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Limiting engine power to reduce CO_2 emissions from existing ships

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SUMMARY

This paper assesses the effectiveness of engine power limitation (EPL) as a means to reduce fuel use and carbon dioxide (CO_2) emissions from existing ships under the International Maritime Organization's (IMO) initial greenhouse gas (GHG) strategy. We model the fleetwide fuel and CO_2 savings of 10% to 60% EPL strategies in 2018 and 2030 for container ships, bulk carriers, and oil tankers. Collectively, these ships accounted for more than half of the CO_2 emissions from international shipping in 2015.

We find that, due to the ongoing prevalence of slow steaming, EPL measures would need to be aggressive in order contribute to IMO's climate goals. Modeling using 2018 real-world ship operations highlights that: (1) CO_2 reductions will not be proportional to EPL because ship engines are already operating far below their maximum power; (2) only 50%+ EPLs would be expected to meaningfully reduce CO_2 from all ships in 2018; and (3) benefits diminish over time if EPL is not required for newer ships, with expected CO_2 emission reductions falling about 60% through 2030 due to fleet turnover and growth. Additionally, 30%+ EPL policies could help avoid a bounceback in future emissions should market conditions spur a return to faster speeds.

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 includes mid- and long-term carbon dioxide (CO_2) intensity and GHG targets that imply 60% to 70% reductions in cumulative GHG emissions through 2075 and a complete decarbonization before the end of the century. The strategy also aims to reduce the CO_2 intensity of international shipping by at least 40% from 2008 levels by 2030. When the strategy was agreed upon, an estimated 30% reduction had already been achieved due to widespread slow steaming by ship operators (Figure 1). This suggests that the 2030 goal may be tightened when IMO revises the strategy in 2023 (Rutherford & Comer, 2018; Ship & Bunker, 2020).

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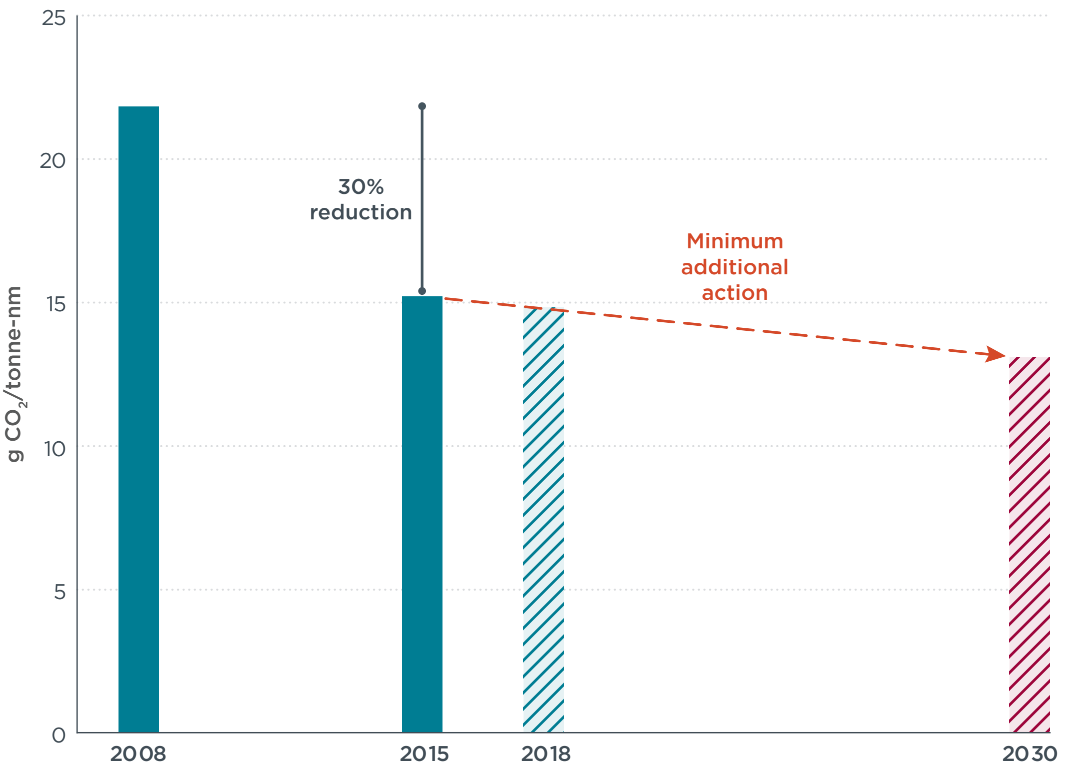

Figure 1. CO_2 intensity of international shipping, 2008 to 2030. *Note*. Derived from Smith et al. (2015), Olmer, Comer, Roy, Mao, and Rutherford (2017), and UNCTAD (2019). Solid bars indicate historical values, while hatched bars indicate projections.

IMO is now developing regulations to support these goals. Earlier this year, IMO tightened new energy efficiency targets for five ship types starting in 2022 (Comer & Rutherford, 2019). IMO is also working to address emissions from the existing fleet. Proposed measures include an operational efficiency standard (IMO, 2019a), in-service speed limits (IMO, 2019b), and technical measures to limit engine power (IMO, 2019c; IMO, 2019e). In March 2020, IMO delegates will gather at the 7th Intercessional Working Group on Greenhouse Gases to further refine short-term measures.

One proposed measure is Japan's Energy Efficiency Index for Existing Ships, or EEXI. This would build upon IMO's existing Energy Efficiency Design Index, or EEDI (IMO, n.d.), which applies to new ships, by applying technical efficiency standards to the existing fleet (Chambers, 2019). Shipowners would have four main means of complying with the EEXI as it is currently understood. New ships that can be certified to future EEDI targets are expected to meet the EEXI without further modifications. Ships in the existing fleet that are not expected to meet future EEDI standards could comply by installing energy efficiency retrofits, through main engine power limitation (EPL), or through early retirement.

EPL is likely 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., n.d.). EPL establishes a semi-permanent, overridable limit on a ship's maximum power (Andersen, 2017) and therefore speed. 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 (International Maritime Organization, 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.[1] 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. A mandatory EPL will not directly reduce fuel use and CO_2 emissions if ships already operate slower than the de facto speed limit implied. This means that the effectiveness of measures like the EEXI and EPL need to be evaluated against real-world conditions.

