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Potential CO_2 reductions under the Energy Efficiency Existing Ship Index

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Summary

This paper assesses the effectiveness of the proposed Energy Efficiency Existing Ship Index (EEXI) as a means to reduce fuel use and carbon dioxide (CO_2) emissions under the International Maritime Organization's (IMO) initial greenhouse gas (GHG) strategy. We model the fuel and CO_2 savings of the EEXI in 2019 and 2030 for container ships, bulk carriers, and oil tankers. Collectively, these ships accounted for more than half of CO_2 emissions from international shipping in 2018.

We find that the EEXI, as proposed, would make only a small contribution to IMO's climate goals and would reduce CO_2 from the 2030 fleet by 0.7% to 1.3% from a baseline without the EEXI. This is due to the continuing prevalence of slow steaming, whereby most ships are being operated at engine loads that would be unaffected by the technical efficiency standard the EEXI sets. On average, in 2019, containers, oil tankers, and bulk carriers were operated between 11 knots and 14 knots, or between 38% to 50% of their maximum continuous rating (MCR). This is well below the engine loads that would be allowable under the EEXI, which range from 65% to 77% MCR. If the EEXI does not limit engine power below what ships already use, it will not result in reductions in ship speed or CO_2. We thus conclude that the main impact of the EEXI would be to codify current operational efficiency gains due to slow steaming.

Three areas of refinement are possible: First, the EEXI could be calculated at a higher load point that takes into account an engine's sea margin. Second, the targets could be implemented as soon as possible and strengthened over time in tandem with the Energy Efficiency Design Index (EEDI). Third, any override of a ship's engine power limit should be policed vigilantly to ensure that it was for safety reasons only. In particular, evaluating the EEXI at 87% of limited MCR would provide greater protection against a bounceback in emissions, should improved market conditions spur a return to faster speeds.

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Introduction and Background

In April 2018, the International Maritime Organization (IMO) adopted an initial greenhouse gas (GHG) strategy for international shipping (Rutherford & Comer, 2018). The strategy aims to reduce the carbon dioxide (CO_2) intensity of international shipping by at least 40% from 2008 levels by 2030, and to reduce absolute GHG emissions at least 50% below 2008 levels by 2050.

According to the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2020), by 2018 the carbon intensity of international shipping had fallen by 22% on the Annual Efficiency Ratio (AER) relative to 2008; this was due, in part, to widespread slow steaming across the industry. This is illustrated in Figure 1, as is the additional 18 percentage point reduction that will be needed to meet IMO's minimum 2030 carbon intensity target.

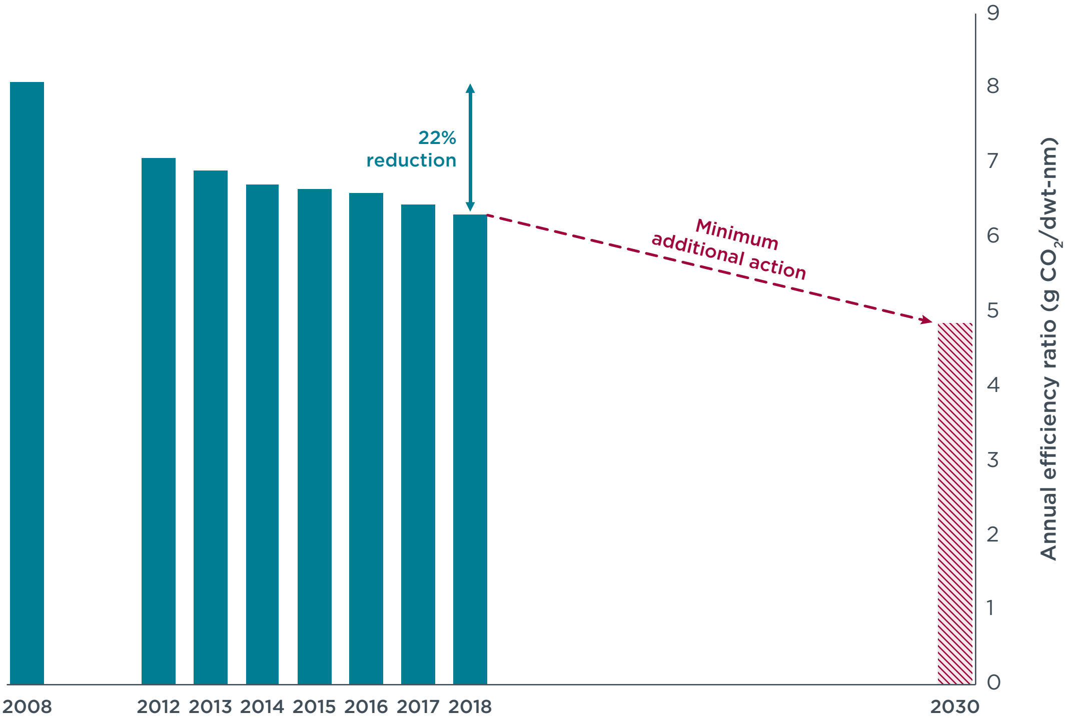

Figure 1. CO_2 intensity of international shipping, 2008 to 2018, compared to IMO's minimum 2030 carbon intensity target. *Note*. Derived from Faber et al. (2020).

The IMO is now developing regulations to support these goals. Last year, it tightened Energy Efficiency Design Index (EEDI) carbon intensity regulations for five types of new ships starting in 2022 (Comer & Rutherford, 2019). The IMO is also developing measures to address emissions from the existing fleet for finalization at the 75th meeting of its Marine Environmental Protection Committee (MEPC 75).

Proposed short-term measures to reduce the carbon intensity of international shipping fall into two categories: operational approaches and technical approaches. Operational approaches include an operational goal-based standard that directly regulates the amount of CO_2 per unit of transport work (IMO, 2019a; IMO, 2019b) and a carbon intensity rating scheme. Based upon the latest "hybrid" proposal, ships will be required to adopt both approaches starting in 2023 to help meet IMO's minimum 2030 carbon intensity goal (IMO, 2020b).

The proposed technical measure is Japan's Energy Efficiency Existing Ship Index, or EEXI, which is supported by Norway, Greece, Panama, the United Arab Emirates, the International Chamber of Shipping, BIMCO, and the International Association of

Independent Tanker Owners (BIMCO, 2020).[1] In essence, the proposal would apply technical efficiency standards to the existing fleet based upon the approach of the EEDI (IMO, 2020a), which only regulates the carbon intensity of newbuild ships. Unlike an operational efficiency standard, the EEXI would limit the amount of CO_2 emitted per unit of transport supply (e.g., deadweight tonne-nautical miles), rather than per unit of transport work.

