the retrofitting of inland waterway vessels, and constructing quay-side shore power connections. The plans also call for restricting the operation of high-emitting vessels along major inland rivers such as the Yangtze, and encouraging the retirement of inland waterway vessels that have been in service for more than 20 years. While the policy direction of promoting alternative, low-emission technologies and accelerating vessel fleet modernization is clear, these measures are mostly voluntary (except for the DECA requirements and the emission standards for new marine engines). They may not provide the regulatory certainty the shipping industry needs to make long-term investments that drastically reduce shipping NO_x pollution.

Drawing from the lessons learned from Europe and the U.S., we provide a few recommendations below for consideration in the formulation of the next Five-Year Plan.

In the near term, we recommend that clean shipping policies focus on boosting the uptake of commercially available NO_x reduction technologies on both new vessels and vessels in operation, in order to further progress towards clean air goals. Another consideration is the adverse impacts of climate change on China's agriculture, ecosystem, water resources, and human health, with the latest research showing that more intense climate extremes, such as increased heat waves and more periods of stagnant air, will worsen existing air pollution in China.[89] In light of those adverse impacts, we recommend long-term clean shipping strategies focus on promoting the co-control of air pollution and the climate impacts of shipping.

- **Tighten engine standards further to drive the commercial availability of clean engines**

While China has introduced China I and II emission standards for engines used on domestic vessels, they are not strict enough to bring about significant NO_x reductions. China could tighten the standards to be on par with U.S. Tier 4 and EU Stage V standards. By doing so, it can drive the adoption of commercially available NO_x control technologies in its domestic vessel fleet. Since the emission standards are technology neutral, vessel owners could choose among compliant technologies based on the vessel operation profile and the accessibility of supporting infrastructure.

There may be concerns that, even with the adoption of stringent standards, the uptake of SCR or LNG propulsion may be slow, as happened in Europe. However, the introduction of EU Stage V-compliant marine engines for inland waterway vessels is slow in Europe largely because of the small size of the domestic shipping engine market. As marine engines are uniquely designed, the costs of developing and certifying new engines are high, which further raises the costs of engines that comply with EU Stage V standards. Engine manufacturers in the EU have, as a result, delayed offering Stage V-compliant marine engines.[90]

China's inland waterway vessel market is much larger than the EU market. With 124,300 vessels in operation as of 2018, the number of inland waterway vessels in China is seven times that of Europe, which only has 18,000 vessels.[91] In addition, there are over 10,379 Chinese-flagged coastal vessels, regulated by national emissions standards. The much larger size of the Chinese market offers a scale that could justify investment in R&D and development of low-NO_x technologies, as long as stricter regulations are adopted to provide market certainty. China can build on its success by using a similar approach that boosts the market—and dramatically brings down the costs—of other clean energy technologies such as electric vehicles, solar and wind.

- **Clean up in-use vessels by adopting an in-use emission requirement, in conjunction with the launch of pilot programs to demonstrate the feasibility of retrofitting and repowering high-emitting vessels**

The MOT has rolled out incentive programs to accelerate the retirement of old vessels, which have shortened the average inland waterway vessel's service life from about 30 to 15 years. However, 71 percent of in-use inland waterway vessels still have emissions at the pre-control level, exceeding the IMO Tier I level.[92] We recommend adopting an in-use emission requirement for all inland waterway and coastal vessels that uses the strictest emission standards currently in effect. Sufficient lead time should be allowed for vessel owners and engine/aftertreatment manufacturers to prepare for the new requirements.

At the same time, pilot programs could be launched to evaluate and demonstrate the feasibility and benefits of repowering or retrofitting high-emitting inland waterway vessels with advanced NO_x control solutions. Engine repowering and retrofit programs could encourage more vessels to be upgraded, especially those vessels that are still fit for service and whose owners are disinclined to retire. The EU Clean Inland Shipping (CLINSH) project, which offers funding and technical support for retrofitting or repowering in-use ships, and conducts onboard and remote measurement programs to monitor emissions reduction benefits, offers a good example for such pilot programs.[xxix]

- **Mandating zero emissions at berth for all inland waterway vessels**

The amended DECA regulations announced in late 2018 required all new inland waterway vessels constructed on or after January 1, 2019 to be shore-power-capable, and to be connected to shore power when docking at shore-power-capable berths, beginning July 2019. Inland waterway vessels in operation that cannot meet China II emission standards must be retrofitted with shore power equipment by January 1, 2022, and must use shore power whenever feasible.[93] While these two requirements should cover most inland waterway vessels, we recommend expanding the shore power mandate to all inland waterway vessels while they are at berth in ports, and at anchorage areas waiting to pass through dams.[xxx] In light of the high population density of cities along main inland waterways, such as the Yangtze River and the Pearl River, a full-scale shore power mandate can further reduce air pollution and noise nuisance, while also simplifying enforcement.

Shore power infrastructure is now being built at major terminals and anchoring areas at and near the Three Gorge Dam, and at ports along the Yangtze River, Pearl River and Jinghang Canal.[94] All ports along the Yangtze River and its main tributaries are planned to become shore power-capable by 2035.[95] With the build-up of the shore power infrastructure, main inland ports are ready to support a full-scale shore power mandate.

[xxix] CLINSH is a EU-funded project launched for promoting clean inland waterway transport through piloting the use and assessing the emission benefits of clean fuels and emissions control technologies, as well as advancing the use of shore power. The project recruited 42 in-use inland waterway vessels. Half of these vessels already had installed emissions control systems (such as SCR/DPF systems or using marinized Euro VI compliant heavy-duty truck engines), or propulsion systems for using cleaner fuels (electric propulsion, Gas-to-Liquid fuels, biodiesel and LNG). A third of these vessels were refitted with advanced emission control systems or clean fuel/propulsion systems. The rest were vessels with conventional engines using diesel, Gas-to-Liquid or renewable diesel fuel. Onboard emissions monitoring equipment was installed on all the recruited vessels. Onboard measurement and remote measurement campaigns were conducted to evaluate and compare performance of different emissions control solutions. See the CLINSH website (www.clinsh.eu) for more information.

[xxx] There are reports that ships passing through dams in China, such as the Three Gorge Dam, typically have to wait for hours, even days, due to limited lock capacity, resulting in air and noise pollution (see for example https://s0.news.ghwx.com.cn/a.html?aid=6220560191274877952&gid=4616194016101269504).

- **Adopt a long-term zero-emission goal for domestic shipping and devise a long-term strategy to position China as a torchbearer of zero-emission shipping**

In the longer term, zero-emission technologies will be the best solution to improve local air quality and combat the climate crisis. China has launched several pilot projects of low- and zero-emission technologies.[96] Two fully electric vessels, a bulk cargo ship and a river cruise ship, are already in service in China (Appendix IV). These pilots are essential to demonstrate technology feasibility and identify possible technical issues. However, experiences in Europe and the U.S. suggest that widespread deployment of zero-emission technologies face enormous challenges, most notably the higher capital costs of the technologies, and the need to build a network of bunkering infrastructure.

To address these challenges, China can consider adopting a zero-emission goal for selected ship categories where grants are provided to enable the adoption of low-emission solutions. The zero-emission mandate, along with funding support, provides regulatory certainty, and reduces the financial risk of investing in the development of zero-emission marine propulsion and the related refueling/charging infrastructure. Ships that operate near densely populated areas and serve fixed routes, such as ferries and river cruise ships in inland port cities, are the prime targets of a zero-emission mandate, given the higher health benefits and the relative ease of building the refueling/charging infrastructure. These vessels can serve as a test-bed for zero-emission technologies.

