TECHNICAL BRIEF

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Updating marine engine emission standards using real-world data: A potential update to IMO's NO_x technical code

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In a recent submission to the International Maritime Organization's (IMO) Marine Environment Protection Committee, several member states proposed reviewing and revising the NO_x Technical Code 2008 (NTC 2008), which is used to certify that marine engines comply with regulatory limits on emissions of nitrogen oxides (NO_x).[1] They pointed to evidence that newer marine engines have higher NO_x emission rates (the difference is statistically significant) than older engines. Some researchers have posited that the NTC 2008's test cycles contribute to this problem, particularly because of their lack of a low-load test point for most engines and their weighting factors, which do not represent how most engines are operated in the real world. A review and revision of the NTC 2008 would present an opportunity to use real-world data about how engines are operated to guide policymakers. The NTC test cycles will also likely be used to determine methane and nitrous oxide emissions in the future, as the IMO is preparing to regulate greenhouse gas (GHG) emissions from ships. This brief presents new analysis that uses Automatic Identification System (AIS) data to estimate real-world engine load distributions and then suggests new NTC engine load test points and weighting factors.

BACKGROUND

The IMO regulates NO_x emissions from marine engines in MARPOL Annex VI Regulation 13, as shown in Table 1.

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[1] International Maritime Organization (IMO), "Proposal for a New Output to Amend MARPOL Annex VI and the NO_x Technical Code 2008, Submitted by Belgium, Canada, Denmark, Finland, Germany, Ireland, Netherlands (Kingdom of the), Norway and United States," document number MEPC 82/14/1, Marine Environment Protection Committee, June 28, 2024, available at docs.imo.org.

Table 1

IMO NO_x regulations for marine engines

Tier	Ship constructed on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n < 130	n = 130 – 1,999	n ≥ 2,000
I	January 1, 2000	17.0	45·n(-0.2) e.g., 720 rpm – 12.1	9.8
II	January 1, 2011	14.4	44·n(-0.23) e.g., 720 rpm – 9.7	7.7
III ***In the North American and the United States Caribbean Sea ECAs***	January 1, 2016	3.4	9·n(-0.2) e.g., 720 rpm – 2.4	2.0
III ***In the North Sea and the Baltic Sea ECAs***	January 1, 2021	3.4	9·n(-0.2) e.g., 720 rpm – 2.4	2.0

Source: IMO MARPOL Annex VI Regulation 13, https://www.imo.org/en/OurWork/Environment/Pages/Nitrogen-oxides-(NOx)-%E2%80%93-Regulation-13.aspx; ECA is Emission Control Area.

The procedures for certifying that engines comply with Regulation 13 are described in the NTC 2008.[2] Emissions are measured on a test cycle and most main engines are certified on the E2 or E3 test cycle; these apply to constant-speed main engines and propeller-law-operated main and auxiliary engines, respectively.[3] The emissions at several engine load test points are measured and weighting factors are applied to calculate the test-cycle-weighted emission factor.[4] (The weighting factors for the E2 and E3 cycles are currently the same.) That result is compared with the limit in Regulation 13 and, if it is below the limit, the engine is issued an Engine International Air Pollution Prevention certificate. The weighting factors (Table 2) are intended to approximate how the engine is expected to be used in the real world and represent the proportion of hours the engine spends at each engine load.

Table 2

IMO NO_x Technical Code (NTC) 2008 weighting factors for the E2/E3 test cycles

Engine load	25%	50%	75%	100%
Weighting factor	0.15	0.15	0.50	0.20

The E2/E3 weighting factors imply that engines spend 70% or more of their time operating at or above 75% engine load. If these weighting factors do not approximate how the engine is operated, then the test-cycle emission factors will differ, potentially substantially, from real-world emission factors. This is especially true when emission factors are a function of engine load, such as methane slip from dual-fuel engines.[5] The current test cycles also fail to regulate emissions at low engine loads (i.e., below

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[2] International Maritime Organization (IMO), "Resolution MEPC.177(58) Amendments to the Technical Code on Control of Emissions of Nitrogen Oxides from Marine Diesel Engines (NO_x Technical Code 2008)," Marine Environmental Protection Committee, October 10, 2008, https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.177(58).pdf.

