

The impact of speed reduction on liner shipping CO₂ emissions

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Abstract

Speed reduction is the best way to significantly reduce CO₂ emissions from international shipping in the short term. This solution, which was not a sustainable option a few years ago when the container markets were booming, has since been implemented by most shipping lines. This article attempts to measure the rate at which CO₂ emissions have already been reduced via slow steaming and to identify the conditions needed for its long-term sustainability. The paper shows that reductions, such as our finding of a 17.3% decrease in emissions since 2008 can only be sustained if the bunker price remains at a minimum of \$300 per ton or if policies are implemented to maintain the fuel price at this level.

1. Introduction

Slow steaming, or the reduction in the speed of vessels, has been implemented in liner shipping markets since 2008. This is a consequence of over-capacity and a rise in fuel price. The delivery of 240 container vessels from March 2007 to March 2009 led to an approximate increase of 10% in capacity (Alphaliner, 2010) while demand was, at the same time, reduced by 10% (UNCTAD, 2009). As a result more than 500 containerships remained idle in January 2010. During the same period, in July 2008, the bunker price of IFO380 (Intermediate Fuel Oil) reached \$700 per ton compared with \$300 in January 2007 and \$400 today. Slow steaming positively addresses over-capacity and surges in the cost of fuel by reducing them both.

A fortunate effect of over-capacity, shrinking demand and slow steaming is the impact on CO₂ emissions. That is to say that emissions are proportional to the amount of fuel burned with a factor of around 3.17 kg of CO₂ emitted per ton (Endresen et al., 2003, Buhaug et al., 2009, Corbett et al., 2003, 2007, 2009, Eyring et al. 2005a, 2005b, 2009). Reducing a vessel's speed by 10% would decrease CO₂ emissions by at least 10-15% (Corbett et al., 2009, Eide et al., 2009, Longva et al., 2010). This, however, was not considered as a viable long-term

option when markets were booming as slow steaming was inducing substantial losses in revenues (Kollamthodi et al., 2008, Corbett et al., 2009, Psaraftis et al., 2010). The recent changes in market conditions have meant that this effect and its long term sustainability is worth studying again¹ and in particular for container vessels, which represented 4% of all vessels in number but generated, with an uncertainty of +/-20%, 206 million tons of CO₂ in 2007 or 20% of all emissions (Buhaug et al., 2009).

This article attempts to provide a more accurate view of the short-term effects of slow steaming by measuring its impact on CO₂ emissions since 2008, its cost effectiveness and the bunker price at which this strategy is sustainable in the long-term. To do so, this paper begins by presenting the methodology used to estimate the amount of CO₂ emitted per liner shipping services and then continues to show how slow steaming influences the result. Estimates are then aggregated by vessel size and by trade using data on 2,051 containerships deployed on 387 services in January 2010. The final section calculates the CO₂ cost effectiveness of slow steaming, assesses how changes in bunker prices affect it and ends by discussing some policy implications.

2. Methodology

This methodology only applies to containerships above 1000 teu using two stroke diesel marine engines and for speed reductions up to a maximum of 30% from design speed. Under such conditions, a speed reduction from S_w to S_{w1} impacts on the main engine fuel consumption at sea (ME_{sea}), with a limited effect on the auxiliary engine consumption. Accordingly, the effect of a speed reduction from s_w to s_{w1} on the total fuel cost (TBC) for a service w of n vessels can be approximated as follows:

$$\Delta TBC_{w,s_w \rightarrow s_{w1}} = \sum_{k=1}^n BP_{IFO,t} \left(\Delta ME_{sea,s_w \rightarrow s_{w1}} \cdot \Delta D_{sea,w \rightarrow w1} + ME_{port} \cdot \Delta D_{port,s_w \rightarrow s_{w1}} \right) \quad (1)$$

$$\text{With } ME_{sea,s_w} = sm_{s_w} \cdot SFOC_{\Delta s_w} \cdot EL_{\Delta s_w} \cdot kWh_k \quad (2)$$