To help, this paper investigates the relationship between varying levels of EPL and CO_2 emissions based upon 2018 real-world ship operations using ICCT's Systematic Assessment of Vehicle Emissions (SAVE) model, as described in Olmer et al. (2017). We find that EPLs of 20% or less would have negligible impacts on ship CO_2 emissions. 30% to 40% EPLs would reduce CO_2 from existing ships modestly, on the order of 2% to 6%. Larger EPLs of 50% or more could meaningfully reduce ship CO_2 by 8% to 19% depending on ship type and size. Importantly, benefits diminish over time if EPL is not required for newer ships, with expected CO_2 emission reductions falling about 60% due to fleet turnover and growth through 2030. 30%+ EPL measures could help avoid a bounceback in future emissions should market conditions change in ways that spur a return to faster speeds.

The rest of this paper is arranged as follows. The next section outlines the methodology used. Following that, we present the results of the modeling, namely, what degree of fuel and CO_2 savings would be expected under EPL scenarios of varying ambition in 2018 and 2030. Subsequently, we conclude and discuss opportunities for future work. An appendix outlining the full modeling results is also provided.

Methodology

Baseline 2018 fleet analysis

The starting point for understanding how much fuel use and CO_2 emissions would be avoided by EPL measures is an understanding of existing engine loads, as estimated from real-world operating conditions. For this study, we used the SAVE model introduced in Olmer et al. (2017) to process calendar year 2018 Automatic Information System (AIS) data purchased from exactEarth (eE).[3] AIS data provide estimates of ship location (latitude/longitude), speed over ground (SOG), heading, draught, etc., 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.[4] We then matched each ship's hourly operational data with its design speed and main engine power using data purchased from IHS.[5]

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[1] EPL, by reducing the baseline available engine power available to operators, could violate IMO's guidelines for minimum propulsion power (Faber, Nelissen, & Shanthi, 2019a). 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).

[2] 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.

[3] https://exactearth.com

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

[5] https://maritime.ihs.com/Account2/Index

We focused on the three ship types—container ships, bulk carriers, and oil tankers—that accounted for more than half of all CO_2 emissions from international shipping in 2015 (Olmer et al., 2017).[6] The SOG, design speed, and main engine power data were used to estimate main engine loads as a percentage of maximum continuous rating, or MCR, for each ship in every hour it operated in the cruise phase in 2018 using the propeller law.[7] Main engine loads were, in turn, used to determine baseline 2018 fuel consumption and CO_2 emissions for each ship, while SOGs and operating hours were multiplied to estimate total distance traveled for each ship in 2018. Only the cruise phase was modeled, but it was modeled for all equipment types—main engine, auxiliary engine, and boiler. CO_2 emissions were estimated by multiplying the mass of fuel used by 3.114, 3.206, and 2.750 for heavy fuel oil, marine gas oil, and liquefied natural gas, respectively.

Estimating EPL effects on the 2018 fleet

Using the above data, we applied a series of scenarios for EPL, 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 2018, 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.[8] Engine specific fuel oil consumption (SFOC), in grams of fuel per kilowatt-hour (g/kWh), was recalculated for the hours in which the SOG also changed.

Since ships that slow down due to EPL travel less distance for the same number of hours in operation, we needed to add new hours back to the modeled EPL fleet in order to move the same amount of cargo. This was accomplished by adding "shadow hours" to account for the missing distance traveled and therefore preserve transport supply. Missing distance traveled could be replaced by operating under-deployed ships more hours in a year, by bringing laid-up ships back into service, or by bringing an extra new ship into service (Faber et al., 2017). Determining which occurs under a future EPL measure is beyond the scope of this work; accordingly, shadow hours were assumed to be operated by each ship at its annual average SOG and main engine load factors in 2018.

For each EPL scenario, CO_2 emission reductions were calculated by comparing the new and shadow fuel consumed to the 2018 fuel consumed for each ship. The results were aggregated by ship type and size (capacity bin) for ease of reference.

Projections to 2030

CO_2 emission reductions from EPL would likely be different in 2030, the year of IMO's carbon intensity target. For example, if new ships delivered after 2018 are not subject to EPL under the EEXI, no corresponding CO_2 reduction would be expected. Therefore, understanding how many ships will be brought into service by 2030 is important for understanding how EPL might contribute to IMO's goal to reduce the carbon intensity of international shipping by at least 40% in 2030.

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[6] In total, 21,722 ships were included in this analysis. We excluded 7% of all containers, bulk carriers, and oil tankers, representing 6% of all AIS signals for those ships, because the SAVE code was not yet able to populate IMO numbers from static AIS signals over to dynamic AIS signals. We have created a matching procedure that will be incorporated into future work. Excluded ships are representative of the 2018 fleet, so we do not expect our conclusions to change.

[7] Cruise phase is defined as when a ship is underway and not maneuvering, anchored, or at berth. Overall, the propeller curve predicts a cubic relationship between hourly ship speed and power demand. Thus, a 10% decrease in speed over ground results in a 27% reduction in fuel use. This effect is reduced over a voyage because more hours are needed to complete the voyage and because slower operations can increase total fuel use by auxiliary engines and boilers. See Faber, Huigen, and Nelissen (2017) for further details.

[8] An update to SAVE from Olmer et al. (2017) includes a variable SFOC that is a function of main engine load. It takes the same approach as Smith et al. (2015).

New ships will be introduced into the fleet either as a direct replacement for an existing ship being retired or as a ship being brought in to meet increased trade demand. To estimate vessel retirement, we used the fleet turnover model developed in Wang and Lutsey (2013), which applies retirement curves by year in service for all ship types. We also used traffic projections from UNCTAD (2017) to estimate growth in the global fleet. For simplicity's sake, we assumed no change in new ship size, utilization (i.e., percentage of deadweight tonnage), or operational hours compared to 2018. Additionally, ships delivered after 2018 are assumed to consume 20% less fuel per unit transport work than in-service vessels due to the EEDI.

The CO_2 effects of EPL measures in 2030 would also change if ship speeds change significantly, and large changes have occurred in the past. For example, operational speeds dropped significantly from 2008 to 2010; during this time, shipowners and operators slowed ships down to absorb overcapacity and bring operational costs in line with lower freight rates in the aftermath of the 2008 global recession (Smith et al., 2015). It is possible that those speeds could rebound by 2030, but projecting ship speeds, which are a function of factors including global shipping capacity, demand, freight rates, and oil prices, is complex.[9]

Still, Table 2 below shows that ship speeds remain depressed in 2018, with little detected increase from 2010 levels. Consequently, for our base analysis, we held ship speeds in 2030 constant at 2018 levels. As a sensitivity case, we also modeled CO_2 emission reductions from EPL measures assuming a baseline 10% increase in ship speeds. Under this scenario, ships would operate in 2030 at approximately the average of 2008 and 2018 speeds.