[3] There is also a D2 cycle for constant speed auxiliary engines and it includes a 10% engine load test point weighted at 0.10. However, the focus of this brief is main engines.

[4] The weighting factors are first multiplied by the g NO_x/hr measured at each engine load test point. Then the weighted g/hr are summed and divided by the sum of engine power (kW) at each engine load test point to achieve a weighted g NO_x/kWh value.

[5] Bryan Comer et al., *Fugitive and Unburned Methane Emissions from Ships (FUMES): Characterizing Methane Emissions from LNG-Fueled Ships Using Drones, Helicopters, and on-Board Measurements* (International Council on Clean Transportation, 2024), https://theicct.org/publication/fumes-characterizing-methane-emissions-from-lng-fueled-ships-using-drones-helicopters-and-on-board-measurements-jan24/.

25%), which often occur when ships are operating close to shore and therefore close to people. This is problematic not only for air pollutant emissions such as NO_X, but also for climate pollution, because methane slip from dual-fuel liquefied natural gas engines increases as engine load decreases.

METHODS

Using the ICCT's Systematic Assessment of Vessel Emissions (SAVE) model, which we updated to align with the methods of the *Fourth IMO GHG Study 2020*, we estimated the main engine load distribution for major ship types in 2019 and 2023 based on AIS data from Spire and ship characteristics data from S&P Global.[6] The main engine loads were calculated as the cube of the ratio of the ship's speed over ground to its maximum speed, with some adjustments to account for the impacts on engine load from weather, draught, and hull roughness, as described in Olmer et al. (2017).[7] When ships have more than one main engine, these loads are combined engine loads, meaning the calculated load factor is an estimate of the total power demanded from the engines at the time divided by the total installed power of all main engines. If we estimate a 50% engine load for a ship that has two main engines of the same rated power, it could be that both engines are operating at 50% engine load, or it could be that one engine is operating at 25% engine load and the other at 75%, or some other combination of engine loads. It gets even more complicated for ships that operate in a diesel-electric engine configuration, as these can have four, five, or even six engines installed. We therefore focused this analysis on the ship types that usually have only one engine: container ships, bulk carriers, oil tankers, and chemical tankers.[8] These four ship types were the source of approximately 63% of total shipping GHG emissions in 2018, according to the *Fourth IMO Greenhouse Gas Study 2020*.[9] The results below are based on more than 117 million combined hours of activity by ships while they were underway, in other words, "cruising," in 2019 and 128 million combined hours while cruising in 2023.

RESULTS

The weighting factors in the NTC 2008 E2/E3 test cycles of 0.50 at 75% engine load and 0.20 at 100% engine load imply that engines are operating at or above 75% engine load 70% of the time. As illustrated in Figure 1, our data show that container ships spent 2.6% of their time at or above 75% main engine load in 2019 and just 2.3% of their time in 2023. For bulk carriers it was 1.8% in 2019 and just 1.6% in 2023. For oil tankers, it was 4.5% in 2019 and 5.8% in 2023. Lastly, for chemical tankers, it was 8.7% in 2019 and 9.5% in 2023. Figure 1 considers the entire fleet of these ship types.

To test whether these trends hold for newer ships, we also analyzed the engine load distribution in 2023 for ships built in 2020 or later. The data represented more than 16 million hours of operation, and the pattern was similar. The data for ships built in 2020 and afterward are published with all the other data in a supplemental material file (see link at the end of this document).

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[6] The SAVE model is detailed in Naya Olmer et al., *Greenhouse Gas Emissions from Global Shipping, 2013–2015* (International Council on Clean Transportation, 2017), https://theicct.org/publication/greenhouse-gas-emissions-from-global-shipping-2013-2015/; and the IMO study is Jasper Faber et al., *Fourth IMO GHG Study 2020* (International Maritime Organization, 2020), https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf. This brief includes content supplied by S&P Global; Copyright © S&P Global, 2023. All rights reserved.

