LIFE-CYCLE CO_2 EMISSIONS OF BULK CARRIERS: A COMPARATIVE STUDY[1]

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ABSTRACT

In order to maintain shipping capacity to serve seaborne trade, new ships have to be built to replace those scrapped. The cost of building, manning, operating, maintaining and repairing a ship throughout its life is borne by society at large through market mechanisms. Gratsos and Zachariadis (2005) had investigated through a cost/benefit analysis how the average annual cost of ship transport varies with the corrosion additions elected at the design stage. The results of that paper clearly indicated that ships built with sufficient corrosion allowances, truly adequate for the ship's design life, have a lower life cycle cost per annum despite the fact that such ships would carry a slightly smaller quantity of cargo. Furthermore the safety and environmental benefits due to the reduced repairs and extended lifetime of such ships were briefly discussed. The debate of how "robust" a ship should be was also transferred to IMO in the context of Goal Based Standards following a submission by Japan which stated that the increased steel weight of a more robust ship will result in increased CO_2 emissions due to a reduced cargo carrying capacity. Greece replied by submitting a summary of the aforementioned paper and preliminary estimations on Life cycle CO_2 emissions disputing the Japanese contentions. However, taking onboard the challenge, an update is provided in the present paper, using the final Common Structural Rules (CSR) of the International Association of Classification Societies (IACS) bulk carrier corrosion margins and taking into account the major environmental implications of the heavier ship scantlings for two bulk carrier size brackets, Panamax and Handymax. The results show that the more robust ships would produce less CO_2 emissions over their lifetime.

NOTE: COMMENTS ON THIS PAPER BY 5 DISCUSSANTS AND THE RESPONSES TO THESE COMMENTS APPEAR AFTER THE END OF THE PAPER (PAGE 24 AND BEYOND)

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NOMENCLATURE

AAC: Average Annual Cost
CSR: Common Structural Rules
CO_2: Carbon Dioxide
EEDI: Energy Efficiency Design Index
GHG: Greenhouse Gases
GBS: Goal Based Standards
IACS: International Association of Classification Societies
IMO: International Maritime Organization
JTP: Joint Tanker Project
NAABSA: Not Always Afloat But Safely Aground
RINA: Royal Institution of Naval Architects
UR: Unified Requirement

1. INTRODUCTION

Shipping transports over 90% of world trade (IMO, 2010). In order to maintain shipping capacity to serve this trade, new ships have to be built to replace those scrapped. The cost of building, manning, operating, maintaining and repairing a ship throughout its life is borne by society at large through market mechanisms.

The results of the economic study of a paper presented at the 2005 RINA conference on the Design and Operation of Bulk Carriers (Gratsos and Zachariadis (2005), hereinafter referred to as the GZ paper), indicated that ships built with corrosion allowances, which are truly adequate for the ship's design life, when all factors have been taken into account, have a lower Average Annual Cost (AAC) for the maintenance of the integrity of their structure. This was demonstrated to be the case, despite the fact that they would carry a slightly smaller quantity of cargo and therefore their income over time would be marginally less. This appears to be a general truth regardless of the inflation environment. Furthermore these ships are more reliable performers having a lower average annual downtime.

The side benefit of such construction would be greater safety since it is accepted that steel renewals do not always restore the effectiveness of a ship's structure. In addition the increased scantlings serve as a much needed safety margin for hull strength and fatigue, especially in view of new satellite data on global wave statistics, indicating more severe spectra than previously predicted. More importantly, it is now admitted even by classification societies themselves, that the rule, minimum required, longitudinal strength (UR S-11) of tankers and bulk carrier requires increase and IACS has scheduled its revision (see, for instance, Mansour and Wasson (1995), Guedes Soares (1996,1999), and JTP (2005), among others). Therefore building ships that will only require the minimum steel renewals during their design life is an added safety benefit.

Furthermore the GZ paper contended that ships built with truly sufficient corrosion allowances do not waste the world's resources or increase environmental pollution.

The international press (e.g., Lloyd's List, Fairplay and others) made extensive references to the paper, even calling it as "the main thrust of arguments" of Greek shipping in criticizing the IACS Common Structural Rules (Fairplay's Solutions and Newbuildings Magazine, 04 May 2006).

The debate moved to IMO in the context of Goal Based Standards for the Construction of Bulk Carriers and Oil Tankers. Following a submission by Japan (MSC 81/6/4) which stated that "advocating too robust a ship is like carrying steel ballast – this leads to increased CO_2 emissions", Greece countered by submitting the results of the GZ paper, including rough preliminary estimations of Life cycle CO_2 emissions (MSC 81/6/17). These showed that, due to the shorter life of a less than robust ship, 50% more such ships are required to satisfy world cargo demands. The additional CO_2 emitted to produce the steel for these ships makes the longer life (more robust) ships more environmentally friendly. But the issue is more complex than simply the difference in lifetimes.

Thus, the authors, taking onboard this criticism, have worked on an update of the GZ paper, using the final IACS CSR bulk carrier corrosion margins and taking into account some of the major possible environmental implications of the heavier ship scantlings for two ship sizes, Panamax and Handymax.

The rest of this paper is organized as follows. Section 2 gives an overview of the results reported in the original paper. Section 3 reports on ship operation experience and Section 4 describes the purpose of this study. Section 5 describes the comparison among the two ship types in terms of carbon dioxide emissions and section 6 presents the paper's conclusions. Some calculations are in the Appendix.

2. PREAMBLE: OVERVIEW OF PREVIOUS RESULTS

For over two decades shipyards and others have promoted the concept of "carry cargo, not steel" and have proceeded to over-optimize ship structures in an attempt to persuade shipowners that it was more beneficial to construct ships in this fashion. The GZ paper showed that this is not the case at least from an economic point of view. The reduced steel repairs of a more robust ship, the reduced downtime and the increased lifetime produce substantially larger economic benefits to the operator, over the lifetime of such ship. Furthermore, designing ships that need to have main structural elements or extensive scantlings replaced during their design life, misrepresents the concept of "Design Life".

The GZ paper investigated, through a cost/benefit analysis, how the AAC of a ship varies with the corrosion additions elected at the design stage. No attempt was made to differentiate between sale and purchase decisions of various owners throughout the ship's life since, regardless of ownership, a ship will continue to be repaired and traded until scrapped. The study used a Panamax bulk carrier. As said before, the results of that study clearly indicated that ships built with corrosion allowances dictated by experience, adequate for the ship's design life, when all factors have been taken into account, have a lower AAC, even though they would carry a slightly smaller quantity of cargo.

Steel renewal requirements were based on actual corrosion rates experienced by the Greek shipping industry, which controls approximately 27% of the world's bulk carrier fleet of all ages, from new buildings to ships of over 25 year of age, built with the pre-CSR corrosion allowances. The same concept of Ship types A and B was used as in the present paper (see Section 4). The then available CSR Draft1 corrosion margins were used.

In making the Life Cycle cost calculations, the authors separately accounted for Daily Running Expenses (DRE), Steel Renewal costs, Downtime (representing the cost of lost opportunity to trade) and Benefits from the greater deadweight capacity of the lighter ship. The calculations took account of the Purchase Price of the ship as a new building, its Sale Price as Scrap at the end of its useful life and reverse the drydocking cost element in the DRE from the time of the last drydocking to the sale of the ship for scrap. They did not take into account the financial costs as these vary between owners. Income data used in the Downtime and Benefit calculations also included estimated adjustments to the earning capacity of ships imposed through the overage insurance premiums presently required by cargo underwriters due to their experience with cargo losses from the over-optimized ships presently trading.

Three series of calculations were attempted: The first series of calculations was divided in two parts. Part A was based on an inflation environment of 2% per annum with a discount rate of 5% per annum, with the other series using varying inflation and discount rates. The third series of calculations used nominal rates i.e. 0% inflation and 0% discount rate. Further to the Life Cycle cost calculations, Cash Flow calculations had been carried out estimating the cash-in/cash-out of the whole project for all above series of calculations.

It is interesting to note that the assumed income/cost figures used then (2004-2005) closely approximate today's (2009 post-crisis) economic climate.

The first series of calculations, Part A, for the low interest rate environment, provided the following results: The Life Cycle cost of SHIP A is USD 2,916,000 per annum (AAC) while the Life Cycle cost of SHIP B is USD 2,185,000 per annum (AAC). In other words SHIP A is about 33.5% per year more expensive to operate. Even if SHIP B for some reason has to be scrapped at 20 years it still has a cheaper Life Cycle cost than SHIP A at $ 2,814,000 per annum (AAC). The additional robustness, strength, safety and reduction of related accidental pollution are just side benefits to the ship owner, his crew and society. Similar results were obtained for the other series of calculations with the AAC difference between ships A and B increasing.