Results and discussion

The results below are presented as follows. Baseline 2018 speeds and main engine load factors are detailed first, and then we discuss changes in operating conditions by EPL scenario. Following that, we present CO_2 emission reductions by EPL scenario and ship type in 2018 and, subsequently, detail the projected benefits in 2030. Full results are in the appendix.

Baseline operational conditions in 2018

The SAVE model was used to estimate the main engine load factor (ME LF), SOG, and hourly fuel consumption for each ship. Average values by ship type and capacity bin, along with the total cruise hours in 2018, are shown in Table 1.

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[9] In an assessment of short-term GHG measures for the European Commission, projected business-as-usual speeds in 2030 in a single study ranged from 10% lower to 12% higher than the 2012 average. See Faber, Nelissen, and Shanthi (2019b).

Table 1. Average ME LFs, SOGs, hourly cruise phase fuel consumption, and total cruise phase hours in 2018

Ship type	Capacity (TEU or dwt)[a]	ME LF (% MCR)	Adjusted SOG (knots)	Hourly fuel consumption (tonne/hr)	Cruise hours (million)
Container	<1,000 TEU	50%	12.0	0.74	3.00
	1,000 – 1,999	43%	13.3	1.25	5.15
	2,000 – 2,999	37%	14.1	1.84	3.08
	3,000 – 4,999	32%	14.7	2.63	4.29
	5,000 – 7,999	32%	15.6	3.79	2.90
	8,000 – 11,999	37%	16.3	4.75	3.55
	12,000 – 14,500	37%	16.2	5.23	1.16
	14,501+	50%	15.3	6.50	0.80
	Average	39%	14.4	2.70	—
Oil tanker	<5,000 dwt	54%	9.0	0.25	2.78
	5,000 – 9,999	53%	9.5	0.41	1.61
	10,000 – 19,999	53%	10.1	0.63	0.57
	20,000 – 59,999	50%	11.3	1.16	1.74
	60,000 – 79,999	50%	11.6	1.40	1.63
	80,000 – 119,999	46%	11.2	1.51	3.80
	120,000 – 199,999	44%	11.3	1.93	2.59
	200,000+	45%	11.7	2.90	3.71
	Average	48%	10.8	1.50	—
Bulk carrier	<10,000 dwt	56%	9.30	0.30	1.69
	10,000 – 34,999	55%	10.9	0.71	6.69
	35,000 – 59,999	52%	11.2	0.90	12.90
	60,000 – 99,999	48%	11.3	1.06	15.68
	100,000 – 199,999	45%	11.0	1.65	6.78
	200,000+	50%	11.5	2.15	3.01
	Average	50%	11.1	1.09	—

[a] TEU = Twenty foot equivalent unit, a standardized measure of carrying capacity for container ships.
dwt = deadweight tonnage, an equivalent unit for oil tankers and bulk carriers.

As shown in the table, in 2018 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 2018 for bulk carriers at 50% MCR (45% to 56% MCR, depending on ship size), followed by oil tankers at 48% (44% to 54%), with container ships operating at even lower engine loads averaging 39% (32% to 50%). This implies that EPL measures would need to be relatively stringent in order to further reduce operational speeds and therefore in-use CO_2 emissions.

Looking at the other operational parameters, SOGs were highest for container ships at an average of more than 14 nautical miles per hour (knots), with oil tankers and bulk carriers both operating at 11 knots on average in 2018. Hourly fuel use rates were the highest for container ships at 2.7 tonnes per hour, followed by tankers at 1.5 tonnes per hour and bulk carriers at about 1.1 tonnes per hour. Total cruise hours, presented here in millions per capacity bin, vary depending on the duty cycle of the ship and the total number of ships in service.[10]

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[10] Annual cruise hours are shown in Table 1 primarily to enable comparisons with the full modeling results provided in the appendix.

To understand overall trends, in particular the longevity of slow steaming practices adopted starting in 2009, unadjusted SOGs for 2018 were compared to speeds derived via SAVE for 2015 in Table 2.[11] Comparable values from 2008, at the peak of ship speeds before the 2008 global recession from Smith et al. (2015) are also presented.

Table 2. Average cruise SOG by ship type and capacity bin in 2008, 2015, and 2018

Ship type	Capacity (TEU or dwt)	SOG (knots)			Change (%)	
		2008[a]	2015[b]	2018	2008 to 2015	2015 to 2018
Container	<1,000 TEU	13.2	12.5	12.3	-5%	-2%
	1,000 – 1,999	15.2	13.6	13.5	-11%	-1%
	2,000 – 2,999	16.7	14.0	14.2	-16%	2%
	3,000 – 4,999	18.1	14.8	14.8	-18%	0%
	5,000 – 7,999	19.7	15.4	15.7	-22%	+2%
	8,000 – 11,999	20.3	15.7	16.4	-23%	+4%
	12,000 – 14,500	19.2	15.9	16.3	-17%	+3%
	14,500+	—	16.9	16.4	—	-3%
Oil tanker	<5,000 dwt	11.3	10.0	9.7	-12%	-3%
	5,000 – 9,999	13.2	10.1	9.9	-24%	-2%
	10,000 – 19,999	14.3	10.3	10.5	-28%	+2%
	20,000 – 59,999	15.8	11.9	11.6	-25%	-3%
	60,000 – 79,999	15.5	12.1	11.8	-22%	-3%
	80,000 – 119,999	15.7	11.6	11.4	-26%	-2%
	120,000 – 199,999	15.5	11.7	11.5	-25%	-1%
	200,000+	16.4	12.4	12.0	-24%	-3%
Bulk carrier	<10,000 dwt	11.6	9.9	9.9	-14%	-1%
	10,000 – 34,999	14.7	11.4	11.2	-23%	-2%
	35,000 – 59,999	15.0	11.6	11.4	-23%	-1%
	60,000 – 99,999	14.9	11.6	11.5	-22%	-1%
	100,000 – 199,999	14.7	11.1	11.2	-25%	+1%
	200,000+	15.6	11.8	11.7	-24%	-1%

[a] From Smith et al. (2015).
[b] From Olmer et al. (2017). 2018 SOGs are unadjusted for speeds corresponding to 100%–150% of maximum main engine power in order to make those comparable to 2015 values.

As shown, average SOGs were similar between 2015 and 2018, dropping on the order of half a percent on an activity-weighted basis. Speeds for the smallest and largest container ships dropped, but they increased somewhat—up to 4%—for medium-size ships carrying between 2,000 and 14,500 TEUs. Speeds for oil tankers and bulk carriers mostly fell between 2015 and 2018. Continued slow steaming in 2018 reinforces the expectation that substantial EPL will be needed to affect operational fuel use.

