Is slow steaming a sustainable mean for reducing liner shipping CO_2 emissions?

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Abstract

Speed reduction significantly reduces in the short term CO_2 emissions from international shipping. This solution, which was not sustainable 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 CO_2 emissions have already been reduced and to estimate, for various markets, the bunker break-even price for which slow steaming is sustainable in the long run. The paper shows that reductions, such as our finding of a 11% decrease in emissions since 2008 can only be sustained for a bunker price of at least $350-400 for the main East-West trades.

1. Introduction

Slow steaming, or the reduction in the speed of vessels, 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 while demand was, at the same time, reduced by 10% (Alphaliner, 2010a, 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 IFO 380cst (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[1].

A fortunate effect of slow steaming is its impact on CO_2 emissions. That is to say that emissions are proportional to the amount of fuel burned with a factor of around 3.17 kg of CO_2 emitted per ton (Endresen et al., 2003, Buhaug et al., 2009, Corbett et al., 2003, 2007, 2009, Eyring et al. 2005a, 2005b, 2009). This effect worth studying in particular for container vessels, which represented 4% of vessels in number but generated around 206 million tons of CO_2 in 2007 or 20% of emissions from international shipping (Buhaug et al., 2009, Psaraftis et al., 2009). Reducing a vessel's speed by 10% would decrease CO_2 emissions by at least 10-15% (Corbett et al., 2009, Eide et al., 2009, Longva et al., 2010), but

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

would induce substantial losses in revenues as the time at sea and the number of vessels required to keep a weekly frequency increase (Kollamthodi et al., 2008, Corbett et al., 2009, Psaraftis et al., 2010).

This article attempts to provide an accurate view of the impact of slow steaming by measuring its effect on liner shipping CO_2 emissions since 2008 and its sustainable in the long-term. To do so, this paper begins by presenting the methodology used and how slow steaming influences emissions. Estimates are then aggregated by trade using data on 2,051 containerships deployed on 387 services in January 2010. The final section calculates the bunker price break-even point at which slow steaming is sustainable, and ends by discussing some policy implications.

2. Methodology

For containerships above 1000 teu using two stroke marine diesel engines, a speed reduction from ds (design speed) to ss (slow steaming) for a vessel k impacts on the main engine fuel consumption at sea ($ME_{k,sea}$), with a limited effect on the auxiliary engine. Accordingly, the effect of a speed reduction on CO_2 emissions for a service w operated with n vessels can be approximated as follows:

$$\Delta CO_{2,ds\rightarrow ss} = 3.17x\sum_{k=1}^{n}\left(ME_{k,sea}xD_{k,sea} + ME_{k,port}xD_{k,port}\right) = 3.17x\Delta FC_{ds\rightarrow ss} \qquad (1)$$

With $ME_{k,sea} = SFOC_k xEL_k xkWh_k$ (2)

3.17 is the emission factor expressed in kg of CO_2 emitted per ton of fuel burned by the main engine (Buhaug et al., 2009, Corbett et al., 2009). $D_{k,sea}$ is the number of days at sea equal to (Distance/24.speed) and ($D_{k,sea}$+$D_{k,port}$) the number of days to complete a rotation or Rot_w.

$ME_{k,sea}$ is the main engine daily fuel consumption at sea and is the product of a Specific Fuel Oil Consumption ($SFOC_k$), an Engine Load (EL_k) and an engine power in kWh_k. We assume that the consumption in port ($ME_{k,port}$) is 5% of the main engine consumption at sea at design speed s_{ds} (EPA, 2000)[2]. Vessels are built for sailing close to design speed, between 70-90% of Maximum Continuous Rate (MCR), a level at which the SFOC is optimal and around 180-195 g/kWh, a value varying with the engine type and with weather conditions.

The impact of slow steaming on fuel consumption depends on the magnitude in speed reduction (Buhaug et al., 2009, Psaraftis et al., 2010, Faber et al., 2010). As long as the speed reduces in small proportions, up to 10-15% reduction, the SFOC remains fairly constant, and as a rule of thumb, the engine power is related to ship speed by a third power. When speed reduces by more than 10%, for instance 30% as it will be assumed in this article, the engine load decreases to around 40% of MCR and the SFOC increases up to +10%, a level varying with the engine characteristics, the vessel type and age as engine retrofitting can, today, limit this impact[3].