China should also contemplate setting a long-term zero-emission goal for domestic shipping to spur innovation in other vessel segments, and devising a longer-term strategy that support the realization of this goal. As a first step, we recommend launching a study to look at the characteristics of different categories of domestic vessels. By examining where they operate, the age of the fleet, and their contribution to carbon emissions, the study could identify emission-free fuel and technology options best suited for each vessel category, and recommend policy instruments to accelerate technology uptake. The study should also explore ways to connect these vessels with zero-emission energy sources in China to ensure they are truly low/zero-emission.

China should also develop a longer-term strategy to advance zero-emission shipping that covers the entire value chain, from shipping companies, shipyards, to fuel/energy providers and ports. Such a strategy should aim at steering stakeholders across the entire value chain toward making shipping emission-free. To ensure actions proposed are well coordinated among various stakeholders, it would be best if the strategy be devised by transport agencies in close collaboration with authorities overseeing industry development and the environment, as well as governments of port cities and provinces, and the shipping industry.

Some European countries anticipate considerable growth in the local and international market for low- and zero-emission solutions in the shipping industry.[97] As a result, substantial government support has been directed to developing zero-emission ferries and cruise ships, as well as zero-emission energy sources, with a view to applying these technologies to seagoing shipping in the future. By setting a zero-emission goal for domestic shipping and laying out a longer-term coordinated action strategy to promote zero-emission shipping, China could drive the R&D and deployment of low- and zero-emission solutions for its large domestic vessel fleet. As China is the world's largest shipbuilding nation, with the world's largest ports, this strategy could also boost the competitiveness of its shipping industry and shipbuilding sector, and position the nation as a global maritime torchbearer in the future, carbon-constrained world.

- **Provide grants and offer emissions-based incentives to support the shipping industry in adopting NO_x emissions control and low/zero-emission maritime solutions, and developing landside fuel infrastructure**

Consider the high initial capital costs of adopting advanced NO_x control systems and low/zero-emission solutions, the government should set aside funding to subsidize initial capital investments on ships and the landside supporting infrastructure. Policymakers could consider setting up special funds for the prevention and control of air pollution targeting shipping (船舶大气污染防治专项基金). Other complementary policies, such as differentiated port dues or tax rates, could also be adopted to accelerate the upgrade or replacement of existing vessels. For instance, in China the vehicle and vessel tax (车船税) is now exempted for "new energy vessels" (e.g., LNG-powered vessels); policymakers can consider modifying the tax rate to be based on the emissions performance of each vessel.

6

FUTURE WORK

Due to the limited scope of this report, a quantitative assessment of the recommended policies (e.g., in terms of cost per ton of emissions reduced) was not included. Such analysis would be useful for comparing the cost-effectiveness of shipping emission-control policies against measures targeting other emission sources, and could be an analysis for supporting the inclusion of these policy recommendations in the 14th Five-Year Plan.

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In devising the long-term strategy for promoting zero-emission shipping, it is also critical to understand the lifecycle air emissions and climate impacts of the assortment of low/zero-emission fuels and propulsion technologies and the potential sources of these fuels in China, in order to select the fuels that offer the best opportunities for emission-free shipping. As an example, LNG has long been considered a "bridge" fuel that could considerably reduce SO_x and particulate emissions and lower carbon and NO_x emissions, but recent studies called into question the lifecycle climate benefits of LNG over diesel fuels if methane leakage during extraction, processing and transport, and methane slip during combustion are fully accounted for.[98] For other fuel options, such as methane, ammonia, electricity and hydrogen, the lifecycle emissions depend on how these fuels are produced. A study that assesses the well-to-tank emissions of various low/zero-emission fuels considering China's specific conditions, especially on renewable energy production, and analyzes issues with integrating the supply and demand of these fuels in China can lay the foundation for devising the country's long-term strategy.

7

CONCLUDING REMARKS

China's key port regions have witnessed considerable improvements in air quality since the DECA regulations required ships to use fuel with a lower sulfur content at berth and near shore. While the effects of DECA regulations are impressive, fuel standards alone can do little to reduce NO_x emissions from shipping, which are central to the formation of secondary particulates and ground level ozone. The policies already in place are also not sufficient to stimulate the uptake of advanced emissions control technologies that can further reduce emissions from ships.

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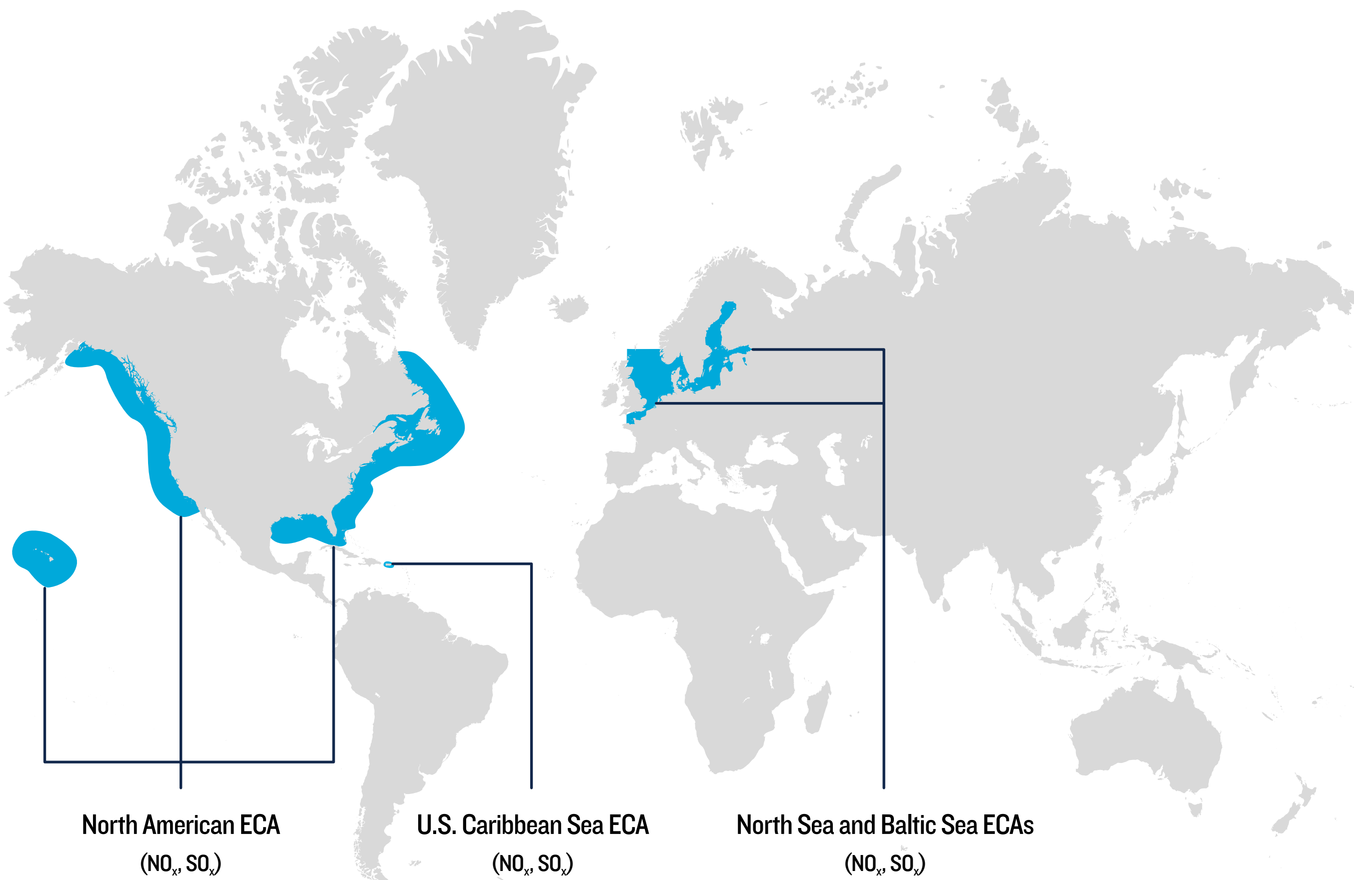
Reviewing the policy experiences abroad, China can start by introducing more stringent controls on domestic vessels, by further tightening emission requirements for new vessels, imposing emission limits on legacy vessels, while at the same time offering incentives and funding support to ease the adoption of low-emission technologies.