[7] Olmer et al., *Greenhouse Gas Emissions from Global Shipping, 2013–2015*.

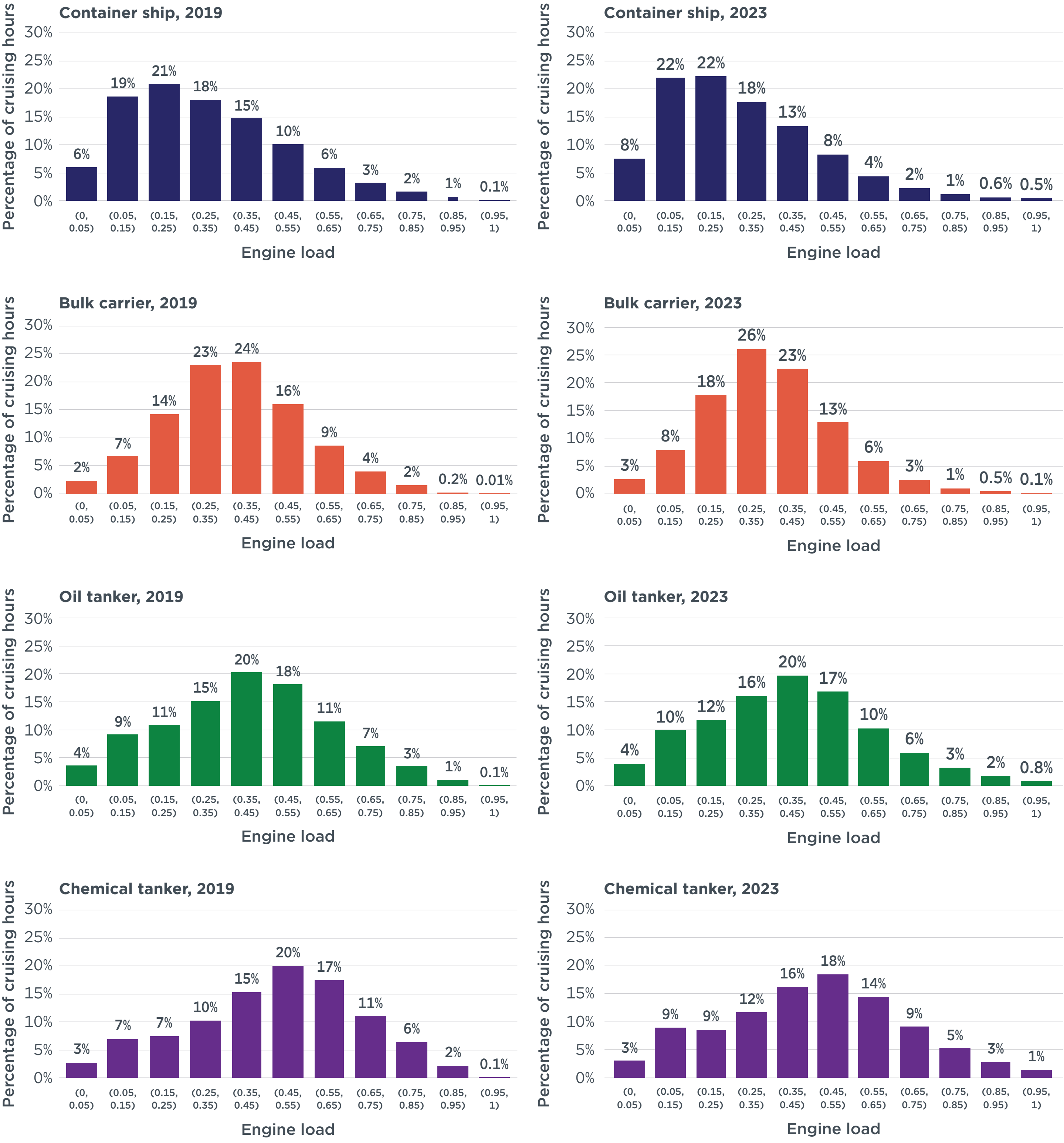
[8] By number of ships, 98% of container ships, 98% of bulk carriers, 83% of oil tankers, and 91% of chemical tankers have one main engine. For container ships and bulk carriers, ships with one main engine account for 96% or more of the cruising hours across all engine load bins presented in this study. For oil tankers, ships with one main engine were responsible for 81% of cruising hours occurring between 0% and 5% combined engine load and 85% between 5% and 15% load; otherwise, oil tankers with one main engine represented 92% or more of cruising hour operations, with a mode of 98%. For chemical tankers, ships with one main engine were responsible for 84% and 86% of cruising hours for the 0%–5% and 5%–15% engine load bins, respectively; otherwise, ships with one main engine represent 90% or more of cruising hours, with a mode of 97%.