We assume here, that, when a vessel is sailing close to its optimal speed, or the pre-steaming era, the SFOC is 195 g/kWh and the engine load 90% of MCR. Then, when the speed reduces by 30%, the SFOC increases to 205 g/kWh. It induces for a typical 4,000 teu containership with an engine of 43,000 kWh and a design speed of 24 knots, that the consumption at sea is 43,000x0.9x195x24/ 1000000= 182 tons per day at design speed. Then, when sailing at -30% or around 17-18 knots, the fuel consumption per day is 43,000x0.40x205x24/1000000= 85 tons per day or around 55% reduction in fuel consumption at sea. These are average values that will be applied to all vessels, although differences exist amongst vessels, trades, but also during a year, as vessels do not always sail at a constant speed[4].

The impact of slow steaming is, however, not limited to its impact on the main engine consumption at sea. With slow steaming, the rotation is stretched by ($\Delta Rot = Distance_w / 24(s_{ds}-s_{ss})$) days, the average number of miles performed in a

[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.
[3] According to one year data gathered from a private operator and for a 4,300 teu containership with a modern engine, the SFOC would only increase from 195 to 198 g/kWh, and the fuel consumption at sea reduces by around 60%.
[4] For instance, and for the 4,000 teu vessel considered, the vessel runs at 10-20% of MCR equivalent to a speed of 12-14 knots during a year.

year and of port calls decrease, although the total time in port for a service can remain similar as more vessels are deployed[5]. Indeed, additional vessels ($\Delta n = n_{ds} - n_{ss}$) are required to keep a weekly frequency at each port of call (Corbett et al., 2009, Pasaraftis et al, 2010). This induces that the long-term sustainability of slow steaming depends on the additional operational costs for the n vessels added ($OC_{\Delta n}$) and on changes in inventory costs (IC) as containers spend more time at sea (ΔRot). The bunker price breakeven point (BP*) for which the observed reduction is sustainable is then:

$$BP^{*} \geq \frac{OC_{\Delta n, ds \to ss} + \Delta Rot_{ds \to ss} x IC_{teu}}{\Delta FC_{ds \to ss}} \qquad (3)$$

As long as the current Bunker Price is significantly more than BP*, slow steaming is viable and one can expect that savings on CO_2 emissions will remain in the future.

3. CO_2 reduction from slow steaming (2008-2010)

The estimation of the impact of slow steaming on CO_2 emissions at the trade level requires two initial sets of information: 1) vessel's fuel consumption at sea at design speed ($ME_{k,\, sea}$) to which a 55% reduction will apply when a service is under slow steaming; 2) service characteristics including the number of days at sea (D_{sea}), in ports (D_{port}) as potential reductions only apply when the vessel is at sea.

To determine $ME_{k,sea}$ information from Lloyd's Register Fairplay (LRF, Jan. 2010) was used. Table 1.A provides the daily fuel consumption for 451 container vessels grouped into 5 categories. We compared these figures with our estimates (Table 1B) based on a load factor of 90%, a SFOC of 195 g/kWh to be multiplied by the engine total kWh, an information available for 1,930 vessels in LRF.

[5] We assume here that the time spent in ports for all vessels within a service remains the same. If not ($D_{port,ss} < D_{port,ds}$) then, 1) there are no specific need for additional Δn_{w1} vessels or for stretching the rotation ($Rot_{ss} = Rot_{ds}$), as long as the number of ports dropped compensate the time lost at sea ($D_{sea,ss} > D_{sea,ds}$); 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.

Table 1. Main engine consumption at sea in tons/day at design speed

	A. LRF database*			B. This work**		
Vessel size In teu	Number of Vessels	Design speed S_{ds}	ME_k at S_{ds}	Number of Vessels	Design speed S_{ds}	ME_k at S_{ds}
1000-2000	94	19.4	53	249	19.6	53
2000-3000	100	20.9	81	368	21.8	89
3000-5000	152	22.9	128	644	23.6	143
5000-8000	93	24.8	209	420	24.9	220
8000+	12	24.4	258	249	24.6	272

* 451 vessels for which consumption at sea is provided.
**1,930 vessels for which the engine kWh is known.