¹ As stated by Maersk Line chief operating officer Morten Engelstoft, "Slow steaming is here to stay" (Lloyd's List, 7 July 2010).

$$\text{and } \Delta EL_{s_w} = \left(\frac{\Delta s_w}{s_k} \right)^{\Delta Power_{s_w}} \quad (3)$$

ME_{sea,s_w} is the main engine daily fuel consumption at sea at speed s_w expressed in knots. We assume that the consumption in port (ME_{port}) is proportional to the main engine consumption at sea at design speed s_k with α_k equal to 5% (EPA, 2000)². $BP_{IFO,t}$ represents the bunker price in t for the main engine (IFO 380cst). $D_{sea,w}$ is the number of days at sea equal to $(Distance_w/24.s_w)$ and $(D_{sea,w}+D_{port,w})$ the number of days to complete a rotation (Rot_w).

ME_{sea,s_w} is the product of a sea margin (sm_w), a Specific Fuel Oil Consumption ($SFOC_{s_w}$), an Engine Load (EL_{s_w}) and an engine power in kWh_k . For two-stroke/slow mode engines sailing at speed s_w close to design speed s_k , the SFOC approximates to 170-190 g/kWh, the average load factor at 80-90% and the sea margin at 10% (MAN B&W Diesel A/B, 2008).

Slow steaming is a reduction in the commercial speed of a service w , and, therefore, in the speed of vessels deployed from s_w to s_{w1} . The impact on fuel consumption at sea depends on the magnitude in speed reduction (Buhaug et al., 2009, Psaraftis et al., 2010, Faber et al., 2010). As long as speed reduction is less than 10% ($s_w/s_k > 0.9$), as a rule of thumb, the engine power is related to ship speed by a third power ($Power_{s_w} = 3$ in equation 3). When reduction is greater than 10% ($s_w/s_k < 0.9$): 1) the engine power is related to speed by more than a third power, a power varying with vessel particulars and ranging from a fourth power according to manufacturers test bed data to a seventh power (Faber et al., 2010, Kollamthodi et al., 2008); 2) the specific fuel oil consumption increases to above 10-15% of optimum $SFOC_{s_k}$ or from 170-190 g/kWh to 187-209 g/kWh (Faber et al., 2010), although new engines and retrofitting can, today, limit this impact.

In this article, we choose to make conservative estimates based on the assumptions that engine power is related to speed by a third power and that the SFOC remains at 190 g/kWh, whatever the speed reduction. A 27.2% reduction

² We ignore the time when vessels are hotelling, transiting through canals and the fact that the use of bow thrusters and the number of reefer containers has an impact on the fuel consumption.

in fuel consumption at sea occurs when the speed reduces by 10% ($1-(0.9)^3$) and a 65.7% reduction is achieved ($1-(0.7)^3$) when the speed reduces by 30%.

The total effect on fuel cost is, however, not limited to the reduction in average fuel consumption per vessel at sea. With slow steaming, the rotation is stretched by ($\Delta Rot_{w1} = \text{Distance}_w / 24(s_w - s_{w1})$) days, the average number of miles performed in a year per vessel decreases by (s_w / s_{w1})%, and the number of ports of call per vessel in a year decreases, although the total time in port remains the same as more vessels are deployed³. Indeed, with the increase in number of days at sea for each vessel ($D_{sea,w1} > D_{sea,w}$), additional vessels ($\Delta n_w = n_w - n_k$) are required to keep a weekly frequency in each port of call (Pasaraftis et al, 2010, Corbett et al., 2009).