[9] Faber et al., *Fourth IMO GHG Study 2020*.

In the NTC 2008 E2/E3 test cycles, the lowest engine load test point is 25% engine load. Meanwhile, we found that container ships spent 46% of their time operating below 25% engine load in 2019 and 52% of their time below 25% engine load in 2023. Bulk carriers spent 23% of their time below 25% engine load in 2019 and 28% in 2023. For oil tankers, it was 24% in 2019 and 26% in 2023. Lastly, for chemical tankers it was 17% in 2019 and 21% in 2023.

Figure 1

Main engine load distributions in 2019 and 2023, based on AIS and S&P Global data



Container ship, 2019

Container ship, 2023

Bulk carrier, 2019

Bulk carrier, 2023

Oil tanker, 2019

Oil tanker, 2023

Chemical tanker, 2019

Chemical tanker, 2023

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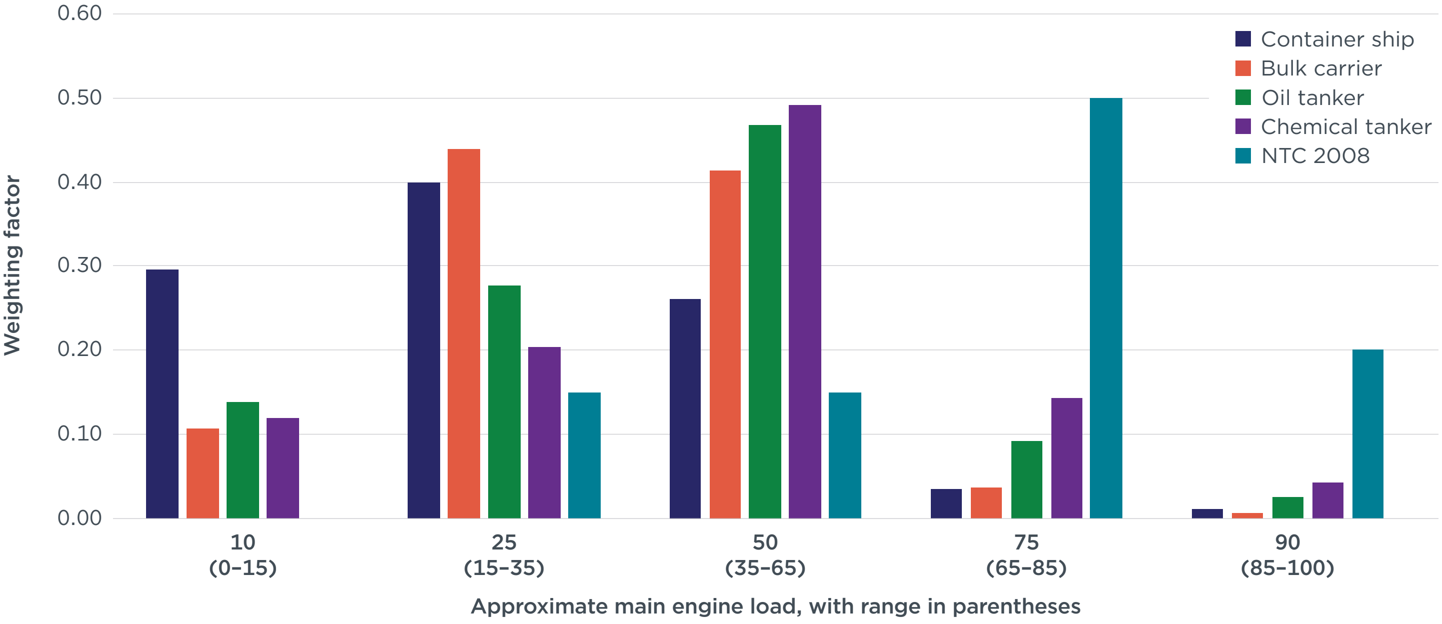
By aggregating the 2023 AIS data into five bins that roughly align with 10%, 25%, 50%, 75%, and 90% engine load, we can compare the estimated real-world weighting factors with the weighting factors in the NTC 2008 (Figure 2). The results show that the NTC 2008 weighting factors overweight emissions at and above 75% engine load and underweight emissions at lower loads.