To assess the impact of slow steaming by trade, information was then gathered from Alphaliner database in January 2010 (Alphaliner, 2010b). For 2,051 over 1000 teu containerships[6], 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 retrieved the status of a service in regards to slow steaming from comments on a service history. Table 2.A provides descriptive statistics according to vessel size. The mean vessel size is 4,485 teu and mean design speed 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 spent at sea in 2008 was similar to Buhaug et al. (2009, p. 195), ranging from 241 to 259 days at sea for 8000+ vessels. The fuel consumption at port is at 5% of values reported in table 1. In 2010, and for vessels deployed in a service run under slow steaming (35.4% of services and 42.9% of vessels), a 55% reduction in fuel consumption at sea is assumed. However, with slow steaming, the average time at sea has increased since 2008, particularly for larger vessels, from 259 to 270 days on average (table 3.B). This result is obtained by adding 2 times one week (on each way) to services reported under slow steaming in 2010, or $Rot_{ss}=Rot_{ds}+14$ days. In 2008, the total bunker consumption for the 2.051 container vessels (number of vessels per category x average consumption) was, according to our estimates, 53.6 million tons in 2008.

[6] 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).

Despite 137 more vessels used (see next section), this level (and CO_2 emissions) decreased by 11.1% to 47.6 million in 2010 as a consequence of slow steaming.

A similar analysis was 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 CO_2 emissions by trade and vessel size, in 2008 and 2010, the later being the slow steaming era. The decrease in emissions is estimated at 11.1% (equal to former reductions in fuel consumption) from 170 million tons of CO_2 in 2008 to 151 million, with a peak for 8000+ teu (-17% reduction), Multi-trades (-16.5%) and Europe/Far East services (-16.4%). This result contrasts with smaller trades, which are less subject to slow steaming.

Table 2. Impact of slow steaming on annual fuel consumption per vessel (2008-2010)

	A. Characteristics of the 2,051 vessels*				B. Days at sea		C. Ship Average fuel oil consumption (in 000 tons per year)		
Vessel size	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	244	9,700	8,997	8,759
2000-3000	398	22.6	2542	21.7	247	250	15,600	15,409	14,666
3000-5000	677	37.2	4087	23.6	250	255	25,200	24,698	22,789
5000-8000	432	65.7	5948	24.9	251	260	37,500	36,695	31,541
8000+	266	75.5	9175	24.6	259	270	46,400	46,727	38,777

* Author calculation from Alphaliner (2010)

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

Table 3. Main characteristics of services in January 2010

	Number of services	% of services Under slow steaming	Number of Vessels	% of vessels under slow steaming	Total Capacity teu	Vessel Number	Rotation days	Ports call	Size Teu	Speed kt
Multi-trades	63	57.1	539	64.2	3,230,508	8.6	72	16	5,994	24.0
Europe / Far East	28	78.6	115	74.8	887,769	4.1	66	14	7,720	24.8
Asia / North America	52	42.3	323	47.1	1,661,017	6.2	50	10	5,142	24.3
North Atlantic	22	22.7	98	30.6	339,966	4.5	40	10	3,469	22.2
Australasia/Oceania related	17	23.5	96	27.1	335,002	5.6	44	10	3,490	23.1
Latin America/Carib. related	73	20.5	314	24.2	886,568	4.4	47	13	2,823	21.8
Mid-East/South Asia related	87	23.0	342	25.7	1,300,282	3.9	39	11	3,802	22.7
South /East Africa related	16	31.3	97	29.9	291,649	5.7	50	9	3,007	21.7
West Africa related	29	20.7	127	37.8	267,517	4.4	53	9	2,106	20.7
Total	387	35.4	2,051	42.9	9,200,278	5.3	53	12	4,485	23.1

Source: Author from Alphaliner database (January 2010)

Table 4. Impact of slow steaming on CO_2 emissions by trades (2008-2010)