Considering the urgency to tackle climate change, and the fact that climate change would exacerbate air pollution in China, the country can benefit from furthering a transition to zero-emission shipping. A transition to zero-emission shipping will not only enable China to meet its clean air and climate goals, but also help the nation maintain its leading position in the global shipbuilding industry, as the global shipping sector strives to achieve the IMO's goal to cut the shipping sector's GHG emissions at least by half before 2050.

Appendix I

Emission Control Areas (ECAs) Designated by the International Maritime Organization



Appendix II
Existing and Adopted Marine Fuel Sulfur Standards in the EU, United States and China[99]

REGION	MARINE FUEL SULFUR REQUIREMENT AND IMPLEMENTATION DATE		
	INLAND WATERWAY VESSELS	DOMESTIC/EU COASTAL VESSELS	OCEANGOING VESSELS
EU	10 ppm (Jan 2011)	1,000 ppm (0.1% sulfur) (Inside ECA and berthing at EU ports: Jan 2015) 5,000 ppm (Passenger ships in EU waters: Jan 2020)	1,000 ppm (Inside ECA and berthing at all EU ports: Jan 2015) 5,000 ppm (Outside ECA: Jan 2020)
United States	15 ppm (CA: Jan 2009; rest of the U.S.: Jun 2012)	15 ppm for Category 1 and 2 engines (California: Jan 2009; rest of the U.S.: Jun 2012) 1,000 ppm for Category 3 engines inside ECA (California: Jan 2014; rest of the U.S.: Jan 2015)	1,000 ppm (Inside ECA: California - Jan 2014; rest of the U.S. - Jan 2015) 5,000 ppm (Outside ECA: Jan 2020)
China[xxxi]	10 ppm (Inland waterway vessel: Jan 2018) (River-sea vessel: Jan 2019)	1,000 ppm (Hainan waters: Jan 2022) 5,000 ppm (Coastal DECA: Jan 2019)	1,000 ppm (River DECA: Jan 2020; Hainan waters: Jan 2022) 5,000 ppm (Coastal DECA: Jan 2019 outside DECA: Jan 2020)

ECA stands for Emission Control Area; CA stands for California; DECA stands for China's Domestic Emission Control Area; the coastal DECA covers China's territorial waters; the river DECA covers the navigable waters of the Yangtze and Xijiang River main lines.

[xxxi] In Hong Kong, China, sulfur in fuel for vessels in domestic trade has been limited to no more than 500 ppm since April 1, 2014. Oceangoing ships that operate within Hong Kong waters have been subject to the same sulfur requirement as the China DECA (5,000 ppm) since January 1, 2019 (*Air Pollution Control [Marine Light Diesel] Regulation Cap 311, S43; Air Pollution Control [Fuel for Vessels] Regulation* Cap 311AB).

Appendix III
Control of Black Smoke from Vessels

Restriction of emissions of black smoke from vessels has been imposed in some regions to indirectly control particulate emissions. The table below summarizes black smoke requirements in effect in regions of the U.S., Europe, and Asia. Black smoke is produced during incomplete combustion, which is the result of insufficient air supply or incorrect fuel injection. The common causes of black smoke emissions include fuel injectors, the air induction system, poor maintenance of air filters, or the incorrect setting of the fuel injection pump or system.[100] Black smoke restrictions are simple to implement, and can encourage better maintenance, though they are not intended as an incentive to upgrade the emission control performance of in-use vessels.

REQUIREMENTS FOR CONTROLLING BLACK SMOKE EMISSIONS FROM VESSELS IN SELECTED REGIONS [101]

REGION/ COUNTRY	COMPLIANCE REQUIREMENT	ASSESSMENT METHOD	RESPONSIBLE AGENCY	PENALTY
Alaska, United States	Opacity of emissions ≤ 20% within 3 miles of coastline[xxxii]	Visual, USEPA Method 9	Trained staff and contracted opacity readers of Alaska Department of Environmental Conservation	US$37,500 per violation (¥263,000)
United Kingdom	No darker than Shade 2	Visual, Ringelmann chart	Local authority	Maximum £5,000 (¥45,200)
Singapore	Excessive soot emission in the opinion of MPA	Unclear	Maritime and Port Authority of Singapore	Maximum S$5,000 (¥25,100)
Hong Kong, China	No darker than Shade 2 (≤ 40% opacity) for 3 minutes	Visual, Ringelmann chart	Marine Department of Hong Kong; accepts reports from the public	Non-local vessel: HK$25,000/50,000 (¥22,600/45,100) Local vessel: HK$10,000/25,000 (¥9,020/22,600)
Qinhuangdao, China	No darker than Shade 2 (≤ 40% opacity) for 3 minutes	Visual, Ringelmann chart	Qinghuangdao Maritime Safety Administration	Non-fishing vessels: ¥3,000-30,000 Fishing vessels: ¥3,000-10,000

MPA stands for Maritime and Port Authority of Singapore.

[xxxii] With exemption to the times when vessels are maneuvering or in port. More information can be found at Alaska Department of Environmental Conservation, "Cruise Ship Air," endnote 101..