Figure 2

Weighting factors derived from 2023 AIS data compared with those in the NTC 2008



Note: The weight for the NTC 2008 bar at 90% engine load is that associated with 100% engine load in the NTC 2008 test cycle.

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Table 3 reports the average weighting factor for each of the five load bins based on the data for container ships, bulk carriers, oil tankers, and chemical tankers presented in Figure 2.

Table 3

Average weighting factors by main engine load bin, based on 2023 AIS-derived main engine load factors for container ships, bulk carriers, oil tanker, and chemical tankers

Engine load	10% (0%–15%)	25% (15%–35%)	50% (35%–65%)	75% (65%–85%)	90% (85%–100%)
AIS average weighting factor	0.16	0.33	0.41	0.08	0.02

POLICY RECOMMENDATION

The engine load distributions presented above show that ships are spending considerable time operating below 25% engine load and little time operating at or above 75% engine load. Therefore, we suggest that the IMO consider revising the NTC 2008 to include a low load test point of 10%, reduce the maximum engine load test point from 100% to 90%, and adjust the weighting factors according to the recommended weighting factors in the bottom row of Table 4.

Table 4

Recommended revised NTC 2008 weighting factors for E2/E3 test cycles based on AIS data

Engine load		10%	25%	50%	75%	90%
Weighting factors	**NTC 2008**	—	0.15	0.15	0.50	0.20[a]
	AIS-derived	0.16	0.33	0.41	0.08	0.02
	Recommended	**0.15**	**0.30**	**0.40**	**0.10**	**0.05**

[a] Associated with 100% engine load in the NTC 2008

The recommended weighting factors largely follow the AIS-derived weighting factors in Table 3, with a few adjustments:

- The recommended 10% engine load weighting factor is set to 0.15 because the AIS-derived average weighting factor was dragged up by the relatively high container ship weighting factor of approximately 0.30 for that engine load bin, while the other ship types were lower, with bulk carriers at 0.11 and oil and chemical tankers at 0.14 and 0.12, respectively.
- The recommended 25% engine load weighting factor of 0.30 is closely aligned with the average AIS-derived value (0.33) and splits the difference between higher AIS-derived weighting factors for bulk carriers and container ships and lower factors for oil and chemical tankers.
- The recommended 50% engine load weighting factor of 0.41 is aligned with the average AIS-derived value, which is lower than the AIS-derived values for oil tankers (0.47) and chemical tankers (0.49), close to the AIS-derived value for bulk carriers (0.41), and higher than the AIS-derived value for container ships (0.26).
- The recommended 75% engine load weighting factor of 0.10 is close to the average AIS-derived value of 0.08 and the average for oil tankers (0.09), and it splits the difference between the relatively higher AIS-derived weights for chemical tankers (0.14) and lower AIS-derived weights for container ships and bulk carriers (between 0.03 and 0.04).
- The recommended 90% engine load weighting factor of 0.05 enables the weights to sum to 1.0. This value is higher than the AIS-derived average for container ships and bulk carriers, which was around 0.01, and slightly higher than the AIS-derived oil and chemical tankers weights, which were 0.03 and 0.04.