	Baseline - 2008 Pre slow steaming 000 tons CO_2	**January 2010 – Slow steaming era 000 tons CO_2**	**% Reduction 2008-2010**
		By trade	
Multi-trades	56,900	47,500	-16.5
Europe / Far East	15,500	12,900	-16.4
Asia / North America	32,600	29,400	-9.7
North Atlantic	6,191	5,778	-6.7
Australasia/Oceania	6,544	6,275	-4.1
Latin America/Carib. related	17,000	16,200	-4.8
Mid-East/South Asia related	24,600	22,900	-6.7
South Africa/East Africa related	5,800	5,460	-5.9
West Africa related	4,963	4,510	-9.1
		By vessel size	
1000-2000	7 ,929	7 ,719	-2,6
2000-3000	24,000	18,500	-4,8
3000-5000	53,000	48,900	-7,7
5000-8000	50,300	43,200	-14,0
8000+	39,400	32,700	-17,0
Total	**170,097**	**150,921**	**-11.2**

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

4. The sustainability of slow steaming

The sustainability of slow steaming (equation 3) implies that the former results need to factor in the cost of adding vessels to a service under slow steaming, as well as the increase in inventory costs for shippers.

The operational costs vary with the number and characteristics of vessels added. We assumed that the number of vessels added is proportional to the number of services under slow steaming, with one vessel added for each service. For these vessels, the average daily operational costs (OC_k) was retrieved from HSH Nordbank et al. (2008) at $7,000 per day for 1000-2000 teu vessels, $8,000 per day for 2000-3000 teu vessels and $9,000 per day for more than 3000 teu vessels. For the inventory costs, we rely on estimates from Eefsen and Cerup-Simonsen (2010) of an average value of $27,331 USD per TEU and a 35% interest rate pro anno.

For instance, knowing that 57.1% of the 63 multi-trades services are under slow steaming in January 2010, 57.1%x63= 36 vessels were added since 2008 for this trade. Considering the characteristics of vessels deployed on multi-trades services, the average daily operating cost is $8,833 (Table 5). The break-even bunker price point (equation 3) is then a function of:

1) annual savings on consumption derived from Table 4 and equal to (56,900-47,500)/(2x3.17) =$1,482 thousand tons of fuel;

2) additional operational costs equal to $(8,833x365) million a year per vessel or $116 million for the 36 vessels added;

3) In-transit inventory costs that for the (64.2%x3.2 million) teu under slow steaming (table 3), with around 70% being full container and spending one additional week at sea, are equal to $(7 days x 27,331 USD/teu x 35%/365)*(64.2% x 3.2 million x 70%)= $266 million.

The bunker break-even price for multi-trades services is then equal to $(116+266) million /(1,482,000 tons) or $259/ton of IFO for slow steaming to be viable. This result suggests that under current bunker prices levels, the likelihood of vessels speeding up and removing the additional capacity is low for multi-trades services. Table 5 presents the results for all trades.

Table 5. Sustainability of slow steaming – Bunker price breakeven point

	Additional vessels in number	**Additional operational costs – in $ million**	**Additional inventory costs – in $ million**	**Break-even IFO bunker price $/ton**
Multi-trades	38	116	266	259
Europe / Far East	22	72.3	85.3	394
Asia / North America	22	71.5	100	345
North Atlantic	5	15.3	13.4	440
Australasia/Oceania	4	12.5	11.7	568
Latin America/Carib. related	15	44.2	27.6	556
Mid-East/South Asia related	20	62.1	43	404
South /East Africa related	5	14.6	11.2	480
West Africa related	6	16.7	13	415

In terms of policy implications, Australia/Oceania, Latin America/Caribbean related trades are for instance, for which the percentage of services under slow steaming were relatively low, with a relative high bunker break-even point due to a low ratio between time at sea when savings occur and time in port when they do not. BP* is more than $550, when the IFO bunker price in Rotterdam was fluctuating between $260 and $470 per ton in 2009, with an average value of $365. For many trades, the break-even point is close to the average value observed in Rotterdam. For these markets, the implementation of a tax levy (MEPC 59/4/5, 2009, MEPC 54/9/48. 2009) on bunkers of around $50 could be enough to break-even and for the achieved reductions in CO_2 emissions to remain in the long run, or for additional reductions to occur.