Table 2 also demonstrates the potential for ships to speed back up if market conditions similar those leading up to 2008 reemerge. On average, ship speeds dropped by 20% from 2008 to 2015 as a result of overcapacity in ship transport supply compared to global maritime trade. Slowing ships down reduces the nautical miles (nm) traveled in a year and reduces transport supply on a dwt-nm or TEU-nm basis; this stabilizes freight

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[11] For this analysis, anomalous speeds in the raw AIS data, as represented by ME LFs above 100% MCR, were adjusted by resetting them to the average cruising speed for that ship in 2018. To allow direct comparison to 2015 speeds as estimated in Olmer et al. (2017), unadjusted figures were used.

rates for a given supply of cargo. The large majority of these reductions occurred by 2010, and there was not significant bounceback as of 2018. The longevity of this slow steaming trend implies that 2018 speeds are a reasonable reference point to model the potential benefits of EPL in 2030.

Tables 1 and 2 only show annual average ME LFs, while the impact of EPLs will be felt at the hourly level. Figure 2 summarizes the distribution of main engine load factors for every container, bulk carrier, and oil tanker analyzed for every cruise hour they operated in 2018.

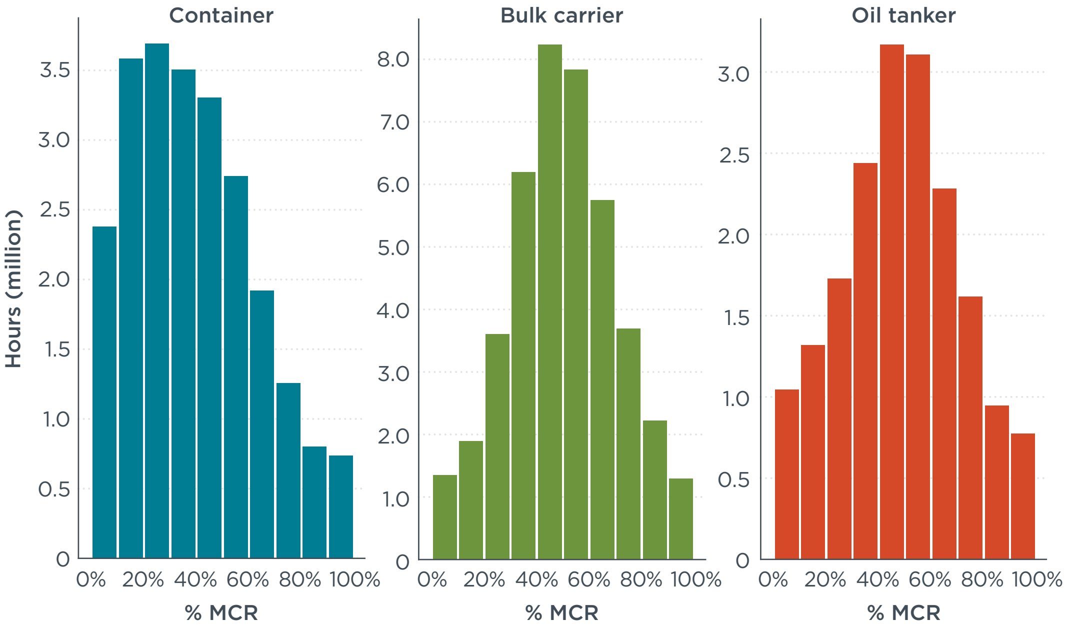

Figure 2. Main engine load factor distribution for containers, bulk carriers, and oil tankers, 2018

Figure 2 reaffirms that the three ship types analyzed were operated at substantially below their maximum speeds and powers in 2018. In addition to the averages varying, the figure also shows some differences between the distribution of ME LFs by hour across the ship types. Container ships, in addition to being operated at the lowest annual average emission factors, 39%, had operational hours that were skewed toward lower load factors, with the most common hours being between 20% and 30% MCR. Bulk carriers had a more normal distribution around their annual average of 50%. Oil tankers also showed a normal distribution, with a prominent spike between 40% and 60% MCR.

Given these baseline 2018 operational conditions, policies that target a set EPL—say, 20%—are unlikely to reduce fuel use proportionately because most ships already operate at well below their maximum main engine power and speed most of the time. Nonetheless, even if a given EPL scenario does not impact the average hour, it will impact any hours when a ship is operating at high speed and therefore high engine load. Finally, while less stringent EPL measures might have no effect on ships operating at 2018 speeds, such measures could avoid the emergence of “latent emissions” from ships that would otherwise speed back up to take advantage of improved market conditions (Smith et al., 2015).

Changes in operating conditions by EPL scenario

The EPL scenarios applied, which range from 10% to 60% cuts in main engine power, generated corresponding changes in operational conditions for ships operating at higher speeds. SAVE outputs included revised ME LFs, associated SOGs, fuel use per hour including auxiliary engine and boilers, and total cruise hours by EPL scenario.

Figure 3 shows the trend of each of these variables, and also total fuel use for oil tankers in 2018. Each value is normalized to 100, with that score equal to the base 2018 case without an EPL.