Shipowners would have four primary means of complying with the EEXI. New ships that can be certified to EEDI targets for 2022 and beyond will meet the EEXI without further modifications. Other ships can comply by installing energy efficiency retrofits, through main engine power limitation (EPL; IMO, 2019c; Chambers, 2019), or through early retirement.

EPL is believed to be the easiest way for older ships to meet EEXI requirements because it requires minimal changes to the ship and does not change the underlying performance of the engine (MAN & PrimeServ, 2016). EPL establishes a semi-permanent, overridable limit on a ship's maximum power and therefore speed (Andersen, 2017). For mechanically controlled engines, this would take the form of a mechanical stop screw sealed by a wire that limits the amount of fuel that can enter an engine (IMO, 2019d). For newer, electronically controlled engines, EPL would be applied via a password-protected software fuel limiter. EPL would be overridable if a ship is operating under adverse weather conditions and requires extra engine power for safety reasons; in that case, the override should be recorded and reported to the appropriate regulatory authority (IMO, 2019c).[2]

EPL could reduce fuel use and CO_2 emissions if it reduces the operational speeds of affected vessels. Since engine load is proportional to the cube of vessel speed—meaning that a 10% decrease in cruise speed reduces hourly fuel use by almost 30%—how any short-term GHG policy interacts with slow steaming practices will strongly influence its effectiveness. Put another way, the EEXI will not directly reduce fuel use and CO_2 emissions if ships already operate slower than the de facto speed limit implied by the required EPL. This means that the effectiveness of technical efficiency measures like the EEXI need to be evaluated against real-world conditions.

This paper investigates the relationship between the proposed EEXI requirements and CO_2 emissions based upon 2019 real-world ship operations. We use ICCT's Systematic Assessment of Vehicle Emissions (SAVE) model, as described in Olmer, Comer, Roy, Mao, & Rutherford (2017), and find that the EEXI as proposed will make only a small contribution to IMO's climate goals. This is due to the continuing prevalence of slow steaming, whereby most ships are being operated at speeds and engine loads that are unaffected by the technical efficiency targets it sets. If designed properly, the EEXI could provide some assurance against future speed increases and promote the early retirement of older ships.

The rest of this paper is arranged as follows. The next section outlines our research methods. Following that, we present the results of the modeling, including what level of EPL would be required under the EEXI for different ship types and ages, how that relates to real-world operations in 2019, and the projected fuel and CO_2 savings for the 2030 fleet. Subsequently, we conclude and discuss opportunities for future work.

1 Several of the co-sponsors, including the International Chamber of Shipping, consider the EEXI to be insufficient on its own and support its adoption along with other measures to promote operational efficiency.

2 EPL, by reducing the baseline available engine power available to operators, could violate IMO's guidelines for minimum propulsion power (Faber, Nelissen, & Shanthi, 2019). Since EPL is meant to be overridable during adverse weather conditions, this is not expected to compromise ship safety, but would likely require revisions to IMO's current minimum propulsion power guidelines (IMO, 2017). Enforcing EPLs by verifying that overrides are appropriate and not used to regularly operate above regulated speeds would be needed to ensure their effectiveness as a GHG reduction measure. An investigation of those challenges is beyond the scope of this work.

Methods

Estimating EPL requirements for the 2019 fleet under the EEXI

The EEXI builds upon the calculation formulas for the EEDI, which establishes legally binding carbon intensity targets for newbuild ships. For most ships, the targets are a function of their deadweight tonnage (dwt) and for cruise ships, they are a function of gross tonnage (gt). The EEDI requires that newbuild ships delivered after 2015 meet increasingly stringent fuel efficiency targets. Ships delivered under Phase 1 (2015), Phase 2 (2020), and Phase 3 (2022 or 2025, depending on ship type) of the EEDI are required to reduce their carbon intensity by 10%, 20%, and 30% or more compared to a baseline of ships of similar size and type built from 1999 through 2008 (Wang, 2011; Comer & Rutherford, 2019).

Under the EEXI, existing ships would be required to meet technical efficiency standards equal to or weaker than EEDI targets for their ship type that will be in effect in 2022. This means that, by definition, newbuild ships delivered in and after that year will already meet the EEXI. The specific targets by ship type and size are shown in Table 1.

Table 1. EEXI reduction factor by ship type and capacity (IMO, 2020b).

Ship type	Size (dwt or gt)	Reduction factor
Bulk carrier	10,000 – 19,999	0 – 20%*
	20,000 – 199,999	20%
	200,000+	15%
Gas carrier	2,000 – 9,999	0 – 20%*
	10,000 – 14,999	20%
	15,000+	30%
Tanker	4,000 – 19,999	0 – 20%*
	20,000 – 199,999	20%
	200,000+	15%
Container ship	10,000 – 14,999	0 – 20%*
	15,000 – 39,999	20%
	40,000 – 79,999	30%
	80,000 – 119,999	35%
	120,000 – 199,999	45%
	200,000+	50%
General cargo ship	3,000 – 14,999	0 – 30%*
	15,000+	30%
Refrigerated cargo carrier	3,000 – 4,999	0 – 15%*
	5,000+	15%
Combination carrier	4,000 – 19,999	0 – 20%*
	20,000+	20%
LNG carrier	10,000+	30%
Ro-ro cargo ship (vehicle)	10,000+	15%
Ro-ro cargo ship	1,000 – 1,999	0 – 5%*
	2,000+	5%
Ro-ro passenger ship	250 – 999	0 – 5%*
	1,000+	5%
Cruise passenger ship	25,000 – 74,999 gt	0 – 30%*
	75,000+	30%

* Reduction rate is linearly interpolated between the ship sizes, with the lower target applying to the smallest ships.

A ship's EEDI score is evaluated at 75% of its installed main engine power, or maximum continuous rating (MCR). This value reflects that the fact that ship engines are usually not operated near 100% MCR. Instead, they are designed with two margins in mind. One is a sea margin that can be accessed to provide higher speed operations, for example in order to make up for a port delay. The other is an engine margin that is only used to keep a ship safe during adverse weather operations.