5. Conclusions

Slow steaming is a cost-effective option to reduce CO_2 emissions in the short-term. This article shows that it has reduced emissions by around 11% during the last 2 years. This reduction is close to the target of -15% for 2018 proposed in MEPC60/4/36, and without implementing any new technology.

This result obviously comes with some limitations related to our assumptions. The assumption that slow steaming is a 30% reduction in the average speed while some services are indeed operated either at a higher or a lower, Super Slow Steaming with -40% in speed, and that even within a service the speed does not remain constant through the year are the first ones. Technical elements were also not considered, as containerships were built to sail at an optimal speed of 20-22 knots and at a 70-90% load factor. When reaching very low speed, as little as 12 knots observed on specific leg of a trade, additional consumption occurs and the quality of exhausts is altered, while design and safety issues arise (Devanney 2010a, 2010b, 2010c, Faber et al. 2010).

To conclude, the changes in freight rates, bunker prices, operating and inventory costs are all impacting on the long-term viability of slow steaming as a mean to reduce CO_2 emissions. If bunker prices go down and freights and inventory costs go up in the future, the arbitrage between operating a vessel at full speed or not will sooner or later arises again. As freights 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 high levels and/or for powerful market-based solutions such as a tax-levy or cap-and-trade system to be implemented and to sustain bunker prices at high levels.

References

Alphaliner Weekly Newsletter. 2010a. Extra Slow Steaming to absorb over 2 percent of ship capacity. Issue No2.

Alphaliner, 2010b. http://www.alphaliner.com/

Buhaug, Ø., Corbett J.J, Endresen, O., Eyring, V., Faber J., Hanayama, S., Lee, D., Lindstad, H., Mjelde, A., Palsson, C., Wanquing, W., Winebrake, J.J., Yoshida, K., 2009. Second IMO Greenhouse Gas Study. International Maritime Organization, London.

Corbett, J.J., Khoeler, H. W., 2003. Updated emission from Ocean Shipping. Journal of Geophysical Research, 108 (D20), 4650, doi:10.1029/2003JD003751.

Corbett, J.J., Winebrake, J.J., Green, E.H., Kasibhata, P., Eyring, V., Lauer, A., 2007. Mortality from Ship Emissions: A Global Assessment. Environmental Science & Technology 41(24), 8512-8518.

Corbett, J.J., Wang, H., Winebrake, J.J., 2009. The effectiveness and costs of speed reductions on emissions from international shipping. Transportation Research Part D 14: 539-598.

Crist, P., 2009. Greenhouse gas emissions reduction potential from international shipping. Joint Transport Research Center OECD/ITF. Discussion paper No 2009-11, May. Retrieved from http://internationaltransportforum.org/jtrc/DiscussionPapers/DP200911.pdf

Devanney, J. 2010a. Efficient, safe reduction of CO_2 emissions from Shipping. Retrieved from http://www.c4tx.org/ctx/pub/tax_vs_ets.pdf

Devanney, J. 2010b. CO_2 emissions from Shipping: the Case for Taking our Time. Retrieved from http://www.c4tx.org/ctx/pub/take_time.pdf

Devanney, J. 2010c. The Impact of EEDI on VLCC Design and CO2 Emissions Retrieved from http://www.c4tx.org/ctx/pub/eedi_athens.pdf

Drewry Shipping Consultant, 2007. Ship operating costs annual review and forecast – 2007/2008. Drewry publication.

Eide, M., Endresen, O., Skjong, R., Longva, Alvik, S., 2009. Cost-effectiveness assessment of CO2 reducing measure in shipping. Maritime Policy & Management 36(4), 367-384.

Endresen, O., Sorgard, E., Sundet, J.K., Dalsoren, S.B., Isaken, I.S.A., Berglen, T.F., Gravir, G., 2003. Emission from international sea transportation and environmental impact, Journal of Geophysical Research, 108(D17), 4560, doi: 10.1029/2002JD002898.

EPA, 2000. Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data, United States Environmental Protection Agency, February.