The aggregated effect on CO₂ emissions at the trade level is proportional to the quantity of tons of fuel burned with 3.17 kg of CO₂ emitted per ton of fuel burned. The abatement cost or CATCH value of one ton of CO₂ (Eide et al. 2009, Longva et al. 2010) for j services is as follows:

$$\text{CATCH}_{\text{CO}_2} = \sum_{w=1}^j \left[\frac{\Delta(TBC)_{w \rightarrow w_1} + AC_{\Delta n_{w1}}}{3.17 \cdot \Delta \sum_{k=1}^{n_w \rightarrow n_{w1}} (\Delta ME_{sea,sw \rightarrow sw1} \cdot D_{sea,sw \rightarrow sw1} + \Delta ME_{port,sw \rightarrow sw1} \cdot D_{port,sw \rightarrow sw1})} \right] \quad (4)$$

4)

The numerator is savings in the Total Bunker Cost (equation 1), plus the capital and operational costs of additional vessels ($AC_{\Delta n_{w1}}$)⁴. The denominator is the

³ We assume here that the time spent in ports for all vessels within a service remains the same. If not ($D_{port,w1} < D_{port,w}$) then, 1) there are no specific need for additional Δn_{w1} vessels or for stretching the rotation ($Rot_{w1} = Rot_w$), as long as the number of ports dropped compensate the time lost at sea ($D_{sea,w1} > D_{sea,w}$); 2) The mean number of miles performed in a year still decreases but this time, due to the reduction in distance. This option still reduces fuel costs, but to the expense of significant deterioration in the quality of services as the number of ports of call is less than before.

⁴ The auxiliary consumption for the additional vessels is not considered here. It can be approximated at 12% of the main engine consumption at sea at design speed according to Buhaug et al. (2009, p. 214).

reduction in CO₂ emissions, which changes with the time spent at sea, in ports and with the number and speed of vessels.

3. CO₂ reduction from slow steaming (2008-2010)

The estimation of the CO₂ slow steaming abatement cost at the trade level requires two sets of information: 1) vessel's fuel consumption at sea at speed s_w (ME_{sea,s_w}); 2) service characteristics including the commercial speed (s_w), number of days at sea ($D_{sea,w}$) and in ports ($D_{port,w}$).

To determine ME_{sea,s_w} , information from Lloyd's Register Fairplay (LRF, Jan. 2010) was used and compared with our estimates (equation 2 and 3). Table 1.A provides results for 451 container vessels from LRF. We compared these figures with estimates (Table 1B) based on a sea-margin of 10%, a load factor of 80%, a SFOC of 190 g/kWh to be multiplied by the engine total kWh (information was available for 1,930 vessels). We also estimated the impact of a reduction of 10% and then of 30% in speed from design speed.

Table 1. Main engine consumption at sea ($ME_{ks a}$) in tons/day

Vessel size In teu	A. LRF database*			B. This work **				
	Number of Vessels	Design speed S_k	$ME_{ks a}$ at S_k	Number of Vessels	Design speed S_k	$ME_{ks a}$ at S_k	at $S_w=S_k$ -10%	at $S_w=S_k$ -30%
1000-2000	94	19.4	53	249	19.6	50.7	36.9	17.4
2000-3000	100	20.9	81	368	21.8	84.5	61.6	29.0
3000-5000	152	22.9	128	644	23.6	136.7	99.7	46.9
5000-8000	93	24.8	209	420	24.9	209.6	152.8	71.9
8000+	12	24.4	258	249	24.6	259.7	189.3	89.1

* 451 vessels for which consumption is known.

**1,930 vessels for which kWh is known.

To assess the impact by trades, the extent of slow steaming needs to be estimated. Information was gathered from Alphaliner database in January 2010. For the 2,051 over 1000 teu containerships that are the focus of this article⁵, Alphaliner identifies the service in which a vessel is deployed, and, for each of the 387 services, the route, frequency, rotation in number of days (Rot) and ports of call. We then retrieved information on the status of a service in regards to slow steaming from comments on the service history. Table 2.A provides

⁵ For the (2,051-1,930) vessels for which the engine kWh was not known, we assumed that their consumption is equal to the mean of the category they belong to (Table 1).

descriptive statistics according to vessel size. The mean vessel size is 4,485 teu, mean design speed is 23.8 knots. In January 2010, 42.9% of vessels were slow steaming (Table 2, column A), a proportion increasing with size (75.5% for 8000+ teu containerships).