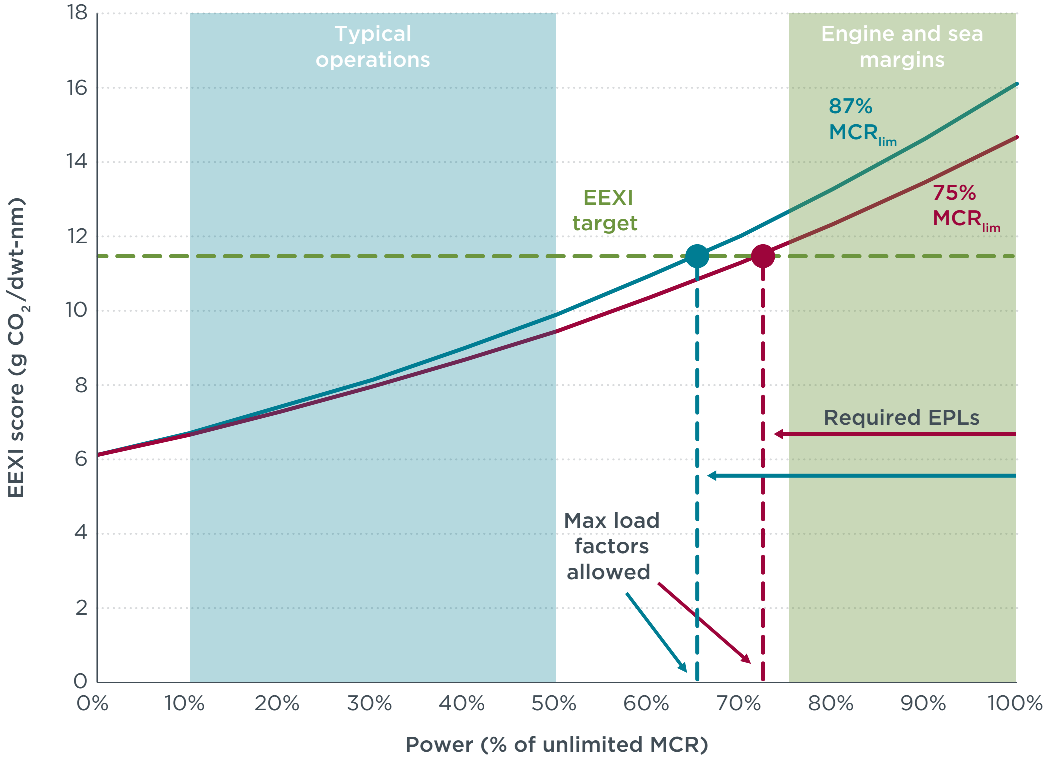

Figure 2. EEXI score by main engine power and evaluation point for a 10,000 TEU container ship.

As currently proposed, a ship's EEXI would be calculated either at 75% of the limited MCR (MCR_{lim}), like the EEDI, or alternatively at a higher 87% MCR_{lim}, to reflect the fact that the engine margin is only rarely used.[3] Figure 2 illustrates how the 87% MCR_{lim} evaluation point would limit a ship's engine power closer to the range at which it typically operates. The blue curve represents the EEXI score of a representative container ship (10,000 TEU capacity) at various EPLs when evaluated at 87% MCR_{lim}, and the red line represents the same at 75% MCR_{lim}. The ship's assigned EEXI target of 11.5 g CO_2/deadweight tonne nautical mile is also shown as a horizontal green line. As indicated, the 87% MCR_{lim} evaluation condition would require a larger (+8%) EPL than the 75% MCR_{lim} condition. This would limit the ship's maximum engine load closer to its typical operations and farther below the engine and sea margins that are less commonly accessed. In this analysis, we evaluate EPL scenarios and speed over ground (SOG) and CO_2 reductions associated with both options.

We analyze here the effect of the EEXI on three ship types—container ships, oil tankers, and bulk carriers—that accounted for 55% of total shipping CO_2 emissions in 2018 (Faber et al., 2020). We model EPL as the sole means to comply with the EEXI and calculate the EPL required by estimating each ship's attained EEXI score and then comparing that to its implied regulatory target under the EEXI.

Estimating the EPL needed by each ship involves the following steps:

3 For a ship without an EPL, its original MCR is equal to MCR_{lim}. For simplicity's sake, we refer to MCR_{lim} for all ships in the remainder of this document.

1. Each ship's EEXI target is calculated using the EEDI reference line, as summarized in Table 2, below, and its EEXI reduction factor from Table 1, which is determined by ship type and capacity (dwt).
2. The attained EEXI score of that ship is estimated using ship characteristics data from IHS Markit.[4] This is done using Equation 1, which is derived from Faber & 't Hoen (2017) with three modifications:[5]
   a. To account for improvements in energy efficiency that have occurred since the EEDI took effect, we apply specific fuel oil consumption (SFOC) assumptions consistent with the *Fourth IMO Greenhouse Gas Study* for slow speed, two-stroke diesel (SSD) engines.
   b. For the largest container ships (120,000+ dwt), the IHS speed field was corrected to reflect a 75% MCR operation condition based upon evidence presented in Faber et al. (2020). For other ship types and sizes, the IHS speed field is assumed to correspond to 100% MCR.
   c. Given the two possible evaluation conditions, two reference speeds (Vrefs) were calculated for 75% and 87% MCR_{lim} operating condition using the propeller law.
4. The EEXI exceedance, attained EEXI/EEXI target – 100%, is calculated. A positive value (%) indicates that an EPL would be required to meet the EEXI, and a negative value indicates compliance through the attained EEXI alone.
5. The engine power limitation for each ship with a positive EEXI exceedance is calculated using Equation 2, derived from IMO (2019e).

Table 2. EEDI reference line for ship types investigated

Ship type	Reference line
Container ship	$174.22 \times (0.7 \times dwt)^{-0.201}$
Oil tanker	$1{,}218.8 \times (dwt)^{-0.488}$
Bulk carrier	$961.79 \times (dwt)^{-0.477}$

Source: IMO (2017).

$$Attained\ EEXI = 3.1144 \times \frac{ME\ SFOC \times \Sigma_{i=1}^{nME} P_{ME,i} + AE\ SFOC \times P_{AE}}{Capacity \times V_{ref}} \quad \text{Equation 1}$$

Where

ME SFOC = Main engine specific fuel oil consumption, assumed to be 205 grams (g), 185 g, and 175 g fuel per kilowatt hour (kWh) for ships built in or before 1983, from 1984 to 2000, and in or after 2001, respectively.

P_{ME} = Main engine power in kW

AE SFOC = Auxiliary engine specific fuel oil consumption, assumed to be 225 g, 205 g, and 195 g fuel/kWh for ships built in or before 1983, from 1984 to 2000, and in or after 2001, respectively.

P_{AE} = Auxiliary engine power in kW

Capacity = 100% dwt for oil tankers and bulk carriers, and 70% for container ships

V_{ref} = Reference speed at either 75% or 87% MCR_{lim}

4 The IHS database provides technical specifications for oceangoing vessels worldwide, including the capacity, build year, and reference speed used in this analysis. See https://ihsmarkit.com/industry/maritime.html

5 Note that Equation 1 assumes that burning 1 kilogram (kg) of marine fuel emits 3.1144 kg of CO_2, which corresponds to the carbon content of heavy fuel oil. In reality, a small number of ships analyzed have engines that burn only marine gas oil (MGO), which has somewhat higher CO_2 emissions per unit fuel (3.206). Since ships with dedicated MGO engines accounted for less than 1% of overall fuel use for the ship types studied in 2019, this assumption should not significantly impact our results.

$$\text{Implied EPL} = 100\% - \left(\frac{MCR_{lim}}{MCR_{ME}}\right) = 100\% - \left(\frac{1}{1 + \text{EEXI exceedance}}\right)^{\frac{3}{2}} \qquad \text{Equation 2}$$

Figure 3 displays the relationship between the attained and target EEXI, the EEXI exceedance, and the resulting EPL for a ship that exceeds its EEXI target by 20% and therefore requires an EPL of 24%.

