DISCUSSION

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

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COMMENT

N Mikelis, IMO, UK

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 billets for cold and hot re-rolling (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 billets, 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 credits and not as debits to the total. In 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 re-rolled 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.

J Kokarakis, Bureau Veritas, Greece

The authors are to be congratulated for an excellent application of 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 CO_2, for a 100 year time frame according to the Intergovernmental Panel on Climate Change (IPCC) [18]. Thus, the environmental impact of a ship can be normalized 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 minimize/control energy consumption and its impact to the environment and to realize 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 generalized.

J Devanney, Centre for Tankship Excellence, USA

The authors have done us a valuable favour by reminding us that environmental concerns often lead to thinking that is short-sighted 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.

C Breinholt, Danish Maritime Authority, Denmark

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 minimize 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.

J Sun, Zhejiang Maritime Safety Administration of 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. The paper, 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 CO_2 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.

AUTHOR'S RESPONSE

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, motor blocks 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 Sulphur 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 sulphur 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 sulphate 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 counter weigh their shorter lifetime.

3. We understand that NOx will increase the level of ozone but reduces 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 NOx, and sulphuric 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 [19 & 20]. These papers 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 de-rated 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 retro-fitted (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 CO_2 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 CO_2 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 this 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.

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