For the sake of comparing our estimates with former studies, we considered that the number of days at sea in 2008 was similar to Buhaug et al. (2009, p. 195) for 2007, ranging from 241 to 259 days at sea for 8000+ vessels. With slow steaming, the average time at sea has increased since 2008, particularly for larger vessels, from 259 to 298 days. This result is obtained by adding one week to the rotation of services under slow steaming, or $\left(\frac{Rot_{w1}}{Rot_w} \cdot D_{sea,w} \right)$ more days at sea with $(Rot_{w1}=Rot_w+7 \text{ days})$.

To analyze the impact of slow steaming on the average bunker consumption, we assumed that the speed was in 2008 at -10% of the design speed (Notteboom et al. 2009). In 2010, services under slow steaming run at -30%. This induces for larger vessels with an average design speed of 25 knots, a service commercial speed s_w equal to around 17-18 knots or Extra Slow Steaming (Alphaliner terminology). With 43% of all vessels under slow steaming (Table 2.A), the global reduction in speed is around 10%.

In 2008, the total bunker consumption for the 2.051 container vessels (number of vessels per category x average consumption) was 53.2 million tons in 2008. Despite an increase in the number of used (see next section), this level of consumption decreased by 17.3% to 44.0 million in 2010 in 2010 due to slow steaming (similar results apply to CO₂ emissions).

Table 2. Impact of slow steaming on average annual fuel consumption

Vessel size	A. Characteristics of the 2,051 vessels*				B. Days at sea		C. Ship Average fuel oil consumption (in 000 tons per year)		
	Number of vessels	% in SS	Mean size in teu	Design speed s _k	2007** and 2008	This work (2010)	2007**	This work (2008)	This work (2010)
1000-2000	278	19.4	1481	19.5	241	266	9,700	8,914	8,529
2000-3000	398	22.6	2542	21.7	247	268	15,600	15,268	14,169
3000-5000	677	37.2	4087	23.6	250	276	25,200	24,473	21,568
5000-8000	432	65.7	5948	24.9	251	292	37,500	36,361	28,512
8000+	266	75.5	9175	24.6	259	298	46,400	46,309	33,950

* Author calculation from Alphaliner (2010)

** from Buhaug et al. (2009, p. 195 and 214)

A similar analysis was then done according to trade. Table 3 shows the characteristics of 387 services aggregated into 8 trades, with an additional category for Multi-trades (services on more than 2 trades such as Round-the-World and Pendulum services). Vessels are deployed first in Multi-trades (26.3% of vessels and 35.1% of capacity), then in Asia/North America (18.1% of capacity) and in Mid-East South Asia (14.1%) trades. The under-representation of Europe/Far East is explained by the fact that most Multi-trade services cover this leg. In January 2008, 78.6% of Europe/Far East services are under slow steaming compared with 58.7% for Multi-trades. These results coincide with the fact that larger vessels are deployed on Europe/Far East and Multi-trade services, with a mean size of 7,720 teu for the former and 5,994 teu for the latter.

Finally, Table 4 compares CO₂ emissions by trade and vessel size, in 2008 and 2010, the later being the slow steaming era. The decrease in emissions is estimated at 17.3% (equal to former reductions in fuel consumption) from 168 million tons of CO₂ in 2008 to 139 million, with a peak for 8000+ teu (-26.7% reduction), Multi-trades (-24.8%) and Europe/Far East services (-25.4%). This result contrasts with smaller trades, which are less subject to slow steaming.