Figure 3 shows how the weighted NO_x emissions (g/kWh) would differ for a hypothetical marine engine that emits the following: 25 g/kWh at 10% engine load; 15 g/kWh at 25%; 10 g/kWh at 50%; 7 g/kWh at 75%; and 5 g/kWh at 90% (100% for NTC 2008). This pattern is loosely aligned with real-world, helicopter-measured NO_x emission rates for Tier II engines published by the ICCT, but it is only hypothetical.[10] The NTC 2008 weighting factors would estimate approximately 7 g NO_x/kWh, which is the same as the emissions at 75% engine load in our hypothetical example. The AIS-derived emission factor would be a bit more than 10 g NO_x/kWh, and using the recommended weighting factors would result in slightly less than 10 g NO_x/kWh, close to the emissions at 50% engine load.

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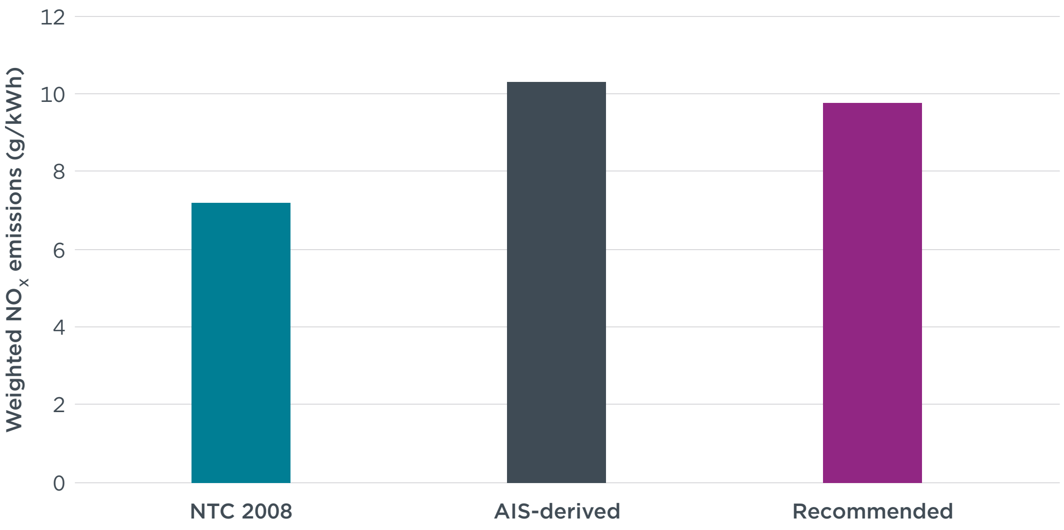
[10] Bryan Comer et al., *Real-World NO_x Emissions from Ships and Implications for Future Regulations* (International Council on Clean Transportation, 2023), https://theicct.org/publication/real-world-nox-ships-oct23/.

Figure 3

NO_x emissions under three weighting factor approaches for a hypothetical engine



Note: The hypothetical engine emits 25 g/kWh at 10% engine load, 15 g/kWh at 25%, 10 g/kWh at 50%, 7 g/kWh at 75%, and 5 g/kWh at 90% (100% for NTC 2008).

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CONCLUSION

This analysis shows that existing IMO NO_x weighting factors are not representative of real-world engine operations, as estimated using AIS-derived main engine load factors, and the certified emission factors likely differ from actual emission rates. Revising the NTC 2008 to add a low-load test point of 10% for main engines, replacing the 100% engine load test point with 90%, and adjusting the weighting factors to approximate real-world engine operations has two main benefits. First, it regulates emissions at low engine loads, which is important for protecting near-shore air quality. Second, it would more closely align certified emission factors with actual values, not only for NO_x but also for other pollutants such as methane and nitrous oxide, which will be important as ships work to comply with upcoming IMO climate regulations.

SUPPLEMENTAL DATA

The engine load distribution data used in this analysis is published at this paper's webpage: theicct.org/publication/updating-marine-engine-emission-standards-using-real-world-data-nov24.

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