Sensitivity analyses were performed on newbuilding prices, freight rates and interest rates but the economic superiority of SHIP B remained strong in all cases.

Thus, the Life Cycle cost calculation results proved that steel renewals increase the Life Cycle cost per annum (AAC) of over-optimized ships (SHIP A) regardless of the benefits from their greater deadweight and give it a greater Life Cycle cost per annum (AAC) than a ship built with higher corrosion margins (SHIP B) in any economic environment (see Fig. 1). It is clear that the percentage difference in Life Cycle cost per annum (AAC) between the two ships increases as the difference between the inflation rate and the discount rate increases. Thus the statement "carry cargo, not steel" does not stand up to scrutiny in any foreseeable economic environment.

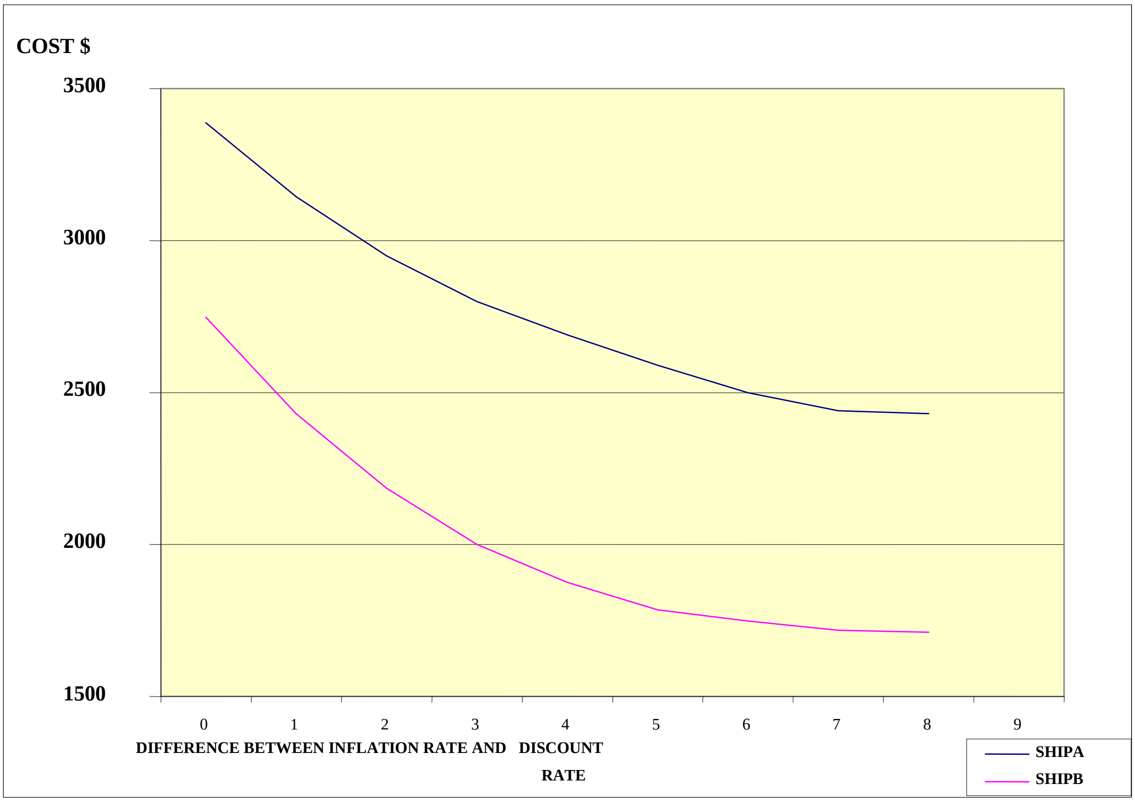

Figure 1: Life Cycle Cost per Annum (AAC) (Gratsos and Zachariadis, 2005)

3. SHIP OPERATION EXPERIENCE

Experience has shown that the pre-CSR corrosion allowances of even the more conservative classification society were marginally adequate for a 20-year design life vessel. The new corrosion allowances in the IACS Common Structural Rules were for the most part further reduced and especially for some critical areas, such as side and bottom shell, even though the new CSR ships are supposedly designed for a 25 year life. It should be pointed out that, following complaints by Greek shipping and International ship operating organizations, IACS improved its final CSR corrosion margins over those of the CSR first draft. However, in most areas they are still smaller than those allowed before CSR and they still fall short of those dictated by experience and many previous corrosion studies (for a list of relevant references, please see Table 1 of the GZ paper).

Many reliable and respected studies on annual corrosion rates for all parts of a ship were performed and published before the development of CSR. Many of these were performed and published by classification societies themselves. It is a wonder why the CSR finally adopted corrosion allowances which reflect much smaller corrosion rates than those published by several IACS members before CSR was conceived (again please refer to Table 1 of the GZ paper).

Parts of bulk carrier structures are known not to be able to maintain coatings and thus corrode faster, the hold structure is a case in point. It makes no financial sense to replace say a 20 mm tank top when an extra 2 mm of corrosion allowance at time of build would have allowed the ship to trade to her design life of 25 years without the renewal of the tank top in question. Such a better design with regard to the tank top would cost 15 times less than the cost of the eventual repairs not including the associated down time. It would also squander fewer resources.

Similarly areas such as side shell plating, heated fuel oil tanks, bottom plating subject to NAABSA trading as well as other locations from experience require more substantial plating. Such experience is fully confirmed by the results of the above mentioned studies.

4. PURPOSE OF STUDY

Having shown in the GZ paper that a robust ship has a lower lifecycle cost than a ship built marginally to comply with the rules, the purpose of the present paper is to estimate and compare the life cycle CO_2 emissions of such ships. We thus compare the life cycle CO_2 emissions of two Panamax and two Handymax bulk carriers built to two different design concepts:

- Ship A is built according to the concept of low initial cost, lighter lightship weight in order to maximize cargo carrying capacity, with corrosion margins according to IACS's new Common Structural Rules (CSR), Final Version.

- Ship B is a ship of identical form and displacement to ship A but with a higher lightship weight due to greater corrosion allowances and particularly so in selected areas commensurate with present industry experience in order to minimize steel renewals (see, for instance, TSCF (1997) and Safety at Sea (2004), among others).

Ship B has overall similar corrosion margins with the pre-CSR ships (typically equivalent to 20-25% of original plate thickness) with further increases in some areas where these pre-CSR margins had proved inadequate (such as bulk carrier hold frames, lower transverse bulkheads, ballast tank scantlings etc.) Alternatively ship B can be arrived at by starting with IACS CSR scantlings (as ship A) and adding the appropriate corrosion margins for true 25 year design life. In that case the required steel addition is more than that of a pre-CSR ship. The ships are otherwise identical having similar coatings, materials, operation and maintenance policies and are assumed to be employed in similar trading patterns.

The calculations for the steel renewals required for ships A and B have been updated to reflect the final IACS CSR corrosion allowances. Tables 8 and 9 in the Appendix show these calculations in detail, and also show the difference in operating days per year expected because of differences in steel renewals.

As alluded to above, it is interesting to note, that a Panamax Bulk carrier built according to previous (20 year) class rules would need only 450 tons of extra steel to reach and exceed the 25 year lifetime. But a Panamax bulker built according to the new (25 year) IACS CSR requires nearly double that extra steel to conform to the advertised design life. Similar considerations pertain for the Handymax ships.

5. CO_2 EMISSIONS COMPARISON

5.1 General considerations

A full-fledged 'cradle-to-grave' comparison of the CO_2 emissions generated by the two alternative designs, ship A and ship B, is a non-trivial task, as there are some components that can be computed in a straightforward manner but other components are more difficult to do so. Here we shall attempt such a comparison, by focusing on the components that we think are the most important and can be calculated with some confidence.

Before we proceed, it is important to establish the framework for comparison. Thus, we shall be requiring both types of ships to produce the same amount of transport work (expressed in tonne-km's) in a year. Not doing so would skew the analysis by comparing these two designs on an unequal basis. However, requiring the same tonne-km's in a year would require some adjustments. The two ship types not only have unequal payloads (ship A's higher than ship B's) but also unequal operating days per year (ship B's longer than ship A's, due to more repair days for ship A). As these two differences work in opposite ways regarding tonne-km's produced in a year, it is not a priori clear which of the two designs would produce more transport work in a year, everything else being equal. But if the tonne-km's are not equal, the question is, how can these designs be made to produce the same tonne-km's in a year? Or, how can the denominator be made common?