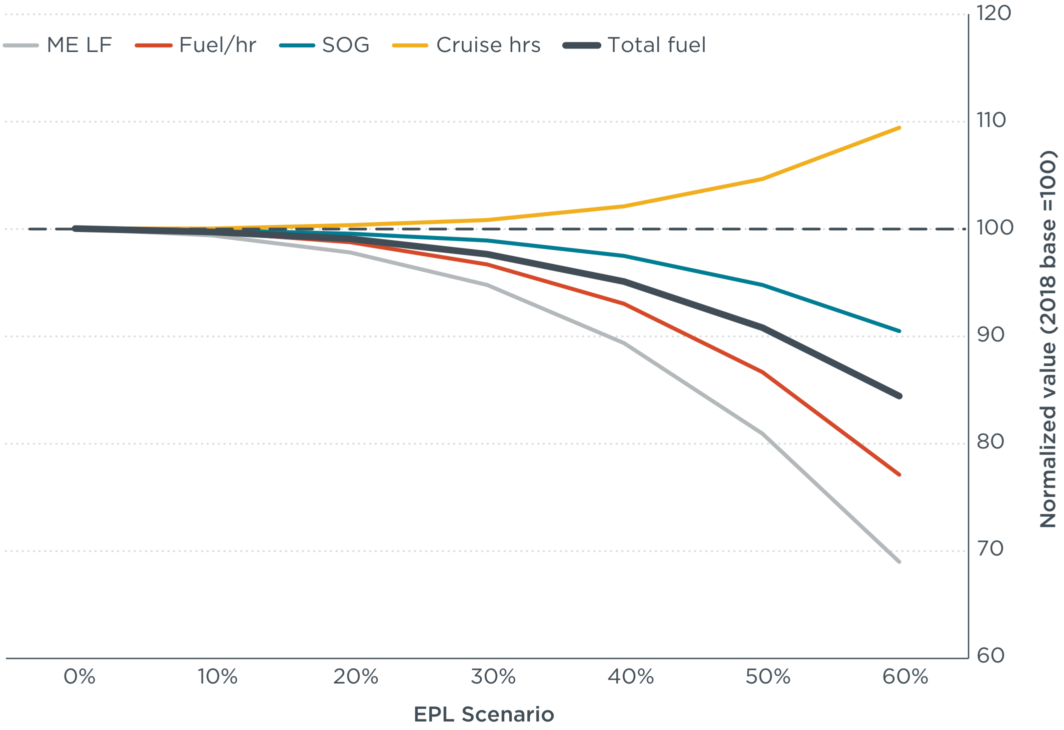

Figure 3. Normalized operational data by EPL scenario for oil tankers, 2018

As shown in Figure 3, four of the variables—main engine load factor (grey line), hourly fuel consumption (orange), total fuel use (thick black), and SOG (blue)—fell as the EPL increased from 0% to 60%. In contrast, cruise hours (yellow line) increased as ship speeds fell in order to maintain the same distance travelled and therefore transport capacity.

As shown in the graph, EPL scenarios of 20% and below had no modeled impact on oil tanker speed, fuel use, or cruise hours in 2018. Starting at 30%, average SOG and fuel use begins to fall, and total cruise hours begin to rise. Fuel per hour falls somewhat slower than the ME LF, owing to the operation of boiler and auxiliary engines with fuel consumptions that are proportional to hours operated, not ship speed. Total fuel use, which is a product of hourly fuel consumed and cruise hours, drops faster than SOG, but at a rate of about half that of the average ME LF.

Power versus CO_2 reduction by ship type in 2018

Baseline 2018 data and the operational changes summarized above were used to estimate the CO_2 emission impacts of 10% to 60% EPL scenarios for container ships, oil tankers, and bulk carriers. The results are illustrated in Figure 4. In each case, the blue bars show the EPL scenarios ranging from 10% to 60%, while the red bars show the associated CO_2 emission reductions for each ship type in 2018.

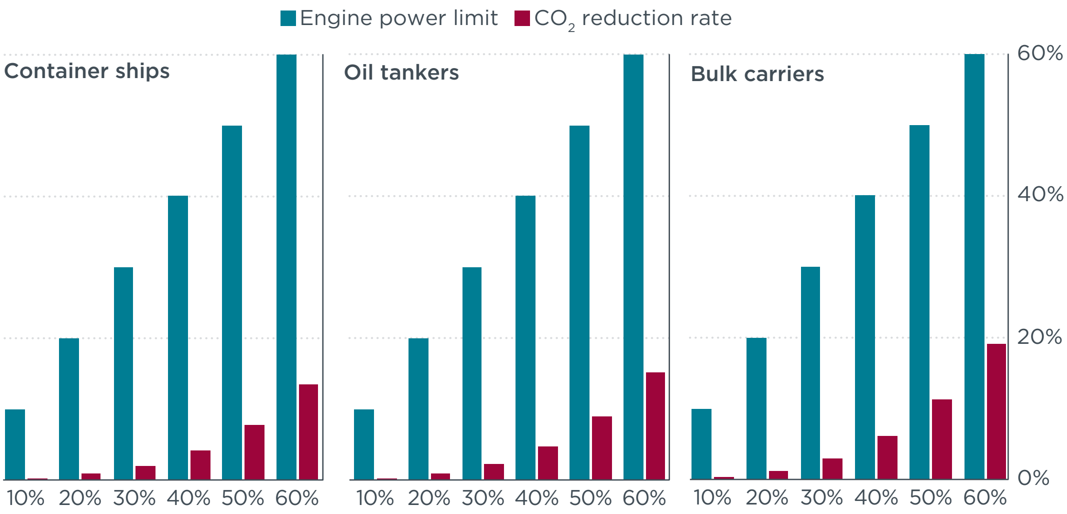

Figure 4. Engine power limitation versus CO_2 emission reductions for container ships, oil tankers, and bulk carriers, 2018 fleet

As Figure 4 shows, modeled CO_2 emission reductions are not proportional to engine power reductions; as EPL is applied, the fuel savings accrue at a significantly slower rate and in a non-linear fashion. The lowest EPL scenarios (10% to 20%), would generate less than 1% cuts in CO_2 for the 2018 fleet. A 30% EPL is estimated to reduce CO_2 by 2% for container ships and oil tankers, and 3% for bulk carriers. CO_2 emission reductions rise more quickly from 40% upward, roughly doubling with each 10% EPL increment and reaching a maximum of 13% to 19% for the 60% EPL scenario. A 50%+ EPL could meaningfully reduce ship CO_2 by 8% to 19% depending on ship type and size. Benefits are similar for bulk carriers and oil tankers and somewhat smaller for container ships, consistent with the main engine and speed trends identified above.

Power versus CO_2 reduction by ship type in 2030

The CO_2 emission reductions outlined in the section above are specific to the 2018 fleet. Benefits would be different in 2030, the year of IMO's carbon intensity target, if ships delivered after 2018 are not subject to EPL. Applying the fleet turnover model to 2018 vessels identifies those still expected to be in service in 2030 plus their fuel use; supplementing those ships with replacements plus new ships to absorb future trade growth identifies the full fuel inventory in that year.

Table 3 shows the projected fuel in 2030 both subject to EPL requirements and total fuel for the three ship types assuming that new ships delivered after 2018 are exempt. The simple average build year for each ship in 2018, and associated annual trade growth rate derived from UNCTAD, are also provided.

Table 3. Total versus EPL-affected fuel consumption by ship type, 2030

Ship type	Average build year, 2018	Annual trade growth[a]	2030 fuel (million tonnes)		% affected
			EPL affected	Total	
Containers	2007	4.5%	23.5	64.7	36%
Oil tankers	2005	2.2%	12.8	27.6	46%
Bulk carriers	2009	3.9%	22.8	51.0	45%
Total	—	—	59.1	143.2	41%

[a] UNCTAD (2019)

As shown, an EPL applied only to existing ships in service as of 2018, and not to newer ships brought into service afterward, would cover on average 41% of 2030 fuel use for these three ship types. That means that fleet turnover and expansion would reduce the share of fuel use subject to EPL by about 60% from 2018 to 2030. More oil tanker fuel use would be covered, owing to slower trade growth, as predicted by UNCTAD, and therefore a smaller number of new vessels being brought into the fleet. In this way, fleet turnover and growth would dilute the effectiveness of an EPL measure that does not apply to all ships.