Appendix IV

Selected Battery-Electric and Plug-in Hybrid Vessels in Operation

VESSEL NAME	VESSEL TYPE	LOCATION OF OPERATION	ONBOARD BATTERY CAPACITY (kWh)	VESSEL CAPACITY	ROUTE LENGTH (KM)	ENTRY INTO SERVICE
Battery-electric						
Ampere	RoPax (passenger and car) ferry	Norway	1,000	360 passengers, 120 cars	5.7	2015
Future of the Fjords	Cruise ship	Norway	1,800	400 passengers	6.5	2018
Prinses Irene (and 5 other boats) R	River cruise	Amsterdam, The Netherlands	Not available	30 passengers	2 days on one charge	2018
Ellen E-Ferry	RoPax ferry	Denmark	4,300	198/147 passengers (summer/winter), 31 cars or 5 trucks	40.7	2019
Hetun	Bulk cargo	Pearl River, China	2,400	2,000 tonnes (DWT)	NA* (80 km on one charge)	2019
Gee's Bend Ferry R	RoPax ferry	Alabama, U.S.	270	132 passengers, 18 cars	2.8	2019
Junlvhao	River cruise	Wuhan, China	2,280	300 passengers	120	2020
Plug-in hybrid electric						
Viking Energy R	Off-shore service vessel	Norway	653	6,013 tonnes (DWT)	NA*	2015
Vision of the Fjords	Cruise ship	Norway	576	400 passengers	32	2016
Elektra	RoPax ferry	Finland	1,060	375 passengers, 90 cars	1.6	2017
Tycho Brahe R	RoPax ferry	Denmark	4,160	1,200 passengers, 240 cars	4	2018
Aurora R	RoPax ferry	Denmark	4,160	1,200 passengers, 240 cars	4	2018
Enhydra	Ferry (Bay tour)	San Francisco, U.S.	160	600 passengers	1 hour on one charge	2018
Hadaroy	RoPax ferry	Norway	2,900	400 passengers, 120 cars	7.7	2019
Roald Amundsen	Cruise/expedition ship	Polar region	1,750	530 passengers	NA*	2019
Ov Ryvingen	Oil recovery and repair ship	Norway	3,000	460 tonnes (DWT)	NA*	2019
Skopphorn	RoPax ferry	Norway	1,808	399 passengers, 120 cars	3.7	2020
Rovdehorn	RoPax ferry	Norway	1,808	399 passengers, 120 cars	3.7	2020

Authors' compilation of data based on industry news reports. NA denotes not applicable, DWT denotes deadweight tonnage. R represents vessels that are retrofitted.

* Route length does not apply, for these vessels do not serve a fixed route.

List of Abbreviations

CA	California
CARB	California Air Resources Board
CCNR	Central Commission for the Navigation of the Rhine
CHC	Commercial Harbor Craft
CSI	Clean Shipping Index
DECA	Domestic Emission Control Area
DPF	Diesel Particulate Filter
ECA	Emission Control Area
EGR	Exhaust gas recirculation
ESI	Environmental Ship Index
EU	European Union
GHG	Greenhouse gas
HC	Hydrocarbon
HKEPD	Hong Kong SAR Environmental Protection Department
IMO	International Maritime Organization
LNG	Liquefied natural gas
MEE	Ministry of Ecology and Environment of China
MOT	Ministry of Transport of China
MSA	Maritime Safety Administration
NH_3	Ammonia
NO_x	Nitrogen oxides
NOK	Norwegian krone
OGV	Oceangoing vessel
PM	Particulate matter
$PM_{2.5}$	Fine particles
ppm	Parts per million
Ropex	Passenger and car vessels
SCR	Selective catalytic reduction
SO_2	Sulfur dioxide
SO_x	Sulfur oxides
UK	United Kingdom
U.S.	United States

Endnotes

1. Tatsuo Takaishi et al., "Approach to High Efficiency Diesel and Gas Engines," *Mitsubishi Heavy Industries Technical Review 45*, No.1 (2008).

2. Mingliang Fu et al., "National- to Port-Level Inventories of Shipping Emissions in China," *Environmental Research Letters* 12, No.11 (2017), https://doi.org/10.1088/1748-9326/aa897a.

3. Ministry of Transport (MOT), *Highway and Waterway Transport Development Statistics Report* (公路水路交通运输行业发展统计公报), 2003-2012, *[in Chinese]*, http://www.mot.gov.cn/fenxigongbao/hangyegongbao/201510/t20151013_1894759.html. MOT. *Transportation Industry Development Statistics Reports* (交通运输行业发展统计公报), 2013-2018, *[in Chinese]*, http://zizhan.mot.gov.cn/zfxxgk/bnssj/zhghs/201803/t20180329_3005087.html.

4. General Office of the State Council, "Notice from the General Office of the State Council of China Regarding the Release of the 3-year Action Plan (2018-2020) for Promoting the Adjustment of Transportation Structure (国务院办公厅关于印发推进运输结构调整三年行动计划 (2018-2020年) 的通知)," September 17, 2018, [in Chinese], http://www.gov.cn/zhengce/content/2018-10/09/content_5328817.htm (accessed June 20, 2019).

5. Yang Zhang *et al., Impacts of Shipping on Air Pollutant Emissions, Air Quality, and Health in the Yangtze River Delta and Shanghai, China,* Special Report 22, Boston, MA: Health Effects Institute, 2019, https://www.healtheffects.org/publication/impacts-shipping-air-pollutant-emissions-air-quality-and-health-yangtze-river-delta. Chen Chen et al., "Ship Emission Impacts on Air Quality and Human Health in the Pearl River Delta (PRD) Region, China, in 2015, with Projections to 2030," GeoHealth 3, Issue 9 (July 2019), https://doi.org/10.1029/2019GH000183.

6. Zhaofeng Lv *et al.,* "Impacts of Shipping Emissions on $PM_{2.5}$ Pollution in China," *Atmospheric Chemistry and Physics* 18 (2018): 15811–15824, https://doi.org/10.5194/acp-18-15811-2018.

7. Huan Liu *et al.,* "Health and Climate Impacts of Ocean-Going Vessels in East Asia," *Nature Climate Change* 6 (2016): 1037–1041, https://doi:10.1038/NCLIMATE3083.

8. Zhang et al., *Impacts on Shipping,* endnote 5. Chen et al., "Ship Emission Impacts," endnote 5.

9. Dashan Jia, Yongbo Ji and Fangfang Jiao, "Rigorously Advance Ship Standardization and Promote High Quality Development of Inland Ships (大力推进船舶标准化 促进内河船舶高质量发展)," *China Waterborne Transport Magazine* 7 (2019), [in Chinese], https://new.qq.com/rain/a/20190816A05B68 (accessed January 29, 2020).

10. Zihang Peng et al., "Emissions from Several Ships Tested by Portable Emission Measurement System," *Ocean Engineering* 116 (2016): 260–267, http://dx.doi.org/10.1016/j.oceaneng.2016.02.035.

11. Yongxian Liang et al., "Estimation of Air Pollution from Vessels at Shenzhen Port," *Environmental Science Survey* 2 (2016), *[in Chinese]*, http://www.cnki.com.cn/Article/CJFDTotal-YNHK201602006.htm. HKEPD, *Hong Kong Air Pollutant Emission Inventory – 2017 Emission Inventory,* 2019, https://www.epd.gov.hk/epd/english/environmentinhk/air/data/emission_inve.html (accessed July 18, 2019). Junlan Feng *et al.,* "The Influence of Spatiality on Shipping Emissions, Air Quality and Potential Human Exposure in the Yangtze River Delta/Shanghai, China," *Atmospheric Chemistry and Physics* 19 (2019): 6167–6183, https://doi.org/10.5194/acp-19-6167-2019. Dongsheng Chen *et al.,* "Estimating Ship Emissions Based on AIS Data for Port of Tianjin, China," Atmospheric Environment 145 (2016): 10-18, http://dx.doi.org/10.1016/j.atmosenv.2016.08.086. Cheng Li et al., "An AIS-based High-Resolution Ship Emission Inventory and its Uncertainty in Pearl River Delta Region, China," Science of the Total Environment 573 (2016): 1-10, https://doi.org/10.1016/j.scitotenv.2016.07.219. Cheng Li et al., "Decadal Evolution of Ship Emissions in China from 2004 to 2013 by Using an Integrated AIS-based Approach and Projection to 2040," *Atmospheric Chemistry and Physics* 18 (2018): 6075–6093, https://doi.org/10.5194/acp-18-6075-2018. Zhang et al., *Impacts on Shipping,* endnote 5.