Table 3. Main characteristics of services in January 2010

	Total						Mean					
	Number of services	%	Number of Vessels	%	Total Capacity teu	%	Vessel Number	Rotation days	Ports call	Size Teu	Speed kt	% in slow steaming
Multi-trades	63	16.28	539	26.3	3,230,508	35.1	8.6	72	16	5,994	24.0	58.7
Europe / Far East	28	7.24	115	5.6	887,769	9.6	4.1	66	14	7,720	24.8	78.6
Asia / North America	52	13.44	323	15.7	1,661,017	18.1	6.2	50	10	5,142	24.3	42.3
North Atlantic	22	5.68	98	4.8	339,966	3.7	4.5	40	10	3,469	22.2	22.7
Australasia/Oceania related	17	4.39	96	4.7	335,002	3.6	5.6	44	10	3,490	23.1	23.5
Latin America/Carib. related	73	18.60	314	15.3	886,568	9.6	4.4	47	13	2,823	21.8	20.5
Mid-East/South Asia related	87	22.48	342	16.7	1,300,282	14.1	3.9	39	11	3,802	22.7	23.0
South Africa/East Africa related	16	4.39	97	4.7	291,649	3.2	5.7	50	9	3,007	21.7	31.3
West Africa related	29	7.49	127	6.2	267,517	2.9	4.4	53	9	2,106	20.7	20.7
Total	387	100	2051	100.0	9,200,278	100.0	5.3	53	12	4,485	23.1	34.8

Source: Author from Alphaliner database (January 2010)

Table 4. Impact of slow steaming on CO₂ emissions (2008-2010)

	Baseline - 2008 Pre slow steaming 000 tons CO₂	January 2010 - Slow steaming era 000 tons CO₂	% Reduction 2008-2010
	By trade		
Multi-trades	56,400	42,400	-24.8
Europe / Far East	15,300	11,400	-25.4
Asia / North America	32,300	27,200	-15.6
North Atlantic	6,135	5,455	-11.1
Australasia/Oceania	6,484	6,033	-7.0
Latin America/Carib. related	16,900	15,600	-7.6
Mid-East/South Asia related	24,300	21,700	-10.8
South Africa/East Africa related	5,747	5,237	-8.9
West Africa related	4,918	4,256	-13.5
	By vessel size		
1000-2000	7,856	7,517	-4.3
2000-3000	19,300	17,900	-7.2
3000-5000	52,500	46,300	-11.9
5000-8000	49,800	39,000	-21.6
8000+	39,000	28,600	-26.7
Total	168,483	139,281	-17.3

Source: Author from Alphaliner database (January 2010) and LRF (2010)

4. Abatement cost and policy implications

The CO₂ cost-effectiveness of slow steaming (equation 2) implies that the former results need to factor in: 1) the cost of adding vessels to a service under slow steaming; 2) the impact on total fuel cost considering IFO bunker prices.

The additional costs vary with the number and characteristics of vessels. We assumed that the number of additional vessels is proportional to the number of services under slow steaming, as one vessel is then added for these services. For instance, knowing that in January 2010, 93 services were offered by 1000-2000 teu vessels and that 12.9% of these services were under slow steaming, 12 (93x12.9%) services added one vessel or 12 additional vessels since 2008. We assumed that these vessels were new, that 80% of the initial capital cost (IC_k) was borrowed and to be paid back in 10 years using immediate annuities. The interest rate was (Libor+2%) or 5% when the investment took place in 2007 (2 years delivery). Indicative 2007 newbuilding prices by category of vessel were retrieved from Drewry Shipping Monthly statistics (2010). To this capital cost, an operational cost (OC_k) of 6,000 USD/day to be paid 365 days a year is added

(Drewry Shipping Consultants, 2007). Under such assumption, the annual cost per vessel (AC_k) is $[(80\% \cdot IC_k \cdot 5\%)/(1-(1+5\%)^{-10}) + (365 \cdot OC_k)]$.

The cost effectiveness (equation 2) is then, for the first category of vessels, a function of: 1) savings on fuel equal to $(7,856-7,517/2)/3.17 \cdot (\$100) = \$5.3$ million per year for a IFO bunker price of \$100 per ton (case 1); 2) additional operational costs equal to \$5.71 million a year⁶ per vessel or \$68.5 million for the 12 vessels added. The CO₂ cost effectiveness is then $(5.3-68.5)/(0.169) = -\$373$ per ton of CO₂. The negative coefficient means that for these vessels, under these prevailing bunker costs, the investment is not cost-effective.