Having estimated which 2018 ships will still be in service in 2030 and having modeled the fuel use of ships not subject to EPL, we can now calculate the overall impact of EPL in 2030 under our base scenario that assumes no increase in ship speeds. Figure 5 summarizes CO_2 emission reductions by three ship types under the EPL scenarios included in this analysis. Results for container, bulk carriers, and oil tankers are shown in blue, red, and yellow bars, respectively. Note that the scale of the y-axis is one-sixth of the x-axis, so that the CO_2 savings by EPL scenario are easier to see; they appear larger than they actually are.

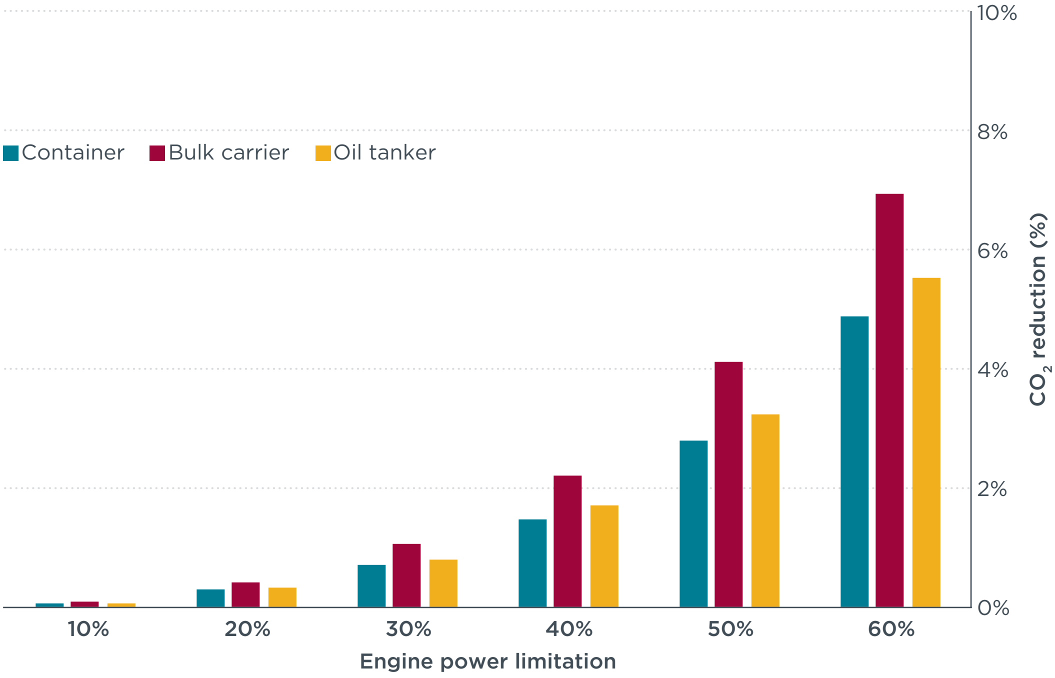

Figure 5. Engine power limitation versus CO_2 reduction for three major ship types, 2030

As shown, limiting main engine power by 30% or less would reduce fuel use and CO_2 emissions by 1% or less in 2030 because existing ships would already be operating well below their implied speed limits and also because of fleet turnover. Intermediate EPL scenarios of 40% to 50% would reduce emissions modestly, between 1% and 4% depending on ship type and size. Limiting main engine power by 60%, the largest limitation investigated, would cut CO_2 emissions by about 6% fleetwide. Larger benefits, consistent with Figure 4, could accrue if EPL were applied to all ships in 2030, including those built after 2018.

Speed sensitivity

We explored the sensitivity of these findings by increasing the speed that every ship operated in every hour in 2018 by 10%, and then applying the EPL scenarios. In order to save computation time, one capacity bin for each ship type was selected that was both a substantial contributor to fuel use and also generally representative of the overall fuel savings for each ship type. This corresponded to capacity bin 6 for container ships and oil tankers and capacity bin 4 for bulk carriers. The results are presented in Table 4, which shows the CO_2 emission reductions by EPL scenario for both the Base and High Speed (+10%) scenarios.

Table 4. CO_2 emission reductions by EPL scenario for the three ship types and two speed scenarios in 2030

Ship type	Capacity (TEU or dwt)	Speed scenario	CO_2 reduction by EPL scenario					
			10% EPL	20% EPL	30% EPL	40% EPL	50% EPL	60% EPL
Container	8,000 – 11,999	Base	0.0%	0.2%	0.6%	1.4%	3.0%	6.1%
		High Speed	0.3%	1.1%	2.3%	4.3%	7.4%	12.0%
Oil tanker	80,000 – 119,999	Base	0.1%	0.3%	0.9%	2.1%	4.3%	7.9%
		High Speed	0.6%	1.7%	3.5%	6.0%	9.5%	14.3%
Bulk carrier	60,000 – 99,999	Base	0.1%	0.4%	1.2%	2.7%	5.4%	10.3%
		High Speed	0.8%	2.1%	4.2%	7.3%	11.7%	18.4%

As the table indicates, CO_2 emission reductions by EPL scenario are sensitive to assumptions about 2030 speeds. This is because as ships speed up, ME LFs increase, and this boosts the number of hours impacted by engine power limits and how much ships need to slow down. Under the High Speed scenario, CO_2 reductions roughly quadruple for the lowest EPL scenarios (10% and 20%), and double for the highest EPL scenarios (50% to 60%).

This finding suggests that the benefit of EPL measures will be sensitive to future changes in speed. A related question is whether less stringent EPL measures could lock in the fuel savings of existing slow steaming practices even if they are not expected to absolutely reduce fuel use below 2018 levels. To investigate this, we compared SOGs across the Base and High Speed scenarios to see how the speed increase is absorbed by various levels of EPL. The results are summarized in Table 5, which also shows the change in average ship speeds in knots by speed scenario and EPL case.