One obvious way to accomplish this is by adjusting speed, that is, compute how much ship A's speed has to be in order for tonne-km's to be the same for both designs. However, we decided that speeds (and hence power plants and installed horsepowers) should be kept the same, so as to keep the differences among the two designs to a minimum. After all, ships will proceed at the maximum speed that their specification would allow (which for the two examined designs is very similar), or they will proceed at speeds dictated by the economic environment (price of fuel vs. freight earned). But if speeds are the same, the only way to equalize tonne-km's in a year is to adjust the number of ships in the fleet. We shall thus compute how many more (or less) ships A are required at any point in time so that total tonne-km's in a year are the same among the two designs, and we shall call this 'the additional ships factor'. This factor can be fractional, with the understanding that if it is (say) 1.001, then one additional ship A would be required at any point in time alongside a fleet of 1,000 ships of type A, so as to produce the same tonne-km's as 1,000 ships of type B. Note that this has nothing to do with the fact that the life-time of ship A is 20 years and that of ship B is 30 years, as it only reflects the number of ships that are operational at any point in time.

5.2 Operational CO_2 emissions

The most straightforward type of CO_2 emissions that can be calculated are emissions generated while the ship is in operation through its lifetime. Here we assume for both ship types that, given each ship's operational days per year, 70% of that time is spent at sea and 30% in port. Daily fuel consumptions at sea and in port are assumed known and are the same for both types, and so are the ship's speeds. No operational emissions are assumed during each ship's idle time (365 days minus operational days).

The results of the comparison are shown in Table 1 for the Panamax case and Table 2 for the Handymax case.

Table 1: Operational CO_2 emissions, Panamax ships

	Ship A	Ship B
Operating days/yr	351	359
Displacement (tonnes)	84,400	84,400
Lightship (tonnes)	11,400	12,200
Idle days/yr	14	6
Payload (tonnes)	71,500	70,700
Payload (40% light cargoes, tonnes)	70,900	70,420
Average speed (knots)	13.30	13.30
Sea days (% of op. days)	70	70
SEA days/yr	245.70	251.30
PORT days/yr	105.30	107.70
Capacity utilization	0.65	0.65
SEA kms/yr	145,248	148,558
Tonne-kms/yr	6,693,736,516	6,799,950,182
Bunkers SEA (T/day) HFO	33.00	33.00
Bunkers port (T/day) HFO	2.50	2.50
Total bunkers SEA /yr HFO	8,108	8,293
Total bunkers PORT/yr HFO	263	269
Total bunkers/yr (tonnes)	8,371	8,562
CO_2 coef	3.021	3.021
$CO_{2,}$ SEA/yr	24,495	25,053
CO_2, PORT/yr	795	813
TOTAL CO_2/yr (tonnes)	25,290	25,866
Grams of CO_2/Tonne-km	3.778	3.804
Additional ships factor	1.0158676	1.000000
Revised total bunkers/yr (tonnes)	8,504	8,562
Revised CO_2/yr (tonnes)	25,691	25,866
Revised tonne-kms/yr	6,799,950,182	6,799,950,182
Life cycle yrs	20	30
No. of cycles in 60 yrs	3	2
Tonne-kms in 60 yrs	407,997,010,937	407,997,010,937
SUBTOTAL 1, CO_2 in 60 yrs (tonnes)	1,541,468	1,551,975

Table 2: Operational CO_2 emissions, Handymax ships

	Ship A	Ship B

Operating days/yr	353	360
Displacement (tonnes)	54,600	54,600
Lightship (tonnes)	8,087	8,700
Idle days/yr	12	5
Payload (tonnes)	45,000	44,400
Payload (40% light cargoes, tonnes)	43,800	43,440
Speed (knots)	13.30	13.30
Sea days (% of op. days)	70	70
SEA days/yr	247.10	252.00
PORT days/yr	105.90	108.00
Capacity utilization	0.65	0.65
SEA kms/yr	146,075	148,972
Tonne-kms/yr	4,158,762,101	4,206,371,043
Bunkers SEA (T/day) HFO	30.50	30.50
Bunkers port (T/day) HFO	2.50	2.50
Total bunkers SEA /yr HFO	7,537	7,686
Total bunkers PORT/yr HFO	265	270
Total bunkers/yr (tonnes)	7,801	7,956
CO_2 coef	3.021	3.021
CO_2, SEA/yr	22,768	23,219
CO_2, PORT/yr	800	816
TOTAL CO_2/yr (tonnes)	23,568	24,035
grams of CO_2/Tonne-km	5.667	5.714
additional ships factor	1.0114479	1.000000
revised total bunkers (tonnes)	7,891	7,956
revised CO_2/yr (tonnes)	23,838	24,035
revised tonne-kms/yr	4,206,371,043	4,206,371,043
life cycle yrs	20	30
no. of cycles in 60 yrs	3	2
tonne-kms in 60 yrs	252,382,262,566	252,382,262,566
SUBTOTAL 1, CO_2 in 60 yrs (tonnes)	1,430,252	1,442,105

Some explanatory notes follow:

1. Operating days and lightship weights for each ship have been calculated according to the analysis presented in the Appendix (see Tables 8 and 9).
2. The calculations are based on an estimated actual payload for each ship which is slightly less than the maximum payload. The reason is that such ships often carry light cargoes and thus the holds' available cubics are fully utilized before reaching the maximum deadweight draft mark. Such cargoes are wheat, coals, etc. Furthermore such ships often load or discharge at ports of reduced draft. Past data from the Greek shipping industry indicates that at least 40% of the loaded cargoes involve light ones or ports and channels of reduced draft. Thus the used actual payloads of the tables use this percentage and assume that, in case of light cargoes, the achieved maximum payload for Panamax is 70,000 tons whereas for Handymax 42,000 tons.

3. Ship capacity utilization is estimated at 65% on the average, taking into account possible route triangularization, meaning that 65% of sea time is laden and 35% is on ballast.
4. Bunker consumptions at sea and in port are taken from data collected in the context of an emissions study funded by the Hellenic Chamber of Shipping (see Psaraftis and Kontovas (2009)).
5. The CO_2 coefficient (tonnes of CO_2 per tonne of fuel consumed) is taken from the latest update of the IMO Greenhouse Gas (GHG) study (Buhaug et al, 2008).
6. A common 'super-life cycle' of 60 years is assumed as the least common multiple of the 20-year life cycle of ship A and the 30-year life cycle of ship B. There will be three cycles of ship A (lasting 20 years) and two cycles of ship B (lasting 30 years) within this period. It is clarified that no ship is assumed to last 60 years.
7. Possible technological advances in ship engines, hull forms, or other (e.g, in the steel fabrication, shipbuilding and ship repair processes), within the above life cycles are not taken into account, and all technical features of ships A and B are assumed to stay constant for the sake of comparison. A more detailed, second-order analysis could try to predict future technological improvements in both A and B that may effect life cycle emissions in both vessels. This was considered as outside the scope of this paper (however, see some further discussion on this point in the concluding section of the paper).

One can observe from the above tables that the life cycle environmental performance of ship A is better than that of ship B, *if CO_2 only due to fuel burned through the ship's lifetime operation is taken into account*. The difference amounts to less than 600 tonnes of CO_2 per ship per year for the Panamax ship and to less 200 tonnes of CO_2 per ship per year for the Handymax ship, but it is a positive difference in favor of Ship A. However, this only accounts for the operational phase of a ship's lifetime. Additional CO_2 emissions will be produced during the ship's lifetime, not connected to the ship's operation but due to activities related to (list is not exhaustive):

- Steel fabrication
- Shipbuilding
- Repairs
- Recycling
- Transport of raw materials and steel

In the sections that follow we shall attempt to look into each of these activities, by making some estimates that we think are on the conservative side (that, is, underestimate total emissions, and, as such, favor ship A vis-à-vis ship B).

5.3 CO_2 emissions due to steel fabrication

CO_2 produced at the steel fabrication stage is assumed to be 1.75 tonnes for each tonne of steel produced (Oxera, 2004). This accounts only for emissions produced at the steel mill, and does *not* account for emissions due to:

- Mining of the raw materials (iron ore, coal, limestone or other)- these emissions will not be examined here, but can be substantial
- Transport of these raw materials to the steel mill (various modes will generally be involved, including the maritime one)- these are included into the ‘transport of raw materials’ emissions, see below
- Transport of steel from the steel mill to the shipyard- these are included into the ‘shipbuilding’ emissions, see below
- Cutting and welding of the steel and other energy use to fabricate the ship- these are also included into the ‘shipbuilding’ emissions, see below

It should be mentioned that the factor of 1.75 is likely to be encountered in ‘state-of-the-art’ steel facilities, but can be higher if this is not the case. Also, the fact that emissions due to mining of raw materials are not taken into account means that the factor of 1.75 quite likely underestimates this component of emissions. A possible future version of this paper could look into these and other factors (for instance, emissions due to surface treatments like paints, etc).