12. HKEPD, *Hong Kong Air Pollutant Emission Inventory,* endnote 11.

13. MOT, "MOT Notice Regarding the Implementation Plan of the Shipping Emission Control Area of the Pearl River Delta, Yangtze River Delta and Bohai Rim (Jing Jin Ji) (交通运输部关于印发珠三角、长三角、环渤海(京津冀)水域船舶排放控制区实施方案)," The Ministry of Transport of China (MOT), December 2, 2015, *[in Chinese],* http://www.gov.cn/xinwen/2015-12/04/content_5019932.htm. MOT, "Notice Released by MOT Regarding the Release of the Implementation Plan for the Shipping Air Emission Control Area (交通运输部关于印发船舶大气污染物排放控制区实施方案的通知), MOT, November 30, 2018, [in Chinese], https://www.msa.gov.cn/public/documents/document/mtel/nzey/~edisp/20181210115712685.pdf.

14. Zhiqiang Liu, "Setting up Shipping Emission Control Area, Switch to Clean Fuel: Substantial Reductions in Shipping Emissions (设立船舶排放控制区，改用清洁能源：船舶减排 大气减负)," *People's Daily,* July 18, 2019 *[in Chinese]*, http://city.huanqiu.com/csyw/2019-07/15159290.html?agt=15422 (accessed August 29, 2019). This refers to the change in ambient SO_2 concentration at the largest ports in China from 2016 to 2017.

15. Liu *et al.,* "Health and Climate Impacts," endnote 7. Oceangoing vessels registered in China accounted for 11 percent of CO_2 emissions from shipping in the South China Sea, less than 10 percent in the East Sea and 31 percent in the Bohai Sea in 2013. As CO_2 emissions are roughly proportional to fuel consumption, the low percentage of the CO_2 contribution of China-flagged ships in the South China, East and Bohai seas suggests that the DECA NO_x requirements applying to China-flagged ships would likely impact only a small fraction of ships visiting China.

16. Fu *et al.,* "National- to Port-Level Inventories," endnote 2, Figure 2c.

17. Xiao Lu *et al.,* "Severe Surface Ozone Pollution in China: A Global Perspective," *Environmental Science and Technology Letters* 5, 8 (2018): 487-494, https://doi.org/10.1021/acs.estlett.8b00366. Daniel M. Westervelt et al., "Mid-21st Century Ozone Air Quality and Health Burden in China Under Emissions Scenarios and Climate Change," *Environmental Research* Letters 14, No.7 (2019), https://doi.org/10.1088/1748-9326/ab260b.

18. IACCSEA, "IACCSEA – A Catalyst for Clean Shipping", International Association for Catalytic Control of Ship Emissions to Air (IACCSEA) website, https://www.iaccsea.com/ (accessed February 5, 2020).

19. International Maritime Organization (IMO), "MEPC 65th Session Agenda Item 4 – Final Report of the Correspondence Group on Assessment of Technological Developments to Implement the Tier III NO_x Emission Standards Under MARPOL Annex VI (MEPC 65/4/7)," London, UK: IMO, February 8, 2013. J. Gibson and O. Groene, "Selective Catalytic Reduction on Marine Diesel Engines," *Automotive Engineering* (October 1991): 18-22.

20. Malcolm Latarche, "In Service Experience of Tier III EGR Systems." ShipInsight, September 22, 2015, https://shipinsight.com/articles/in-service-experience-of-tier-iii-egr-systems (accessed April 5, 2019). IMO, "Comments to the Approval at MEPC 65 of Amendments to the Effective Date of the NO_x Tier III Standards," MEPC 66th Session, Agenda Item 6, London, UK: IMO, December 24, 2013.

21. DNV GL, "DNV-GL NO_x Tier III Update – Choices and Challenges for On-Time Compliance," https://www.dnvgl.com/maritime/publications/NOx-TIER-3-Update-download.html?cookie-consent=1 (accessed April 10, 2019). DNV GL, "Alternative Fuels Insight," https://afi.dnvgl.com/ (accessed February 9, 2020).

22. MAN Diesel & Turbo, *Technology for Ecology: Medium Speed Engines for Cleaner Air,* https://marine.man-es.com/docs/default-source/shopwaredocuments/technology-for-ecologyb574f4e240cb4e5e84e04fcd-258d3c0d.pdf?sfvrsn=babfbabl_5 (accessed April 28, 2019). DNV GL, "DNV-GL NO_x Tier III Update," endnote 21.

23. Ioannis Bakas, "Principles of Marine Main Engines Running on LNG," in *On the Mos Way Network – Module #5 – Propulsion and Power Generation Training of LNG Driven,* October 27, 2015, https://www.onthemosway.eu/on-the-mos-way-network-module-5-propulsion-and-power-generation-training-of-lng-driven-vessel/ (accessed February 5, 2020). DNV GL, "DNV-GL NO_x Tier III Update," endnote 21.

24. DNV GL, "Alternative Fuels Insight," endnote 21.

25. Hulda Winnes et al., "NO_x Controls for Shipping in EU Seas," IVL and CE Delft Report Commissioned by Transport and Environment, 2016. Maritime Knowledge Centre, TNO and TU Delft, *Methanol as an Alternative Fuel for Vessels - Public Final Report,* January 15, 2018, https://platformduurzamebiobrandstoffen.nl/wp-content/uploads/2018/02/2018_MKC_TNO-TU-Delft_Methanol-as-an-alternative-fuel-for-vessels.pdf.

26. IMO, "MEPC 65th Session," endnote 19.

27. See Vincent Wee, "New Port of Rotterdam App Cuts Waiting Time by 20%, Reduces CO_2 Emissions," *Seatrade Maritime News,* May 23, 2018, https://www.seatrade-maritime.com/europe/new-port-rotterdam-app-cuts-waiting-time-20-reduces-co2-emissions. Edwin Lopez, "Port Optimizer Gives Cargo Owners 2 Weeks More Notice, Long Beach Pilot Finds," Supply Chain Dive website, November 9, 2018, https://www.supplychaindive.com/news/Long-Beach-GE-Port-Optimizer-pilot/541877/ (accessed February 3, 2020).

28. Kjeld Aabo and Michael Witt, "MAN B&W 2-stroke Engines – Ocean Going Vessels Retrofit Technology," presented at the Ocean Going Vessels Retrofit Technology Forum, Los Angeles, CA, December 5, 2018, http://www.aqmd.gov/docs/default-source/ocean-going-vessels/ogv-

technology-forum---website-slides---2018-12-05.pdf. CIMAC, "Guide to Diesel Exhaust Emissions Control of NO_x, SO_x, and Particulates, Smoke and CO_2 – Seagoing Ships and Large Stationary Diesel Power Plants," 2008, https://www.cimac.com/cms/upload/Publication_Press/Recommendations/Recommendation_28.pdf. IACCSEA, "The Technical and Operational Capabilities of Marine Selective Catalytic Reduction," https://www.iaccsea.com/wp-content/uploads/2018/12/IACCSEA-Marine-SCR-Technical-and-operational-capabilities-2013.pdf (accessed March 2, 2020). Elizabeth Lindstad and Agathe Rialland, "LNG and Cruise Ships, an Easy Way to Fulfill Regulations—Versus the Need for Reducing GHG Emissions", *Sustainability,* Vol. 12 (2020), doi:10.3390/su12052080. W. Addy Majewski, "Selective Catalytic Reduction," Dieselnet Technology Guide, 2005, https://dieselnet.com/tech/cat_scr.php (accessed October 2, 2018). MAN Energy Solutions, "MAN B&W Two-stroke Marine Engines Emission Project Guide for Marpol Annex VI Regulations, 9th Edition," MAN Energy Solutions, Copenhagen, Denmark, 7020-0145-09, (2018), https://marine.man-es.com/applications/projectguides/2stroke/content/special_pg/7020-0145-09_uk.pdf. WinGD, "Selective Catalytic Reduction FAQ," 2018, https://www.wingd.com/en/documents/general/brochures/scr-technology-faq.pdf/ (accessed April 10, 2019). MAN Diesel & Turbo, Technology for Ecology, endnote 22. IMO, "MEPC 65th Session," endnote 19. DNV GL, "DNV-GL NO_x Tier III Update," endnote 21.