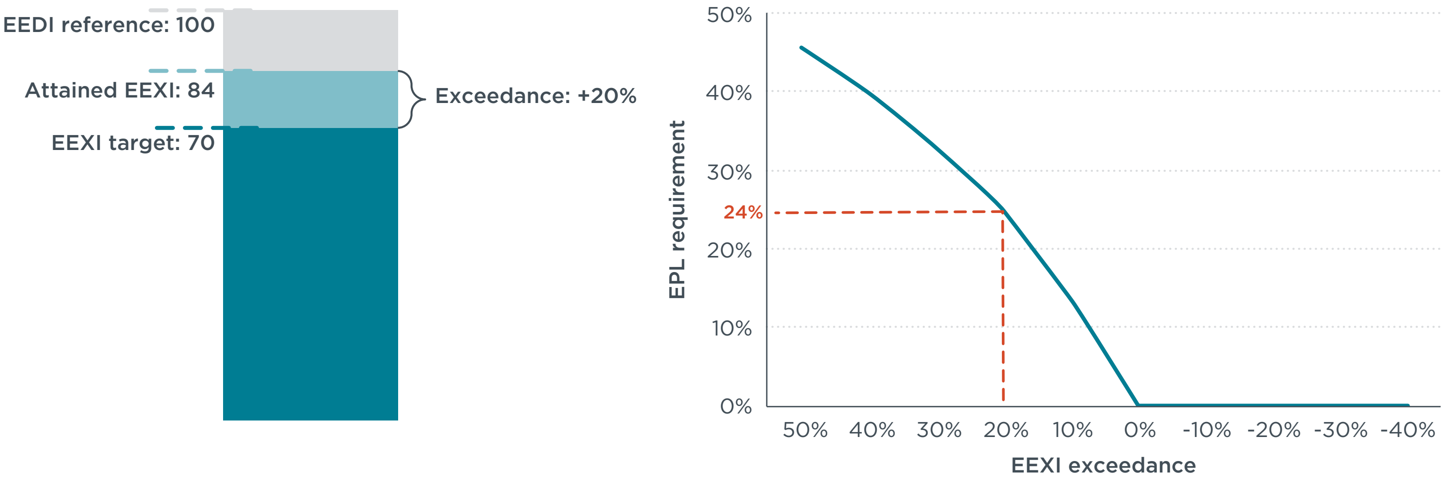

Figure 3. EEXI exceedance and EPL required.

Baseline 2019 fleet analysis

In most cases, we expect that ships that do not already meet their EEXI target by virtue of their attained EEXI will meet it via EPL, as it is the lowest-cost, least-invasive means of compliance. Since the EPL reduces the maximum speed of the ship, if that corresponds to lower operational speeds, fuel use and CO_2 will fall. Translating the magnitude of the savings therefore requires understanding existing engine loads, as estimated from real-world operating conditions. For this study, we used the SAVE model introduced in Olmer et al. (2017) and updated with SFOCs from the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2020).

The updated model was used to process calendar year 2019 Automatic Identification System (AIS) data purchased from exactEarth (eE) for container ships, bulk carriers, and oil tankers.[6] AIS data provide estimates of ship location, SOG, heading, draught, and more for all ships over 300 gross tonnes as frequently as every few seconds. SAVE was used to process the raw eE data; we removed bad data (e.g., incorrect latitude/longitude and erroneous SOG values), interpolated between missing AIS signals, applied adjustment factors affecting fuel consumption, and aggregated the resulting data into hourly averages.[7] We then matched each ship's hourly operational data with its design speed and main engine power using data purchased from IHS.[8]

Using SAVE, we estimated main engine loads as a percentage of MCR for each ship for every hour it operated in the cruise phase in 2019.[9] Main engine loads were, in turn, used to determine baseline 2019 fuel consumption and CO_2 emissions for each ship. Only the cruise phase was modeled, but it was modeled for all equipment types—main engines, auxiliary engines, and boilers. CO_2 emissions were estimated by multiplying the mass of

6 https://www.exactearth.com

7 SAVE adjustment factors correct for weather effects, hull fouling conditions, circuitous routing, and ship ballast conditions, among other things. See Olmer et al. (2017).

8 https://maritime.ihs.com. This study covers only ships that appear in both the eE 2019 AIS and IHS Market fleet data, or "Type 1" ships. See Faber et al. (2020).

9 Cruise phase is defined as when a ship is underway and not maneuvering, anchored, or at berth.

fuel used by 3.114, 3.206, and 2.750 for heavy fuel oil, marine gas oil, and liquefied natural gas, respectively.

Estimating EEXI effects on the 2019 fleet

The EPL requirements for individual ships were translated into revised main engine load factors, SOGs, fuel per hour, and hours in service using the methods outlined in Rutherford, Mao, Osipova, and Comer (2020). That study developed a series of EPL scenarios, starting with a 10% reduction and going all the way up to a 60% power reduction (i.e., the engine being able to operate at no higher than 40% of its original MCR during normal operations). Using SAVE, we identified every hour that each ship engine operated above that limit in 2019, reset the engine power to the new maximum allowed under the EPL, recalculated the matching new, slower SOGs, and estimated the fuel and CO_2 emission savings of those recalculated speeds.

Also per Rutherford et al. (2020), we added "shadow hours" to ensure that ships that now sail more slowly cover the same amount of distance in a given year to preserve transport supply. These shadow hours could be accomplished by the same ship or similar ships. In this analysis, shadow hours were assumed to be operated by the same ship, sailing at its average 2019 SOG and main engine load factors. For each EPL scenario, we then compared how SOG and CO_2 changed relative to the 2019 baseline, according to Rutherford et al. (2020). For each ship, SOG and CO_2 changes were linearly interpolated between the six EPL scenarios where necessary; thus, results for a ship requiring a 25% EPL are reported as the average of the 20% and 30% EPL scenarios.

Projections to 2030

By 2030, CO_2 emission reductions from the EEXI will be different in than in 2019, as new ships will be introduced either as a direct replacement for an existing ship being retired or as a ship being brought in to meet increased trade demand. New ships built in 2022 and thereafter will already comply with the EEXI requirements by virtue of their compliance with the equivalent EEDI requirements. Retirements were estimated using retirement curves developed by Wang and Lutsey (2013); fleet growth was estimated using United Nations Conference on Trade and Development (UNCTAD, 2019) data. In all cases, new ships brought into the fleet due to retirement or trade growth are assumed to meet the EEXI without EPLs for the reasons stated above.