5.4 CO_2 emissions due to shipbuilding

This involves shipyard energy use for various reasons (electricity for equipment and offices, welding, gas heating, gas cutting, transport of plates and equipment, sea trials of ship, etc). Kameyama et al (2004) estimate CO_2 due to yard activities, including electricity, welding, cutting and plate forming, transport within the yard, etc, at 11% of total CO_2, the rest (89%) being attributed to steel production. Therefore one can use a factor of 1.75*11/89 = 0.216 per tonne of steel processed at the yard.

5.5 CO_2 emissions due to repairs

Here we are talking about repairs for steel replacement only, as all other repairs are assumed to be the same. Emissions due to fabrication of this steel are accounted for in section 5.3 above. These repairs involve all shipyard-related activities to cut, transport and weld the replacement plates on the ship. As some 43% of the CO_2 directly emitted at the shipyard is due to sea trials (Kameyama et al, 2004), the rest (57%) amounts to 0.216*0.57 = 0.123 tonnes of CO_2 per tonne of steel. In addition to that, we have to account for cutting off the old steel from the ship, assumed to be of equal weight to the replacement steel . Data from specialized Greek repair companies (e.g. NAVEP Ltd) indicate that cutting one tonne of steel uses some 60 kg of liquid propane (C_3H_8). That produces exactly 3 times as much CO_2 in weight, therefore the CO_2 factor for cutting can be estimated to be 0.18 per tonne of steel cut. Thus, the total CO_2 factor for repairs is estimated at 0.123+0.18 = 0.303 per tonne of replacement steel.

5.6 CO_2 emissions due to recycling

As regards recycling, this activity involves cutting of steel plates, of weight equal to the lightship. We use the same CO_2 factor of 0.18 per tonne of steel cut, as in the previous section. Emissions due to remelting the recycled steel are not taken into account, therefore the factor of 0.18 is likely to underestimate this component of emissions. Emissions due to transporting the recycled steel to the steel mill are accounted for in the next section.

Tables 3 and 4 summarize the calculations of sections 5.3 to 5.6 for the two sizes of ships and present new CO_2 subtotals.

Table 3: Various other CO_2 emissions for Panamax ship

Steel fabrication	Ship A	Ship B
Lightship (tonnes)	11,400	12,200
Replacement steel (tonnes)	1,700	900
Total (tonnes)	13,100	13,100
Adjusted for 'additional ships factor' (tonnes)	13,308	13,100
Total steel in 60 years (tonnes)	39,924	26,200
CO_2 steel fabrication coef	1.750	1.750
CO_2 in 60 yrs due to steel fabrication (tonnes)	69,866	45,850
Shipbuilding		
Total steel in 60 years (tonnes)	39,924	26,200
CO_2 shipbuilding coef	0.216	0.216
CO_2 in 60 yrs due to shipbuilding (tonnes)	8,623	5,659
Repairs		
CO_2 repair coef	0.303	0.303
Steel renewed in 60 yrs (tonnes)	5,100	1,800
Adjusted for 'additional ships factor' (tonnes)	5,181	1,800
CO_2 in 60 yrs due to repairs (tonnes)	1,570	545
Recycling		
CO_2 recycling coef	0.18	0.18
Steel scrapped in 60 yrs (tonnes)	34,200	24,400
Adjusted for 'additional ships factor' (tonnes)	34,743	24,400
CO_2 in 60 yrs due to recycling (tonnes)	6,254	4,392
SUBTOTAL 2, CO_2 in 60 yrs (tonnes)	1,627,782	1,608,422

Table 4: Various other CO2 emissions, Handymax ship

Steel fabrication	Ship A	Ship B
Lightship (tonnes)	8,087	8,700
Replacement steel (tonnes)	1,440	710
Total (tonnes)	9,527	9,410
Adjusted for 'additional ships factor' (tonnes)	9,636	9,410
Total steel in 60 years (tonnes)	28,908	18,820
CO_2 steel fabrication coef	1.750	1.750
CO_2 in 60 yrs due to steel	50,589	32,935

fabrication (tonnes)		
Shipbuilding		
Total steel in 60 years (tonnes)	28,908	18,820
CO_2 shipbuilding coef	0.216	0.216
CO_2 in 60 yrs due to shipbuilding (tonnes)	6,244	4,065
Repairs		
CO_2 repair coef	0.303	0.303
Steel renewed in 60 yrs (tonnes)	4,320	1,420
Adjusted for 'additional ships factor' (tonnes)	4,369	1,420
CO_2 in 60 yrs due to repairs (tonnes)	1,324	430
Recycling		
CO_2 recycling coef	0.18	0.18
Steel scrapped in 60 yrs (tonnes)	24,261	17,400
Adjusted for 'additional ships factor' (tonnes)	24,539	17,400
CO_2 in 60 yrs due to recycling (tonnes)	4,417	3,132
SUBTOTAL 2, CO_2 in 60 yrs (tonnes)	1,492,826	1,482,667

5.7 CO_2 emissions due to transport of raw materials and steel

Finally as regards emissions generated from the transport of the raw materials needed to produce the steel of these ships, including steel renewal, we assume a 'raw materials' factor of 2.66, that is, for every tonne of steel to be produced, 2.66 tonnes of raw material (iron ore, coal, limestone, etc) are needed (Worldsteel, 2009). As an illustration, we assume that these raw materials are hauled by ship only, over an average distance of 3,484 nautical miles (6,452 km), corresponding to a trip from Port Hedland, Australia, to Busan, Korea. The amount of raw materials to be hauled correspond to the 'super-life cycle' of 60 years. Also we assume that the 'carbon footprint' of the ships that carry these raw materials is 4 grams of CO_2 per tonne-km (that would correspond to a large bulk carrier- see Psaraftis and Kontovas (2009)).

Similar calculations pertain to recycling. The transport of the steel that is scrapped from the scrap yard to the steel mill would produce some CO_2. How much, depends on the distance. If the steel furnace is in India or Bangladesh, then the distance is short, but then one would have to haul the steel to China, Korea or Japan. If one hauls the scrap metal over a long distance to the steel mill, it will again produce CO_2 to haul it. So either way some steel will have to be hauled, unless of course scrap metal is melted locally for other purposes[2]. Again as an illustration we assume an average distance of 4,136 nautical miles (7,760 kms), corresponding to a trip from Chittagong, Bangladesh, to Dalian, China. Either way we assume that the amount of steel to be

[2] If this is the case, raw materials would have to be hauled to the mill for shipbuilding steel production from an unspecified location, and that would also require energy and produce emissions.

hauled is the lightship steel for the two ship types, over 60 years. Again we assume a 4 grams of CO_2 per tonne-km carbon footprint for the ship that would transport this steel.

The resulting calculations are shown in Tables 5 and 6, which also present the total CO_2 emissions.

Table 5: CO_2 emissions from the transport of raw materials and steel, Panamax ship

Transport of raw materials and steel	Ship A	Ship B
Lightship steel needed in 60 yrs (tonnes)	39,924	26,200
Steel renewed in 60 yrs (tonnes)	5,181	1,800
Total steel in 60 years (tonnes)	45,105	28,000
Raw materials factor	2.66	2.66
Raw materials for total steel (tonnes)	119,978	74,480
Average distance (km)	6,452	6,452
Tonne-kms for raw materials	774,098,246	480,544,960
Grams CO_2 per tonne-km of ship to transport raw materials or steel	4.00	4.00
Tonnes CO_2 for raw materials	3,096	1,922
Average distance (km) for scrap	7,760	7,760
Tonne-kms for scrap	309,807,116	203,312,000
Tonnes CO_2 for scrap	1,239	813
TOTAL CO_2 for transport of raw materials and steel (tonnes)	4,336	2,735
TOTAL CO_2 **in 60 yrs (tonnes)**	1,632,117	1,611,157

Table 6: CO_2 emissions from the transport of raw materials and steel, Handymax ship

Transport of raw materials and steel	Ship A	Ship B
Lightship steel needed in 60 yrs (tonnes)	28,908	18,820
Steel renewed in 60 yrs (tonnes)	4,369	1,420
Total steel in 60 years (tonnes)	33,278	20,240
Raw materials factor	2.66	2.66
Raw materials for total steel (tonnes)	88,519	53,838
Average distance (km)	6,452	6,452
Tonne-kms for raw materials	571,121,612	347,365,357
Grams CO_2 per tonne-km of ship to transport raw materials or steel	4.00	4.00
Tonnes CO_2 for raw materials	2,284	1,389
Average distance (km) for scrap	7,760	7,760
Tonne-kms for scrap	224,327,565	146,043,200
Tonnes CO_2 for scrap	897	584
TOTAL CO_2 for transport of raw materials	3,182	1,974

and steel (tonnes)		
TOTAL CO_2 **in 60 yrs (tonnes)**	1,496,008	1,484,641

It is important to point out that, even though these results seem to be marginal on a per ship basis (a difference on the order of 1% between ship A and ship B), they can be substantial overall if we take into account the number of ships in the fleet. In 2007, and according to the Lloyds-Fairplay ship database, there were some 1,383 Panamax ships and some 1,732 Handymax ships in the world fleet (among a total of 6,462 dry bulk carriers). Assuming an identical performance of all ships in the fleet per size bracket, Table 7 summarizes the total CO_2 produced by these fleets over 60 years and on a per year basis.