29. Daniel Chatterjee and Klaus Rusch, *SCR Technology for Off-highway (Large Diesel Engine) Applications, Urea-SCR Technology for deNO$_x$ After Treatment of Diesel Exhausts,* I. Nova and E. Tronconi (eds.), 2014, https://doi: 10.1007/978-1-4899-8071-7_2. W. Addy Majewski, "Diesel Particulate Filters," Dieselnet Technology Guide, 2019, https://dieselnet.com/tech/dpf.php (accessed December 3, 2019). DECSE, "Diesel Emission Control Sulfur Effects Program: Phase I Interim Report No. 4," U.S. Department of Energy, Engine Manufacturers Association, and the Manufacturers of Emission Controls Association, January 2000, https://www.osti.gov/biblio/755351-diesel-emission-control-sulfur-effects-decse-program-phase-interim-data-report-diesel-particulate-filters-final-report. MAN Diesel & Turbo, "Tier III Two-Stroke Technology," August 2012, https://marine.mandieselturbo.com/docs/librariesprovider6/technical-papers/tier-iii-two-stroke-technology.pdf?sfvrsn=18. MAN Energy Solutions, "MAN B&W Two-stroke Marine Engines," endnote 28.

30. Chatterjee and Rusch, SCR Technology, endnote 29. DNV GL, "DNV-GL NO_x Tier III Update," endnote 21.

31. Dieselnet, "United States: Marine Diesel Engines," 2011, https://dieselnet.com/standards/us/marine.php (accessed February 6, 2020). Dieselnet, "EU: Nonroad Engines," 2016, https://dieselnet.com/standards/eu/nonroad.php (accessed February 6, 2020).

32. Dieselnet, "United States," endnote 31.

33. VDMA, "Exhaust Emission Legislation: Diesel and Gas engines," VDMA Engines and Systems, 2017, http://www.musvdma.org/emission (accessed February 8, 2020).

34. EUROMOT and CESNI, "Inland Waterways Transport Sector – Frequently Asked Questions," 2019, https://www.cesni.eu/wp-content/uploads/2018/11/FAQ_Engines_en.pdf (accessed April 11, 2020). CESNI, 2019. European Standard Laying Down Technical Requirements for Inland Navigation Vessels, European Committee for Drawing up Standards in the Field of Inland Navigation (CESNI), https://www.cesni.eu/wp-content/uploads/2018/12/ES_TRIN_2019_en.pdf.

35. Maritime Safety Administration (MSA), "Rules for Statutory Inspection of Ships and Offshore Equipment - Technical Regulations for Statutory Inspection of Inland Ships," 2011 *[in Chinese]*. Maritime Safety Administration (MSA), "Rules for Statutory Inspection of Ships and Offshore Equipment - Technical Regulations for Statutory Inspection of Inland Ships, Notice of 2015 Amendments," 2014 *[in Chinese]*.

36. California Air Resources Board (CARB), "Overview of Commercial Harbor Craft Regulation," May 2016, https://ww2.arb.ca.gov/sites/default/files/2019-03/chcfactsheet0516.pdf.

37. Ibid.

38. CARB, "Compliance Guidelines for the Commercial Harbor Craft Regulation," 2017, https://ww2.arb.ca.gov/sites/default/files/2019-03/complianceguidelines021017.pdf.

39. CARB, "Presentation at the Public Workshop to Discuss Additional Requirements for the Commercial Harbor Craft (CHC) Regulation," presented at CARB CHC public workshop, Long Beach, December 4, 2018, https://www.arb.ca.gov/ports/marinevess/harborcraft/presentations/chc120418pres.pdf.

40. Ibid.

41. Christa Sys and Thierry Vanelslander (edited), *Future Challenges for Inland Navigation: a Scientific Appraisal of the Consequences of Possible Strategic and Economic Developments Up to 2030,* Antwerp : University Press Antwerp, 2011.

42. VDMA, "Exhaust Emission Legislation," endnote 33.

43. Jarl Schoemaker of Port of Rotterdam Authority, personal communications via email, April 30, 2020

44. Helge Hermundsgård "Norway Challenges the Cruise Industry to Operate Emission Free," *DNV GL Maritime Impact – Our expertise in stories,* February 25, 2019, https://www.dnvgl.com/expert-story/maritime-impact/Norway-challenges-the-cruise-indtry-to-operate-emission-free.html (accessed March 31, 2019).

45. Paul Hockenos, "Guilt-Free on the Sea," *Hakai Magazine,* September 18, 2018, https://www.hakaimagazine.com/features/guilt-free-sea/?x-id=PS_smithsonian (accessed April 19, 2019).

46. CARB, "Public Hearing to Consider the Proposed Control Measure for Ocean Going Vessels at Berth – Staff Report: Initial Statement of Reasons," October 15, 2019, https://ww3.arb.ca.gov/regact/2019/ogvatberth2019/isor.pdf.

47. City of Rotterdam, "2010 Rotterdam Port Management Bye-Laws (version: March 2018)," Articles 4.6 and 4.7 (2018), https://www.portofrotterdam.com/sites/default/files/rotterdam_port_management_bye-laws.pdf.

48. Peter Mollema, "LNG and Shore Power," presented at NRDC Port and Shipping Emission Control Roadshow, September 21-25, 2015. The mobile app can be accessed at: https://www.parklineaqua.nl/.

49. NO_x Fund, "New Rates of Payment From 2020," The NO_x Fund website, October 15, 2019, https://www.nho.no/samarbeid/nox-fondet/the-nox-fund/news/new-rates-of-payment-from-2020/ (accessed December 10, 2019).

50. DNV GL, "Technical advisory for the Norwegian NO_x Fund," https://www.dnvgl.com/maritime/advisory/technical-advisory-norwegian-nox-fund.html?cookie-consent=1 (accessed December 10, 2019).

51. NO_x Fund, "New Support Rates and Conditions for NO_x Reducing Measures," The NO_x Fund website, 2018, https://www.nho.no/samarbeid/nox-fondet/the-nox-fund/news/new-support-rates-and-conditions-for-nox-reducing-measures/ (accessed June 18, 2019). NO_x Fund, "Adjustment in Support Conditions," The NO_x Fund website, September 3, 2019.

52. Alvar Mjelde and Øyvind Endresen. "Air Emissions from Shipping in the ASEAN Region," *Report for Norwegian Maritime Authority,* DNV GL, Norway, 2018, https://d333mq0i40sk06.cloudfront.net/documents/Air-Emissions-from-Shipping-In.pdf.