The CO_2 effects of the EEDI would also change if ship speeds change significantly. Previous work (Olmer et al., 2017; Rutherford et al., 2020; Smith et al., 2015) and the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2020) show that ship speeds for container ships, bulk carriers, and oil tankers have been largely flat since 2013, with the bulk of the speed reductions occurring from 2008 to 2010. For this reason, and consistent with Rutherford et al. (2020), we assume no change in speeds in 2030 relative to 2019.

Results and discussion

In this section, we first present the EPLs that are implied under the EEXI for the 2019 fleet, summarized by ship type and size. Second, we summarize baseline speeds and main engine load factors in 2019. Following that, we present operating speed changes that would have occurred if the EEXI was in effect in 2019 and, subsequently, projected fuel use and CO_2 savings attributable to the EEXI out to 2030. The section ends with some thoughts on the indirect effects of the EEXI.

Engine power limitations required under the EEXI

Individual EPL limitations for each ship were calculated using the methods highlighted above. To validate the calculation method, we investigated trends over time in both the EEXI exceedance and implied EPL for container ships, tankers, and bulk carriers in operation in 2019 under the 75% MCR_{lim} evaluation condition. The results are shown in Table 3. The final period, from 2015 to 2019, corresponds to Phase 1 of the EEDI. Allowable MCR, in percentage, is simply 100% minus the required EPL.

Table 3. Results by ship type and build year, 75% MCR_{lim} evaluation condition

Ship type	Parameter	Build year			
		1970–1984	1985–1999	2000–2014	2015–2019
Container	EEXI exceedance	+51%	+26%	+28%	-1%
	EPL required	45%	29%	30%	9%
	% MCR allowed	55%	71%	70%	91%
Oil tanker	EEXI exceedance	+43%	+26%	+23%	+23%
	EPL required	42%	30%	27%	22%
	% MCR allowed	58%	70%	73%	78%
Bulk carrier	EEXI exceedance	+62%	+25%	+25%	+13%
	EPL required	49%	27%	27%	15%
	% MCR allowed	51%	73%	73%	85%

As shown in Table 3, the EEXI exceedance, implied EPL, and percentage MCR allowed are all sensitive to build year and ship type. Newer ships subject to the first phases of the EEDI are closest to complying with the EEXI requirements; they exceed their EEXI targets by -1% (pass on average) to 23% and, correspondingly, require EPLs ranging from 9% for containers to 22% for oil tankers.[10] Put the other way, container ships delivered since 2015 could use up to 91% of their MCR, whereas oil tankers would be limited to 78% MCR. This means that container ships could sail closer to their maximum speeds than oil tankers. New container ships are closest to meeting the EEXI, while tankers are farthest away.

Several conclusions can be drawn from Table 3. First, the EEXI would require larger EPLs for older ships, which would reduce their maximum speeds more than for newer ships. Thus, it may help promote the retirement of older vessels, particularly those manufactured before 1985. Second, since all three ship types will be subject to more stringent Phase 2 EEDI standards starting in 2020, and by definition will meet the EEXI through EEDI compliance starting in 2022, it is reasonable to expect that no EPL will be required for new ships delivered from 2020 onward.[11]

Table 4 summarizes the required EPLs by ship type and ship size by capacity. EPLs and allowable MCRs are shown under both evaluation conditions, 75% and 87% MCR_{lim}.

10 On average, container ships built on or after 2015 would meet the EEXI but still require an EPL because some ships will exceed the EEXI and therefore require an EPL even if other ships in the same cohort do not. As an example, if half of the ships in a cohort pass the EEXI by 10% and the other half fail by 10%, the average EEXI exceedance would be zero but the average EPL required would be the average of zero and 13.3%, or 6.7%.

11 For tankers and bulk carriers, the 2022 EEXI requirements are largely equivalent to 2020 EEDI standards. For container ships, the EEXI standards are somewhat more stringent that the 2020 EEDI standards; still, given that Phase 1-compliant container ships largely already meet the EEXI, it seems likely that Phase 2 compliance from 2020 on will be sufficient to meet the EEXI requirements.

Table 4. EPL required by ship type and size, 75% and 87% MCR_{lim} evaluation condition

Ship type	Capacity (TEU or dwt)	EPL required at		Allowable MCR	
		75% MCR_{lim}	87% MCR_{lim}	75% MCR_{lim}	87% MCR_{lim}
Container	<1,000 TEU	6%	14%	94%	86%
	1,000 – 1,999	16%	24%	84%	76%
	2,000 – 2,999	10%	18%	90%	82%
	3,000 – 4,999	28%	36%	72%	64%
	5,000 – 7,999	35%	43%	65%	57%
	8,000 – 11,999	25%	33%	75%	67%
	12,000 – 14,449	24%	33%	76%	67%
	14,500 – 19,999	17%	25%	83%	75%
	20,000+	14%	21%	86%	79%
	Average	24%	32%	76%	68%
Oil tanker	<5,000 dwt	27%	33%	73%	67%
	5,000 – 9,999	18%	25%	82%	75%
	10,000 – 19,999	22%	30%	78%	70%
	20,000 – 59,999	40%	48%	60%	52%
	60,000 – 79,999	28%	37%	72%	63%
	80,000 – 119,999	19%	29%	81%	71%
	120,000 – 199,999	27%	36%	73%	64%
	200,000+	27%	36%	73%	64%
	Average	26%	35%	74%	65%
Bulk carrier	<10,000 dwt	—	—	100%	100%
	10,000 – 34,999	26%	36%	74%	64%
	35,000 – 59,999	24%	34%	76%	66%
	60,000 – 99,999	19%	29%	81%	71%
	100,000 – 199,999	31%	40%	69%	60%
	200,000+	19%	29%	81%	71%
	Average	23%	33%	77%	67%

Note: TEU means twenty foot equivalent unit, a standardized measure of carrying capacity for container ships. dwt means deadweight tonnage, a standardized measure of carrying capacity for oil tankers and bulk carriers.

As shown in Table 4, EPLs required under the 75% MCR_{lim} condition varied from 6% for the smallest container ships to 40% for mid-sized oil tankers; this corresponds to allowable MCRs ranging from 94% down to 60%. On average, all three ship types required similar (23% to 26%) EPLs under the 75% MCR_{lim} evaluation condition. EPLs required under the 87% MCR_{lim} evaluation condition were eight to 10 percentage points higher than the 75% MCR_{lim} condition, with 32% to 35% average EPLs required for that case, depending on ship type.

Rutherford et al. (2020) concluded that EPLs of 30% would begin to provide a measure of protection against future bouncebacks in ship speeds, and therefore emissions, in response to improved market conditions. Higher EPLs would provide even greater assurance against these "latent emissions." As shown in Table 4, the EEXI at the 75% MCR_{lim} condition would fall short of that threshold for all ship types. The EEXI at the 87% MCR_{lim} evaluation condition would just meet that threshold for all three ship types.