Table 5 provides results for IFO380 bunker prices of \$100, \$300 and \$600 (case 1-3) and for all vessel sizes. Results show that slow steaming is not a viable option for smaller vessels (less than 2000 teu) as savings are too limited to cover the additional costs. The reason is that these vessels are deployed in services with short distances, and therefore, spend a too limited time at sea where economies of scale on fuel take place. This first result is a concern as for a large number of vessels, 278 (1000-2000) teu in our sample plus around 2,000 vessels less than 1000 teu that were not considered in this article, slow steaming is not an option. This represents 50% of vessel numbers, although fortunately less in total contribution to CO₂ emissions, which are proportional to vessel size. The second result is that for vessels over 2000 teu, bunker fuel must cost more than \$300 per ton for slow steaming to be economical, and accordingly, for the achieved reduction in CO₂ to be sustainable.

⁶ This value is close to the Container time charter rate (Drewry Shipping Monthly statistics, 2010) that was around \$15,000 per day for a 1,500 teu vessel in 2007 or \$5.4 million for a year.

Table 5. CO₂ cost efficiency of slow steaming in \$/ton

Vessel size	CO ₂ reductions in 000 tons 2008-2010	N services	% of services under slow steaming in 2010	Additional vessels required	Newbuilding prices in 2007 - million USD	Annual Capital and operational costs - million USD	Cost efficiency IFO= \$100/ton (1)	Cost efficiency IFO= \$300/ton (2)	Cost efficiency IFO= \$600/ton (3)
1000-2000	-188	93	12.9	12	34	5.71	-373	-310	-216
2000-3000	-751	73	17.8	13	45	6.85	-77	-14	+81
3000-5000	-3,373	104	29.8	31	60	8.41	-63	0	+95
5000-8000	-5,807	74	62.2	46	100	12.55	-67	-3	+91
8000+	-5,582	43	79.0	34	130	15.66	-74	-11	+84

Figure 1 demonstrates how the cost-efficiency changes with IFO bunker prices and for vessels larger than 2000 teu. It shows that for 2000-3000 teu vessels, IFO price should be at least at \$320 per ton for slow steaming to be cost-efficient. The best situation is for 3000-5000 teu vessels for which a bunker price at \$300 is enough to compensate the cost of additional vessels. For a fuel price varying from \$240 to \$600/ton, the CATCH CO₂ ranges from [+\$30; -\$50] for a 8000+ teu vessel, results slightly lower than the [-\$20; -\$100] range in Longva et al. (2010).