Table 5. Engine power limitation versus SOG for three major ship types and speed scenario, 2030

Ship type	Capacity (TEU or dwt)	Speed scenario	Average SOG by EPL						
			None	10% EPL	20% EPL	30% EPL	40% EPL	50% EPL	60% EPL
Container	8,000 – 11,999	Base	16.3	16.3	16.3	16.2	16.1	15.9	15.5
		High Speed	17.9	17.9	17.8	17.6	17.3	16.8	16.1
		Change	+10%	+9%	+9%	+8%	+7%	+6%	+4%
Oil tanker	80,000 – 119,999	Base	11.2	11.1	11.1	11.1	10.9	10.6	10.1
		High Speed	12.2	12.1	12.0	11.8	11.5	11.0	10.4
		Change	+9%	+9%	+8%	+7%	+5%	+4%	+3%
Bulk carrier	60,000 – 99,999	Base	11.3	11.3	11.3	11.2	11.0	10.7	10.2
		High Speed	12.4	12.3	12.1	11.9	11.6	11.1	10.4
		Change	+9%	+9%	+8%	+6%	+5%	+3%	+2%

As shown in the table, with no EPL, average speeds in the High Speed scenario in 2030 would be about 18 knots for container ships and about 12 knots for oil tankers and bulk carriers. As EPLs are applied, the gap between the Base and High Speed scenarios begins to close, which demonstrates that the EPL begins to absorb the speed increase.[12]

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[12] As shown in Table 5, the starting difference in speed without EPL was exactly 10% for container ships and slightly less (9%) for oil tankers and bulk carriers. The difference between these ship types arises because the SAVE model resets any hours corresponding to ME LF above 100% MCR back to 100% MCR. Because, on average, oil tankers and bulk carriers operated at relatively higher load factors and speeds in 2018, more high speed hours were reset to the maximum for those two ship types in the High Speed scenario, and the initial 10% speed increase was correspondingly reduced slightly to 9%.

At a 30% EPL, the initial speed increase has fallen by about one-third; by 60% EPL, it has largely disappeared. Little dampening effect is seen for the 10% and 20% EPL scenarios. In this way, EPL stringencies of 30% and above start to provide insurance against future speed increases from the existing fleet.

Conclusions

This study analyzed the potential fuel and CO_2 emission savings attributable to limiting the engine power of major ship types in the existing fleet. It highlighted that EPL needs to be set at a level stringent enough to lower maximum speeds to the point where they begin affecting significant numbers of operational hours. Separately, the monitoring and sanctioning of excessive overrides of engine power limits, an issue not analyzed here, is likely to be an important factor in ensuring the effectiveness of EPL measures.

Our analysis found that intermediate EPLs of 40%–50% would reduce CO_2 emissions modestly, between 1% and 4% depending on ship type and size. The most aggressive EPL scenario modeled, 60%, would reduce CO_2 fleetwide in 2030 by about 6% if applied only to ships already in service in 2018, and up to triple that amount if also applied to newer ships. EPLs of 30% or more could help prevent a bounceback in operational speeds and associated CO_2 emissions if ships face an incentive by 2030 to speed up in response to improved market conditions.

There are three broad implications of this work. First, EPL will not proportionately reduce CO_2 because most ships today are already operating at well below their maximum speeds and, therefore, well below MCR. Second, EPLs would need to be stringent (50%+) to meaningfully reduce CO_2 emissions below expected 2030 levels for existing ships. Third, EPLs would need to be applied to all ships, not just current vessels in-service, if they are to substantially reduce the carbon intensity of shipping overall. Otherwise, the fraction of ships that require no action increases as older ships are retired from the fleet and are replaced with new, more efficient ships.

This analysis focused on EPL as a sole, independent means of reducing ship CO_2 emissions. In reality, EPL is likely to be one of several strategies that shipowners can use to meet a measure like Japan's proposed EEXI. Those options, including energy efficiency retrofits and early retirement, also deserve investigation. Moreover, the level of EPL required for a given ship under the EEXI will vary as a function of its technical efficiency. Further work is needed to estimate EPL requirements as a function of a given ship's attained EEDI score in order to directly assess the merits of the EEXI.

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Appendix – full results

Table A1. Average main engine load factor, speed over ground (SOG), hourly fuel consumption, and total cruise phase hours by engine power limitation (EPL) scenario, ship type, and capacity.

		10% EPL				20% EPL				30% EPL			
Ship type	**Capacity (TEU or dwt)**	**ME LF**	**SOG**	**Fuel use (t/hr)**	**Cruise hrs (10^6)**	**ME LF**	**SOG**	**Fuel use (t/hr)**	**Cruise hrs (10^6)**	**ME LF**	**SOG**	**Fuel use (t/hr)**	**Cruise hrs (10^6)**
Container	<1,000 TEU	50%	12.0	0.73	3.00	49%	12.0	0.72	3.01	47%	11.9	0.69	3.03
	1,000 – 1,999	43%	13.3	1.24	5.15	42%	13.2	1.22	5.16	41%	13.2	1.19	5.19
	2,000 – 2,999	37%	14.0	1.84	3.08	37%	14.0	1.82	3.09	36%	14.0	1.79	3.10
	3,000 – 4,999	32%	14.7	2.63	4.29	32%	14.7	2.62	4.29	32%	14.7	2.59	4.30
	5,000 – 7,999	32%	15.6	3.79	2.90	32%	15.6	3.78	2.90	32%	15.6	3.75	2.91
	8,000 – 11,999	37%	16.3	4.74	3.55	37%	16.3	4.72	3.55	37%	16.2	4.66	3.56
	12,000 – 14,500	37%	16.2	5.22	1.16	37%	16.2	5.20	1.16	37%	16.2	5.15	1.16
	14,500+	50%	15.2	6.43	0.80	48%	15.2	6.29	0.80	46%	15.0	6.07	0.81
Oil tanker	<5,000 dwt	53%	9.0	0.25	2.78	52%	9.0	0.25	2.80	49%	8.9	0.24	2.82
	5,000 – 9,999	53%	9.5	0.41	1.61	51%	9.4	0.40	1.62	49%	9.3	0.39	1.63
	10,000 – 19,999	53%	10.1	0.63	0.57	52%	10.0	0.62	0.57	49%	10.0	0.60	0.58
	20,000 – 59,999	50%	11.3	1.16	1.74	49%	11.2	1.15	1.74	48%	11.1	1.12	1.76
	60,000 – 79,999	49%	11.6	1.40	1.63	49%	11.5	1.39	1.63	48%	11.5	1.36	1.64
	80,000 – 119,999	46%	11.1	1.51	3.81	45%	11.1	1.49	3.81	44%	11.1	1.47	3.84
	120,000 – 199,999	44%	11.3	1.93	2.59	44%	11.3	1.92	2.59	43%	11.3	1.89	2.61
	200,000+	45%	11.7	2.89	3.71	44%	11.7	2.87	3.72	43%	11.6	2.82	3.74
Bulk carrier	<10,000 dwt	55%	9.3	0.30	1.69	54%	9.2	0.29	1.70	51%	9.12	0.28	1.71
	10,000 – 34,999	55%	10.9	0.71	6.70	54%	0.9	0.69	6.72	51%	10.8	0.67	6.78
	35,000 – 59,999	52%	11.2	0.90	12.91	51%	11.2	0.89	12.9	49%	11.1	0.87	13.05
	60,000 – 99,999	48%	11.3	1.05	15.69	48%	11.2	1.04	15.7	47%	11.2	1.02	15.83
	100,000 – 199,999	45%	11.0	1.65	6.78	45%	11.0	1.64	6.80	44%	10.9	1.60	6.83
	200,000+	50%	11.5	2.14	3.01	49%	11.5	2.11	3.02	48%	11.4	2.06	3.04