Baseline operational conditions in 2019

Average 2019 main engine (ME) load factor (LF), SOG, and total cruise phase fuel consumption by ship type and size are shown in Table 5.

Table 5. Average ME LFs, SOGs, and cruise phase fuel consumption by ship type and size for 2019

Ship type	Capacity (TEU or dwt)	Avg ME LF (% MCR)	Avg SOG (knots)	Fuel consumption, cruise phase (Mt)
Container	<1,000 TEU	49%	11.9	2.2
	1,000 – 1,999	41%	13.0	6.4
	2,000 – 2,999	35%	13.7	5.2
	3,000 – 4,999	31%	14.4	10.4
	5,000 – 7,999	30%	15.3	10.9
	8,000 – 11,999	36%	16.0	15.9
	12,000 – 14,449	35%	15.8	5.9
	14500 – 19999	48%	15.1	2.8
	20,000+	53%	15.7	1.5
	Average/total	**38%**	**14.1**	**61**
Oil tanker	<5,000 dwt	55%	9.0	0.7
	5,000 – 9,999	53%	9.5	0.7
	10,000 – 19,999	52%	10.0	0.4
	20,000 – 59,999	49%	11.2	2.0
	60,000 – 79,999	49%	11.5	2.2
	80,000 – 119,999	46%	11.2	5.6
	120,000 – 199,999	45%	11.3	4.9
	200,000+	46%	11.8	10.8
	Average/total	**49%**	**10.8**	**27**
Bulk carrier	<10,000 dwt	56%	9.3	0.5
	10,000 – 34,999	54%	10.8	4.6
	35,000 – 59,999	51%	11.1	11.5
	60,000 – 99,999	49%	11.2	16.6
	100,000 – 199,999	45%	10.9	10.3
	200,000+	48%	11.3	5.8
	Average/total	**50%**	**11.0**	**49**

Note: TEU means twenty foot equivalent unit, a standardized measure of carrying capacity for container ships. dwt means deadweight tonnage, a standardized measure of carrying capacity for oil tankers and bulk carriers. ME LF means main engine load factor. SOG means speed over ground. Mt means million tonnes.

As shown in Table 5, in 2019, ships continued to be operated far below their maximum power (100% MCR) and therefore below their design speeds. Annual average ME LFs were highest in 2019 for bulk carriers, which operated at an average of 50% MCR (range of 45% to 56% MCR, depending on ship size), and they were followed by oil tankers at 49% (range of 45% to 55%). Container ships operated at considerably lower engine loads averaging 38% (range from 30% up to 53% for the very largest ships). Since these values are lower than the allowable MCRs shown in Table 4, direct emission reductions under the EEXI will be limited because it may not further reduce operational speeds. In that case, CO_2 emissions would not decrease.

Looking at the other operational parameters in Table 5, SOGs were highest for container ships, with an average of more than 14 knots. Oil tankers and bulk carriers both operated at about 11 knots on average in 2019. Cruise fuel use was the highest for container ships at more than 61 million tonnes (Mt) of fuel, followed by bulk carriers (49 Mt) and then oil tankers (27 Mt).

While Table 5 only shows annual average ME LFs, the impact of EPLs will be felt at the hourly level. Figure 4 summarizes the distribution of 2019 cruise-phase ME LFs for container ships, bulk carriers, and oil tankers.

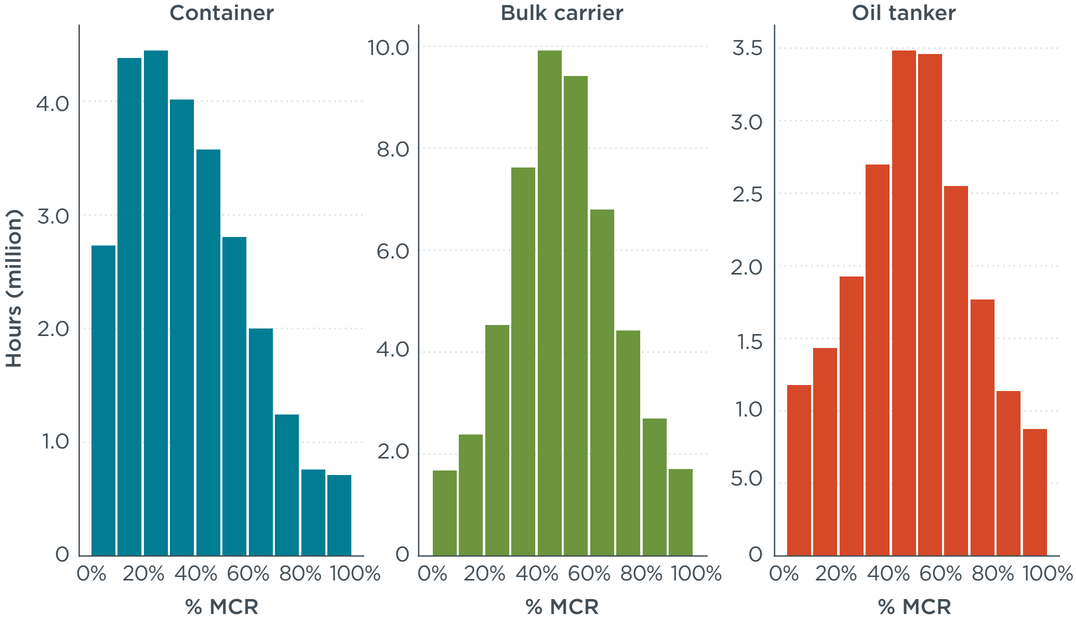

Figure 4. Main engine load factor distribution for container ships, oil tankers, and bulk carriers, 2019

Figure 4 reaffirms that the three ship types were typically operated well below 100% MCR in 2019. The distribution of ME LFs varies by ship type. Container ship ME LFs are skewed toward lower load factors, most commonly between 10% to 30% MCR. Both oil tankers and bulk carriers had more normal distributions centered around their annual averages of about 50% MCR. This implies that larger EPLs will be required to reduce operating speeds and emissions from container ships relative to oil tankers and bulk carriers.

EEXI's effect on ship speeds of the 2019 fleet

The impact of the EEXI will vary depending on how the EPL required compares to a given ship's operating speeds and therefore main engine load factors. For each ship type and size, the effect of the EEXI on ship cruise speeds at both the 75% and 87% MCR_{lim} evaluation conditions are shown in Table 6 and Figure 5.