Engelstoft M., 2010. Slow steaming is here to stay. Lloyd's List, 7 July 2010.

Eyring, V., Köhler, H.W., van Aadrdenne, J., Lauer, A., 2005a. Emissions from international shipping: 1. The last 50 years. Journal of Geophysical Research110, D17305.doi: 10.1029/2004JD005619.

Eyring, V., Köhler, H.W., Lauer, A., Lemper, B., 2005b. Emissions from international shipping: 2. Impact of future technologies on scenarios until 2050. Journal of Geophysical Research 110, D17306.doi: 10.1029/2004JD005620.

Eyring, V., Isaksen, I. S.A., Berntsen, T., Colins, W.J., Corbett, J.J., Endersen, O., Grainger, R. G., Molldanova J., Schlager H., Stevenson D.S., 2009. Transport impacts on atmosphere and climate: Shipping. Atmospheric environment. Doi: 10.1016/j.atmosenv.2009.04.059

Faber J., Freund M., Köpke M., Nelissen D., 2010. Going slow to reduce emissions. Can the current surplus of maritime transport capacity be turned into an opportunity to reduce GHG emissions? Sea at Risk publishing, Available at seas-at-risk.org.

HSH Nordbank, 2008. Operating Costs 2008. A study on the operating costs of German ships. Retrieved from www.hsh-nordkank.com

Eefsen T., Cerup-Simonsen B., 2010. Speed, Carbon emissions and supply chain in container shipping. Proceedings of the International Association of Maritime Economists Conference, Lisbon, 7-9 July.

Kollamthodi, S., Brannigan, C., Harfoot, M., Skinner, I., Whall, C., Lavric, L., Noden, R., Lee, D., Buhaug, Ø., Maritnussen, K., Skejic, R., Valberg, I., Brembo J.C., Eyring, V., Faber J., 2008. Greenhouse gas emissions from shipping: trends, projections and abatement potential. Final Report to the Shadow Committee on Climate Change. AEA Energy, September.

Longva, T., Eide, M., S., Skjong, R., 2010. Determining a required energy efficiency design index level for new ships based on a cost-effectiveness criteria, Maritime Policy & Management 37(2): 129-143.

MAN B&W Diesel A/S, 2008. Propulsion trends in container vessels, Copenhagen, Denmark.

MEPC 29/4/24, 2009. Prevention of Air Pollution from Ships. A methodology for establishing an emission cap in an ETS for international shipping. Submitted by Norway, 8 May 2009.

MEPC 54/9/48, 2009. Prevention of air pollution from ships. Comments on MEPC 59/4/2 and 59/4/4 and an additional approach to addressing maritime GHG emissions. Submitted by USA. 22 May 2009.

MEPC 59/4/5, 2009. Prevention of air pollution from ships. An international fund for Greenhouse gas emissions from ships. Submitted by Denmark. 9 April 2009.

MEPC 60/INF 8, 2009. Prevention of Air Pollution from Ships. Practical aspects on a global emissions trading scheme for international shipping. Submitted by France, 18 December 2009.

MEPC 60/4/36, 2009. Analysis on the appropriate values of the reduction rates of the required EDDI. Submitted by Japan, 15 January 2010.

Notteboom, T.E., Vernimmen, B., 2008. The effect of high fuel costs on liner service configuration in container shipping, Journal of Transport Geography 17(5), 325-337.

Notteboom, T., Cariou, P., 2009. Fuel surcharge practices of containers shipping lines: Is it about cost recovery or revenue-making? Proceedings of the International Association of Maritime Economists Conference, Copenhagen, 24-26 June.

Psaraftis, H. N., Kontovas, C. A., 2009. CO2 emission Statistics for the World Commercial Fleet. WMU Journal of Maritime Affairs 8 (1), 1-25.

Psaraftis, H. N., Kontovas, C. A., 2010. Balancing the economic and environmental performance of maritime transportation. Transport. Res. Part D (2010), doi: 10.1016/j.trd.2010.05.001

Unctad, 2009. Review of Maritime Transport 2009. Retrieved from http://www.unctad.org/en/docs/rmt2009_en