Table 7: Fleet CO_2 statistics

PANAMAX	Ship A	Ship B
Number of ships in fleet (2007)	1,383	1,383
Fleet CO_2 in 60 yrs (tonnes)	2,257,218,085	2,228,230,597
Per year (tonnes)	37,620,301	37,137,177
Difference per year (tonnes)	483,125	
Grams of CO_2 per tonne-km	4.000	3.949
HANDYMAX		
Number of ships in fleet (2007)	1,732	1,732
Fleet CO_2 in 60 yrs	2,591,085,621	2,571,397,475
Per year	43,184,760	42,856,625
Difference per year (tonnes)	328,136	
Grams of CO_2 per tonne-km	5.928	5.883

Finally we should mention that for this analysis to be complete, several more issues could be examined. For example type A ships will require several more paints which produce CO_2 and volatile compounds to manufacture and apply. Such refinement could be the scope of future work; however it is clear that due to the increased resources required for type A ships, such considerations will only increase the environmental difference between the two ship types in favor of ship B.

6. CONCLUSIONS AND DISCUSSION

Based on the results shown above, it can be safely concluded that for both the Panamax and Handymax sizes, the life cycle environmental performance of ship B is better than that of ship A, at least as far as CO_2 is concerned. It is speculated that similar results also hold for other ship sizes and types.

Just for these two ship sizes, and based on the sizes of the current fleet, operating ship of type A would produce about 790,000 tonnes of CO_2 per year more than if ship B were used instead. 790,000 tonnes is not a negligible quantity. Percentage-wise the difference may not be substantial globally, but at least the comparison serves to disprove the statement that ship B is environmentally worse than ship A by carrying ‘steel ballast’. Moreover, higher corrosion margins are likely to contribute to a better life cycle safety performance of ship B versus ship A.

It can also be seen that for both these sizes total CO_2 emissions in a ship’s life cycle are some 5-6% higher than operational CO_2 emissions alone, even though in our opinion the real level of non-operational emissions has been underestimated in our paper and these are likely to he higher. As world fleet current operational emissions are estimated on the order of a billion tonnes per year (Buhaug et al (2008) and Psaraftis and Kontovas (2009)), 5-6% is some 50-60 million tonnes of additional CO_2 per year, to the extent the same percentage is true globally. Similarly, 1% (the difference between ship A and ship B), to the extent it is also true for other ship types and sizes, is some 10 million tonnes of CO_2 per year. These may be small percentages, but worthy of note in absolute terms.

Coming back to the issue to what extent possible advances in ship design, engine technology, and others can be factored into a life cycle analysis that spans 20 and 30 years of ship life, the following can be said:

a) Historically technological improvements in ships and their equipment occur in small steps over many years. This is expected to continue with no major technological leaps. Thus, it is not expected that technological advancements will be so large to make replacing a 15-20 year old ship with a new one economically feasible (solely from an efficiency point of view).

b) IMO’s GBS and class rules, require the design life of ships to be 25 years. Thus irrespective of future technological improvements, the aim will always be to achieve the most economically and environmentally efficient ship (of at least 25 year lifetime) with current technology.

c) Modern designs are not always more fuel efficient than older designs. Unfortunately, despite more awareness toward environmental performance, efficiency is sacrificed to reduce initial cost. To save a small portion in building costs, shipyards do not increase the size of installed main engine in line with the larger size and capacity ships which they build. Result: Modern ships are underpowered with their engine operating in real sea conditions near the very inefficient maximum horsepower point. Thus we see modern designs burning much more than past designs of same type ships. Not only that but we see small ships (say Supramax 57,000 DWT) built by advanced shipbuilding countries burning 37-38 tonne/day fuel while the larger ships they were building 12 years ago (say Panamax size 75,000 DWT) were burning only 33 tonnes/day. This is because the Panamax ships are not underpowered and thus are operating at the efficient point of 75-80% maximum horsepower in real sea conditions.

d) Shipyards continue to push for this environmentally unacceptable status quo (of fitting main engines with just enough capacity to perform at the ideal, calm “sea trial” conditions) and through their IMO influence, try to set the new EEDI regulation to be a measure of a ships performance “at sea trial” (i.e. on paper) instead of a ships real sea performance.

We end this paper by noting briefly that the subject under study has recently attracted the attention of the IMO. With submission MEPC 60/4/16, Greece has pointed out the fact that Ship A will have a lower Energy Efficiency Design Index (EEDI) than that of Ship B, even though its life cycle emissions are higher. Given the prominent role that EEDI will take in assessing a newbuilding's environmental performance, Greece has suggested a correction factor f_i = (DWT before enhancements)/(DWT after enhancements), in order to avoid the penalization of ships built to higher structural standards than those envisaged by the standard classification society rules. Examples include increased longitudinal strength capability (Bending Moments and Shear Forces) so that operation at the design limits is avoided, enhanced corrosion margins for reduced repairs and better structural fatigue performance, enhanced classification society's structural notations (e.g. cargo grab notations), increased bow reinforcement for slamming protection, etc. In general, these will involve thicker steel plates and girders (over the regulation minimum) applied in the ship's hull including stern and bow areas, tanks, and holds.

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APPENDIX
TABLE 8

STEEL RENEWAL SCENARIOS

SHIP A: As per IACS new proposed CSR (final version) corrosion margins

Panamax Lightship 11,400 MT
Handymax Lightship 8,087 MT

Max expected Lifetime 20 years (due to reduced corrosion margins necessitating expensive repairs - see write up). Specified corrosion margins are overall less than half of those required for 25 year lifetime (based on corrosion rates experience, past studies and pre-CSR class regulations). It follows that such margins will be exhausted much earlier than the design life, at which time major steel replacement will be required.

A major improvement of final CSR corrosion margins from the first draft of CSR was the increased margins for hold bulkheads and lower hold areas. However the inadequate corrosion margins for side shell and ballast tank internals, and to a smaller extent, hold frames, increase repairs at year 15 on dramatically. The possibility of a CSR ship economic life extending beyond 20 years is still very remote, since at year 20 extensive replacements of deck, sides and bottom shell will be required (thousands of tons).

Estimated Steel Replacement (MT) of Ship A:

Age	for Panamax	for Handymax	
10	50+ MT	50+ MT	Some frames, balast internals
13	170+ MT	140+ MT	Some Frames, various ballast internals, top hoppers
15	480+ MT	400+ MT	Various, some upper side shell, ballast internals, underdecks
18	1,000+ MT	850+ MT	Various ballast, substantial side shell, some deck, some bottom
Total	**1,700+ MT**	**1,440+ MT**	(conservative estimate with very good maintenance)

Scrapping dictated by financial necessity at 20 years.

SHIP B: To arrive at the lightship and performance of ship B there are two alternative but equivalent methods. One is to start with a ship built to pre-CSR scantlings and proceed to upgrade the corrosion margins of certain needed areas. The other way is to start with a CSR scantlings ship and upgrade its corrosion margins as needed (based on past studies and experience).

First method: We start with a vessel built as per old regulations with corrosion margins of some parts upgraded for same lifetime as the rest of the ship (which with maintenance can be 27 years, scrapping at 30 years, see write up). I.e. the ship has overall similar corrosion margins with the pre-CSR ships (typically equivalent to 20-25% of original plate thickness) with increases in some areas where the pre-CSR margins had proved inadequate as follows: Hold frames: increase corrosion allowance by 80-90% (almost double). All height of hold transverse Bulkheads, underdecks, tank internals (selected), tanktops, double bottom longitudinal bulkheads: increase allowance by about 50%. Hold hoppers top and bottom: increase by abt. 40%, and various other selected increases.

EXTRA WEIGHT for 30 year lifetime of a pre-CSR ship (PANAMAX EXAMPLE):

FRAMES	(3 mm extra):	70 mt
TANKTOP	(3 mm extra):	100 mt
H.BULKHD	(2 mm extra):	35 mt
UNDERDECK	(3 mm extra):	35 mt
DECK LONG.	(3 mm extra):	25 mt
HOPPERS	(2 mm extra):	85 mt
BAL. SCANTL.	(selected):	100 mt
	TOTAL :	**450 mt**

Lifetime 27 years + (actual 30 years)

Second Method: We proceed to incorporate the IACS new CSR scantlings but with all corrosion margins upgraded for 25 year lifetime as follows.