Table 6. EEXI's impact on SOG, based on the 2019 fleet under the 75% MCR_{lim} and 87% MCR_{lim} evaluation conditions

Ship type	Capacity (TEU or dwt)	Mean SOG			% SOG change	
		2019	75% MCR_{lim}	87% MCR_{lim}	75% MCR_{lim}	87% MCR_{lim}
Container	<1,000 TEU	11.9	11.9	11.9	0.0%	-0.2%
	1,000 – 1,999	13.0	13.0	13.0	-0.1%	-0.4%
	2,000 – 2,999	13.7	13.7	13.7	0.0%	-0.1%
	3,000 – 4,999	14.4	14.4	14.4	-0.2%	-0.4%
	5,000 – 7,999	15.3	15.2	15.2	-0.3%	-0.6%
	8,000 – 11,999	16.0	15.9	15.9	-0.2%	-0.4%
	12,000 – 14,449	15.8	15.8	15.7	-0.1%	-0.3%
	14500 – 19999	15.1	15.0	14.9	-0.5%	-1.1%
	20,000+	15.7	15.6	15.5	-0.4%	-0.8%
	Average	**14.1**	**14.1**	**14.1**	**-0.2%**	**-0.4%**
Oil tanker	<5,000 dwt	9.0	8.8	8.7	-1.4%	-2.5%
	5,000 – 9,999	9.5	9.4	9.4	-0.5%	-1.0%
	10,000 – 19,999	10.0	10.0	9.9	-0.8%	-1.5%
	20,000 – 59,999	11.2	10.9	10.7	-2.7%	-4.7%
	60,000 – 79,999	11.5	11.4	11.3	-0.9%	-2.1%
	80,000 – 119,999	11.2	11.1	11.1	-0.3%	-0.8%
	120,000 – 199,999	11.3	11.3	11.2	-0.6%	-1.5%
	200,000+	11.8	11.7	11.6	-0.8%	-1.7%
	Average	**10.8**	**10.7**	**10.6**	**-0.9%**	**-1.8%**
Bulk carrier	<10,000 dwt	9.3	—	—	—	—
	10,000 – 34,999	10.8	10.7	10.6	-1.0%	-2.2%
	35,000 – 59,999	11.1	11.1	11.0	-0.7%	-1.1%
	60,000 – 99,999	11.2	11.2	11.1	-0.3%	-1.0%
	100,000 – 199,999	10.9	10.8	10.7	-0.9%	-1.8%
	200,000+	11.3	11.3	11.2	-0.3%	-0.9%
	Average	**11.1**	**11.0**	**11.0**	**-0.6%**	**-1.3%**

As shown in Table 6, the EEXI is estimated to require minor operational changes for oil tankers, but little for bulk carriers and container ships. For oil tankers, the 75% MCR_{lim} condition would have reduced average operational speeds by about 1% in 2019, and slightly more than 2% under the 87% MCR_{lim} condition. Container ships, on average, would need to slow down by 0.2% or 0.4% under the 75% MCR_{lim} and 87% MCR_{lim} conditions, respectively. Figure 5 presents the SOG change for both the 75% MCR_{lim} and 87% MCR_{lim} condition for additional clarity.

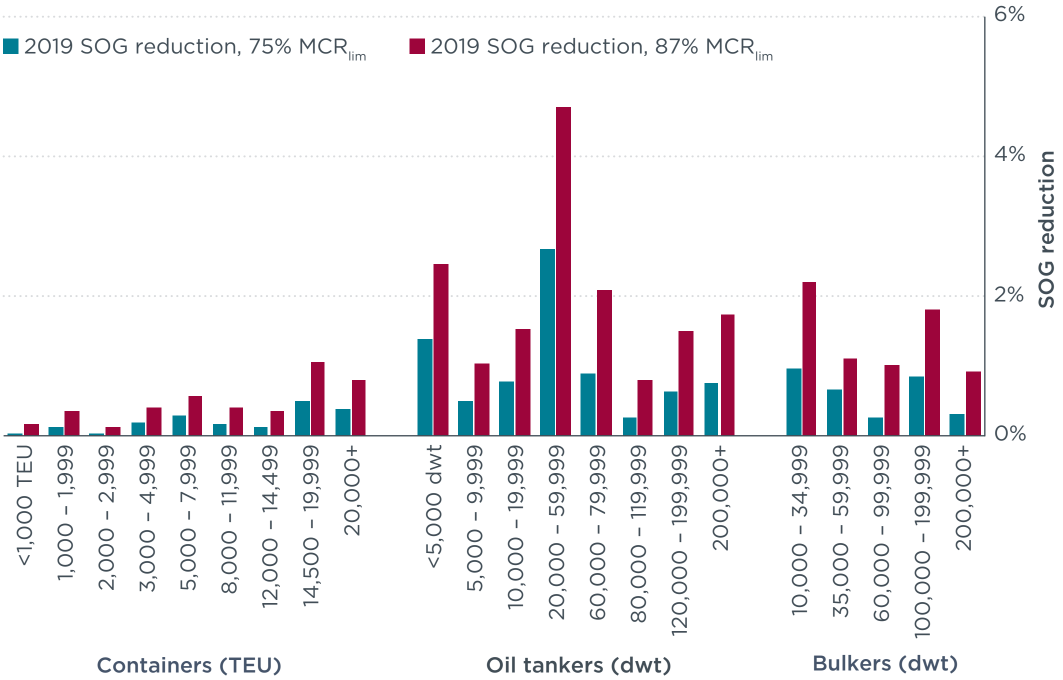

Figure 5. Speed over ground reductions for three major ship types in 2019 by EEXI evaluation condition, 75% and 87% MCR_{lim}.

EEXI CO_2 reduction by ship type in 2030

If the EEXI had been applied to all ships in 2019, these SOG changes would have reduced operational CO_2 emissions by 1.4% and 2.9% after taking into account fleet turnover and growth, if evaluated at 75% and 87% MCR_{lim}, respectively. However, the benefits of the EEXI will become diluted over time as new ships that already comply due to their EEDI score enter the global fleet. Accordingly, the CO_2 benefits of the proposed policy should be assessed after taking into account fleet turnover and growth.

Table 7 shows total projected 2030 fuel consumption by ship type and how much fuel would be consumed by ships in operation in 2019 that would require EPLs under the EEXI. 2030 was selected for analysis because of the IMO's mid-term carbon intensity goal and because the EEXI is expected to be fully implemented at that time.

Table 7. Projected total fuel consumption by ship type in 2030 and the proportion that would require EPLs

Ship type	Average build year in 2030	Annual trade growth[a]	2030 fuel consumption (Mt)		% subject to EPLs
			Subject to EPLs	Total	
Containers	2007	4.5%	24.0	61.2	39%
Oil tankers	2005	2.2%	14.2	27.2	52%
Bulk carriers	2009	3.9%	23.9	49.2	49%
Total	—	—	62.1	137.5	45%

[a] *Source:* UNCTAD (2019)

The EEXI is expected to require EPLs from ships that will account for about 45% of 2030 fuel consumption for these three ship types. The remaining 55% of fuel use for these ship types would be unaffected because it would be consumed by new ships built after 2019 that comply with the EEXI without EPLs. More oil tanker fuel use would be covered, owing to the slower trade growth predicted by UNCTAD, and therefore a smaller number of new vessels being brought into the fleet.