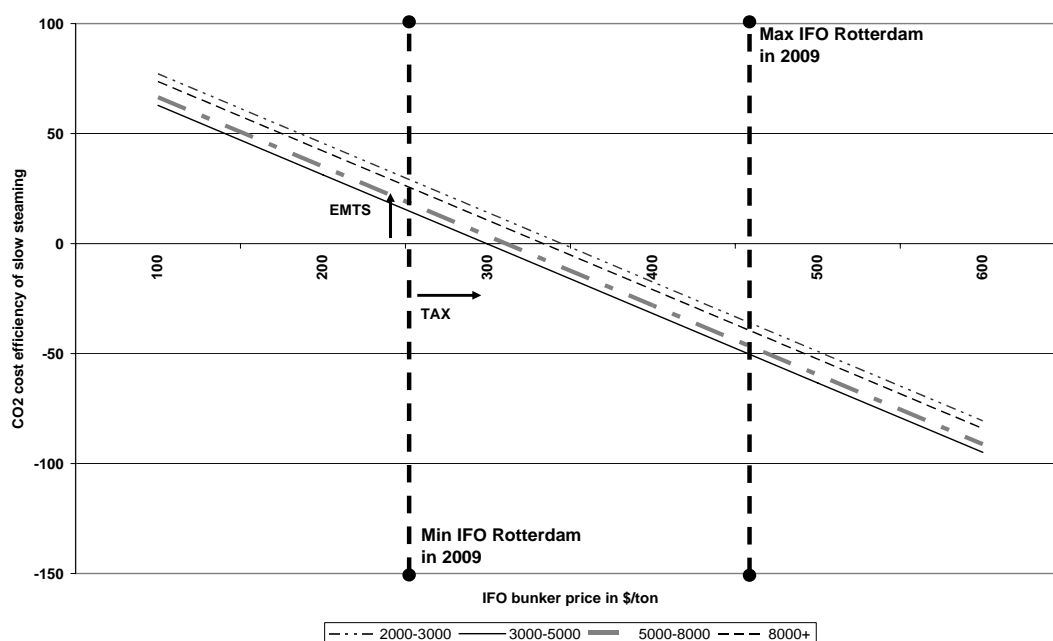


Figure 1. Impact of IFO bunker price on slow steaming CO₂ cost efficiency

In terms of policy implications, when the IFO bunker price goes down to around \$250, which was the minimum value in year 2009 in Rotterdam, a tax levy (MEPC 59/4/5, 2009, MEPC 54/9/48, 2009) of at least \$50 (\$300-\$250) would be necessary to break-even for (3000-5000) teu vessels and at least \$100 for 8000+ teu vessels. These levels can be compared with the \$90 estimated in Corbett et al. (2009, Figure 2- scenario 2).

For a Maritime Emission Trading Scheme (MEPC 29/4/24 2009, MEPC 60/Inf.8 2009), the price of one ton of CO₂ should be at least \$40 in such configuration (IFO prices at \$250). Obviously, if none of these schemes are implemented, and if bunker price remains sensibly below \$250 per ton, the likelihood of vessels speeding up and removing the additional capacity is then high.

5. Conclusions

Slow steaming is the best short term cost-effective option to reduce CO₂ emissions. This article shows that it has reduced emissions by around 17.3% during the last 2 years. This reduction is above the target of 15% reduction for 2018 proposed in MEPC60/4/36, and without implementing any new technology.

However, the article also stresses that its long term sustainability remains questionable and highly dependant on the level of bunker prices. This likelihood is even more limited considering that some elements were not taken into account. For instance, the logistical and opportunity costs for shippers having their cargo spending at least one additional week at sea lowers the quality of services and could, if a quick recovery of the world economy occurs, undermine slow steaming and its beneficial impact on CO₂ emissions. Technical issues also exist as containerships were built to sail at an optimal speed of 20-22 knots and at a 80-85% load factor for the largest units. When reaching very low speed, as little as 12 knots observed on specific trades, additional consumption occurs and the quality of exhausts is altered, while design and safety issues arise (Devanney 2010a, 2010b, Faber et al. 2010).

This article obviously comes with limitations. The assumption that slow steaming is a 30% reduction in the average speed while some services are indeed operated either at a higher (Slow Steaming around -20% in Alphaliner terminology) or a lower (Super Slow Steaming around -40%) speed, and that even within a service the speed does not remain constant are the first ones. Another limitation is the conservative assumption on the cubic relationship between speed and engine power.

To conclude, changes in freight, bunker, shipbuilding, second-hand or scrapping markets (Kollamthodi et al., 2008, Corbett et al., 2009, Psaraftis et al., 2010) are all impacting the long term viability of slow steaming as a mean to reduce CO₂ emissions. If bunker prices go down or demand goes up in the future, the arbitrage between operating a vessel at full speed or not will sooner or later arises again. As demand will sooner or later goes up, the only chance for slow

steaming to remain sustainable in the long term is for bunker prices to remain at more than 300 \$/ton, or powerful market-based solutions (tax or cap-and-trade) to sustain bunker prices at this level.

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