	CSR PROVIDED CORR MARGIN		REQUIRED CORR MARGIN	EXTRA WEIGHT (MT) PANAMAX	HANDY
HOLD FRAMES	FROM 4.5 MM	TO	7 MM	60	42
TANKTOP	FROM 5.5 MM	TO	7.5 MM	65	44
TOP HOPPERS	FROM 3.5 MM	TO	7 MM	80	56
BOTTOM HOPPERS	FROM 5.5 MM	TO	7 MM	28	21
LOWER BULKHEADS	FROM 6.5 MM	TO	7 MM	4	3
STOOLS/UDECKS	FROM 4.0 MM	TO	7 MM	40	29
SIDE SHELL	FROM 3.5 MM	TO	5 MM	88	74
HOLD SHELL	FROM 3.5 MM	TO	5 MM	38	28
DECK	FROM 4.0 MM	TO	5.5 MM	50	40
BOTTOM	FROM 3.0 MM	TO	5 MM	80	66
U/DECK LONGIT.	FROM 4.0 MM	TO	6 MM	16	11
GIRDERS/FLOORS	FROM 3.0 MM	TO	5.5 MM	114	96
TOP SIDE WEBS	FROM 3.5 MM	TO	5.5 MM	63	47
OTHER BALLAST	FROM 3.0 MM	TO	5.5 MM	72	56
			TOTAL	**800**	**613**

Thus, Panamax Lightship at 12,200 MT
Handymax Lightship at 8,700 MT

Note that to arrive at a 30 year lifetime ship, a Panamax pre-CSR ship needs 450 metric tons (see above) of additional corrosion margins, whereas a current CSR ship needs nearly double that amount (800 MT).

ESTIMATED STEEL REPLACEMENT OF SHIP B (In 30 years):

		for Panamax	for Handymax	
Age	13	0 MT	0 MT	
“	15	20 MT	20 MT	
“	18	80 MT	50 MT	Internals
“	20	120 MT	80 MT	Some frames, various
“	23	180 MT	150 MT	Frames, bulkheads, internals
“	25	200 MT	160 MT	Various
“	28	300 MT	250 MT	Various
Total:		**900 MT**	**710 MT**	

Scrapping age 30+ years, if it is possible to employ the ship further. If scrapping is done at 25 years, then only 400 mt of repairs estimated will have been carried out for the Panamax and 300 mt for the Handymax.

TABLE 9

DOWN TIMES DUE TO DRYDOCKINGS AND STEEL REPAIRS

Notes

1. For good maintenance, it is assumed that owner elects to drydock ships at years 3 and 8, even though current regulations permit skipping these drydocks.
2. Steel replacement is assumed in China due to lower costs. A 7 ton/day steel replacement rate is assumed. This rate can vary for small or large pieces from 5 to 10 or even 12 tons per day for some good yards. However the popularity of Chinese yards has resulted in yard overbookings and thus usual waiting delays for the arrived ship. This is not expected to change in the near to medium term future since more ships are being delivered whereas new yard construction in China has stalled. Thus a 7 ton/day production rate is considered a good average even for large repairs.

SHIP A

	PANAMAX		HANDYMAX	
YEAR	STEEL	DOWNTIME	STEEL	DOWNTIME
	MT	*DAYS*	*MT*	*DAYS*
01				
02				
03		9		9
04				
05		9		9
06				
07				
08		9		9
09				
10	50	9	50	9
11				
12				
13	170	24	140	20
14				
15	480	69	400	54
16				
17				
18	1000	143	850	121
19				
20				
TOTAL	1700	272	1440	234

THUS **PANAMAX A** REPAIR DAYS = 272 IN 20 YRS = 14 D/YR ->
THUS OPER DAYS 351

HANDY A REPAIR DAYS = 234 IN 20 YRS = 12 D/YR -> THUS OPER DAYS 353

SHIP B

YEAR	PANAMAX STEEL	PANAMAX DOWNTIME	HANDYMAX STEEL	HANDYMAX DOWNTIME
	MT	*DAYS*	*MT*	*DAYS*
01				
02				
03		9		9
04				
05		9		9
06				
07				
08		9		9
09				
10		9		9
11				
12				
13		9		9
14				
15	20	9	20	9
16				
17				
18	80	12	50	9
19				
20	120	17	80	11
21				
22				
23	180	26	150	21
24				
25	200	29	160	23
26				
27				
28	300	43	250	36
29				
30				
TOTAL	900	181	710	154

THUS **PANAMAX B** REPAIR DAYS = 181 IN 30 YRS = 6 D/YR ->
THUS OPER DAYS 359

HANDY B REPAIR DAYS IN 30 YRS = 154 = 5 D/ YR -> THUS OPER DAYS 360/YR

**IJME LIFECYCLE PAPER BY GRATSOS ET AL (2010)
COMMENTS BY 5 DISCUSSANTS AND RESPONSES TO THESE COMMENTS**[3]

All responses are at page 29 and beyond

(1) NIKOS MIKELIS, International Maritime Organization

The authors are to be thanked and congratulated for pursuing their efforts towards a holistic assessment and comparison of ships built in accordance with minimum classification rules, and ships built to more robust designs incorporating corrosion margins commensurate to longer operating life. Having concluded in their earlier work that the robust ship, compared to the minimum scantlings' ship, is economically advantageous over its life time, in this paper the authors compare the carbon footprint of the robust ship against the ship built to current minimum class rule requirements.

The paper contributes a reasoned methodology and useful data to the debate that is taking place in the context of rational Goal Based Standards. It is hoped that the paper will generate further debate which should eventually lead to generally accepted conclusions on meaningful minimum design and classification rule standards.

The writer wishes to bring the authors' attention to one wrong assumption, one error and one omission they have made in the way they have accounted for ship recycling in their analysis. Although the magnitude of the resultant error is small enough not to affect the conclusions reached in the paper, it is nevertheless better to discuss these issues here so that possible future applications of the authors' methodology may account properly of the ship recycling phase of a ship's life cycle.

The authors have assumed (see section 5.7) that steel produced from ship breaking in the major ship recycling centres in India and Bangladesh is exported to industrial centres, such as Japan, Korea, or China. In Tables 5 and 6, the authors account for CO_2 emissions from the transport of the recycled steel from the recycling States to these major industrial centres. In fact steel produced from ship breaking in the recycling centres of South Asia is not exported but instead is used in the domestic construction industries (buildings, bridges, etc). The analysis should therefore have assumed that the production of steel from ship breaking simply reduces a country's needs for imports of scrap steel and steel bilets for cold and hot rerolling (and on some occasions may also reduce the imports of iron ore for smelting).

This brings us to the error in the paper's accounting of CO_2 emissions from transport relating to ship recycling. As noted above, if the ship recycling countries did not produce steel from ship breaking, then these countries would have to import equivalent quantities of scrap steel, or steel bilets, or iron ore, in order to satisfy the needs of their construction industries. The more steel that is being obtained from ship breaking, the less steel (or scrap, or iron ore) has to be imported. It should therefore follow that the CO_2 emissions from transport relating to ship recycling in Tables 5 and 6 of the paper should in fact be accounted as <u>credits</u> and not as <u>debits</u> to the total. In

[3] The comments and the responses appear in *Intl J Maritime Eng, Oct-Dec. 2010*– © RINA

other words, Ship A, in the 60 year super-cycle, yields more steel for ship recycling (greater lightship), and consequently results in fewer emissions from the transport of fewer raw materials.

Finally, the authors may wish to include in their methodology one additional consideration for the recycling phase. The production of rerolled steel (i.e. steel from ship recycling) leads to lesser CO_2 emissions than the production of new steel from smelting of iron ore. This additional consideration would yield another credit for Ship A in Tables 3 and 4. It has to be noted however that this credit would be much smaller in value than the debit arising from the emissions from steel fabrication (i.e. new steel that would be needed if the recycled steel was not available). Again, this is a secondary contribution whose inclusion in the analysis would not change this excellent paper's conclusions.