Figure 6 summarizes CO_2 emission reductions in 2030 for the three ship types under the proposed EEXI for both the 75% and 87% MCR_{lim} evaluation conditions.

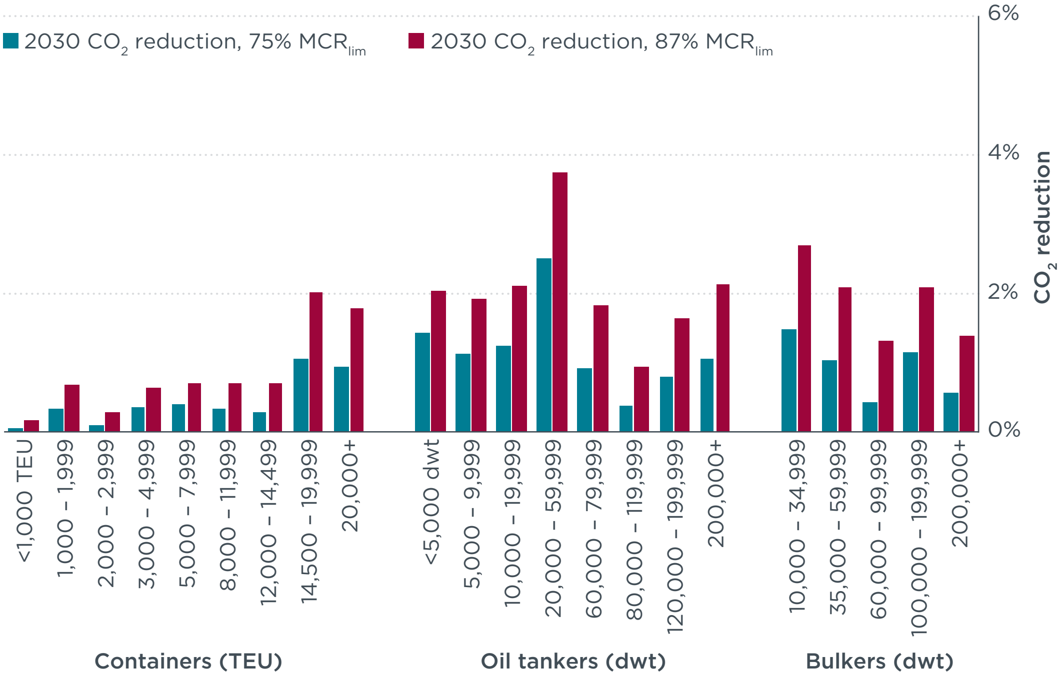

Figure 6. CO_2 reduction for three major ship types in 2030 by EEXI evaluation condition, 75% and 87% MCR_{lim}

As shown, the EEXI evaluated at the 75% MCR_{lim} operating condition would reduce fuel use and CO_2 emissions by 0.7% in 2030, and about double (1.3%) for the 87% MCR_{lim} condition. There are two key reasons for this low figure: (1) Ships will already largely operate below their allowable MCRs under the EEXI if current slow steaming practices continue; and (2) Fleet growth and turnover will reduce the share of ships that require EPLs under the EEXI. More CO_2 would be reduced from tankers, 1.0% and 1.9% reductions for 75% and 87% MCR_{lim}, respectively, because of their higher baseline ME LFs in 2019 and somewhat larger share of 2030 fuel use subject to EPLs. The smallest impact would be on container ships—0.4% and 0.7% reductions for 75% and 87% MCR_{lim}, respectively—due mostly to their lower baseline ME LFs in 2019.

These results assume no increase in ship speeds from 2019 to 2030. Previous work (Rutherford et al., 2020) suggests that these results are sensitive to assumptions about 2030 speeds. This is because as ships speed up, ME LFs increase, and this boosts the number of hours and associated fuel consumption and emissions impacted by EPL. That work concluded that EPL stringencies of 30% and above start to provide assurance against future speed increases from the existing fleet. This implies that evaluating the EEXI using the 87% MCR_{lim} operating condition could help lock in the fuel savings of existing slow steaming practices even if it is expected to only marginally reduce fuel use below the 2030 baseline.

Conclusions

This study analyzed the potential fuel use and CO_2 emission savings attributable to the EEXI. It highlighted that container ships, oil tankers, and bulk carriers continued to be operated at well below their maximum speeds and power in 2019 due to ongoing slow steaming practices. That limits the direct emissions reduction potential of the proposed EEXI. In short, the main impact of the EEXI will be to codify current operational efficiency gains due to slow steaming rather than to slow ships down further. Thus, the

EEXI alone will not be sufficient to stop shipping CO_2 from growing through 2030, the year of IMO's CO_2 intensity target.

The EEXI, as proposed, would only marginally reduce CO_2 from the 2030 fleet, but it would be more impactful if evaluated at higher engine loads. Evaluation at 75% MCR_{lim} would require EPLs of less than 30%, while 87% MCR_{lim}, which would take into account a ship's engine margin, would require somewhat higher (32% to 35%) EPLs. Accordingly, the 75% MCR_{lim} evaluation condition would reduce CO_2 by less than 1% from a baseline without the EEXI. Evaluating the EEXI at 87% MCR_{lim} would roughly double CO_2 reductions, up to 1.3% in 2030. Evaluating the EEXI at 87% MCR_{lim} could also help mitigate a bounceback in emissions if market conditions spur a return to faster speeds. Larger 2030 CO_2 reductions from the no-EEXI baseline would be expected if ships speed up relative to current speeds, although from a higher baseline of emissions.

There are three broad implications of this work. First, if the EEXI is selected as one of IMO's short-term GHG measures, IMO policymakers should choose to evaluate the EEXI at 87% MCR_{lim}. Doing so would roughly double its benefits and provide a stronger safeguard against latent emissions increases under future speed increases. Second, if the EEXI is taken forward, it should apply as soon as possible and IMO member states should consider ratcheting up the EEXI targets to be in line with future phases of the EEDI that will require higher technical efficiency for ships. Third, IMO should establish a means of monitoring and sanctioning non-safety related overrides of EPLs, an issue not analyzed here, to safeguard the already limited benefits of the EEXI.

This analysis focused on EPL as a sole, independent means of reducing ship CO_2 emissions under the EEXI. In reality, EPL is likely to be one of several strategies that shipowners would use. Those options, including energy efficiency retrofits and early retirement, also deserve investigation. Further work is needed to assess the full impacts of the EEXI if it is adopted by the IMO.

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