53. DNV GL, "Alternative Fuels Insight," endnote 21.

54. NO_x Fund, *Annual Report 2017,* 2018, Figure 11 [in Norwegian], https://www.nho.no/siteassets/nox-fondet/rapporter/2018/nox-fondet-arsrapport-2017_oppslag.pdf (accessed February 28, 2020).

55. Renilde Becqué, Freda Fung and Zhixi Zhu, "Incentive Schemes for Promoting Green Shipping," NRDC, January 2018, https://assets.nrdc.org/sites/default/files/incentive-schemes-promoting-green-shipping-ip.pdf.

56. Per Kågeson, *Market-based Instruments for NO_x abatement in the Baltic Sea,* A Report for Air Pollution and Climate Secretariat (AirClim), the European Environmental Bureau (EEB) and the European Federation for Transport and Environment (T&E), 2009.

57. Tobias Lindé and Inge Vierth, "An Evaluation of the Environmentally Differentiated Fairway Dues in Sweden 1998–2017," VTI, 2018, http://vti.diva-portal.org/smash/get/diva2:1186525/FULLTEXT01 (accessed April 27, 2019).

58. Selma Brynolf et al., "Compliance Possibilities for the Future ECA Regulations Through the Use of Abatement Technologies or Change of Fuels," *Transportation Research Part D,* 28 (2014): 6-18.

59. Port of Rotterdam, "General Terms and Conditions – Including Port Tariffs, Annex I," 2019, https://www.portofrotterdam.com/sites/default/files/general_terms_and_conditions_including_port_tariffs_2019.pdf?token=7KUIF2MH (accessed April 1, 2019). Jarl Schoemaker of Port of Rotterdam Authority, personal communications via email, April 30, 2020. The 100% discount is intended to be temporary to stimulate innovations, though an end date has not been specified.

60. Schoemaker, Jarl, "Sustainable Shipping: Air Quality, Climate Change and Energy Transition," presented at the MOT Transportation Planning and Research Institute Study Tour, Rotterdam, October 13, 2017.

61. Port of Rotterdam, "General Terms," endnote 59.

62. Port of Rotterdam, "ESI Discount," Port of Rotterdam website, https://www.portofrotterdam.com/en/shipping/sea-shipping/port-dues/discounts-on-port-dues/esi-discount (accessed February 9, 2020).

63. Port of Rotterdam, "General Terms," endnote 59.

64. A.P. Møller - Mærsk A/S, *2018 Sustainability Report,* 2019, https://investor.maersk.com/static-files/57bf2e50-075d-49f2-a94c-129e68e407cc

65. Norwegian Government, *The Government's Action Plan for Green Shipping,* June 20, 2019, https://www.regjeringen.no/contentassets/2ccd2f4e14d44bc88c93ac4effe78b2f/the-governments-action-plan-for-green-shipping.pdf.

66. Ibid.

67. Statistics Norway, "Electricity," Statistics Norway webpage, 2019, https://www.ssb.no/en/elektrisitet (accessed December 19, 2019).

68. Norwegian Government, *The Government's Action Plan,* endnote 65.

69. Norwegian Government, *The Government's Action Plan,* endnote 65.

70. Hyon AS and Enova SF, "Grants for Fuel-Cell R&D Maritime Transport Projects in Norway," *NGV Global News,* December 14, 2018, https://www.ngvglobal.com/blog/grants-for-fuel-cell-rd-maritime-transport-projects-in-norway-1214 (accessed April 8, 2019). Trond Moengen, "Commitments Through PILOT-E in 2018 Are Clear," Enova website, https://www.enova.no/pilot-e/tilsagn-gjennom-pilot-e-i-2018-er-klare/ (accessed April 8, 2019).

71. Enova, *Annual Report 2018,* 2019, https://www.enova.no/about-enova/ (accessed December 11, 2019). Andreas Fjærvoll Larsen and Elise Dale, "Support Schemes for Green and Sustainable Shipping in Norway," Wikborg Rein, September 13, 2018, https://www.wr.no/en/news/publications/green-shipping/support-schemes-for--green-and-sustainable-shipping-in-norway/.

72. Norwegian Government, *The Government's Action Plan,* endnote 65.

73. Norwegian Ministry of Petroleum and Energy, "Enova," Energy Facts Norway website. https://energifaktanorge.no/en/et-baer-ekraftig-og-sikkert-energisystem/enova/. Hyon AS and Enova SF, "Grants for Fuel-Cell," endnote 70. Moengen, "Commitments Through PILOT-E," endnote 70.

74. Norwegian Government, *The Government's Action Plan,* endnote 65.

75. Larsen and Dale, "Support Schemes," endnote 71.

76. Miljøkommune, "Climate Bet – Support for Climate Action in the Municipalities (Klimasats - støtte til klimasatsing i kommunene)," 2019 *[in Norwegian]*, http://www.miljokommune.no/Temaoversikt/Klima/Klimasats--stotte-til-klimasatsing-i-kommunene/ (accessed December 17, 2019). Norwegian Government, The Government's Action Plan, endnote 65.

77. Kristin Ystmark Bjerkan et al., "Governance in Maritime Passenger Transport: Green Public Procurement of Ferry Services," *World Electric Vehicle Journal,* 10(4), 74 (2019), https://doi.org/10.3390/wevj10040074

78. Daniel Bjarmann-Simonsen, "Norway – Pioneering Sustainable Shipping," presented at the Maritime Battery Forum Conference, March 7, 2018. https://www.regjeringen.no/no/aktuelt/watts-up/id2593310/ (accessed April 8, 2019). Marie Launes, "Norwegian Parliament Adopts Zero-Emission Regulations in the Fjords", Norwegian Centers of Expertise, May 3, 2018, https://maritimecleantech.no/2018/05/03/norwegian-parliament-adopts-zero-emission-regulations-fjords/. Norwegian Government, *The Government's Action Plan,* endnote 65.

79. Government of the Netherlands, "Sector and Governments Joining Forces to Promote Clean Inland and Sea Shipping," June 16, 2019, https://www.government.nl/latest/news/2019/06/14/sector-and-governments-joining-forces-to-promote-clean-inland-and-sea-shipping (accessed January 15, 2020). CLINSH, "Dutch Government Provides €79 Million for Retrofitting Inland Navigation," April 29, 2020, https://www.clinsh.eu/news.html?read=61-dutch-government-provides-79-million-for-retrofitting-inland-navigation (accessed May 26, 2020).
Green Deals, "GD230 Green Deal on Maritime and Inland Shipping and Ports", November 22, 2019, https://www.greendeals.nl/sites/default/files/2019-11/GD230%20Green%20Deal%20on%20Maritime%20and%20Inland%20shipping%20and%20Ports.pdf (accessed June 26, 2020).

80. Port of Rotterdam, "Incentive Scheme Climate-Friendly Shipping Launched," January 21, 2019, https://www.portofrotterdam.com/en/news-and-press-releases/incentive-scheme-climate-friendly-shipping-launched (accessed May 21, 2020).

81. Shore Power Calandkanaal, "Shore Power in the Calandkanaal in Rotterdam Will Drastically Reduce Local Emissions and Noise," 2020, https://www.walstroom.nu/ (accessed May 26, 2020).