		40% EPL				50% EPL				60% EPL			
Ship type	**Capacity (TEU or dwt)**	**ME LF**	**SOG**	**Fuel/hr**	**Cruise hrs (10^6)**	**ME LF**	**SOG**	**Fuel/hr**	**Cruise hrs (10^6)**	**ME LF**	**SOG**	**Fuel/hr**	**Cruise hrs (10^6)**
Container	<1,000 TEU	44%	11.8	0.65	3.06	39%	11.5	0.60	3.13	34%	11.0	0.52	3.26
	1,000 – 1,999	39%	13.0	1.14	5.24	36%	12.8	1.07	5.34	31%	12.3	0.97	5.51
	2,000 – 2,999	34%	13.9	1.73	3.12	32%	13.7	1.64	3.16	28%	13.3	1.51	3.25
	3,000 – 4,999	31%	14.6	2.54	4.31	29%	14.5	2.45	4.35	27%	14.2	2.29	4.43
	5,000 – 7,999	31%	15.6	3.69	2.91	30%	15.4	3.55	2.94	27%	15.1	3.29	2.99
	8,000 – 11,999	35%	16.1	4.55	3.58	33%	15.9	4.32	3.63	30%	15.5	3.93	3.73
	12,000 – 14,500	36%	16.1	5.02	1.17	34%	15.9	4.77	1.19	30%	15.4	4.33	1.22
	14,500+	44%	14.8	5.75	0.82	40%	14.4	5.30	0.84	34%	13.7	4.61	0.88
Oil tanker	<5,000 dwt	45%	8.7	0.22	2.87	40%	8.4	0.20	2.96	34%	8.0	0.18	3.09
	5,000 – 9,999	45%	9.2	0.36	1.66	40%	8.9	0.33	1.71	34%	8.5	0.30	1.79
	10,000 – 19,999	46%	9.8	0.57	0.59	41%	9.5	0.53	0.61	34%	9.0	0.47	0.64
	20,000 – 59,999	45%	11.0	1.07	1.78	40%	10.6	0.99	1.83	34%	10.1	0.87	1.92
	60,000 – 79,999	45%	11.3	1.30	1.67	41%	10.9	1.20	1.72	34%	10.4	1.05	1.80
	80,000 – 119,999	42%	10.9	1.41	3.88	38%	10.6	1.32	3.98	33%	10.1	1.18	4.16
	120,000 – 199,999	41%	11.1	1.83	2.63	38%	10.9	1.72	2.69	33%	10.4	1.54	2.81
	200,000+	41%	11.5	2.72	3.78	38%	11.2	2.55	3.87	33%	10.8	2.27	4.04
Bulk carrier	<10,000 dwt	47%	9.0	0.26	1.74	41%	8.7	0.24	1.80	35%	8.3	0.21	1.89
	10,000 – 34,999	48%	10.6	0.63	6.90	43%	10.2	0.57	7.11	36%	9.7	0.48	7.49
	35,000 – 59,999	46%	10.9	0.82	13.24	42%	10.6	0.75	13.63	35%	10.1	0.65	14.32
	60,000 – 99,999	44%	11.0	0.98	16.05	40%	10.7	0.90	16.47	34%	10.2	0.79	17.29
	100,000 – 199,999	42%	10.8	1.55	6.90	39%	10.6	1.44	7.05	34%	10.2	1.28	7.33
	200,000+	45%	11.2	1.96	3.08	41%	10.9	1.80	3.17	35%	10.4	1.55	3.32

Table A2. CO_2 emission reductions by EPL scenario for three major ship types, 2030

Ship type	Capacity (TEU or dwt)	CO_2 reduction by EPL scenario					
		10% EPL	20% EPL	30% EPL	40% EPL	50% EPL	60% EPL
Container	<1,000 TEU	0.2%	0.6%	1.3%	2.4%	4.1%	6.7%
	1,000 – 1,999	0.1%	0.5%	1.1%	2.1%	3.7%	6.2%
	2,000 – 2,999	0.1%	0.3%	0.7%	1.3%	2.5%	4.3%
	3,000 – 4,999	0.0%	0.2%	0.4%	0.9%	1.9%	3.6%
	5,000 – 7,999	0.0%	0.1%	0.2%	0.6%	1.4%	3.0%
	8,000 – 11,999	0.0%	0.2%	0.6%	1.4%	3.0%	6.1%
	12,000 – 14,500	0.0%	0.2%	0.6%	1.6%	3.7%	7.7%
	>14,500	0.4%	1.4%	3.0%	5.3%	8.9%	15.3%
Oil tanker	<5,000 dwt	0.4%	1.2%	2.5%	4.5%	7.0%	10.3%
	5,000 – 9,999	0.4%	1.1%	2.3%	4.4%	7.3%	11.3%
	10,000 – 19,999	0.3%	0.8%	1.9%	3.6%	6.3%	10.1%
	20,000 – 59,999	0.1%	0.4%	1.1%	2.3%	4.4%	7.5%
	60,000 – 79,999	0.1%	0.4%	1.0%	2.2%	4.5%	8.3%
	80,000 – 119,999	0.1%	0.3%	0.9%	2.1%	4.3%	7.9%
	120,000 – 199,999	0.1%	0.3%	0.9%	1.9%	4.0%	7.7%
	200,000+	0.1%	0.4%	1.0%	2.2%	4.5%	8.5%
Bulk carrier	<10,000 dwt	0.3%	1.0%	2.1%	3.8%	6.3%	9.8%
	10,000 – 34,999	0.2%	0.8%	1.8%	3.7%	6.8%	11.7%
	35,000 – 59,999	0.1%	0.6%	1.5%	3.2%	6.2%	11.3%
	60,000 – 99,999	0.1%	0.4%	1.2%	2.7%	5.4%	10.3%
	100,000 – 199,999	0.1%	0.4%	1.0%	2.2%	4.5%	8.6%
	200,000+	0.2%	0.6%	1.6%	3.3%	6.5%	12.1%