(2) JOHN KOKARAKIS, Bureau Veritas, Greece

The authors are to be congratulated for an excellent application of LCA on a ship. Life Cycle Analysis (LCA) applied on a ship, attempts to quantify the full range of environmental impacts associated with the vessel by considering all inputs of resources and materials and all outputs of wastes and pollution at each stage of the ship's life. In their work they consider (for Handymax and Panamax sizes) a design complying with the CSR rules (Ship A) and another somewhat enhanced design with heavier scantlings (Ship B). Key assumption is that the lifetimes of the rule-compliant and the enhanced-scantlings design are respectively 20 and 30 years. Nevertheless, independently of the validity of the lifetime ratio between the two designs it is a fact that the more robust ship will be subject to reduced repairs and will be available more time for carrying cargo. Table below reflects the CO_2 emissions in a percentage form for the two sizes considered:

Handymax Size CO_2 emissions	***Ship A***	***Ship B***
Operation	**95.60**	**97.13**
Steel Fabrication	**3.38**	**2.22**
Shipbuilding	**0.42**	**0.27**
Repair	**0.09**	**0.03**
Recycling	**0.30**	**0.21**
Transport of raw materials and steel	**0.21**	**0.13**
Panamax Size CO_2 emissions	***Ship A***	***Ship B***
Operation	**94.45**	**96.33**
Steel Fabrication	**4.28**	**2.85**
Shipbuilding	**0.53**	**0.35**
Repair	**0.10**	**0.03**
Recycling	**0.38**	**0.27**
Transport of raw materials and steel	**0.27**	**0.17**

It is observed that CO_2 associated with ship operation has the lion's share percentage wise but it is interesting to note the final conclusion of the paper that the more robust vessel will have a lower overall CO_2 footprint in this cradle-to-grave analysis. This interesting and important conclusion is attributed to the cascade of effects considered in the overall production, operation and scrapping of the ships.

Although CO_2 is the most important greenhouse gas and is the largest emission from a ship, quantifying the total amount of overall harmful emissions produced is the key to examining the environmental impact of a ship. The environmental impact from the ship is a combination of CO_2, SOx, and NOx emissions. The capacity of NOx to contribute to the warming of the atmosphere is for example 310 times higher than CO2, for a 100 year time frame according to the Intergovernmental Panel on Climate Change (IPCC) (Houghton, *et al*, 1996). Thus, the environmental impact of a ship can be normalised to CO_2-equivalence index to describe its overall contribution to global climate change.

LCA of ships could be used to assist shipbuilding companies to identify and quantify opportunities to minimise/control energy consumption and its impact to the environment and to realise cost savings by making more effective use of available resources. The environmental dimension in ship design should be an integral part of the holistic approach of ship design. The rational use of shipbuilding materials should not only reduce the negative environmental impacts and energy consumption but should also have positive economic gains. Furthermore the generation of ship-specific LCA software tools like for example LCA-Ship, SSD and SimaPro will assist in the incorporation of environmental impact studies in ship design such as the current one. It is necessary that the interesting conclusions in this study be further analyzed by such tools in order to be generalised.

Houghton, J.T.; Meira Filho, L.G.; Callander, B.A.; Harris, N.; Kattenberg, A.; Maskell, K., eds. (1996). Climate Change 1995. The Science of Climate Change. Published for the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

(3) JACK DEVANNEY, Center for Tankship Excellence, USA

The authors have done us a valuable favor by reminding us that environmental concerns often lead to thinking that is shortsighted and not in the interest of robust, reliable ships. In this regard, I would very much like to hear their opinion of EEDI, and the reduction in installed power that EEDI will effectively mandate.

(4) CHRISTIAN BREINHOLT, Danish Maritime Administration

A part of the Greek study "Life-cycle CO_2 emissions of bulk carriers: a comparative study" was presented by Greece at MEPC 60 in MEPC 60/4/16 "The Energy Efficiency Design Index (EEDI) and Life Cycle Considerations". My comments are confined to part 5 of the study.

It is argued that in the total life cycle of 60 years, the CO_2 emission from building and operating three ships of type A, i.e. ships built according to IACS´s new common structural rules (CRS), is higher than the CO_2 emissions from two ships of type B in the same period, where ship B is described as *"a ship of identical form and displacement to ship A, but with a higher lightship weight due to greater corrosion* *allowances and particularly so in selected areas commensurate with present industry experience in order to minimise steel renewals".*

The study calculations are made for two types of bulk carriers – Panamax ships with a displacement of 84,400 tonnes and Handymax ships with a displacement of 54,600 tonnes.

In part 5 of the study, the explanatory note No. 7 to table 1 states that: *"Possible technological advances in ship engines, hull forms, or other (e.g. in the steel fabrication, shipbuilding and ship repair processes), within the above life cycles are not taken into account, and all technical features of ships A and B are assumed to stay constant for the sake of comparison. A more detailed, second-order analysis could try to predict future technological improvements in both A and B that may effect life cycle emissions in both vessels. This was considered as outside the scope of this paper (however, see some further discussion on this point in the concluding section of the paper)."*

This assumption is not based on a realistic scenario, as also pointed out by Denmark at MEPC 60. It is assumed that the three ships of type A and the two ships of type B are built without any technical improvements at all.

At MEPC 61 the Working Group on energy efficiency measures for ships agreed on draft regulations on energy efficiency for ships, where a reduction rate of 30 % in year 2025 is proposed for bulk carriers. Further reduction rates can be expected in the following decades and such reductions will be possible due to the development in the energy efficiency technologies forced by the general requirement for reducing CO_2 emissions in order to reduce the impact on the climate.

Furthermore there is a general trend in the industry to look for increased energy efficiency.

Accordingly it is obvious that ship number two of both type A and type B will be more energy efficient than ship number one and that ship number three of type A will again be more energy efficient than ship number two of both type A and type B.

In the study it is further stated that the additional CO_2 emissions from steel fabrication, shipbuilding, repairs, recycling and transport of raw materials and steel will also be the same when building the three ships of type A and the two ships of type B, respectively.

It is again obvious that these CO_2 emissions will be less for ships built in the future. The transport of raw materials and steel will be more efficient due to the energy efficiency design index, etc., and the steel fabrication, shipbuilding, repair and recycling will be more energy efficient due to the general requirements for reducing the CO_2 emissions in order to reduce the impact on the climate and the general trend in the industry to look for increased energy efficiency.

Finally, it is assumed that ships of type A will have considerably more idle days/yr than ships of type B. Panamax ships of type A are assumed to have 14 idle days/yr, whereas ship of type B will have 6 idle days/yr (downtime due to dry-docking and steel repairs).

In the calculations of the downtime, in table 9 in the appendix to the study, a steel replacement rate of 7 tonnes /day is assumed. This seems very low, especially for the calculated repairs for 18-year-old ships of type A. It does not seem probable that shipowners will use the average of 143 days, more than one third of a year, for dry-docking and steel repairs (1.5 year before it is assumed taken out of service), and consequently the “additional ship factor” used in the calculations for the ships of type A should be lower.

If the study “Life-cycle CO_2 emissions of bulk carriers: a comparative study” should be used as an argument to build ships with a life cycle of 30 years instead of 20 years, it is clear that the technological development resulting in more efficient ships, more efficient shipyards, more efficient steel fabrication, and more efficient recycling must be included in the calculations. This again would most likely give the result that, based on the CO_2 emission, it will be better to have three energy-efficient and more modern ships through the 60-year period than two less efficient and less modern ships.

(5) SUN JUN, Zhejiang Maritime Safety Administration, People’s Republic of China

I had been always entangled in a question-whether in shipping safety and energy efficiency are contradicted or compatible. Gratsos and his colleagues give me a clear and perfect answer-both could be achieved simultaneity. *Life-Cycle Co2 Emissions Of Bulk Carriers: A Comparative Study*, from a holistic perspective, through a const/benefit analysis, shows convincingly that a robust ship built with sufficient corrosion allowances will have better environmental performance or less CO2 emission than so-called “energy efficient” ship which have a lower Energy Efficiency Design Index (EEDI). It provides a very important, persuasive and timely message or evidence not only for shipping and ship-built industries, but also for governments, particularly for those negotiators and policy-makers on emission reduction from shipping.

AUTHORS' RESPONSES TO ALL

First of all, we would like to thank all five respondents for taking the time to read the paper and provide their comments, all of which we found very interesting.

Responding to Nikos Mikelis's comments first, we note that steel is manufactured mainly in blast furnaces or electric arc furnaces (EAF). Scrap is used as a feedstock in both processes. The more scrap used in steel production the less energy is required, therefore the emissions generated per tonne of steel produced through the use of scrap are less.

It is true that most scrap steel used as feed stock for steel production is exported by industrialised economies, which seem to have a surplus. It follows that India and Bangladesh would use the scrap from ships they recycle for their own needs, instead of importing similar quantities. The scrap imported by steel producing countries comes from longer distances than those from India and Bangladesh to Japan and Korea. The scrap imported is generally from sources other than ships (i.e. cars, cans, motorblocks and turnings, steel from scrapped infrastructure or buildings etc.).

Our example of Japan importing scrap from India was used for the purpose of showing a direct cycle. In the real world scrap used for steelmaking, and therefore shipbuilding, the preponderance of which is in the Far East would travel longer distances thus creating overall greater emissions if looked at from a global perspective.