82. Port of Rotterdam, "Shore Power Trial for Coasters in Rotterdam," Press Release, December 16, 2019, https://www.portofrotterdam.com/en/news-and-press-releases/shore-power-trial-for-coasters-in-rotterdam (accessed May 26, 2020). Green Port, "Shore Power Trial for Coasters in Rotterdam," December 18, 2019, https://www.greenport.com/news101/energy-and-technology/shore-power-trial-for-coasters-in-rotterdam (accessed May 21, 2020).

83. WPSP, "World Ports Climate Action Program," World Ports Sustainability Program (WPSP) website, https://sustainableworldports.org/world-ports-climate-action-program/ (accessed May 21, 2020).

84. Matthew Wall, "How Amsterdam's Canal Boats are Going Electric – at a Cost," *BBC News,* October 9, 2018, https://www.bbc.com/news/business-45783085 (accessed January 30, 2020).

85. Netherlands Enterprise Agency, *Electromobility in the Netherlands* – Highlights 2015, 2016. https://www.rvo.nl/sites/default/files/2016/07/Brochure percent20Electromobility percent20Engels.pdf

86. Municipality of Amsterdam, *Clean Air Action Plan (Actieplan Schone Lucht)*, April 2019, [in Dutch] file:///Users/Freda_Fung/Downloads/actieplan_schone_lucht_2019.pdf.

87. Toby Sterling, "Amsterdam's Boats Go Electric Ahead of 2025 Diesel Ban", *Reuters,* March 3, 2020, https://www.reuters.com/article/us-climate-change-netherlands/amsterdams-boats-go-electric-ahead-of-2025-diesel-ban-idUSKBN20Q1W7.

88. UK Department for Transport, *Clean Maritime Plan,* London, UK, 2019, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf.

89. Government of the People's Republic of China (PRC), *The People's Republic of China Third National Communication on Climate Change,* December 2018, https://unfccc.int/sites/default/files/resource/China%203NC_English_0.pdf (accessed January 31, 2020). Chaopeng Hong et al., "Impacts of Climate Change on Future Air Quality and Human Health in China," *PNAS* 116, No. 35 (2019):17193-17200, https://doi.org/10.1073/pnas.1812881116.

90. VBW (Association for European Inland Navigation and Waterways), "VBW and VSM Welcome Initiative of the Federal Ministry of Transport (BMVI) for the Approval of EURO VI and NRE Engines for Inland Waterway Vessels," VBW Press Release, November 5, 2018, *[in German]* https://www.vbw-ev.de/en/275-vbw-und-vsw-begruessen-initiative-des-bundesver-kehrsministeriums-bmvi-zur-zulassung-von-euro-vi-und-nre-motoren-fuer-binnenschiffe.html (accessed April 20, 2019).

91. MOT, "2018 Transport Industry Development Statistics Announcement (2018年交通运输行业发展统计公布)," April 2, 2018 *[in Chinese]*, http://www.chinahighway.com/article/63052.html (accessed June 22, 2019). STC-NESTRA, "D6.8 Roll-Out Plan for Innovative Greening Technologies and Concepts," Report for PROMINENT project, April 27, 2018.

92. Jia et al., "Rigorously Advance Ship Standardization," endnote 9.

93. MOT, "Notice Released by MOT," endnote 13.

94. State Grid, "Shore Power at Port Outlines the Picture of a Green Yangtze (港口岸电 描绘绿色长江新画卷)," State-owned Assets Supervision and Administration Commission of the State Council website, August 16, 2018 *[in Chinese]*, http://www.sasac.gov.cn/n2588025/n2588159/c9379452/content.html (accessed February 13, 2020). International Energy Network, "Six Ministries Announcing the Division of Labor and Timeline to Further Advance Shore Power Usage (六部委进一步推进船舶靠港使用岸电工作任务分工及完成时限)," International Energy Network website, January 28, 2019 [in Chinese], https://www.in-en.com/article/html/energy-2277582.shtml (accessed February 13, 2020).

95. MOT, "MOT's Opinion on Advancing High Quality Development of Yangtze River Maritime Transport (交通运输部关于推进长江航运高质量发展的意见)," July 1, 2019 *[in Chinese]*, http://xxgk.mot.gov.cn/jigou/syj/201907/t20190709_3222903.html (accessed January 31, 2020).

96. CPSIA, "Hetun Battery Electric Cargo Ship Completed Trial Voyage Early This Year, with a Range of 80 km (今年年初,"河豚"号纯电动船舶试航行,续航力可达80公里)," *China Innovation Strategic Alliance of Lithium Ion Power System Industrial Technology (CPSIA)*, March 12, 2019 [in Chinese], http://www.elecfans.com/d/883983.html (accessed February 20, 2020). China Battery Network, "EVE Energy and China Ship Propulsion Research Institute signed agreement to jointly promote new energy vessel development (亿纬锂能与中船动力研究院签约 共同推进新能源船舶发展)," December 5, 2019, *[in Chinese]*, https://finance.sina.com.cn/stock/relnews/cn/2019-12-05/doc-iihnzhfz3733222.shtml (accessed February 20, 2020).

97. Norwegian Government, The Government's Action Plan, endnote 65. UK Department for Transport, Clean Maritime Plan, endnote 88.

98. Nikita Pavlenko, Bryan Comer, Yuanrong Zhou, et al., *The Climate Implications of Using LNG as a Marine Fuel*, ICCT Working Paper 2020-02, 2020, https://theicct.org/publications/climate-impacts-LNG-marine-fuel-2020. Lindstad and Rialland, "LNG and Cruise Ships," endnote 28.

99. European Council Directive 2012/33/EU (2012). European Council Directive 2009/30/EU (2009). California Code of Regulations § 93118.5 (2006). *United States Code* §80.510, (c) and (k). MOT, "Notice Released by MOT," endnote 13.

100. W. Addy Majewski and Magdi K. Khair, *Diesel Emissions and Their Control*, SAE International, USA, 2006. Mohit Sanguri, "Causes of Marine Diesel Engine Exhaust Black Smoke from Funnel," Bright Hub Engineering website, https://www.brighthubengineering.com/marine-engines-machinery/66725-black-smoke-from-the-funnel-what-to-do/ (accessed December 9, 2019).

101. Alaska Department of Environmental Conservation, "Cruise Ship Air," https://dec.alaska.gov/water/cruise-ships/cruise-air/ (accessed December 9, 2019). United Kingdom *Clean Air Act 1993, Section 44*, 1993, https://www.legislation.gov.uk/ukpga/1993/11/section/44. Hong Kong Marine Department, "Control of Dark Smoke Emission from Vessels. Maritime Department Notice No. 92 of 2014," 2014, https://www.mardep.gov.hk/en/notices/pdf/mdn14092.pdf. Maritime and Port Authority of Singapore, "Control of Smoke Emission by Vessels in Port," *Port Marine Circulars* No. 5 (2018), https://www.mpa.gov.sg/web/portal/home/port-of-singapore/circulars-and-notices/port-marine-circulars/detail/6b8b3ece-ff98-4bb4-88ae-d3246e5dbd3b. Qinhuangdao City Government, "Interim Measures for the Prevention and Control of Air Pollution from Vessels in Qinhuangdao (秦皇岛市船舶大气污染防治暂行办法)," November 8, 2019 *[in Chinese]*, http://www.qhd.gov.cn:81/article/314/111394.html (accessed December 9, 2019).

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