We acknowledge Dr. Mikelis's point regarding Tables 5 and 6. In our scenario we have assumed that scrap metal in Bangladesh is hauled to China to be used in a steel mill. If scrap metal is used locally in Bangladesh, raw materials would have to be hauled to the Japanese, Korean or Chinese mills for shipbuilding steel production from an unspecified location, and that would also require energy and produce emissions which have to be accounted for. In that sense, and for the examined scenario, Tables 5 and 6 are correct in accounting emissions generated by carrying scrap metal from Bangladesh to China (as per our illustrative example). What is indeed missing is an account of the emissions generated by importing raw materials or scrap from an unspecified location to Bangladesh, to cover the difference between ship A and B as regards scrap metal generated, to cover the needs of Bangladesh in steel. However, this quantity is estimated to be rather small and very unlikely to change the final results of our paper. One could actually also attempt to estimate the additional emissions generated by building the extra ships necessary for this additional transport of raw materials, the additional emissions generated by air transport for flying the crews of these extra ships, the additional emissions generated by manufacturing the extra aircraft necessary to fly these crews, and so on. But one has to stop somewhere.

Regarding finally Dr. Mikelis's point on rolled steel, we agree that including this into the analysis would make no significant difference.

Coming now to John Kokarakis's comments, we first note that NOx and SOx emissions are outside the scope of our paper. NOx and SOx emissions from ships, according to all studies, appear to have a cooling effect on the environment. Still, we do not believe that the environmental impact of a ship can be normalised to CO_2 equivalence index to describe its overall contribution to global climate change at this point in time when full understanding of the climatic effects of ship emissions is not available. Eventually something along these lines may be able to be approximated in the future.

Ship engine emit Sulfur oxides (SOx), Nitrogen oxides (NOx), Particulate matters (PM) and Carbon dioxide (CO_2). Papers we have seen have different and sometimes conflicting views. Measures taken for land based pollution may be inappropriate for pollution out at sea. For example:

1. To reduce potential health and acid rain related problems, low sulfur distillates may be appropriate on or close to shore as acknowledged by IMO with the establishment of Emission Control Areas in sea areas of Northern Europe meeting specific environmental criteria. On the other hand for the production of these distillates, refineries will need to emit at least 15% more CO_2 and other pollutants depending on the level of purification required. If such fuels are not required at sea the world would have a net saving in CO_2 emissions. Furthermore the high cost of the distillates in SECAs could cause modal shifts of cargo, resulting in more emissions and congestion from less efficient transport systems.

2. Studies show that sulfate aerosols act as a sun shield. Together with BC they appear to be five to six orders of magnitude more potent than CO_2 which should counterweigh their shorter lifetime.

3. We understand that NOx will increases the level of ozone but reduce Methane life time thus giving a net cooling effect. Additionally altering or redesigning two stroke engines to reduce NOx emissions will increase their fuel consumption (a fuel penalty as it has been referred to in IMO by about 5% if not more), therefore the overall ship related CO_2 emissions will increase.

4. In terms of ocean acidification, nitric acid, formed from NO_x, and sulfuric acid formed from SOx emissions contribute a few percent compared to carbolic acid created by CO_2 on a global scale.

In December 2008 the Hellenic Chamber of Shipping, realising the conflicting information, organised a working group that comprised six (6) internationally acclaimed environmental experts as well as experts from the Greek government and the shipping community who considered that further investigation was required to understand the extent of the impact of shipping on the climate. This is clearly stated in recent papers:

-Shipping Emissions: From Cooling to Warming of Climate-and Reducing Impacts on Health by Jan Fuglestvedt, Terje Berntsen, Veronika Eyring, Ivar Isaksen, David

S.Lee and Robert Sausen, (ENVIRONMENTAL Science & Technology Viewpoint) and

-Transport impacts on atmosphere and climate: Shipping by Veronika Eyring, Ivar S.A. Isaksen, Terje Berntsen, William J. Collins, James J. Corbett, Oyvind Endresen, Roy G. Grainger, Jana Moldanova, Hans Schlager, David S. Stevenson. (ELSEVIER)

The above and other, sometimes conflicting information, appear to indicate that more should be known to fully understand the effect of the emissions of ocean going ships so that whatever measures are proposed move in the right direction. The solution should not create more problems that it solves.

Regarding Jack Devanney's comments, one can certainly write volumes regarding EEDI, the analysis of which is outside the immediate scope of this paper. In our opinion, EEDI is an index that has a variety of problems, some of which have been described by Greece's recent submissions to the IMO (documents MEPC 60/4/15, MEPC 60/4/16 and MEPC 60/4/17, among others). One major concern is the push for underpowered ships which, thanks to the efforts of Greece, has been somewhat alleviated by agreeing to use an engine's derated MCR in the calculation. Furthermore, the attention drawn to the issue has resulted in efforts by IACS and others to investigate a "minimum required power" to keep a safe speed in rough weather. Perhaps an even more serious concern relating to this paper is EEDI's push for the lightest ships possible in order to increase deadweight. On that front too, Greece achieved majority IMO agreement to at least exclude from the calculation the extra steel weight resulting from voluntary structural enhancements which increase safety. The debate on EEDI is far from over and we hope to have the chance to discuss the various facets of the problem in another occasion.

Coming now to Christian Breinholt's comments, his main argument is that we have not taken into account possible technological advances that may happen during the 20 years of ship A and the 30 years of ship B's lifetimes, or the combined 60 year super-cycle of both. He also argues that such technological advances will weigh in favour of ship A, as these advances will be significant during a period of 60 years. We have already acknowledged in the paper that we do not consider differences in technology as these are second-order effects. We think it is self evident that the 60 year super-cycle is only an accounting tool to bring two ships of unequal life cycles to a common denominator as regards emissions on a yearly basis. Nobody suggests that one will operate 3 ships of type A for 20+20+20 years in a row, or two ships of type B for 30+30 years in a row.

But even if we want to consider technological advances, the only technological difference between the two ship types will manifest itself during the 10 year time frame from the scrapping of ship A to the scrapping of ship B, is that a ship built to replace the scrapped ship A can perhaps employ some technological improvements which the existing ship B cannot, in the remaining 10 years of its life. But this is so only if these improvements cannot be retrofitted. Unless one expects miracles in hydrodynamic developments or vastly more efficient engines within any future 10 year interval (we do not), we think that most technological advances will be retrofittable (fins/ ducts/props/paints, etc). Thus they could be installed on any existing ship.

For technological developments that cannot be retrofitted, say, a more efficient engine that the ship A replacement will have at year 20 while ship B will continue to use the same old engine during years 21-30, a similar argument exists with the replacement of ship B at year 30. The ship B replacement will have a more efficient engine than the one of the ship replacing ship A for the period between year 31 and 40, and so on.

Furthermore, the argument seems to be a circular one. According to this, a 10 year design life ship will be even better than a 20 year design ship, and so on. However new IMO SOLAS regulations (Goal Based Standards) require that ships henceforth are designed with a 25 year design life. So one cannot advocate ever shorter design lives. The issue we tackle here is building ships which on paper comply with the 25 year design life requirement (using IACS CSR for their construction) but actually cannot reach that age without excessive, costly and environmentally unfriendly repairs. With some rather minor structural upgrades, as specified in our paper, these ships not only reach their design life with normal maintenance and repairs but can easily exceed it.

Regarding the arguments on CO2 emissions during building, repairing, recycling etc., although we agree that these will be reduced for all ships in the future, again we need to point out that in comparing the two ship types, the only relevant differences will be those of any 10 year differential period. But some of these activities will work in favour of the longer life ship B (e.g. a ship scrapped at year 20 will emit more CO2 than a ship scrapped 10 years later, due to possible technological improvements in scrapping).

With regard to the steel replacement rates used in calculations, these are real averages for steel repairs of these type of ships (bulk carriers) in China. Repairs at other countries may be slightly faster but much more expensive (shortening the economic life of ship further). Nevertheless, we do state that this rate could be as much as 12 tons/day in some good yards resulting in a best case scenario of 83 days downtime for the last 3 years. The results would not change in substance. Whether an owner will consider such repairs totally depends on the then economic environment. We should also note that the amount of calculated steel to be replaced (based on IACS CSR corrosion margins) has not been challenged to date. It is reminded these calculations have been submitted to IMO and Japan and IACS have commented on other issues of the (original) paper but not on the true wear (corrosion) rates of steel structures used in our paper.

This is because we used actual repair data in conjunction with past classification society studies (fully disclosed and substantiated) which, unfortunately, IACS CSR chose to ignore in setting the rule corrosion margins.

Last but not least, we have no specific response to Sun Jun's comments, for which we thank him.